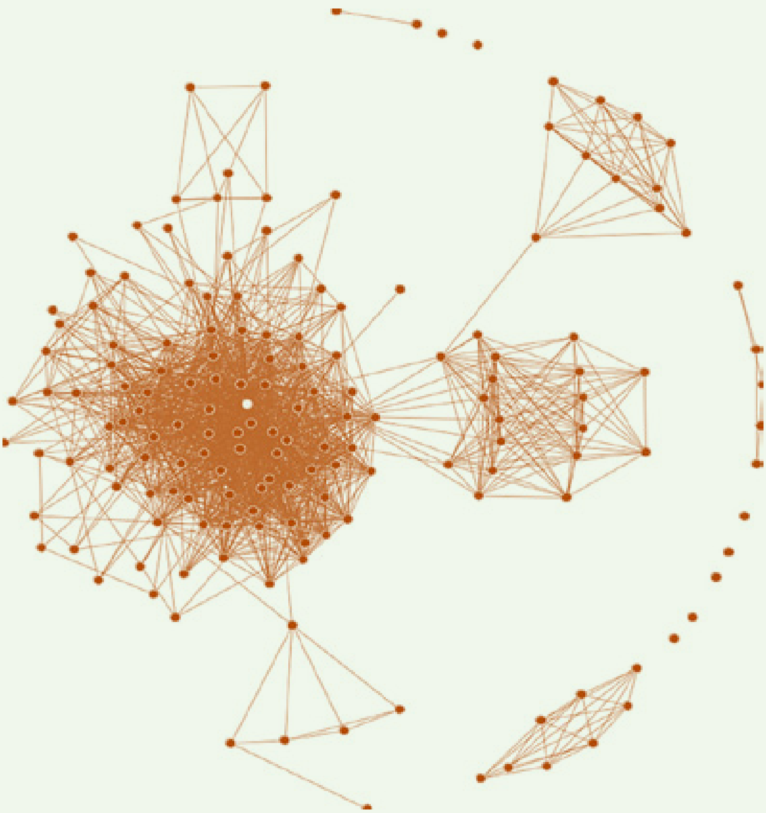
green chemistry, green engineering and eco-innovation

Towards a More Sustainable Petrochemical Industry

Determinants of Brazilian Petrochemical Companies´ Engagement in GCE-Based Eco-Innovation Processes



Paulo A. Freire da Silva

Green Chemistry, Green Engineering and Eco-Innovation Towards a More Sustainable Petrochemical Industry:

Behavioral Determinants of Brazilian Petrochemical Companies´ Engagement in GCE-Based Eco-Innovation Processes

Green Chemistry, Green Engineering and Eco-Innovation Towards a More Sustainable Petrochemical Industry:

Determinants of Brazilian Petrochemical Companies´ Engagement in GCE-Based Eco-Innovation Processes

Groene Chemie, Groene Techniek en Eco-innovatie
Naar een Duurzamere Petrochemie:

Determinanten van de Betrokkenheid van Braziliaanse Petrochemische Bedrijven in Eco-innovatie op basis van Groene Chemie

Thesis

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> "No matter who you are, no matter where you go, in your life, at some point you gonna need somebody to stand by you".

For some reason these words and their meaning penetrated deeply and strongly supported my beliefs from the very first time I heard them. They were sung by the wonderful street singer Roger Ridley, who used to perform in 3rd Street Promenade, Santa Monica, California before he passed away in 2005.

They were introductory words to the song, "Stand by Me". I never had the opportunity to see Roger singing live, but his message was disseminated worldwide through a video, which continues to have impact and it is still touching and inspiring many people today. It expresses my feelings regarding the individuals who helped me throughout my Ph.D. process. Therefore, I dedicate the following paragraphs to express my most profound gratitude to those who helped me along this journey.

First, I would like to dedicate this thesis to my wife Ivone and to my mother Branca. Without their unconditional love, support and encouragement my engagement and continuation on this thesis development process would not have been possible.

I would like to express my most profound and special gratitude to Dr. Carlos Montalvo Corral of the Netherlands Organisation for Applied Scientific Research and to Professor Donald Huisingh of Erasmus University whose endless dedication, mentorship, support and encouragement were fundamental for the success of this research. I would also like to thank Dr. Leo Baas of Erasmus University of for his continual and significant support and guidance. A special thanks also goes to Dr. Gemma Jones, whose words of encouragement and support greatly helped me to overcome times of doubts and difficulties. I would also like to express my sincere gratitude to Professor Wim Hafkamp, of Erasmus University, for his clear and insightful inputs, especially during the final phase of the development of my thesis.

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I am grateful to my colleagues and classmates Margarita Juárez Nájera and Samuel B. Moore for the long discussions and exchanges of ideas we had at the initial steps of my Ph.D. process. They were of immense value and helped me in delineating some useful approaches to this research.

The responsibility of writing a thesis research´s acknowledgements is as great as the conception and development of the thesis itself. Although much simpler to write, it carries the responsibility associated with gratitude. Gratefulness is included among the noblest of human virtues. In that context, I am also grateful to innumerable individuals whose contributions helped me to make this thesis research become a reality.

This thesis research´s author hopes that this thesis will contribute to building a cleaner and more sustainable world where mistakes from the past can be overcome and nature´s gifts can be preserved for healthful societies for the present and for the long-term future.

Summary

It is the general wisdom, within the petrochemical industrial sector, that technological changes, for the development of cleaner products, processes and services, is a basic requirement for companies to achieve advanced states of environmental and economic sustainability in the 21st century.

It is also agreed that to innovate is essential for this industry make the necessary advancements and to reconcile the firms´ interests of being profitable, in the short-term, with their long-term capacity to evolve with societal pressures to ensure worker's and consumer's health within a sustainable biosphere. Despite these corporate perspectives, companies´ decisions to engage in the process of change, through technological and management innovations, is contingent on a series of elements that determine companies' eco-innovative behavior.

This thesis was designed to gain insight into the aspects and determinants that influence eco-innovative behavior of companies in the Brazilian petrochemical sector. Drawing on Icel Ajzen´s Theory of Planned Behavior (TPB), on Montalvo Corral´s TPB-based structural descriptive innovation-directed behavioral model and on Franco Malerba´s Sectoral Systems of Innovation (SSI) framework as its major theoretical frameworks, this study was designed to obtain answers to these research questions:

- What is the extent to which Brazilian petrochemical companies are willing to innovate based upon the *Twelve Principles of the Green Chemistry* and the *Twelve Principles of Green Engineering* (GCE) as approaches to more sustainable behavior?
- How can their willingness to change be documented and explained and what are its main determinants?
- What are the sector´s main agents, mechanisms and actions, which are integral to its implementation of GCE and to going beyond them in the future?

More specifically, this research investigated the extent and the strength to which these companies intend or are willing to engage, in the next five years, in technological and managerial eco-innovation processes. Such engagement would, in part, be based upon their acceptance and use of GCE as a means to promote technological and management changes for the development and production of cleaner and more sustainable products, processes and services**.**

In this thesis research, the determinants of willingness to innovate encompassed elements from a variety of domains such as the environmental, socio-economic, technical, management, business, ethical, moral, institutional, sociological, and personal realms. They were investigated as the key elements for the potential development of corporate, sectoral and public policies devoted to the promotion of eco-innovation processes. In parallel, such policies were expected to be powerful elements in the adoption of GCE as the guidance and primary frameworks in the processes of technological and management changes to sustainable production of ecologically, socially and economically sound processes, products and services.

The results of the statistical analyses of the research´s quantitative empirical survey responses from thirty-six respondents from eleven of twenty-two basic and intermediate petrochemicals

manufacturing companies in the Brazilian context were used to obtain insights into corporate leader's awareness and on their willingness to lead their companies to make changes in GCE. These insights were used to:

- Measure the degree of willingness of Brazilian petrochemical companies to engage in GCE based eco-innovation processes, in the next five years, as a function of: (a) the managers´ attitudes towards such engagement, (b) the social and personal pressures with regard to the adoption of cleaner and more sustainable processes, products and services, and (c) the managers´ perceived control over the requisites and opportunities to engage in such GCE-based processes;
- Identify the main determinants of their willingness in the context of the research;
- Identify the most favorable conditions for their willingness to be transform into actions;
- Build upon the willingness determinants and on the best conditions for the chemical companies' leaders to act upon their willingness by developing recommendations for governmental, sectoral and corporate policies designed to enhance the probability of the implementation of GCE frameworks within the Brazilian petrochemical companies.

The most favorable conditions for willingness enhancement were found to be based upon managers´ perceptions within five of the nine behavioral domains included in this study: environmental risks, economic risks, social pressures, knowledge and technologies, and actors and networks. In parallel, the results of the statistical validation of the research´s behavioral model documented the plausibility and the adequacy of the proposed approach for eco-innovation studies and attested to its generalizability, thereby, making it utilizable in different industrial sectoral contexts.

As the second phase of the empirical information gathering, an in-depth qualitative survey, based upon face-to-face interviews with six companies' managers, one leader of the Brazilian Chemical Industry Association (ABIQUIM) and the two Environmental Protection Agency managers were performed to obtain deeper understanding of the implications and applications of the results obtained from this thesis research´s quantitative survey.

This phase of the research provided company leaders, who participated in the quantitative survey, the opportunity to review and reflect upon the researcher's findings from that survey. They were invited to reflect upon the actual and planned changes that their companies have made or are committed to make to transform their operations to be more environmentally and socio-economically sound as they continue on their sustainability journey.

In addition to corroborating the findings of the quantitative survey, the in-depth interviews provided evidence that Brazilian petrochemical companies have moved beyond intentionality to implementation of technical and non-technical policies, programs and supportive strategies for their on-going sustainability responsibilities.

With regard the use of GCE principles by the companies, the Chemical Manufacturer Association's (ABIQUIM) "Responsible Care" framework was found to be providing the stimulus for enhancing their awareness and commitment to make changes in accord with the GCE principles. It was found that although some of their changes were not explicitly based upon the GCE frameworks, many of their directives, guidelines and principles that have been incorporated within the company's institutional policies, goals, procedures and production processes match the GCE principles. Those types of behavioral changes were implemented in planned and structured ways and some were based upon intuitive insights for making the needed improvements. These findings documented the companies' strong willingness to engage in GCE-based eco-innovation processes that were predicted, based upon the findings of the initial quantitative study.

The qualitative survey also showed that future governmental efforts should address development and application of more efficient policies that seriously focus upon preventing or solving problems at their sources and not only or primarily upon treating the symptoms of the problems via "end-of-pipe" pollution control approaches after they occur.

The in-depth interviews underscored the central importance of partnerships comprised of companies, trade associations, governmental environmental agencies and non-environmental organizations for developing the climate, conditions and *stimul*i for the introduction, implementation and management of the GCE-based, technical and non-technical changes at the company and sectoral levels, and governmental levels. In addition, it revealed the importance of cooperative relations among relevant agents such as schools, universities, research centers, the press, suppliers, stockholders and customers.

The quantitative and qualitative surveys indicated the importance of ABIQUIM´s Responsible Care Program (RCP) as a key and fundamental instrument for promotion of implementation of GCE and GCE-based innovation processes in the Brazilian petrochemical industry.

The recommendations for policies and procedures based upon the statistically analyzed willingness determinants from the quantitative study were verified by the companies´ managers in the in-depth interviews. Therefore, the recommendations for policies aimed at accelerating the needed transitions include:

- **Environmental risk communication:** the EPA, ABIQUIM and the companies should co-work to improve their environmental risk communications to help company leaders to understand the risks of not changing and the business opportunities for them, which are evolving from "green markets" for more sustainably produced products, and services;
- **The use of ABIQUIM´s RCP:** the companies and ABIQUIM should make extensive and intensive use of the RCP to catalyze and enhance corporate changes toward sustainability. It should increasingly be built upon GCE-based eco-innovation principles and related international approaches;
- **Elements that were shown to be important and relevant in the generation and in the enhancement of willingness to eco-innovate in GCE:**
    - The accessibility to relevant information for knowledge generation;
    - The existence of mechanisms for knowledge integration;
    - The identification of technological opportunities;
    - The development of advanced innovation capabilities;
    - The availability of individuals holding key innovation and "change-agent" capabilities;

- The engagement in strategic alliances with actors that are external to companies´ realm, and
- The engagement in networks of collaboration aiming at eco-innovating in GCE.

Opportunities for future research include: (a) longitudinal studies of changes in the Brazilian petrochemical industrial sector, (b) benchmarking Brazilian companies with each other and with international front-runners, (c) innovation economics, and (d) agent-based computerized simulations.

This thesis author is convinced that there are many research opportunities to help to better understand the factors, which influence individuals´ attitudinal, social, personal, and behavioral intentions for implementing eco-innovative changes. Such research can create better understanding of the dynamics of environmental and economic changes within which more efficient and effective policies and strategies can be developed to more effectively catalyze the transition from GCE-based behavioral intentions into eco-innovative courses of action.

Samenvatting

In de petrochemie vindt men dat de ontwikkeling van schone producten, processen en diensten een basisvereiste is voor bedrijven om economische en ecologische duurzaamheid te bereiken in de 21e eeuw. Men is het er ook over eens dat innovatie essentieel is bij het verzoenen van belangen op de korte en lange termijn. Op de korte termijn speelt dan vooral het belang van winstgevendheid; op de lange termijn vooral het maatschappelijk belang van de gezondheid van werknemers en consumenten in een duurzame biosfeer. Daarin speelt echter een aantal aspecten en determinanten die het eco-innovatieve gedrag van bedrijven bepalen; die worden in dit proefschrift onderzocht bij bedrijven in de Braziliaanse petrochemie. *Icel Ajzen's Theory of Planned Behavior* (TPB), het daarop gebaseerde model van Montalvo Corral en het *framework van Systems of Innovation* (SSI) van Franco Malerba werden gebruikt als theoretische fundamenten. De volgende onderzoeksvragen stonden centraal:

- In hoeverre zijn petrochemiebedrijven in Brazilië bereid om te innoveren op basis van de *Twelve Principles of Green Chemistry* en de *Twelve Principles of Green Engineering* (tezamen aangeduid met GCE) als benaderingswijzen van duurzamer gedrag?
- Hoe kan hun bereidheid worden vastgesteld en verklaard, en welke zijn de belangrijkste determinanten van die bereidheid?
- Welke zijn in deze sector de belangrijkste actoren, mechanismen en acties bij de implementatie van GCE? Nu, en in de toekomst?

In dit onderzoek ging het specifiek om de mate waarin en de kracht waarmee deze bedrijven zich de komende vijf jaar willen inzetten voor eco-innovatie op het gebied van management en techniek. Die inzet zou deels voortkomen uit hun acceptatie en gebruik van GCE als een middel om veranderingen in techniek en management te bevorderen waarmee productieprocessen, producten en diensten schoner en duurzamer worden.

De determinanten van de bereidheid tot innoveren kwamen uit diverse domeinen, zoals milieu, economie, techniek, management, ondernemen, ethiek, moraliteit, instituties, de samenleving en het individu. Deze werden onderzocht als sleutelfactoren voor de mogelijke beleidsontwikkeling in bedrijven, sectoren en bij de overheid voor het bevorderen van eco-innovatieprocessen. Van zulk beleid werd een sterke invloed verwacht op de opname van GCE.

In het kader van dit onderzoek is een enquête gehouden die een respons opleverde van zesendertig respondenten uit elf van de tweeëntwintig bedrijven in de Braziliaanse petrochemie. De resultaten van de analyse van deze respons leverde inzichten in de bereidheid van leiders om in hun bedrijven voorop te gaan in bij eco-innovaties op het gebied van GCE. Op basis van deze inzichten was het mogelijk om:

- De mate van bereidheid te meten bij Braziliaanse oliemaatschappijen om actief te worden op het gebied van GCE en eco-innovatie, in de komende vijf jaar, afhankelijk van (a) de attitude van deze managers, (b) de sociale en persoonlijke druk waaraan zij bloot staan om dit te doen, en (c) de mate waarin managers denken dit te kunnen doen binnen de randvoorwaarden en hun mogelijkheden.

- De determinanten aan te wijzen van hun bereidheid in de context van dit onderzoek;
- De meest gunstige condities aan te wijzen waarin hun bereidheid kan leiden tot actie.
- Daarop voort te bouwen met aanbevelingen aan overheids-, sector- en corporate beleid om de kans op implementatie van GCE in de Braziliaanse petrochemie te vergroten.

De meest geschikte condities waaronder managers aan GCE willen gaan werken blijken te liggen in vijf van de negen gedragsdomeinen die in dit onderzoek onderscheiden worden: milieurisico, economisch risico, sociale druk, kennis en technologie, evenals actoren en netwerken. De statistische validatie van het gedragsmodel in dit onderzoek onderbouwde de plausibiliteit en de passendheid van de voorgestelde benadering van eco-innovatie. Daarmee blijkt het bedragsmodel dus toepasbaar te zien in de context van verschillende industriële sectoren.
In een tweede fase van informatieverzameling werden diepte-interviews gehouden met zes managers uit Braziliaanse oliemaatschappijen, één manager van de Vereniging van de Braziliaanse Chemische Industrie (ABIQUIM), en twee managers van het Braziliaans Milieuagentschap. Daardoor werd een dieper inzicht verkregen in de implicaties en mogelijke toepassingen van de resultaten uit de enquête. In deze fase kregen de bedrijfsmanagers die hadden meegedaan aan de enquête de gelegenheid te reflecteren op de bevindingen uit die enquête. Hen werd ook gevraagd te reflecteren op de feitelijke en voorziene veranderingen die hun ondernemingen in milieu- en sociaaleconomisch opzicht duurzamer maken. De diepte-interviews bevestigden de bevindingen uit de enquête, en leverden aanvullend bewijs dat petrochemische bedrijven in Brazilië verder zijn dan alleen de intentie om beleid, programma en strategieën te implementeren gericht op duurzame ontwikkeling.

Het ‘Responsible Care’ programma van ABIQUIM bleek het bewustzijn en de betrokkenheid bij bedrijven voor het toepassen van de principes van GCE te vergroten. Hoewel sommige van de veranderingen bij bedrijven niet expliciet gebaseerd zijn op toepassing van de principes van BCE blijken veel richtlijnen, instructies in het beleid en het productieproces dat wel te zijn. Het gaat om geplande en geprogrammeerde gedragsveranderingen; sommige waren gebaseerd op meer intuïtieve inzichten. Deze bevindingen lieten de sterke bereidheid bij bedrijven zien om GCE en eco-innovatie toe te passen, in lijn met de bevindingen uit de eerdere enquête.

De diepte-interviews lieten verder zien dat de overheid efficiënt beleid zou moeten ontwikkelen gericht op het voorkomen en oplossen van problemen aan de bron, en niet alleen op de aanpak van de symptomen met een ‘end-of-pipe’ benadering. Ook bleek samenwerking tussen bedrijven, brancheorganisaties, overheden en Ngo’s van belang voor het ontwikkelen van het klimaat, de condities en de prikkels voor veranderingen in afzonderlijke bedrijven, sectoren van het bedrijfsleven en bij overheden. Daarnaast blijken nog bredere samenwerkingsverbanden belangrijk te zijn met bijvoorbeeld scholen, universiteiten, onderzoeksinstellingen, de pers, toeleveranciers, aandeelhouders en klanten.

Zowel de enquête als de diepte-interviews lieten het belang zien van het Responsible Care programma van ABIQUIM. Dat is een sleutel en een fundamentele bouwsteen voor GCE en de daarop gebaseerde innovatieprocessen in de Braziliaanse petrochemie.

De statistische analyse van de enquête en de resultaten van de diepte-interviews liggen in elkaars lijn, en leiden tot de volgende beleidsaanbevelingen:

- **Milieurisico en communicatie:** het Braziliaans milieuagentschap, ABIQUIM en de bedrijven moeten samenwerken om de communicatie over milieurisico's te verbeteren, en de managers van bedrijven te helpen de risico's te doorgronden van een gebrek aan verandering, en het missen van kansen voor hun bedrijven welke voortvloeien uit de vergroening van markten, ofwel uit de toenemende vraag naar duurzaam geproduceerde producten en diensten.
- **De toepassing van Responsible Care:** de bedrijven en ABIQUIM moeten meer en beter gebruik maken van het responsible care programma om veranderingen in bedrijven teweeg te brengen die bijdragen tot een duurzame ontwikkeling. Dit zou moeten gebeuren met eco-innovatie en internationale benaderingen die gebaseerd zijn op GCE.
- **Belangrijke elementen ter bevordering van de bereidheid tot eco-innovatie en groene chemie:**
    - De toegankelijkheid van relevantie informatie over groene chemie;
    - Het bestaan van mechanismen voor de integratie van kennis;
    - Het identificeren van technologische kansen;
    - Het ontwikkelen van innovatievaardigheden;
    - Individuën met belangrijke innovatie-vaardigheden, in de rol van 'change-agent';
    - Strategische allianties tussen bedrijven en externe actoren, evenals
    - De deelname in netwerken voor eco-innovatie in groene chemie.

Toekomstig Onderzoek zou zich moten richten op (a) longitudinale analyse van veranderingen in de Braziliaanse petrochemie, (b) het benchmarken van Braziliaanse bedrijven, en het vergelijken van hun prestaties met die van voorlopers wereldwijd, (c) de economie van innovatie, en (d) computersimulaties van het gedrag van individuele actoren.
Deze auteur is ervan overtuigd dat er veel mogelijkheden zijn voor verder onderzoek naar individuele gedragsfactoren - sociaal en persoonlijk, naar intenties en feitelijk gedrag – in relatie tot eco-innovaties. Zulk onderzoek kan leiden tot een beter begrip van de dynamiek van milieu- en economische veranderingen en de rol daarin van efficiënter en effectiever beleid en strategie voor de omzetting van gedragsintenties in eco-innovaties.

Table of Contents

List of Figures

List of Tables

LIST OF Boxes

Acronyms and Abbreviations

:	Page citation
α	Cronbach alpha
$\sum ak_b$	Scale to assess perceived access to knowledge
$\sum app_b$	Scale to assess perceived appropriability[1] of innovation
$\sum avc_b$	Scale to assess perceived availability of actors holding key capabilities
$\sum cmt_b$	Scale to assess perceived knowledge cumulativeness
$\sum cp_b$	Scale to assess perceived community pressure
$\sum ecr_b$	Scale to assess the perceived economic risk and business opportunity
$\sum evr_b$	Scale to assess perceived environmental risks
$\sum inst_b$	Scale to assess perceived institutions
$\sum mp_b$	Scale to assess perceived market pressure
$\sum nwc_b$	Scale to assess perceived networks of collaboration
$\sum pn_b$	Scale to assess perceived personal norm pressure
$\sum rlp_b$	Scale to assess perceived professional roles pressure
$\sum rp_b$	Scale to assess perceived regulatory pressure
$\sum sac_b$	Scale to assess perceived strategic alliances with external actors
$\sum si_b$	Scale to assess perceived self-identity pressure
$\sum to_b$	Scale to assess perceived technological opportunities
$\propto$	Proportionality between two scores
A	Attitude towards the behavior
ABIQUIM	Brazilian Chemical Industry Association
ak_b	*b*th belief of perceived access to knowledge
AN	Actors and networks
app_b	*b*th belief of perceived appropriability of innovation
avc_b	*b*th belief of perceived availability of actors holding key capabilities
BLS	Baseline scenario
BRIC	Refers to Brazil, Russia, India and China: a group of countries with emergent economies
CCPA	Canadian Chemical Producers Association
CGE	Green chemistry and green engineering
cmt_b	*b*th belief of perceived knowledge cumulativeness
cp_b	*b*th belief of perceived community pressure
ECR	Economic risk and business opportunities
ecr_b	*b*th belief of perceived economic risk and business opportunity
EPA	Environmental Protection Agency
EV	Expectancy value model
EVR	Environmental risk perception
evr_b	*b*th belief of perceived environmental risks

[1] This word, although not included in a standard dictionary, is used in the literature of technological innovation to denote the capacity to appropriate the benefits derived from an innovative activity (Montalvo Corral, 2002: 110), and will be used in this research.

F	Statistical F test to identify if the model best fits the population from which the data were sampled
GPS	Global Product Strategy
ICCA	The International Council of Chemical Associations
INST	Institutions
$inst_b$	*b*th belief of perceived institutions
ISO	International Organization for Standardization
KTC	Knowledge and technologies
LCA	Life Cycle Analysis
MERIT	Maastricht Economic Research Institute Innovation Technology
mp_b	*b*th belief of perceived market pressure
NAS	National Academy of Sciences
nwc_b	*b*th belief of perceived networks of collaboration
OECD	Organization for Economic Co-operation and Development
PBC	Perceived behavioral control
PN	Personal norm pressure
pn_b	*b*th belief of perceived personal norm pressure
PSFP	Perceived social factors pressure
R&D	Research and development
R^2	Coefficient of determination
RCP	Responsible Care Program
RLP	Professional roles pressure
rlp_b	*b*th belief of perceived professional roles pressure
rp_b	*b*th belief of perceived regulatory pressure
RTC	Rational Choice Theory
S	Sustainability
sac_b	*b*th belief of perceived strategic alliances with external actors
SD	Sustainable development
SE	Standard error
SI	Self-identity
si_b	*b*th belief of perceived self-identity pressure
sig	Statistical significance
SP	Social pressure
SSI	Sectoral System of Innovation
TIB	Theory of Interpersonal Behavior
to_b	*b*th belief of perceived technological opportunities
TPB	Theory of Planned Behavior
TRA	Theory of Reasoned Action
UNEP	United Nations Environmental Programme
USEPA	United States Environmental Protection Agency
W	Willingness to innovate in Green Chemistry and Green Engineering
WBCSD	World Business Council for Sustainable Development

1. Introduction

> "The world needs more chemistry. Our science has brought remarkable progress to society—and created problems along the way. Yet today's chemists are the key to solving environmental problems. Looking forward, the challenge is to discover additional pathways to chemical products and processing which will enhance and sustain the quality of life around the world." (J. Lawrence Wilson)[2]

The conception, development and implementation of technological change towards advanced states of sustainability of its products, processes and services, in the Brazilian petrochemical sector, has not been and does not represent an easy achievement. The contextual factors of many different natures represent influential determinants for such changes. Identifying significant determinants of Brazilian petrochemical companies´ willingness to engage in Green Chemistry and Green Engineering-based eco-innovation processes represents a contribution to the long journey towards the development of the next generation of a more environmentally benign petrochemical sector.

At the onset of this thesis research, the author expressed his expectation to contribute to the solution of the dilemma that was highlighted by the Committee on Grand Challenges for Sustainability in the Chemical Industry, which was convened by the United States National Academy of Sciences. It concluded, in its December 2005 report, that in "going forward, the chemical industry is faced with a major conundrum, the need to be sustainable (balanced economically, environmentally, and socially in order to not undermine the natural systems on which it depends), and the lack of a more coordinated effort to generate the science and technology to make it all possible" (Wilson *et al*., 2006, 52).

1.0 Societies versus the Chemical Industry: a Long Standing Environmental Debate

For more than a century, the petrochemicals manufacturing industry has occupied a central role in socio-economic domains of western societies. It is virtually impossible to conceive of contemporary and envisioned future societies, in the developed and developing economies, without the presence of the chemical industry and its related contributions to the socio-economic development and welfare of nations and people.

Unfortunately, the chemical industry has also caused significant disasters globally. Its other face emerges from the sector´s unfavorable characteristics of being a major biosphere-polluting agent[3] and from its reliance on the use of finite nonrenewable natural resources as sources of materials and energy inputs for its production processes.

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[2]. Wilson, J.L. (1996), *Synergy* (editorial), *Chemical and Engineering News,* June, 3rd, American Chemical Society (cf. Vision 2020, 2001).

[3]"Biosphere: irregularly shaped envelope of the earth's air, water, and land encompassing the heights and depths at which living things exist. The biosphere is a closed and self-regulating system, sustained by grand-scale cycles of energy and of materials—in particular, carbon, oxygen, nitrogen, certain minerals, and water. The fundamental recycling processes are photosynthesis, respiration, and the fixing of nitrogen by certain bacteria. Disruption of basic ecological activities in the biosphere can result from pollution". (The Columbia Encyclopedia, Sixth Edition. Columbia University Press. 2004).

These characteristics, in association with the dominant capitalist tenets and practices of constant expansion and continuous growth, in a world of limited resources, have generated conflicts with the broad, socio-environmental interests of societies. Additionally, these production practices and the current technological regimes also put the petrochemical sectors´ long-term survival at risk by depleting the ecological, human, social and organizational capitals that are basic and essential for its functioning and survival.

As a result, a longstanding debate was started in the late 1960s in the political, academic, governmental and broad societal spheres with regard to a variety of issues, which were enveloped within the sustainability (S) and sustainable development (SD) debate. Such topics included the limits to economic growth and the interactions and interdependence between industry and the environment. The debates also included discussions over the use of economic development models that take into consideration the depletion of natural resources, the resilience capacity of the environment, the finitude of the natural capital, the limitations imposed by biophysical laws, and societal wellbeing (Georgescu-Roegen, 1971, Jiménez Herrero, 2001). A complementary reading on these issues as wells as some views on environmental sustainability in the industrial sector and the importance of greener production processes are presented in Appendix I.

> "Development of *what*? Development for *whom?* Development of every man and woman—of the whole man and woman—and not just the growth of things, which are merely means. Development geared to the satisfaction of needs beginning with the basic needs of the poor who constitute the world's majority; at the same time, development to ensure the humanization of man by the satisfaction of his needs for expression, creativity, conviviality, and for deciding his own destiny" (*Dag Hammarskjöld Foundation,* 1975: 9).

This debate produced global sustainability aspirations that have their foundations on the change of societal perceptions that grew as a product of four decades of observation and discussions. Such perceptions led societies to a clearer view of the interrelations between the socio-economic and the ecological-environmental processes that, according to Jiménez Herrero (2001), are grounded on:

a) The perception of a global environmental change dynamics (planetary scale), motivated mainly by human actions based on economic nature that are supported by a dominant and unsustainable system;
b) The reaction and strategic adaptation of the socioeconomic system, in harmony with the dominant economic forces and interests, to the global environmental planetary and social changes generated by themselves;
c) The beginning of a structural transformation process which now appears in the integration between environment and development and between economy and ecology under a common platform of global sustainability; and
d) The visualization of a paradigmatic change in what the environmental (economic and social) challenges are concerned (new paradigms), as well as changes in the conventional theories related to development and economy fully incorporating the SD and ecological economy concepts.

In this context, the societal perception of the chemical sector as a major polluter and natural nonrenewable resources consumer generated strong disputes and tensions between societies, the chemical industries and governments.

After about forty years of disputes and pressures, the evolution of knowledge and the understanding of the severity of the impacts of the chemical industry on the biosphere and on the socio-economic realm have changed the perception of the chemical industrial sector with regard the relations between the industry and societies´ long term socio-environmental aspirations. Currently, there are many signs that the sector acknowledges the need for cleaner and more sustainable (environmentally, socially and economically) products, processes and systems.

Currently, the major chemical companies' and chemical industry trade associations' web pages or their official declarations of intentions towards societal relations and wellbeing, display their commitment to S and SD. Besides statements on economic and market issues, they profess their commitment to environmental and social causes as core values in their business. This reflects not only on their desire for business success and perpetuation, but it also reveals a search for societal legitimacy and acceptance *via* a tacit societal license to operate, which is primarily based on environmental, ethical and moral values.

Without it, it is extremely difficult for a corporation to endure in modern societies since, besides the tangible costs associated with legal litigations and with environmental protection, companies are also affected in the concealed intangible costs that are represented by their market values, such as their image, which is of uppermost value.

Companies´ image and reputation[4] are of intangible value and have direct impact in one of the most precious corporate assets: their brand. The lack of societal credence makes companies extremely vulnerable (ENDS, 2005). Today, societies expect companies to take legal and moral responsibility for their negative environmental impacts. It is important to remark that, once negative environmental impacts are widespread in obvious or in latent forms, they can have vast impacts for very long periods. This has profound effects on the environmental and socio-economic space and may deeply affect the continuity of the chemical industry.

1.1 Innovating in Green Chemistry and Green Engineering: A Way to Reconciling the Petrochemical Industry´s Interests and Societal Environmental Self-Interests

Although the evolution of the petrochemical industry-society relations over socio-environmental issues has undisputedly occurred, there are signs that the promotion of satisfactory structural changes, at the company and sector levels, for the development of the next generation of chemical enterprises is still in its infancy. According to Montalvo Corral (2002), one of the core arguments that can explain such a lag between intention and pro-environmental[5] action is represented by the conflict between individual interests in the short term, with long-term individual and social interests.

[4] Research has demonstrated that between 50 and 90% of a company's market value can be attributed to reputation and other intangibles (Blackburn, 2007).

[5] "Most cases of **environmental behavior** can be, based on the knowledge of environmental science or ecology, judged according to their impact on the environment, and labeled as environmentally friendly or unfriendly. (…) **Pro-environmental behavior** is such behavior which is generally (or according to knowledge of environmental science) judged in the context of the considered society as a protective way of environmental behavior or a tribute to the healthy environment" (Krajhanzl, 2010: 252. Bold added).

In this respect, the main argument of this thesis is that a clear understanding of the factors that can contribute to promoting behavioral changes, related to the preservation of the environment and the creation of economic and social welfare, represents a powerful approach in helping planners and decision- makers to foster the industrial transition processes to more sustainable states

In the extensive universe of possibilities that can help to promote the convergence of industry´s and societies' broad self-interests regarding the environmental protection, this thesis researcher explored the identification of important contextual determinants of pro-environmental behavior that can explain why firms might leave well-established routines and switch to highly uncertain technological innovation processes. That is, a change from current consolidated technological regimes to the development of new ways of producing goods and services, which are socially, environmentally and economically more sustainable.

1.1.1. Environmental and Socio-Economic Sustainability of the Industrial Sector: Why to Intervene and Promote Technological Changes in the Production Processes

Section 1.1.1 presents an analysis of some of the connections and aspects involved in the relationships between the industrial (petrochemical) sector and its surrounding environmental, social and economic landscapes.

It centers the analysis on the sector´s environmental sustainability and sustainable development, at its core activity (i.e. product synthesis) represented by the production processes.

This allows for a justification of the importance of the continuous promotion of innovation and technological changes in the petrochemical domain. These changes are essential for the development of cleaner and environmentally and economically more sustainable products and production processes.

By placing the production processes at the center of the analysis, this section was designed to show the extent to which it influences and is influenced by the various types of variables (environmental and socio economic capitals) involved in the creation of economic and social welfare and utility.

The Relationships between the Industry´s Production Processes, Welfare Creation and Sustainability

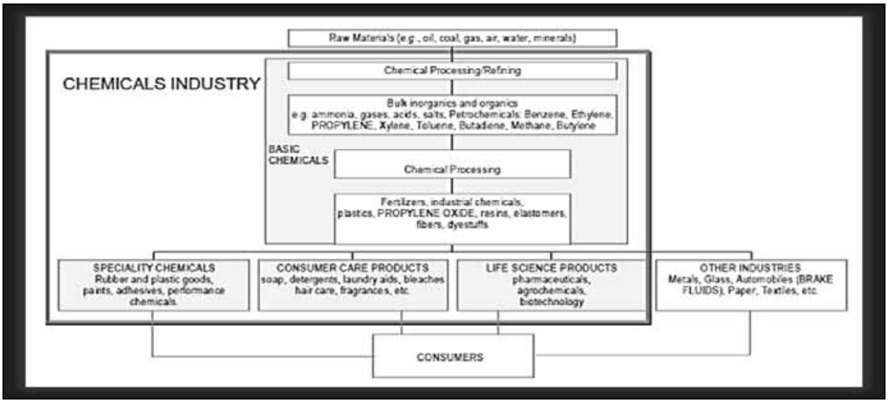
The size of the chemicals market, the chemical industry's strategic importance, its intrinsic capacity to fulfill societies' material needs, its power of generating and maintaining millions of direct and indirect jobs worldwide, and its capacity of generating revenues, make it a solid, vigorous, economically and politically powerful business worldwide. A collapse of or a strong decay in the chemicals industry's activities could generate enormous socio-economic problems.

Nevertheless, besides its evident social, economic and political power and its importance, the industry has two vulnerable points that constitute threats not only to its economic sustainability but also for the sustainability of the environment and societies: (a) its dependence on nonrenewable materials and energy sources and (b) its present extensive environmental polluting power and the negative impacts upon human health, upon the economy and upon the biosphere as a whole as a consequence of its operations.

Figure 1.1 provides an overview of the chemical and petrochemical industries´ materials flows from raw materials through consumer gods.

Without making much consideration about the industry´s current material recycling capacity and potentialities, it can be argued that its activities are sensitive to unbalances and decays in quantity (availability) and quality of natural feedstock's inputs.

Figure 1.1- Overview of the chemical industry from raw materials through to consumers goods and services



Source: OECD (2001: 23)

This indicates that sustainability and sustainable development issues in the chemicals industry apart from its relations to employment and other socio-economic, legal, ethical etc. aspects, it is dependent on:

a) The capacity of nature of providing feedstock and energy sources of renewable character;
b) The biosphere's capacity to absorb the industry´s residues and
c) The industry's capacity of not polluting and destroying the biosphere's life support systems.

One way that is useful for the clarification and for the understanding of this mutual dependency is to observe the influences, the behavior and the relationships (feedback loops) of the environmental and socio-economic variables in the light of economic and social welfare and utility creation by the sector´s productive and service activities.

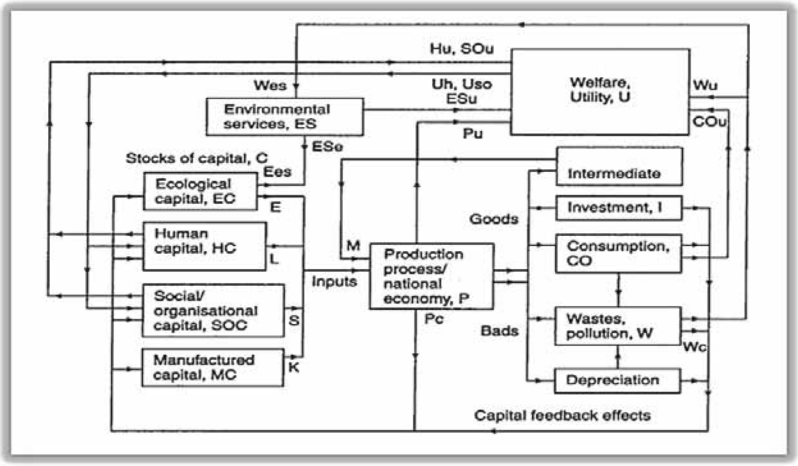
In this thesis, this was done *via* the use of the model that diagrammatically links a production function to a utility function. This model was proposed by Paul Ekins (2000) and is presented in Figure 1.2.

Ekins[6] (*ibid*), described the process of economic and social welfare and utility creation in terms of the linear and feedback cause and effect relations between the stocks of the

[6] The description of the model, used in this section, was extracted from Ekins (2000: 52 through 56)

different capitals and flows of services that are inputs to the production processes. Social welfare and utility are also described in terms of the stocks and flows that are generated as outputs of these processes.

Figure 1.2- Welfare and utility creation process by the industrial production processes according to Paul Ekins



Note: In the flow descriptors, the upper case letters denote the source of flow, the lower case letters denote destination. (Ekins, 2000: 53)
Source: Ekins (2000)

Each relationship and feedback presented in the model constitutes a part of a system of complex interactions between different variables. In order to maintain this exposition at a simple level and to attain the objectives of this discussion, a linear analysis of these relationships between these variables (represented as letters in the diagram) was conducted by Ekins (2000) and is presented in the following paragraphs.

It is useful to note that, with regard to matter, energy and entropic states, Ekins (*ibid*) is in agreement with Daly (1987), Georgescu-Roegen (1971), Hueseman (2003), McMahon and Mrozek (1997) and Smoulders (1995) about the limitations imposed by the biophysical laws (e.g. the first and second laws of thermodynamics) to economic growth and about the hierarchal relations between the economy and the environment.

He argued that the system depicted by the model can be regarded as a closed system, *i.e.* there is the absence of matter exchange through the system's boundaries at the same time that energy flows, received from the sun, permeate these boundaries and heat is radiated back into space. High-grade energy (low entropy) that is used as input into the production will emerge as low-grade energy (high entropy).

According to Ekin´s model, the creation of welfare and utility by the production processes depend on the stocks of four different capitals and on the contribution of the intermediates generated by the production processes. Each of them provides flows of services that are used as inputs to the production processes in the following manners (cf. Figure 1.2):

- **Ecological capital (*EC*)** - provides three sets of environmental services. Two of them have direct influence on the production processes. The first (***E***), provides resources (raw materials) for production and the second provides the capacity for the absorption/transformation of wastes (***Wc***). Where these wastes add to improve the stock of ecological capital (e.g. through recycling), they can be regarded as investment in such capital. "The third type of environmental functions (or services) does not contribute directly to the production, but it is also very important because it provides the basic context and conditions within which production is possible at all" (*ibid*: 54). This third class of services is produced directly from the environmental capital independently of the human activities but it is surely affected by them. They comprise the basic environmental services (***ES***) that include "survival services" (*e.g.* climate and ecosystem stability, ozone layer protection against ultra-violet radiation from space etc.) and "amenity services" that provide beauty of wild areas and other natural areas.

- **Human capital (*HC*) and human capital services (*L*) -** represent the human's capacities for work and can be seen to include aspects such as knowledge, skills, health and motivation;
- **Social/organizational capital (*SOC*) and services (*S*)** – comprise the network of organizations through which the individuals´ contributions are coordinated. While human capital is intrinsically related to the human associated issues (e.g. characteristics, capabilities, perceptions, beliefs etc.) social and organizational capital is associated with the way they interact.
- **Manufactured capital (*MC*) and services (*K*)-** represent the material assets (*e.g.* machines, buildings, infrastructure) that contribute to the production processes but are not embodied in the outputs and are usually consumed in periods of time greater than one year; and
- **Intermediates (*M*)** - represents outputs from other processes that are used as inputs in subsequent processes. They are either embodied in the outputs (*e.g.* plastics, metals etc.) or are immediately consumed in the production processes (*e.g.* fuels).

According to Ekins (*ibid*), the outputs of the production processes have favorable and unfavorable sides. This can be understood by observing their influences and effects upon the environment, humans, organizations, societal assets and on economic and social welfare and utility. According to Figure 1.2, outputs generated by the production processes are categorized as "goods" (desired) and "bads" (undesired).

Under the heading of "goods", it can be found the desired outputs from the production processes as well as positive externalities associated with them. The "goods" are comprised of Consumption (***CO***), Investments (***I***) and the Intermediates (***M***) that are used as inputs to other subsequent processes in the economy. Note that, although consumption promotes a direct contribution to welfare (***COu***) it also has its downside in the extent that consumption (***CO***) generates pollution and wastes.

The undesired outputs from the production processes (***P***) that cause negative environmental, social and economic impacts represent the "bads". They are comprised of the unfavorable and undesired outputs as well as of any negative externalities, associated with them that contribute to the environmental decay and represent threats to human health, economy and welfare. They are presented in Ekins´ model as depreciation and as the wastes (***W***) generated by the production processes. In parallel, "bads" can be considered negative investments because they negatively affect the capital stocks.

It is important to note that these outputs, “goods” and “bads”, have direct influences on the ecological (***EC***), human (***HC***), social/organizational (***SOC***) and manufactured (***MC***) capitals *via* the establishment of circular flows (feedback loops).

In relation to the environment, the disposal of the “goods” and “bads” outputs incur in their return to the ecological capital (***EC***), where they may have positive, negative or neutral effects on the environmental services (***ES***).

The influences related to the generation of wastes can directly affect economic and social welfare and utility (***Wu***) by the production of undesired aspects (pollution, heat, noise etc.) or indirectly (***Wc***) by:

- Reducing the productivity of the environmental resources (***EC***) and affecting the environmental services (***Wes***). This promotes the unbalance in the circular relations of the ecological capital services (***Ees***) and the environmental services (***ESe***);
- Affecting the social/organizational capital (***SOC***);
- Damaging the human capital (***HC***) *via* threats to human health, and
- Promoting decays to manufacturing capital (***MC***) by damaging material assets.

It is also important to note that, besides the contributions from the work processes (***Pu***), from consumption (***COu***) and from the environmental services (***ESu***) in the development of economic and social welfare, it is important to note that it is also a function of social and organizational structures (***SOu***) (e.g. family, organizations etc.). Social and organizational aspects are, in turn, affected reciprocally by the level of the individuals´ welfare (***Uso***).

Human and social capital stocks are also sensitive to the outputs from the work process (***Pc***). According to Ekins (*ibid*: 55), human capital and welfare also relate in a reciprocal fashion: “a happy worker will be more productive (***Uh***) and a healthy worker will be happier as well as more productive (***Hu***)” (*ibid*: 55).

In conclusion, it can be argued that Ekins´ (2000) model provided a good view of the roles, the influences, and the relations of the production processes with the environmental and socio-economic variables that are central to the industry´s sustainability. Additionally, it clarified the relationships of the diverse variables within the industrial-societal domain, such as the production processes, and the associated social, economic and organizational elements. These elements provide opportunities to intervene in order promote the eco-innovative technological and managerial changes that are essential to achieve greener and more sustainable technologies, products and services in order to help society to make progress toward sustainable development.

Cleaner Products and Process Technologies within the Production Processes: an Important Contribution to the Industrial, Societal and Environmental Sustainability

Ekins´ (*ibid*) model (system) provided a conceptual base for the understanding of the importance of the production processes in societal welfare creation. It was equally useful for enhancement of the understanding of how the involved feedbacks (positive and negative) relations may produce advantageous and disadvantageous outcomes to the environment, to individuals and to the social structures in a chain of linear, non-linear and complex cause and effect relationships. It is important to note that this helps industrialists and other stakeholders to better understand the dimensions and the mutual interactions of the production processes with environmental and socio-economic factors.

It is important to underscore that the analysis of Ekins´ model explains and confirms the aforementioned perceptions regarding two central vulnerable points of the chemicals industry: the sector´s dependence on nonrenewable materials and energy sources and its present polluting potential constitute threats to both the industry´s as well as to societal sustainability.

A sustainable form of industrial development is intrinsically associated with industry´s capacity to develop cleaner and more sustainable technologies for processes, products and services. They are required to be less polluting, less dependent upon nonrenewable sources of materials and energy at the same time that they must become increasingly eco-efficient, eco-effective[7] and be in harmony with socio-economic-environmental dimensions.

Based on Ekin´s model, it can be argued that the promotion of technological changes aimed at production processes and upon products and services, in the chemicals industry, *via* the development and introduction of cleaner and more sustainable products and process technologies, is an important strategy to help to take industry to advanced states of sustainability.

Such advancements are expected to promote the creation of economic and social welfare and utility under conditions that can preserve and improve the environment and develop the social, organizational, human and manufactured capitals. As previously noted, this coincides with the core objective of this thesis researcher of identifying important variables (*inter alia* environmental, social, organizational, human, economic) that may represent drivers for companies in the Brazilian petrochemical sector to engage in eco-innovation activities. Such activities are intended to develop and to promote the acquisition and implementation of innovative cleaner and more sustainable technologies that are based on the principles of Green Chemistry and Green Engineering (GCE) (cf. Chapters 4 and 6).

GCE constitutes a way of doing chemistry and engineering in a more environmentally sustainable fashion (Anastas and Warner, 1998). According to the experts in the chemical industry, GCE represent very important routes and powerful approaches for meeting the petrochemical industry´s environmental and economic sustainability challenges (National Academy of Sciences, 2006; Wilson *et al*., 2006). The fundamentals of GCE that make them important for the "new" and more environmentally sustainable chemical industry and society are reviewed in Chapter 2.

[7] For an explanation of the concepts of eco-efficiency and eco-effectiveness refer to notes 21 in Chapter 2, and note 67 in Chapter 4.

Innovating in Green Chemistry and Green Engineering: A Powerful and Viable Approach towards Advanced States of the Petrochemical Sector

Among the many technological approaches and directions for technical change that have been proposed worldwide, this thesis research incorporated, as its *focus* of study, the promising approach proposed by the principles of Green Chemistry and Green Engineering (GCE) frameworks for the design of the synthesis of more benign chemicals, production processes and services.

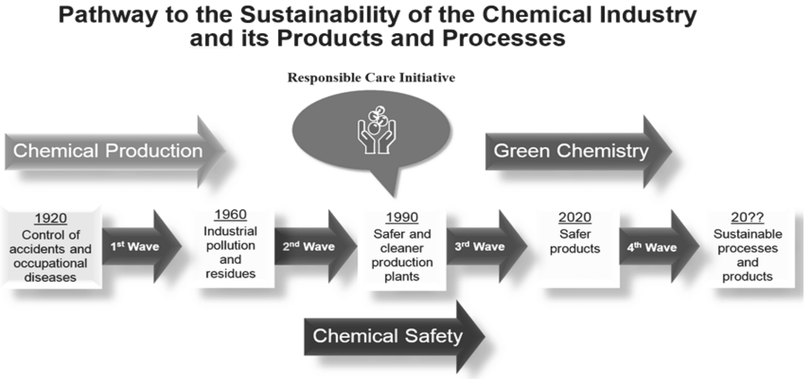
> "Green Chemistry is the design, development, and implementation of chemical products and processes to reduce or eliminate the use and generation of substances hazardous to human health and the environment. It is an innovative, non-regulatory, economically driven approach toward sustainability. The unequivocal value of Green Chemistry to the business and to the environment is illustrated through industrial examples. Green Chemistry must be recognized for its ability to address sustainability at the molecular level." (Manley *et al.*, 2008: 743)

> "Green Engineering, defined as the design of systems and unit processes that obviate or reduce the need for the use of hazardous substances while minimizing energy usage and the generation of unwanted by-products, is the next generation of environmental protection in chemical engineering." (Anastas *et al.*, 2000b: 1)

In this respect, GCE represents design frameworks that provide guidance for companies to overcome one of the main problems in the chemical industry, which, according to ENDS (2005) is the failure to address the single most important step chemical companies can take to make their facilities less vulnerable to accidents and attack - using inherently safer chemicals and technology (ENDS, 2005).

The idea of developing of the next generation petrochemical sector, *via* the principles of Green Chemistry and Green Engineering (GCE), inexorably connotes the sense of something that has not yet been created nor developed. This work advocates that at this statement´s most basic level resides the need for innovating. "The future cannot be predicted, but futures can be invented (Gabor, 1963: 18).
Figure 1.3 highlights how the Brazilian Chemical Industry Association places GCE in the journey to the sustainability of the chemical industry and its products and processes.

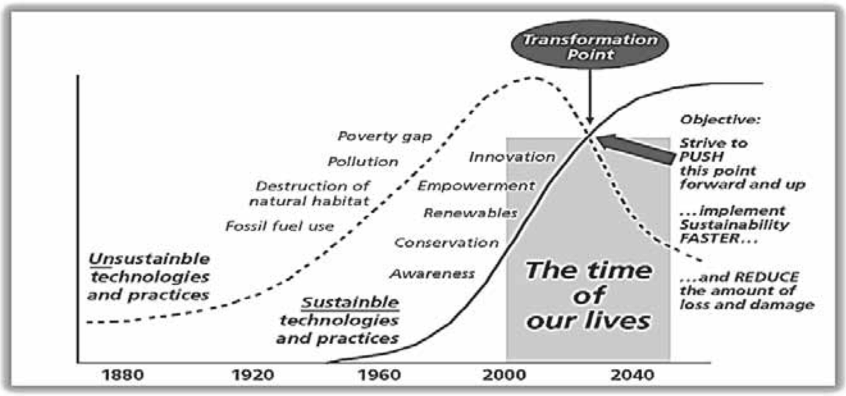
Figure 1.3- Pathway to the sustainability of the chemical industry´s products and processes



Source: adapted from ABIQUIM[8]

Atkisson´s (2010) "Hope Graph" (Figure 1.4) illustrates the aspirations towards eco-innovation and technological change that are part of the long journey in the direction of increasingly more advanced states of sustainability.

Figure 1.4- Alan Atkisson´s hope graph towards sustainability



Source: Alan Atkisson (2010)

The promotion of technological change aimed at more advanced states of sustainability, *via* the engagement of companies in GCE-based eco-innovation activities belongs to the class of initiative that, according to Montavo Corral (2002: 2), "are problematic to implement at the societal level. If implemented at all, this occurs after the ideas overcome a long chain of resistance to change from individuals and organizations". In addition, there is a significant gap between the intent and its operationalization (*ibid*).

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8 Source: ABIQUIM https://www.google.com.br/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CC4QFjAA&url=http%3A%2F%2Fwww.desenvolvimento.gov.br%2Farquivos%2Fdwnl_1295883074.ppt&ei=Jsg1UrCkDYPU8wSzt4DQCQ&usg=AFQjCNHV-oBef4nRZDBtn_OzeNzB0v8TvA&bvm=bv.52164340,d.eWU. Accessed in August 2013.

In the context of this thesis research, overcoming long chains of resistance to innovating in GCE and diminishing the cognition-action gap implies the promotion of changes. Such changes, towards sustainability, should be effected in the perceptions, beliefs[9], and ultimately in the behavior of companies.

In this respect, the identification of variables (determinants) and conditions that can influence, explain and ultimately determine such behavioral changes must be based upon a robust theoretical framework. Such theoretical grounds should support the integration of the behavioral theory into the innovation domain and its associated theoretical grounds.

By understanding, predicting and explaining these influences on the development of companies´ intention (willingness) to engage in GCE-based innovation processes aimed at promoting the sustainability of the companies and biosphere, it is expected that this work will contribute to diminish the "somewhat strange neglect of the behavioral aspects related to the innovation process" (Beckenbach and Daskalakis, 2008: 181).

In contrast to situations in which innovation is seen purely as an economic activity, this thesis research contributes to the field of behavioral economics, which "uses evidence of psychology and other disciplines to create models of limits on rationality, willpower and self-interest, and explores the implication in economic aggregates" (Camerer, 2006: 181).

1.2 The Behavioral Model and this Research´s Qualitative Survey Questionnaire

In order to systematize and operationalize the theoretical grounds that underpin this thesis objective to identifying the variables (determinants) and conditions that can influence, explain and ultimately determine companies´ engagement in GCE-based eco-innovation processes, a structural descriptive behavioral model was proposed. It occupied a central place in the theoretical structure of this work by incorporating and intertwining several contributing theories that can help to explain the pro-behavioral intention formation.

The model, at its most basic level, merges the two main theoretical bodies of this thesis research: (a) Icek Ajzen´s (1991) "Theory of Planned Behavior" (TPB), and (b) the Franco Malerba´s (2002, 2004) Sectoral System of Innovation (SSI) framework. It also included elements of Harry C. Triandis´ (1977) "Theory of Interpersonal Behavior" (TIB) and the concept of personal moral norms (Schwartz, 1977). The model represented a modified version of Montalvo Corral´s (2002) TPB based structural descriptive behavioral model for explaining environmentally innovative behaviors (eco-innovations).

The TPB is a social psychology based behavioral theory in which the "true goal of the theory is explaining human behavior, not merely predicting it" Ajzen (1991: 189). The theory postulates that the behavioral intention is the immediate predecessor of actual

[9] "Contemporary analytic philosophers of mind generally use the term "belief" to refer to the attitude we have, roughly, whenever we take something to be the case or regard it as true (…) Forming beliefs is thus one of the most basic and important features of the mind, and the concept of belief plays a crucial role in both philosophy of mind and epistemology". Schwitzgebel, E. (2006), *Belief*, in Edward N. Zalta (ed.), The Stanford Encyclopedia of Philosophy, Stanford, CA (http://plato.stanford.edu/entries/belief/). Accessed in October, 2012)

behavior performance. That is, the TPB framework postulates that performing a specific behavior is mediated by the behavioral intention.

The behavioral intention is in turn directly influenced by three behavioral constructs: attitudes (*A*), subjective norms (*SN*) and (*PBC*) perceived behavior controls. A specific behavior is considered explained once its determinants have been traced back to its underlying beliefs (Montalvo Corral, 2002).

In order to establish a link between the behavioral intention and its underlying beliefs, this thesis researcher´s behavioral model was developed to include a third level of explanation regarding the behavioral domains.

According to Ajzen (1988), behavioral domains are defined as the specific areas of experience and knowledge from which salient beliefs arise. In the process of construction of the model, the antecedents of the main components of the model were traced to the underlying beliefs and a variety of bodies of literature were drawn upon to operationalize beliefs. Such a procedure was possible due to the *meta* theoretical characteristic of the TPB.

For the purposes of this thesis research, these behavioral domains were defined as:

Environmental risks	Roles	Knowledge and technologies
Economic risks	Personal norms	Actors and networks
Social Pressure	Self-identity	Institutions.

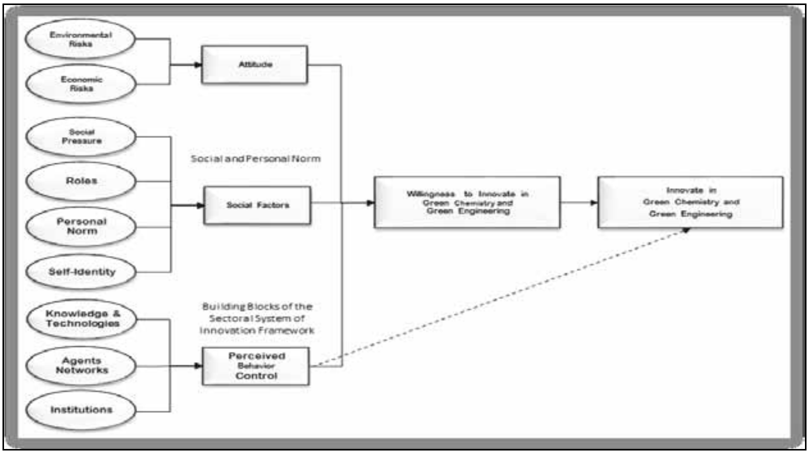
Thorough descriptions and analyses of the beliefs associated with these behavioral domains are presented in Chapter 5.

The examination of the three constructs that influence intention-behavior is fundamental for reaching the predictive reliability and the understanding of any behavior (*ibid*).

The *PBC* represents the TPB construct that accounts for the explanation and prediction of behaviors that are not under volitional control. The SSI framework was introduced in the *PBC* construct as a means to evaluate firms' control over the requisites and opportunities required to engage in GCE-based eco-innovation processes.

The meta-theoretical characteristic of the TPB allowed for the integration of various bodies of theory into the model. This provided great flexibility in the sense that the model can be constructed or "modified according to the needs of the study, instead of allowing the study to be molded according to the possible rigidities of the models" (Montalvo Corral, 2002: 113). Figure 1.5 shows a simplified outlook of this thesis research´s behavioral model.

Figure 1.5- Outline of the thesis research´s structural descriptive model.



Source: author

In this thesis research, the TPB based behavioral model was operationalized in "real world" situations to capture perceptions of individuals relative to their perceptions regarding their companies´ engagement in GCE-based eco-innovation activities.

In order to operationalize the behavioral model, a structured questionnaire was constructed, based on the behavioral model´s constituting elements. The application of the questionnaire to firms in the Brazilian petrochemical sector generated the empirical data. That data, in addition to providing information for the identification of the determinants or barriers for companies to engage in GCE-based eco-innovation activities, they were also required for testing the reliability of the questionnaire and the statistical validity of the model.

Although the results of this thesis research´s qualitative survey provided clear insights on companies' willingness and its determinants, it lacked knowledge on managers´ underlying motivations for the development of such willingness and on the relations between the company and the sector levels regarding the promotion, diffusion, and the implementation of GCE-based initiatives in the Brazilian petrochemical context.

In order to overcome this shortcoming, the thesis author conducted a supplementary investigation with important agents at the company and at the sector levels. As noted in Section 4.7, this investigation was conducted *via* a series of in-depth interviews that were based on open-ended questions. As a way to deepen such knowledge, these interviews were designed and developed based on this thesis research´s quantitative survey results (cf. Chapter 6 and Sections 7.1, 7.2 and 7.3 of Chapter 7) and were intended to:

a) Verify the qualitative survey findings through a triangulation method (cf. Section 4.7 of Chapter 4);
b) Explain, and promote a deeper understanding with respect the underlying motivational elements for willingness development;
c) Explore the relations between company and sector levels with regard the responsibilities and incentives for the promotion and implementation of GCE-based initiatives, and
d) Identify current and future initiatives that reflect such willingness and that supported companies' commitment to actually proceed beyond willingness by

implementing actual CGE innovative technological solutions for their products, processes and services;

e) Document the current state of the use of the GCE principles in the Brazilian petrochemical sector.

1.3 The Case Study

This thesis was devoted to gaining insight into the aspects that influence eco-innovative behavior of companies in the Brazilian petrochemical sector. More specifically, it investigated the extent and the strength of these companies´ intentions (willingness) to engage, in the next five years, in technological GCE-based eco-innovation processes. It was expected that such engagement can contribute to the promotion of technological changes associated with the development of cleaner and more sustainable products, processes and services**.**

In addition to measuring companies´ willingness, this thesis research identified its main determinants and the most favorable conditions for such willingness to be transformed into action. Finally, yet importantly, building upon the willingness determinants and on the best conditions for the chemical company leasers to act upon their willingness, recommendations for innovation policies were developed. Such policies can also be developed at the sector and the governmental levels in order to enhance the probability of the implementation of GCE frameworks within the Brazilian petrochemical companies. It is expected that these policies can drive behavioral changes in ways that will favor the development and implementation of the GCE as baseline frameworks for technological changes that can develop a more sustainable petrochemical sector as well as foster and stimulate companies to deliberately engage in GCE-based eco-innovation processes.

This author hopes that this thesis contributes to the development and implementation of chemical's policies that address health and environmental problems and which motivate industry to invest in green chemistry/green engineering approaches by closing the mentality and technology gaps that separate the current petrochemical companies from actively striving to achieve the desired states of sustainability.

1.3.1 The Size and the Importance of the Brazilian Petrochemical Sector in Brazil and Worldwide and Expansion Perspectives

In the Brazilian context, the chemical industry represents a powerful and significant driver of the Brazilian economy. Its contribution to the national economy, in 2008, reached the level of 3.1 percent of the nation´s gross domestic product (GDP). In terms of the statistics regarding the industrial segments alone, the chemical sector´s share of the industrial GDP was 10.3 percent in 2008. This makes the sector the third highest sectorial contributor to Brazil's economy (ABIQUIM, 2010).

In the global perspective, the Brazilian chemicals industry is ranked among the ten largest producers of chemicals in the world.

Table 1.1- Most important players in the world chemical and petrochemical industries (in net sales 2008)

Country	Revenues (in US$ billion)
United States	689
China	549
Japan	298
Germany	263
France	159
Korea	133
United Kingdom	123
Italy	123
BRAZIL	**122**
India	98
The Netherlands	82
Russia	78
Spain	75
Total	**2,792 trillion**
Total World Output	**3,7 trillion**

Source: ABIQUIM (2010a)

Despite its size, the Brazilian chemicals sector has more ambitious plans for the next ten years. In July 2010, the chemical sector, represented by the *Brazilian Chemical Industry Association* (ABIQUIM), presented its plans for this decade. The sector´s strategic intent is to invest an excess of US$ 167 billion, in the period from 2010 to 2020, to place the Brazilian chemicals sector, by the year 2020, among the five largest chemical sectors in the world with a surplus production of chemicals and by being a world leader in renewable chemical feedstock (*ibid*, 2010).

1.3.2 Big Size, Big Challenges

The Brazilian chemical and petrochemical sector show significant numbers regarding its size and its importance for the Brazilian economy. These figures are expected to increase as the sector effects its expansion plans for this decade[10].

The current and projected figures regarding the petrochemical sector represent their motive for societal satisfaction as the sector is and will continue:

- To create utility, welfare, a large numbers of jobs ;
- To improve living conditions;
- To be the base of the materials used by societies;
- To generate large amounts of revenue etc.

On the other hand, the sector is a great source of concern when it comes to meeting the societal aspirations regarding the environment as it uses nonrenewable natural resources as sources of materials and energy inputs for its production processes, and products and it emits toxic materials that are harmful to people, animals and to the environment. Thereby, they generate numerous negative impacts on the biosphere and society.

It has been documented that, in the last twenty years, companies in the Brazilian petrochemical sector have made substantial advancements with regard to environmental management and reduction of emissions to the environment. The petrochemical sector, both at the company and at the sector levels, have responded to environmental challenges

[10] For complete numbers and information on the Brazilian chemical and petrochemical industries and the plans for the near future, refer to ABIQUIM (2010a and 2010b).

with voluntary initiatives such as the Responsible Care Program, the Global Product Strategy and are engaged in a series of others e.g. ISO 18000 series, to site a few.

These initiatives undisputedly promoted huge advances towards cleaner products and processes and helped to reduce negative environmental impacts. They will surely continue to do so. Despite these clear advancements, the petrochemical sector is still at its infancy in its journey towards environmental sustainability as it mostly relies on products and processes technologies that are unsustainable.

Chemicals are used in innumerable processes and products, and at some point in their life cycle many of them come in contact with people—in the workplace, in homes and through air, food, water, and waste streams. Eventually, in one form or another, nearly all of them enter the earth's finite ecosystems. New technologies are needed that incorporate economical and environmentally safer processes, use less energy, and produce fewer harmful byproducts.

With respect the current generation of chemicals, they pose an enormous load of preoccupation on societies as they by entering in contact with humans can inflict a vast array of threats to public and environmental health. "Effects on public and workers´ health can manifest in the short-term or be potentialized over the course of human lifespan. Chemical exposures represent one of many environmental factors that can induce disease directly and can also influence the initiation, progression, or recurrence of other disease processes" (Wilson *et al*., 2006: 25). There is growing evidence in animal studies that some chemicals can disrupt biological processes at very low doses. The biological and ecological effects of chemicals are of growing importance given the scale and pace of chemical production globally. In 1993, the National Academy of Sciences reported that children are uniquely vulnerable to the effects of chemical exposures during all periods of fetal, infant, and child development (*ibid*).

In addition, there is a lack of knowledge on the toxicity of a large quantity of commodity chemicals that are produced both as final products and as by-products of manufacturing processes in a pure or in the form of chemical mixtures. Carcinogenic, toxic, mutagenic, persistent and bio-accumulative chemicals are of highest concern as they can give rise to effects during longer times and over larger distances than other chemicals.

Dispersion of chemicals into the environment has produced a number of major ecological disruptions at local, regional and global scales, whose effects continue today. The depletion of the ozone layer, the contamination of air, pollution of surface and groundwater, contamination of soil, the acidification of soil and water, the depletion of natural and nonrenewable natural resources, and bio-diversity losses, are illustrative of a larger list of negative environmental impacts that are produced by the petrochemical industry. It is also important to highlight the universal concerns regarding the long-term consequences of the environmental damages caused by the chemical and petrochemical sectors.

According to Wilson *et al.* (2006), the lack of information on chemical's toxicity, is a challenge towards cleaner and safer chemical products and processes. This underscores the need for improved chemicals management practices. Their studies revealed that an evaluation of three hundred companies in California showed, for example, "that chemical toxicity was massively overlooked and that, combined, these companies were unaware of the presence of about 55 carcinogenic chemicals and over 200 'extremely hazardous substances' used in chemical products" (*ibid*: 40). It can be argued that new technologies are needed that incorporate economically and environmentally safer products and processes, which use less energy, and produce fewer harmful byproducts. Environmental technologies make SD possible by reducing risk, improving process efficiency, and by creating products and processes that are environmentally beneficial or benign (*ibid*).

Defining the Boundaries of the Scope of the Thesis Research

The petrochemical sector produces a diverse and immense array of products. From the primary petrochemicals through the end user products, literally thousands of chemicals are developed and produced. This product diversity is associated with specific technologies and companies' specific processes regarding markets and learning processes. The petrochemical sector is a vast sector harboring companies with heterogeneous characteristics, which, often, constitute sectors within a sector.

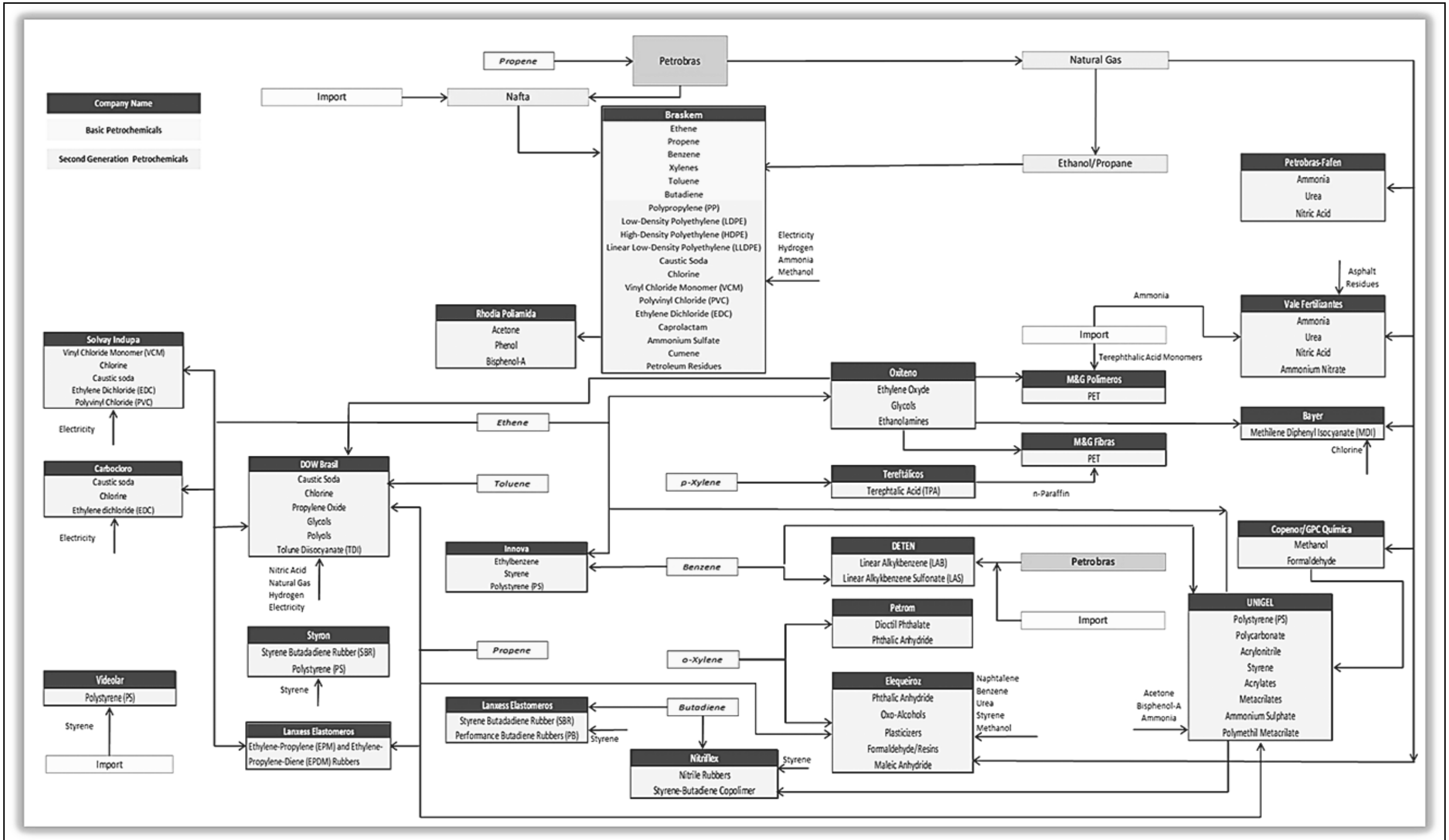
In this universe of diversity, in order to keep this study faithful to the definitions of: (a) sectors: "a sector is a set of activities which are unified by some related product groups for a given or emerging demand and which share some basic knowledge." (Malerba, 2005a: 65), and (b) sectoral system of innovation:

> "A definition of sectoral system of innovation and production as a set of new and established products for specific uses and the set of agents carrying out interactions for the creation, production and sale of those products has been provided. According to this definition, sectoral systems have a knowledge base, demand technologies, and inputs. The agents composing a sectoral system are individuals and organizations, which are characterized by specific learning processes, competencies, beliefs, objectives, organizational structure and behaviors, and interact through processes of communication, exchange, co-operation, competition and command processes, which are shaped by institutions." (Malerba, 2002: 261)

the scope of study for this thesis research was limited to the basic and the intermediate petrochemical products manufacturing companies[11] because by sharing most characteristics predicted by both definitions, they can be characterized as a sector. In this sense, this study used as reference the *Brazilian Chemical Industry Association´s 2010 Brazilian Chemical Industry Yearbook* (ABIQUIM, 2010b), in which the structure of the Brazilian petrochemical industry is presented. In order to account for companies' mergers that occurred in the year of 2011, modifications were made relative to the original information. Therefore, the structure of the Brazilian petrochemical sector was considered to be comprised of: (a) a company that produces both basic and second generation (intermediate) petrochemicals, and (b) twenty companies that produce second generation petrochemicals (cf. Figure 1.6). They constitute, therefore, the universe of study of this thesis research.

[11] Basic or first generation petrochemical companies: process nafta and natural gas (the basic petrochemicals raw-materials) in order to produce basic petrochemical products such as ethylene, propene, butadiene, benzene etc. Second generation petrochemical companies: process the basic petrochemicals in order to produce intermediate petrochemical products that supply the third generation petrochemical companies. Third generation petrochemical companies, in turn, manufacture products that supply end user markets.

Figure 1.6- The structure of the Brazilian petrochemical industry



Source: modified from ABIQUIM (2010b)

1.4 The Structure of the Thesis

The following paragraphs present a detailed structure of this thesis. Chapter 2 was entirely focused upon Green Chemistry and Green Engineering. Its prime objective was to explore their underpinning concepts, principles, approaches and their importance and relations to innovation processes in the development of more environmentally and economically sustainable technological solutions for products and production processes.

In this respect, Chapter 2 provided an explanation of the objectives and principles governing GCE and connected them to the technological and knowledge *Grand Challenges* for the sustainability of the chemical enterprise. It also discussed the importance and the relations of GCE to eco-innovation and technological transition processes.

The objective of Chapter 3 was to present and examine the theoretical foundations that support and represent the scientific pillars of this thesis.

In this chapter, the theoretical elements that are related to technological change, to innovation and to behavioral intentions formation processes were presented. They constituted the theoretical basis that underpinned the development of the research´s instrument (behavioral model) that was used to study the determinants of companies´ willingness to engage in GCE-based eco-innovation processes.

Chapter 4 presented the research design and the methods that were used in this research. This chapter provided a thorough and seamless research specification. Starting from the definition of the case study, this chapter plunges into the methodological aspects of the development of the structural descriptive behavioral model that was developed for explaining and predicting companies´ engagement in GCE-based eco-innovative behavior. Within this domain, the behavior under study was defined according to the four criteria for behavior definition: action, target, context and time.

In addition, Chapter 4 explained the methodological and theoretical aspects associated with the development and application of the thesis research questionnaire. This questionnaire represented the instrument for measuring the variables proposed in the behavioral model (e.g. measurement principle used in the questionnaire, the use of semantic differential as a rating technique, questionnaire wording, and format and context, questionnaire structure, sampling and survey methods etc.). In conclusion, the validation of the model and of the questionnaire was discussed.

Chapter 5 presented, in detail, the process of construction of this thesis research´s structural descriptive behavioral model. The model is comprised of a modified version of Montalvo Corral´s (2002) innovation related structural descriptive behavioral model.

At its basic level, the modifications of the model were designed to promote the adaptation of the original model to the requisites of this thesis research for eco-innovation in sectors. In this sense, the theoretical elements of Malerba´s (2002, 2004, 2005) "Sectoral Systems of Innovation" (SSI) approach were incorporated to the structure of the Montalvo Corral´s (*ibid*) model.

The model helped "to organize knowledge generated in diverse areas of innovation studies to explain and to predict the conditions upon which innovative behaviors of organizations in specific contexts could occur" (Montalvo, 2006: 313).

Additionally, this researcher conducted work to enhance the explanatory power of the TPB based behavioral model. In order to study the influences of norms, not prescribed by the TPB, additional social norm elements from Triandis´ "Theory of Interpersonal Behavior" (TIB) (Jain and Triandis, 1997; Triandis, 1977) and the personal moral norm (Schwartz, 1977) were incorporated to the model´s social pressures construct.

Departing from the presentation of Montalvo Corral´s model (Section 5.1), Chapter 5 highlighted the development of the TPB based structural descriptive behavioral model custom modified for the objectives of this research. In addition, Chapter 5 presented the system of hypotheses used to test and empirically validate the behavioral model and to identify the significant determinants of willingness.

In Chapter 6, the results of the thesis research´s survey were used to provide a thorough analysis of the perceptions, of companies´ top and mid-level managers and decision-makers, with respect the beliefs that determined the willingness to engage in eco-innovation processes. In parallel, they allowed for a complete mapping of the determinants of willingness. The results of the analyses, in addition to presenting how these actors perceived each belief, helped to answer the first question of this thesis research regarding the degree to which companies in the Brazilian petrochemical sector are willing to deliberately engage in GCE bases eco-innovation processes.

In parallel, Chapter 6 presented the complete results of the statistical analyses. These analyses were performed, by this researcher, to test the reliability of the questionnaire and to determine the statistical validity of the thesis research´s structural descriptive behavioral model.

Chapter 7 used the results of the thesis research´s quantitative survey and of the statistical analyses in a different manner. It searched for and identified the inputs and conditions under which willingness could be elevated to its most favorable level.

Based on these elements, recommendations were made for the development of policies and strategies, at the meso (the sector) and the micro (companies) levels, aimed at the promotion, diffusion and implementation of the GCE frameworks and GCE-based eco-innovation processes.

Chapter 7 contains results of a further exploration of the findings of this thesis research. This exploration was conducted *via* qualitative in-depth interviews. The interviews were designed to test the thesis research´s results and to elicit further insights into the companies´ managers, environmental agencies staff and trade association representatives regarding the sector level's actual implementation of initiatives to support GCE in the entire petrochemical sector. They also elicited responses that revealed the degree of preparedness of the companies with respect to their engagement in GCE eco-innovation initiatives.

The author concluded the thesis with Chapter 8 by presenting a summary of the results and conclusions and by providing the final considerations, which included recommendations for further research.

Appendix A presented the results of the detailed statistical analyses regarding to the reliability of the thesis research´s questionnaire. Appendices B and C provided the details of statistical analyses results associated with the behavioral model´s content and construct validity. Appendix D presented the behavioral domains and behavioral domains´ scale's correlation analysis results.

Appendix E presented the thesis research´s qualitative survey questionnaire that was used to survey managers and decision-makers in the Brazilian petrochemical sector, in respect to their perceptions and beliefs related to their companies´ engagement in GCE-based eco-innovation processes.

Appendix F presented the transcriptions of the in-depth interviews (qualitative survey) conducted at the micro (companies) and meso (environmental agencies and the trade association) levels.

Appendix G showed, in graphic format, the profile of the surveyed companies in the Brazilian petrochemical sector.

Appendix H is a supplement to Chapter 3, which presents background considerations on technical change and innovation processes. In this respect, and in order to stress and highlight the importance of innovation in the economy, Appendix H showed the relations of innovation to competitiveness in the economic sphere. In addition, it highlighted the evolutionary aspects of innovation and the relations to technological and economic change. Complementarily, relevant theoretical aspects of the structure of technological change (technological paradigms, trajectories and regimes) were introduced.

Also, appendix H presented and discussed the systemic nature of innovation (systems of innovation) as supporting elements for a better understanding of the origins and application of the SSI framework. Finally, because eco-innovation processes´ characteristics are different from "normal innovations", aspects regarding eco-innovation were presented in the last part of Appendix H.

Appendix I is a complementary reading to Chapter 1. It addressed the problematic of environmental sustainability in the industrial domain and its relations to products and production process technologies. This includes considerations on the depletion of natural resources, the resilience capacity of the environment, the finitude of the natural capital, the limitations imposed by biophysical laws, and societal wellbeing as wells as some views on environmental sustainability in the industrial sector and the importance of greener production processes.

This thesis research´s structure is presented pictorially in Table 1.2.

Table 1.2– The structure that was used to guide this study on the determinants of Green Chemistry and Green Engineering-based eco-innovation in the Brazilian petrochemical sector

<table>
<tr><th colspan="12">CONCEPTUAL AND THEORETICAL ASPECTS OF WILLINGNESS TO INNOVATE IN GREEN CHEMISTRY AND GREEN ENGINEERING</th></tr>
<tr><td colspan="4">CHAPTER 1
Introduction</td><td colspan="4">CHAPTER 2
Fundamentals and Principles of
Green Chemistry and Green Engineering</td><td colspan="4">CHAPTER 3
Theoretical Framework</td></tr>
<tr><th colspan="12">METHODOLOGICAL ASPECTS OF THE THESIS RESEARCH</th></tr>
<tr><td colspan="6">Chapter 4
Research Design and Implementation Methods</td><td colspan="6">CHAPTER 5
The Development of a Behavioral Model and a System of Hypotheses of Willingness to Eco-Innovate</td></tr>
<tr><th colspan="12">RESULTS AND CONCLUSIONS</th></tr>
<tr><td colspan="4">CHAPTER 6
Companies´ Planned Behavior in Eco-Innovating in Green Chemistry and Green Engineering</td><td colspan="4">Chapter 7
Leveraging Companies´ Willingness to Engage in Eco-Innovation Processes</td><td colspan="4">Chapter 8
Summary of the Results and Conclusions</td></tr>
<tr><th colspan="12">APPENDICES</th></tr>
<tr><td colspan="3">Appendix A
Reliability Statistics</td><td colspan="3">Appendix B
Results of the Statistical Content Validation of this Thesis' Research´s Behavioral Model</td><td colspan="3">Appendix C
Results of the Statistical Construct Validation of this Thesis' Research´s Behavioral Model</td><td colspan="3">Appendix D
Behavioral Domains and Behavioral Domains´ Scales Correlation Analysis</td></tr>
<tr><td colspan="3">Appendix E
Thesis Research´s Questionnaire for the Quantitative Survey</td><td colspan="3">Appendix F
Protocols of the In-Depth Interviews (Qualitative Survey</td><td colspan="3">Appendix G
Profiles of the Surveyed Companies</td><td colspan="3">Appendix H
Considerations on Innovation Processes: Economic Competitiveness, Evolutionary Perspectives, Structure of Technical Change, the Systemic Nature of Innovation and Eco-Innovation</td></tr>
<tr><td colspan="12">Appendix I
Some Views on Environmental Sustainability in the Industrial Sector: the Importance of Greener Production Processes</td></tr>
</table>

2. Fundamentals and Principles of Green Chemistry and Green Engineering

> "The past is done. Finished. The future does not exist. It must be created microsecond by microsecond by every living being and thing in the universe."
>
> -Edward Teller

> "But the future does not yet exist and may not exist for any given individual or even for the whole species. Its truth cannot be discovered and known, but it must be created."
>
> -Horst Hutter

2.0 Introduction

The main objective and commitment of the author of this thesis was to contribute in identifying the variables that could be important motivating elements for Brazilian petrochemical companies to engage in technological eco-innovation processes that are based on the Green Chemistry end Green Engineering (GCE) frameworks. These processes were expected to develop ways to accomplish advanced states of environmental and economic sustainability.

As has been explained in Chapter 1, there is no sole solution for the sustainability challenges. It is all a matter of what the perceived present needs are, of what is envisioned for the future, of what is to be sustained, what is to be developed, how, when and for how long specific actions should be performed (cf. Section 2.0). Complementarily, these factors are deeply dependent on a number and variety of contextual factors.

In order to translate these statements to the context of this research, it can be argued that, although technological change processes towards eco-innovative, cleaner and more sustainable products, production processes and systems are primarily associated with environmental sustainability, they have a much broader focus as they can promote significant benefits to the industry´s "Triple Bottom Line" [12].

On the other hand, cleaner products and production process technologies can provide important contributions to the sustainability of nature (earth, biodiversity and ecosystems), life support systems (ecosystem services, resources and the environment) and communities (groups and places). They can promote the development of people (life expectancy, education); of economy (wealth, productive services, sustainable consumption) and of society (institutions, social capital, states, and regions) (cf. Figure 1.2 in Chapter 1).

Chapter 2 was built upon the content of Section 1.1 of Chapter 1 in a complementary manner. It was solely focused upon GCE. In this Chapter, the prime objective was to explore their underpinning concepts, principles, approaches and their importance and relations to eco-innovation processes aimed at the development of cleaner products, processes and services. It is important to highlight the fact that although GCE belong fundamentally to the techno-scientific domain, the acceptance of their principles, as well as their use and implementation in the "real world", are dependent on a variety of contextual

[12] The term Triple Bottom Line (TBL) or "people, planet, profit" was coined in 1994 by John Elkington and "focuses corporation's attention, not just on the economic value that they add, but also on the environmental and social value that they add, or destroy". (Elkington, 2004: 3)

framework conditions that comprise behavioral and a diversity of environmental and socio-economic aspects (cf. Chapter 6).

As noted in Chapter 2, the insertion of the GCE into the behavioral and innovation domains was approached *via* the development of a structural behavioral model that was designed to explain and measure companies´ intentions (willingness) to engage in eco-innovation activities that are based on GCE.

It corresponded to a framework that was grounded upon a meta-theoretical model based upon the behavioral, "Theory of Planned Behavior" (Ajzen, 1991; Ajzen and Madden, 1986), and innovation, "Systems of Innovation" (specifically the "Sectoral System of Innovation" framework – Malerba, 2002, 2004), theoretical domains.

This thesis author built upon them and took into consideration other theoretical aspects from the environmental, economic, social, personal, technological, organizational, institutional and knowledge development and acquisition domains. The theoretical fundamentals and the construction of this model are presented in Chapters 2 and 6. Thus, Chapter 2 is devoted to present the foundations of GCE, as required by the objectives of this thesis research, that was outlined in previous paragraphs.

In this respect, Chapter 2 provided an explanation of the objectives and principles governing GCE (Section 2.2) and connected them to the technological and knowledge *Grand Challenges* for the sustainability of the chemical enterprise (Section 2.1). Section 2.3 discussed the importance and the relations of GCE to eco-innovation and technological transition processes.

The concluding part of Chapter 2, Section 2.4, provided a systemic view of the GCE´s position in the domain of this thesis research. This was attained by diagrammatically integrating Chapters 3, 4 and 6. Such diagrammatic representation clarified the relations of the environmental and socio-economic sustainability demands and pressures for cleaner and more sustainable products, processes and systems with the framework conditions for the engagement of companies in processes of eco-innovation that are based on the principles recommended within GCE.

2.1 Sustainability in the Petrochemical Industry: Where do Green Chemistry and Green Engineering Fit in?

GCE are about technological changes and eco-innovation. In order to make clear that technological changes and eco-innovations do not come out from the blue nor they stand alone as self-sufficient drivers of more sustainable types of industrial development, it is important to acknowledge that:

> "Technical innovations alone will not suffice to ensure that sustainable technology is adopted. Correct framework conditions[13] are required to enable successful investment in Green Chemistry and Green Engineering" (Jenk *et al.*, 2004: 545).

[13] Attitudinal, management, informational and policy

In this respect, in this thesis research, these framework conditions are represented by the pre-conditional variables that can influence companies´ willingness to invest in GCE-based eco-innovative activities (cf. Chapter 2 and 6).

Since Chapters 3 and 5 covered the aspects related to innovation theory and to behavioral aspects of innovation, this section is designed to place GCE within the realm of technological change (products, processes and systems) as a means of changing manufacturing activities to integrate increasingly higher levels of sustainability.

2.1.1 Grand Challenges and Research Needs for Sustainability in the Chemicals Processing Industry

There is much documentation about the efforts developed by governments, the academy and the industry to foresee the future and to envisage solutions for the existing sustainability challenges in the chemical industry.

In the last twenty years, organizations and initiatives have produced valuable studies containing a vast amount of information regarding these challenges and proposed a substantial number of alternative pathways towards sustainability in the chemicals sector. Organizations such as the International Council of Chemical Associations (ICCA, e.g. Responsible Care Global Charter, Global Product Strategy), the American Chemical Society (Jones, 2009), the Chemical Industry Vision 2020 Technology Partnership[14] [15](Vision 2020; 1996, 2000, 2001, 2004), the International Technology Research Institute – World Technology Division (WTEC, 2001), the Organization for Economic Cooperation and Development (OECD, 2001 and 2008a), the Rand Corporation (Rand, 2003) occupied the front line in planning, foreseeing and finding sustainable pathways for the chemicals industry of the future.

In these studies, chemicals management, health and safety, present and future technological challenges and research needs for the sector to perform its production activities in more sustainable fashions are among the important and recurrent topics covered.

Such studies gathered and promoted the convergence of knowledge, expertise and the efforts of an enormous number of professionals and organizations worldwide and molded the current visions and beliefs on the present and future technological needs of the chemicals industry for the development of more sustainable chemical and petrochemical enterprises. Since the analysis of these initiatives and their contributions as well as many

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[14] "The Chemical Industry Vision 2020 Technology Partnership (Vision2020) is an industry-led process among public and private sector stakeholders in the chemical and allied industries. Vision2020 seeks to expand the amount of funding available for pre-competitive R&D in priority areas. Through collaborative efforts among industry, national laboratories, and academia, the Vision2020 Partnership fosters step-change technology innovation, which may be beyond the risk threshold of individual companies." (http://www.chemicalvision2020.org/about.html). Site accessed in November 2010).

[15] How Vision2020 Came to Be. In 1994, the White House Office of Science and Technology Policy requested an industrial perspective on how the U.S. government could better allocate R&D funding to advance the manufacturing base of the U.S. economy. In response, chemical industry leaders created the report Technology Vision 2020: The U.S. Chemical Industry, which spawned the creation of Vision2020 (Vision 2020, 2004).

others in this domain, is beyond the limits of this research, it was intentionally left out of this text.

Among those works, the document published by the National Academy of Sciences (2005), *The Sustainability in the Chemical Industry: Grand Challenges and Research Needs***,** drew attention because of its clear message with regard to the main challenges, time frames, overall research needs and transitions pathways. It reflected the perceptions of specialists representing major chemicals manufacturing companies, consulting and research organizations, sustainability institutes, chemical societies and a broad range governmental and academia representatives.

> "Key players in chemistry and chemical engineering sectors believe that generating economically **viable alternatives to current reliance on fossil fuels** and **business practices** that degrade the regenerative capabilities of natural systems—sustainability—are critical to global leadership by the U.S. chemical industry" (NAS, 2005: vii, bold added).

Many factors indicate that the ideas and contents presented in the report were positively accepted by important and mainstream organizations and the chemical industry as a whole. This is exemplified by the American Chemical Society (ACS), which categorized the *Grand Challenges* as a "landmark report"[16]. On the other hand, important topics presented in the report can be identified in initiatives carried out by important organizations such as the ICCA´s "Responsible Care Global Charter" (RCGC). The RCGC symbolizes the commitment, of the worldwide chemical industry to the concept of sustainable development through *inter alia* sustainable technologies, education, research, collaboration, energy efficiency.

In this respect, the *Grand Challenges* have inspired further developments conducted by the industry, governmental organizations, academia and other sectors that have ties with the chemical industry and share common interests regarding sustainability issues. This is demonstrated by a number of seminars and conferences promoted by important organizations, such as the ACS and The United States National Science Foundation (NSF, 2007)[17,18], which were supported by international market and non-market organizations such as UNESCO and world leader companies either from the chemical and non-chemical sectors.

The document is good reference and its usage in the context of this research was justified for placing GCE among the central topics of this research.

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[16] cf. American Chemical Society webpage at:
http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_ARTICLEMAIN&node_id=222&content_id=WPCP_012184&use_sec=true&sec_url_var=region1&__uuid=56dc3db5-ef5b-410e-b648-a40d46ea0a66, accessed in January, 2011.

[17] "The National Science Foundation (NSF) is an independent federal agency created by (The United States) Congress in 1950 'to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense'." (cf. http://www.nsf.gov/about/). Accessed in January, 2011.

[18] e.g., American Chemical Society Green Chemistry Institute 14th Annual Green Chemistry & Engineering Conference: Innovation and Application (http://acswebcontent.acs.org/), 15th Annual Green Chemistry and Engineering Conference and 5th International Conference on Green and Sustainable Chemistry (http://acswebcontent.acs.org/gcande/). Accessed in January, 2011.

> “The purpose of this study was to assist the chemical ‘industry’ in defining the necessary research objectives to enable the ongoing transition towards chemical products, processes, and systems that will help achieve the broader goals of sustainability. (…) this report identifies a set of overarching Grand Challenges for Sustainability in chemistry and chemical engineering, and makes recommendations about areas of research needed to address those Grand Challenges″ (NAS, 2005: 1)

As the report was designed to be a starting point for further analysis and developments on areas that present unique challenges and opportunities for sustainability research, it did not provide an in-depth economic analysis or policy assessment needed to promote sustainability in the chemical industry (*ibid*).

Considering that economic analyses and policy assessments are not among the objectives of this thesis research, the *Grand Challenges* provided a good fit to this study′s objective to highlight and emphasize the relevance of GCE concepts and approaches. GCE were interpreted as important and valuable guiding frameworks for eco-innovation efforts to promote increasingly sustainable forms of development in the chemicals processing sector.

Although some of its contents were derived from other publications, its clearness regarding the definitions of the main challenges, time frames, overall research needs and transition pathways, provided an easy understanding of the role that GCE should play in the technological change towards the sustainability of chemical and petrochemical sectors. The consulted publications were specific on some technological trajectories and provided an holistic view on the matter.

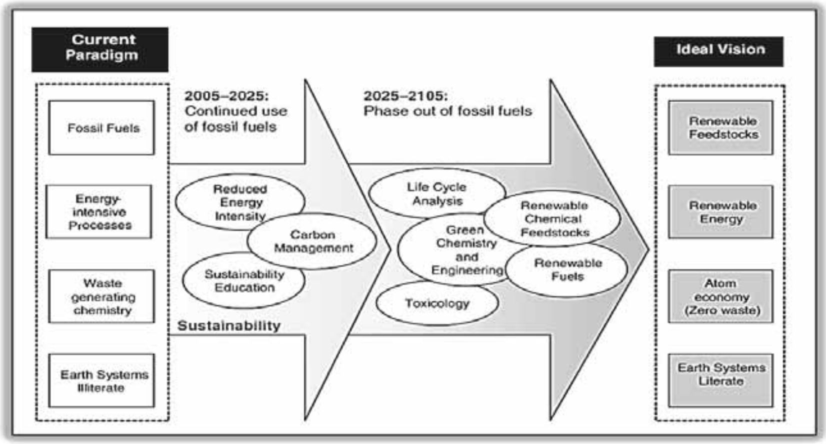
In addition, the document has the unique characteristic of providing integrated challenges and showed the relationships and interconnectivity of GCE with the other challenges such as toxicology, renewable chemical feedstocks, fuels and energy sources.

Coinciding with the fundamentals predicted by the systemic nature of eco-innovation (cf. Chapter 2), the thesis highlights points that are fundamental when addressing sustainability in the chemicals processing industry:

- “Working toward sustainability goals is both wide in scope and deep in complexity;
- Addressing sustainability necessarily cuts across all disciplinary boundaries and requires a broad systems view to integrate the different and competing factors involved;
- Involves the creative design of products, processes, systems, and organizations, and the implementation of smart management strategies that effectively harness technology and ideas to prevent environmental problems before they arise, and
- Requires strategic connections between scientific research and technological development”. (*ibid*: 2)

Figure 2.1 presents the *Grand Challenges* for sustainability in the chemical processing industry domain. They addressed the requirements for the transition from the current paradigms of the chemical industry to an ideal view that comprises the use of renewable feedstocks and energy and the decreasing generation of wastes resulting from of the use of the concepts such as the atom economy[19]. In addition they highlighted the need for the enhancement of literacy on the dynamics of the biosphere functioning (interconnectivities of ecological systems, material and energy circular flows etc.) as a condition for the development of a more sustainable chemical industry.

Figure 2.1- The Grand Challenges for sustainability in the chemicals processing industry: from the current paradigm to an ideal vision of the future (2005-2105) according to the United States National Academy of Sciences



Source*:* NAS (2005: 4)

According to the report, the justification for the choice of the eight *Grand Challenges* (represented as ovals in Figure 2.1) stems from the fact that they represent the greatest scientific and technical challenges for addressing sustainability´s *triple bottom line* (*ibid*).

With regard to the time dimension of sustainability (when? and how long?), the report addresses this issue by challenging the chemical industry to make changes away from the sole dependence on fossil fuels, as sources of feedstocks and energy, and on business practices that degrade the regenerative capabilities of natural systems. In this respect, the document projects a time span of one hundred years (from 2005 through 2105), for a transition from the chemical industry´s current established paradigms (cf. Figure 2.1).

> "Although it is anticipated that the total amount of fossil fuels (coal, natural gas, and oil) available can support current and future needs for at least another hundred years (…), at some point there must be a shift from nonrenewable fossil fuels to renewable sources."(*ibid*: 44)

Based on these premises the document establishes two time horizons for achieving the ideal vision of a sustainable chemical industry:

[19] Atom economy is one of the 12 Principles of Green Chemistry (cf. 4.2.1). It is the chemical processing principle that is designed to avoid the loss of atoms in a chemical synthesis. The atom economy is a concept related to waste reduction and efficiency maximization in materials use that is underpinned by the principle of syntheses design in ways so that the final product contains the maximum proportion of the starting materials.

- The first time interval is comprised of a twenty-year period between 2005 and 2025. This period is characterized by the continued use of fossil fuels as the prevailing energy and feedstocks source. In this period, education to promote sustainability and measures to manage carbon and the reduction of the energy intensity will play a major role, and
- The second time interval is comprised of the subsequent eighty years. During this period it is considered that fossil fuels will be phased out, signifying that alternative renewable sources of energy and feedstocks will be fundamentally needed and critical just like the provision of sustainable solutions based on GCE built on the understanding of the full life cycle impacts and toxicology of chemicals (*ibid*).

Although it was not explicitly posed in the report, it is this thesis author´s belief that the time-frames associated with these two periods suggest that the period of one hundred years is a reference point that is associated to the envisioned economical availability of fossil fuels. This argument was based on the fact that the report made it clear that "at some point (before the one hundred years - note added) there must be a shift from nonrenewable fossil fuels to renewable sources."(*ibid*: 44).

Some Considerations on Long Term Planning for Technical Change

Although this thesis author is in full agreement with what has been proposed as the *Grand Challenges* for the chemical industry, there remains a criticism with regard to the proposed time-frames (one hundred years) for partial and complete transitions to take place.

It is this thesis author's opinion that planning for one hundred years is a time-frame for technical change that is too long into the future and it is not in harmony with the current urgent biosphere´s environmental needs.

Based on widely published proofs of environmental decay (climate change; air, soil, water pollution and their consequences on economic and biosphere systems, materials scarcity etc.), the achievement of solutions in shorter-term periods became necessary. In addition, since "scenario literature has shown that scenarios or future visions are never realized exactly as they are planned" (Quist, 207: 14), planning for objective actions for such long time horizons is likely to make things even more unrealistic. This perception is grounded on the changing, complex and dynamic character of the socio-technological and economic variables (e.g. environmental, economic, market, geographical, social, personal, political *etc*.) that influence technological change processes.

In respect to the report's methodological aspects that produced this time-frame, the *Grand Challenges* besides making some remarks highlighting that *brainstorming* was used in its development no other mention was made concerning the methodological issues. In this thesis author´s opinion, the report might have been conceived based, even if intuitively, on two different visions of the future. The first, related to the time dimension, was associated with the perception of the likely future (*forecasting* approach). The second, related to the ideal vision of an environmentally sustainable chemical enterprise, was underpinned by a normative or desired future approach (for references on futures and scenarios study cf. Quist, 2007).

“Approaches using desirable or normative futures are highly important from the viewpoint of sustainable development. *Backcasting*[20] is a well-known example of such an approach” (Quist, 2007: 17), and “due to its normative and problem-solving character, *backcasting* approaches are much better suited to address long-term problems and sustainability solutions" (*ibid*: 19). In this respect, the interest, applicability and number of *backcasting* studies are growing, especially in Europe (*ibid*).

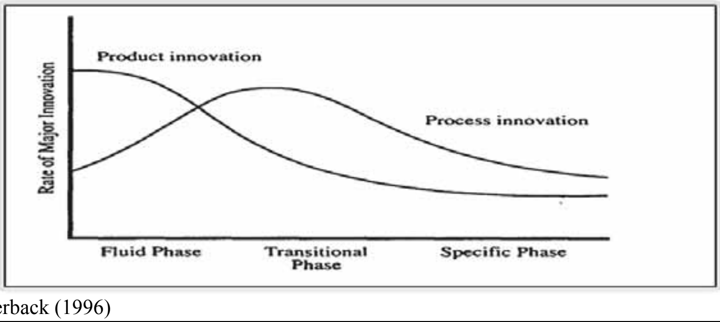
Without making further consideration on *backcasting* theory[21], which is not within the objectives of this research, and taking advantage of the large experience accumulated by researchers in *backcasting*-based long-term sustainability studies, it was concluded that planning for two generations is currently the most widely used approach. According to Quist (2007: 47), “*backcasting* experiments focus on time spans of 50 years and system innovations”. Additionally, some of these studies put emphasis on a follow-up period, that is comprised of the first five to ten years following the conclusion of the studies, in order to “analyze to what extent the system innovation towards the vision is ‘on track’” (*ibid*: 14).

An additional and reinforcing argument for a two-generation long-term planning time-frame comes from the *Board on Sustainable Development of the National Research Council (American National Academy of Sciences)*. In their view:

> “(…) two generations is a realistic time-frame for scientific and technological analysis that can provide direction, assess plausible futures, measure success—or the lack of it—along the way, and identify levers for changing course”. (NAS, 1999: 3)

Influences on the determination of time frames for long term planning can also be affected by the technological changes and the innovation domains. One possible approach can be assigned to the idea that industrial innovation of products and processes can be described as cyclical and each cycle is composed of three interdependent phases that start from concepts generation, go through maturity and finally reaches decline of technologies and their replacement by new products and processes concepts (Utterback, 1996) (Figure 2.2).

Figure 2.2- Innovation cycles of products and production processes according to Utterback



Source: Utterback (1996)

[20] “*Backcasting* means literally looking back from the future. It can be seen as the opposite of forecasting, which looks from the present to the future in a prospective way. In *backcasting* the desirable future is envisaged first, before it is analyzed how it could be achieved by looking back from this future and identifying what steps need to be taken to bring about that future” (Quist, 2007: 11).

[21] For a review of *backcasting* studies and methodology refer to Quist, 2007.

- **Fluid phase:** is characterized by the development of the concepts of products and production processes;
- **Transitional phase**: is characterized by diminishing products and production process innovations and their replacement by frequent changes in the production processes;
- **Specific phase:** is defined by a leveling off the rate of innovation and the slowing of technical change in products and production processes. (cf. Montalvo Corral, 2002).

Another possible approach that can influence the definition of long-term planning time-frames in the industrial domain exploits the cyclical nature of technological changes. It is associated with Schumpeter's long-waves theory of technological change. It "explains the technological revolutions underlying the 'Kondratieff'[22] cycles, or long waves, of economic development" (Wonglimpiyarat, 2005:1350) that comprise cycles of fifty years.

This approach can be understood *via* the concept of the "technological paradigm" (for a thorough definition of "technological paradigm" cf. Chapter 2). According to Freeman and Perez (1988), "technological paradigm"[23] "indicates periods in which particular pervasive technologies, methods of production and economic structures reinforce and co-evolve with one another" (Geels, 2005: 68).

In conclusion, from the perspective of what was reviewed in this section, there is complete agreement on the part of this thesis author with the proposed eight grand challenges and research needs for the sustainability in the chemical industry. On the other hand there is a criticism related to its proposed time-frame. It seems rather long and time frames of forty to fifty years seem to be more appropriate.

The same time frame for long-term planning was adopted by the World Business Council for Sustainable Development. (WBCSD). Their vision was presented in its 2010 report *Vision 2050: The New Agenda for Business*.

Based on the observations, projections and expectations of the companies and experts who contributed to its development, the report "developed a vision of a world well on the way to sustainability by 2050, and a pathway leading to that world – a pathway that will require fundamental changes in governance structures, economic frameworks, business and human behavior. It emerged that these changes are necessary, feasible and offer tremendous business opportunities for companies that turn sustainability into strategy" (WBCSD, 2010: 1).

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[22] Kondratieff cycles is a theoretical approach proposed by the Russian economist Nikolai Dmitriyevich Kondratiev that explains the capitalist economy growth as having a cyclic behavior. The cycles consist of alternating periods between high sectoral growth (boom) and periods of relatively slow growth (depression). For the Kondratieff cycles (or long waves) theory, refer to: Solomos Solomou (1990), *Phases of Economic Growth, 1850-1973: Kondratieff Waves and Kuznets Swings*. Cambridge University Press

[23] cf., Freeman C, Perez C (1988) *Structural crises of adjustment, business cycles and investment behaviour*, in: G Dosi, C Freeman, R Nelson, G Silverberg, L Soete (eds) *Technical change and economic theory*, Pinter Publishers, London/New York: 38-66.

Among other important issues, the report highlights the importance that the global economy approaches a state that is based on true-value economics[24] and quality of life. Innovative technology, knowledge and finance solutions developed and spread by business help increase global bioproductivity[25].

In this long-term vision, by 2050, better management of ecosystem services and deployment of technologies that improve eco-efficiency and bioproductivity will be widely used. Greenhouse gas emissions will peak and begin to decrease and biodiversity will have begun to flourish again. According to their report, "Markets reward positive actions and penalize negative ones, such as pollution" (*ibid*: 19).

In order to support the achievement of the *Vision 2050*, a pathway was developed and nine elements of this pathway were developed to connect this sustainable future with the present. "The elements of the pathway demonstrate that behavior change and social innovation are as crucial as better solutions and technological innovation" (*ibid*, 2).

In some sense this time-frame logic coincides with the one proposed in this research: a time frame of five years for companies in the Brazilian petrochemical sector to start their engagement in eco-innovative activities based in GCE aiming at a forty-year time horizon for achieving major products and production processes more sustainable technological changes.

2.1.2 Green Chemistry and Green Engineering: a Centerpiece in the Chemical Industry´s Sustainability Needs

Although the *Grand Challenges* are depicted in Figure 2.1 in a clear and orderly way, it is necessary to draw attention to the fact that they are neither, static nor isolated entities.

One of the most expected final achievements of the *Grand Challenges* framework is the development of new and eco-innovative technologies, and cleaner products that can fulfill the requirements set by envisioned states of sustainability for the chemical industry in one hundred years.

Apart from economic, social, personal, policy, corporate and other related factors, not taken into consideration in this chapter (cf. Chapter 6), these innovative technological solutions are expected to be developed as a result of specific combinations of the complementarities, interdependences and the interactions of the eight overarching *Grand Challenges*. The characteristics, complementarities and relations between the knowledge fields that underpin the Grand Challenges are presented in

[24]"True-value pricing: pricing that comprises the full cost and benefits of the product/service – economic, social and environmental". (WBCSD, 2010: 69)

[25]Bioproductivity: amount of biological productivity required to renew the biotic resources humans use (food, timber, etc.) and to absorb their waste (mainly to compensate for their CO2, emissions from energy use). (WBCSD, 2010: 69).

Table 2.1- The grand challenges for advanced states of sustainability in the chemicals processing industry and current research needs

Grand Challenges	Research Needs
1. Green and Sustainable Chemistry and Engineering	
Discover ways to carry out fundamentally new chemical transformations utilizing green and sustainable chemistry and engineering, based on the ultimate premise that it is better to prevent waste than to clean it up after it is formed	Identify appropriate solvents, control thermal conditions, and purify, recover, and formulate products that prevent waste and that are environmentally benign, economically viable, and generally support a better societal quality of life.
2. Life Cycle Analysis	
Develop life cycle tools to compare the total environmental impact of products generated from different processing routes and under different operating conditions through the full life cycle. This area will play an increasingly significant role in the chemical industry in the longer term as fossil fuels are phased out of use and application of green chemistry and engineering practices become critical.	Improvements are needed in the quantity and quality of data required for such comparisons and in the approach used to evaluate life cycle metrics. There needs to be an appropriate understanding of the methodology of life cycle analysis, the influence of the life cycle inventory data on the analysis results, the interpretation of the results, and how the results will be used.
3. Toxicology	
Understand the toxicological fate and effect of all chemical inputs and outputs of chemical bond forming steps and processes.This is already an area of concern for the chemical industry, and will be increasingly important as fossil fuels are phased out of use and application of green chemistry and engineering practices become critical.	• Development of critical tools for improved understanding of structure-function relationships for chemicals and chemical mixtures in humans and the environment. This includes computational and genomic approaches. • Development of methods to communicate this information to effectively move it from science disciplines and bench research to application in product designs.
4. Renewable Chemical Feedstocks	
Derive chemicals from biomass—including any plant derived organic matter available on a renewable basis, dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes, and other waste materials. This is a long term challenge that will become increasingly important as fossil fuels are phased out over the next 100 years.	Development of a catalog of biomass derived chemicals, building on what the United States Depertment of Energy (DOE) has already begun, to provide the research community with starting points in the development of alternative pathways to achieve the desired end materials. • Explore obtaining current basic chemicals such as simple aliphatics and aromatics, as well as fundamentally new compounds from platforms such as lignin, sugar, or cellulose. • Improve biomass processing—including pretreatment as well as the breakdown processes for transforming biomass material into chemicals.
5. Renewable Fuels	
Lead the way in the development of future fuel alternatives derives from renewable sources such as biomass as well as landfill gas, wind, solar heating, and photovoltaic technology. This is another long term challenge that will become increasingly important as fossil fuels are phased out over the next 100 years.	• In the area of solar energy technology: — reduce the cost and environmental impact of producing photovoltaic systems; — directly use solar energy for cost-effective splitting of water to produce hydrogen; — improve heat transfer fluids that enable direct use of solar energy for meeting some of the heating requirements of the chemicals processing industry (CPI); and — advance storage systems for solar generated electric power. • Simultaneously develop biomass derived fuels together with chemical feedstocks, while addressing the energy intensity of chemical processing.

Continued on the next page

Table 2.1 Continued

Grand Challenges	Research Needs
6. Energy Intensity of Chemical Processing	
Continue to develop more energy efficient technologies for current and future sources of energy used in chemical processing. Addressing this challenge will be critical during the continued use of fossil fuels as the predominant source of energy and chemical feedstocks over the next 20 years, and will continue to be important even when renewable energy resources are predominant.	• Develop more energy and cost efficient chemical separations, especially effective alternatives to distillation. • Explore biotechnology and other emerging technological solutions. Research and development needs in these areas include reducing production costs, increasing stability, and discovering catalysts with greater specificity. • Better understand the mechanisms of friction, lubrication, and wear of interacting surfaces (tribology)—which leads to one third of the loss of the world's energy resources in present use.
7. Separation, Sequestration, and Utilization of Carbon Dioxide	
Develop more effective technology and strategies to manage the resulting carbon dioxide (CO2) from current and future human activity. Addressing this challenge will also be critical during the continued use of fossil fuels as the predominant source of energy and chemical feedstocks over the next 20 years, and will continue to be important as long as carbon based fuels are in use.	• Develop energy and cost efficient technologies for CO2 separation from flue gas and the atmosphere. • Develop technologies for CO2 sequestration that will address the technical feasibility of making and storing compressed forms of CO2 in geological formations and elsewhere. • Explore utilizing low cost, nontoxic, and renewable CO2 as a feedstock for entirely new materials and for new routes to existing chemicals such as urea, salicylic acid, cyclic carbonates, and polycarbonates.
8. Sustainability Education	
Improve sustainability science literacy at every level of society, from informal education of consumers, citizens and future scientists, to the practitioners of the field, and the businesses that use and sell these products. Advances in chemistry and engineering must be accompanied by cross disciplinary education in sustainability science and its application to the business community. This includes greater understanding of earth systems science and engineering, ecology, green chemistry, biogeochemistry, life cycle analysis, toxicology. Addressing this challenge will be critical over the next 20 years as changes in thinking are needed to make the transition to more sustainable processes, products, and systems.	• Provide professional development opportunities for educators to learn more about sustainability and how it can be advantageously incorporated into their research and teaching. This includes providing incentives for faculty to change curricula while addressing the needs of graduate students entering this complex field. • Persuade professional societies to integrate sustainability and green chemistry and engineering concepts into standardized testing, accreditation, and certification programs .This also includes developing educational materials such as lab modules, LCA modules, and new textbooks that infuse sustainability and green chemistry concepts into the core material. • Incorporate sustainability concepts across secondary and tertiary education curricula. This includes chemistry and chemical engineering as well as the educational practices in professional schools such as medicine, law, and business, with particular emphasis on management education and schools that educate buyers, advertisers, and designers of consumer goods. • Provide professional development for current and future managers and executives. Equally important is the communication of sustainability thinking to middle and upper level managers and executives in business management and incorporation of sustainability objectives in annual performance goals as well as corporate strategy.

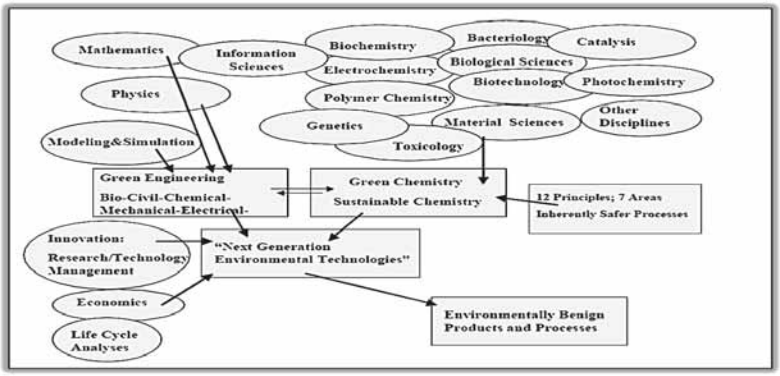
Source: transcribed and adapted from NAS (2005)

As noted in Section 2.1.1, as far as the environment is concerned, the *Grand Challenges* framework aims at the development of products and production processes that are environmentally benign. This places GCE frameworks at a central position in eco-innovation processes that targets technological change as a means for the chemicals processing industry to attain higher states of sustainability.

The CGE principles focus on “the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances” (Anastas and Kirchhoff, 2002: 686) and at prescribing the use of types of feedstocks and energy that are renewable.

As noted in Section 2.1.1, working toward sustainability goals is both wide in scope and deep in complexity. In this respect, GCE draw contributions not only from the knowledge base that pertains to the other overarching *Grand Challenges.* Contributions for the development of GCE-based technologies stem from numerous other scientific fields (cf. Figure 2.3). This justifies the selection of CGE as an appropriate framework for the design of products, processes and systems within the realm and objectives of this research.

Figure 2.3- Green Chemistry and Green Engineering represented as a convergence of many disciplines



Source*:* Rand Corporation (2003: 12)

2.2 After All, What are Green Chemistry and Green Engineering All About?

GCE, in combination with behavioral and innovation theories are the central *foc*i of this thesis research. Despite their importance and justifications for their roles as conceptual centerpieces for helping the chemical industry to generate the next generation of environmentally benign technologies, GCE´s fundamentals, characteristics, conceptual frameworks and objectives were only slightly addressed in the previous chapters and sections. In order to provide a better understanding of their importance for helping to effect the technological changes that are required for making real progress toward sustainable societies, the following paragraphs take a deeper look into GCE.

2.2.1 Green Chemistry: Concepts and Framework

Throughout the last forty years, societies around the world have experienced a profound transformation in their perceptions and beliefs regarding the relations between the chemical industry, the planet´s biosphere and the types of approaches and measures that should be undertaken for the preservation of both parts.

From the times of (sometimes lenient) *Command and Control* policies for pollution abatement to the contemporary tenets gravitating around the principles and concepts of Pollution Prevention, Cleaner Production, Corporate Social Responsibility, Sustainability and Sustainable Development, significant efforts have been undertaken by the global chemical sector to:

> “Operate the production processes as so to minimize the entry of residues and waste products into the environment, both qualitatively and with respect to their hazardous potential, and to utilize raw materials and energy with maximum efficiency” (Christ, 1999: 5).

In this respect, numerous technological pathways and options that endeavored to integrate environmental protection into the productions processes (*ibid*, 1999) and to promote eco-efficiency[26] regarding raw materials and energy efficiency (Eder, 2003) have been proposed and implemented in the chemical sector. As an interesting sample of the diversity of these efforts, Christ (1999) reported on an array of technological advancements that have been conducted by leading chemical industries in Europe to:

- Prevent or reduce emissions and residues by the modification or optimization of chemical syntheses pathways;
- Prevent emissions by optimized operational techniques;
- Process integrated recycling of auxiliaries and by-products;
- Recovery of raw materials or auxiliaries for the production process by reprocessing residues;
- Utilize residues and joint products by inter-linking of production processes, and
- Save energy and prevent emissions originated in the fossil fuels combustion processes by the utilization of process energy, recovery of energy from residues and higher process efficiency.

The aspirations for a new way of doing industrial chemistry that would be more “benign” to the environment evolved in the wake of the societal perception that: (a) the dilution of pollutants into the environment and (b) the command and control schemes did not represent the solution for the depletion of the biosphere and the human health. The highest priority for the problematic of industrial pollution was then allocated to source reduction[27].

Green Chemistry emerged under the source reduction tenet with the clear proposal of being an innovative, non-regulatory, economically driven approach toward sustainability (Manley *et al.*, 2008).

> “Green Chemistry is the design, development, and implementation of chemical products and processes to reduce or eliminate the use and generation of substances hazardous to human health and the environment. It is an innovative, non-regulatory, economically driven approach toward sustainability. The unequivocal value of Green Chemistry to the business and to the environment is illustrated through industrial examples. Green Chemistry must be recognized for its ability to address sustainability at the molecular level.” (Manley *et al.*, 2008: 743)

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[26] Eco-efficiency is a concept and a management philosophy, developed by the World Business Council for Sustainable Development that encourages businesses to search for environmental improvements that yield parallel economic benefits. It is related to the idea of creating more goods and services with ever less use of resources, waste and pollution.
http://www.wbcsd.org/Plugins/DocSearch/details.asp?DocTypeId=25&ObjectId=MTc5OTI. Accessed in January, 2011.

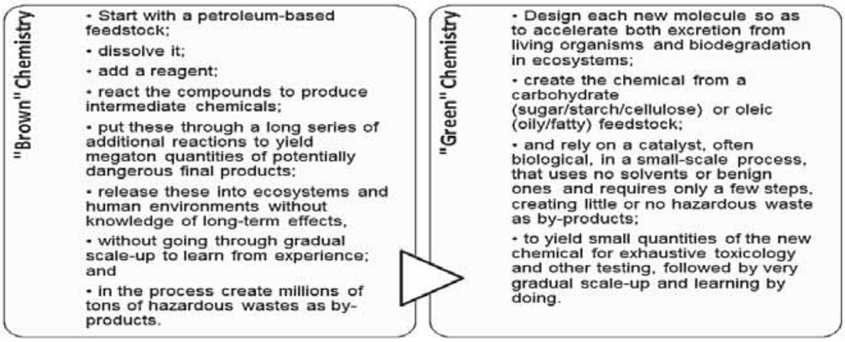
[27] “In the United States, the Pollution Prevention Act of 1990 established source reduction as the highest priority in solving environmental problems” (Anastas and Kirchhoff, 2002: 686).

The Green Chemistry approach is strongly committed to design and to invent the next generation of the material and energy base that will supply our society and economy. Green Chemistry contributes to this effort by understanding chemistry and by designing chemicals from their fundamental level. This is conceptually approached by reducing risks acting directly on their toxic roots, *i.e.* by designing products and processes that are less hazardous as opposed to the previous view that prioritized the risk reduction initiatives upon reducing exposure (Anastas and Warner, 1998).

$$\text{Risk} = f(\text{hazard}, \text{exposure})$$

Two examples are presented as a demonstration of the differences between the older paradigms of doing industrial chemistry and the new ones aimed at advanced states of sustainability. In the first one, Woodhouse and Breyman (2005) argued that Green Chemistry has begun to promote a profound transformation in the methods, raw materials, by-products, and end products of chemical synthesis by migrating from the twentieth-century´s *brown* chemistry "formula" of doing industrial chemistry to more sustainable and benign forms of developing products and processes (*green chemistry*) (Figure 2.4).

Figure 2.4- Industrial chemistry migration from "brown" towards "green" chemistry



Source: author. - adapted from Woodhouse and Breyman (2005).

> "On the current trajectory, these problems will broaden and deepen. Altering this course will require a chemicals policy that motivates industrial investment in the design, manufacture, and use of cleaner chemical technologies, known collectively as green chemistry. Green chemistry represents a primary, long-term solution to many of the chemical problems, and it is a key element of an industrial development strategy that is environmentally, socially, and economically sustainable" (Wilson et al., 2006:9).

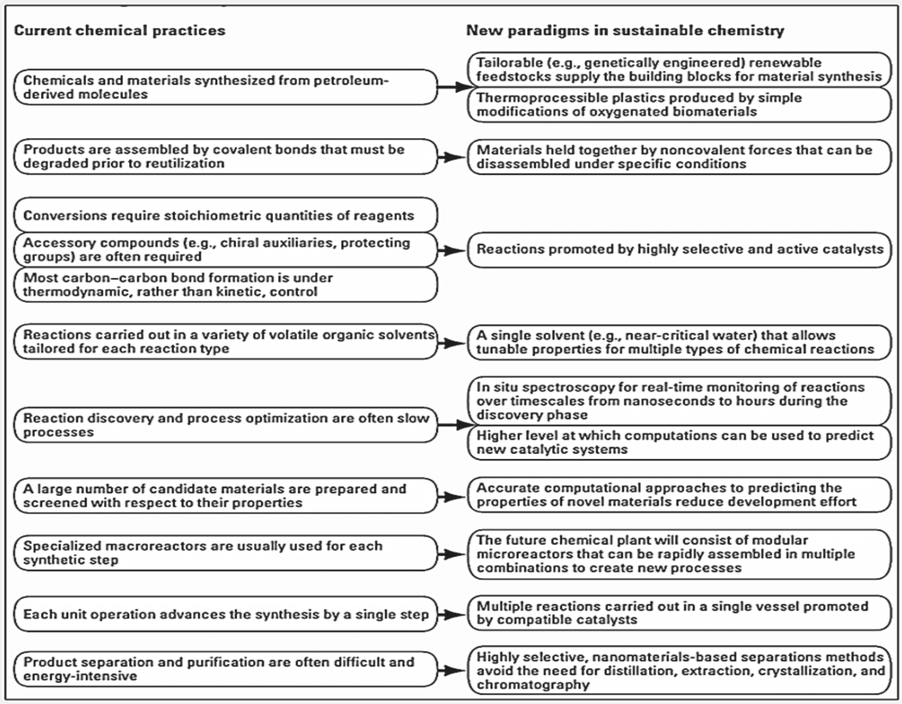
The second example comes from the National Science Foundation:

> "An ideological shift is required in the chemistry community as a whole, from current chemical practices to new paradigms in sustainability chemistry (…) Change will come about when chemists have the tools to use renewable resources with few byproducts produced by simpler, less energy-intensive, and more efficient processes to power our society. A sustainable future will

come about when chemists can control and monitor chemical reactions more effectively." (National Science Foundation, 2007: 4842).

These perceptions and principles are presented in Figure 2.5.

Figure 2.5- Converting current practices of chemical syntheses to new paradigms in sustainable chemistry



Source: National Science Foundation (2007: 4843)

After its inception in 1991[28], Green Chemistry evolved and produced a significant quantity and diversity of successful "green" technological advancements[29]. In parallel, the attainment of higher degrees of maturity in sustainable chemistry identified an array of research needs in areas that could take the industry into advanced states of sustainability[30] (cf. Anastas *et al.*, 2000a; Anastas and Kirchhoff, 2002; Anastas and Beach 2007; EPA, 2010; Jenck *et al.*, 2004; Lankey and Anastas, 2002; Manley *et al.*, 2008; Poliakoff *et al.* 2002; Sheldon, 2007; Woodhouse and Breyman 2005).

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[28] "In 1991, the Office of Pollution Prevention and Toxics in the U.S. Environmental Protection Agency launched the first research initiative of the Green Chemistry Program: The Alternative Synthetic Pathways research solicitation" (Anastas and Kichhoff, 2002: 687).
[29] For examples, refer to http://www2.epa.gov/green-chemistry.
[30] Polymers, solvents, catalysis, bio based/renewables, analytical method development, synthetic methodology development, and the design of safer chemicals can be cited as examples of areas that required new research for the development of more sustainable chemical processes.

Throughout those twenty years of developments and initiatives, Green Chemistry principles emerged and evolved from a considerable amount and diversity of knowledge and skills and provided a structured design framework, composed by twelve principles that can be a reality in practice and not merely a design theory (Anastas and Beach, 2007). *The Twelve Principles of Green Chemistry* (cf. Table 2.2) are accepted as a reference for the design of products, processes and systems that can cause less harm to people, to the planet and enhance the competitiveness of companies.

These *principles*, proposed by Paul Anastas, and John Warner (1998) provide a comprehensive framework for guidance in doing chemistry and designing processes, products and systems in a more "benign" manner. In addition, they can be didactic in disseminating stronger and more robust views of sustainability in the chemical industry. They can as well help to foster changes, in the perceptions and beliefs of those whose professional activities are related to the chemical sector, regarding the short, medium and long terms sustainability needs of the sector. These changes are expected to promote new environmental behaviors that facilitate and induce more favorable levels of companies´ willingness to prioritize investments in greener technological options for their manufacturing processes.

Table 2.2- The Twelve Principles of Green Chemistry

1. Prevention	• It is better to prevent waste than to treat or clean up waste after it has been created.
2. Atom Economy	• Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. Less Hazardous Chemical Syntheses	• Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. Designing Safer Chemicals	• Chemical products should be designed to effect their desired function while minimizing their toxicity.
5. Safer Solvents and Auxiliaries	• The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. Design for Energy Efficiency	• Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. Use of Renewable Feedstock	• A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. Reduce Derivatives	• Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
9. Catalysis	• Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Design for Degradation	• Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. Real-time analysis for Pollution Prevention	• Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. Inherently Safer Chemistry for Accident Prevention	• Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

Source*:* Anastas and Warner (1998)[31]

Although the *Grand Challenges* for the sustainability of the chemical industry are eight in number, they individually and collectively present a vast universe of possibilities for promoting technological changes. In the case of Green Chemistry, by observing its twelve principles, it can be argued that the framework can function as the hub that incorporates and operationalizes the fundamentals contained in the other elements of the *Grand Challenges*.

The concept of "atom economy", a basic concept and principle in Green Chemistry, promotes the possibility of reducing the generation of waste by incorporating of all the atoms of a reactant into the product molecule (Anastas and Beach, 2007). Green Chemistry strives for efficiency. Stereo-chemical specificity permeates the atom economy which "has

[31] Extracted from the United States Environmental Protection Agency Internet site at: http://www.epa.gov/gcc/pubs/principles.html, accessed in December, 2010.

replaced the time honored metric of yield as a standard by which to measure the quality of a synthetic methodology" (Anastas and Warner, 1998: 11).

Green Chemistry goes far beyond waste reduction and pollution prevention as it incorporates in the analysis the entire life cycle of the materials and energy processes as an opportunity for designing eco-innovations (Manley *et al.*, 2008). Knowledge in toxicology is basic in the design of increasingly harmless of materials. The use of alternative renewable energy and material source is a must in Green Chemistry. Education is fundamental to the construction of the knowledge base that underpins the companies' capabilities and the eco-innovation processes.

The possibilities for technical eco-innovations in Green Chemistry are vast. As they are context dependent, they are developed in number and quality that is proportional to the scientists' and engineers' ingenuity, creativity and competence. This is exemplified by the universe of diversity and the amplitude of green chemistry applications that are embodied in the "United States Presidential Green Chemistry Awards" (PGCA)[32]. Since 1996, the PGCA program recognized approximately five individuals and organizations each year. Typically, the U.S. EPA presents one award in each of the following categories and focus areas (a detailed description of the three focus areas is presented in Box 2.1):

- **Small Business**: a small business for a green chemistry technology in any of the three focus areas.
- **Academic**: an academic investigator for a technology in any of the three focus areas.
- **Focus Area 1**: an industry sponsor for a technology that uses greener synthetic pathways.
- **Focus Area 2**: an industry sponsor for a technology that uses greener reaction conditions.
- **Focus Area 3**: an industry sponsor for a technology that includes the design of greener chemicals." (United States Environmental Protection Agency-EPA)[33]

[32] "The Presidential Green Chemistry Challenge was established to recognize and promote innovative chemical technologies that prevent pollution and have broad applicability in industry. The Challenge is sponsored by the Office of Chemical Safety and Pollution Prevention of the United States Environmental Protection Agency (EPA) in partnership with the American Chemical Society Green Chemistry Institute and other members of the chemical community". (EPA), http://www.epa.gov/gcc/pubs/pgcc/presgcc.html. Accessed in January, 2011).
[33] http://www.epa.gov/gcc/pubs/pgcc/award_categories.html

Box 2.1- United Stares Presidential Green Chemistry Awards´ focus areas

THE USE OF GREENER SYNTHETIC PATHWAYS

This focus area involves implementing a novel, green pathway for a new chemical product. It can also involve using a novel, green pathway to redesign the synthesis of an existing chemical product. Examples include synthetic pathways that:

- Use greener feedstocks that are innocuous or renewable (e.g., biomass, natural oils);
- Use novel reagents or catalysts, including biocatalysts and microorganisms;
- Are natural processes, such as fermentation or biomimetic synthesis;
- Are atom-economical, and
- Are convergent syntheses.

THE USE OF GREENER REACTION CONDITIONS

This focus area involves improving conditions other than the overall design or redesign of a synthesis. Greener analytical methods often fall within this focus area. Examples include reaction conditions that:

- Replace hazardous solvents with solvents with a lesser impact on human health and the environment;
- Use solventless reaction conditions and solid-state reactions;
- Use novel processing methods that prevent pollution at its source;
- Eliminate energy- or material-intensive separation and purification steps, and
- Improve energy efficiency, including reactions running closer to ambient conditions.

THE DESIGN OF GREENER CHEMICALS

This focus area involves designing and implementing chemical products that are less hazardous than the products or technologies they replace. Examples include chemical products that are:

- Less toxic than current products;
- Inherently safer with regard to accident potential;
- Recyclable or biodegradable after use, and
- Safer for the atmosphere (e.g., do not deplete ozone. or form smog).

Source: United States Environmental Protection Agency (USEPA)[34]

It is out of the scope of this thesis research to carry out an in-depth analysis of the major advancements achieved by Green Chemistry studies and its applications in areas such as, research, innovation, education and policy by a variety of market and non-market organizations. Despite such argumentation, the author acknowledges that giving "real world" examples is necessary to illustrate and enhance the value of this study.

In this respect, once again this thesis author calls upon the PGCA to illustrate the arguments on the importance and the possibilities for innovation that fulfill the Green Chemistry visions. Other examples can be found in Anastas and Kirchhoff, 2002; Anastas and Beach, 2007; Kirchhoff, 2003; Manley *et al*, 2008; McDonough *et al*, 2003; Nameroff *et al*, 2004).

Table 2.3 presents the technological areas and the number of their respective technologies that have been awarded since 1996[35].

[34] http://www.epa.gov/gcc/pubs/pgcc/focus.html

[35] For the complete list of the awarded technologies refer to the United States Environmental Protection Agency´s Green Chemistry webpage at http://www.epa.gov/gcc/pubs/pgcc/technology.html.

Table 2.3- United States Presidential Green Chemistry Awards winners by technology (1996-2010)

Technology Area & Number of Technologies	
	Biotechnologies - Including use of biological processes or microorganisms (22) - Genetic Engineering (8) - Use of Isolated Enzymes (8)
	Polymers - Chemical Polymers (12) - Biopolymers, excluding the use of isolated enzymes (10)
	Renewable Resources -Technologies that use a renewable resource in place of a petroleum-based or depleting resource (22)
	Solvents - Carbon Dioxide (6) - Solvent-Free Processes (7) - Water (excluding fermentations) (9) - Alternative Solvents (3)
	Safer Chemicals (23)
	Synthetic Processes (24)
	Chemical Catalysts (16)
	Analysis (2)

Source: author - adapted from EPA at http://www.epa.gov/gcc/pubs/pgcc/technology.html. Accessed in January, 2011)

2.2.2 Green Engineering: Concepts and Framework

> "Industrial chemists do not accomplish these transformations alone. Engineers are needed to apply engineering principles and to analyze each chemical reaction, both individually and in conjunction with all the steps, which make up the entire chemical process. The overall objective is to produce chemicals using the raw materials with the lowest cost, minimize capital investment, protect the environment, and ensure the health and safety of those employees that work to manufacture and transport chemical products." (Vision 2020, 2001: 2)

In the chemicals industry, the advent of new materials, products, processes, and systems would not be possible without the combination of the ingenuity, capabilities and the intellectual foundations of industrial chemists and engineers. The design of target molecules and their processes conditions by chemists are complemented by the engineers´ capabilities for designing, constructing and operating large-scale chemical processing plants to make the manufacture of materials and products possible at a commercial scale.

The environmentally unsustainable aspects of the chemical enterprise that are incorporated in its technological paradigms[36], trajectories[37] and regimes[38], as we presently know, are a result of how chemists and engineers have seen the industry and its relations to the economy, society and environment.

The chemical industry cannot undergo structural technological changes towards more advanced states of environmental sustainability unless profound changes occur in the way chemistry and engineering are perceived, designed and implemented. That means that detaching chemistry from engineering in two separate universes cannot solve the

[36] For a definition of technological paradigm, refer to Appendix H.
[37] For a definition of technological trajectories, refer to Appendix H.
[38] "A technological regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artifacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures" (Rip and Kemp, 1998: 340).

challenges for a more sustainable future. Chemistry and engineering should go hand in hand.

> "The decisions made by chemists in designing chemical products and processes directly impact the options available to engineers. The physical and chemical properties of a material, for example, dictate the type of reactor that must be used in a given process. The task of the engineer is simplified when chemists design products and processes that reduce or eliminate the use and generation of hazardous substances. Green chemistry provides a foundation on which to build green engineering." (Kirchhoff, 2003: 5349)

As stated in Section 2.2.1, Green Chemistry fundamentals provide a comprehensive framework, for the design of the synthesis of chemicals that are more benign, production processes and products that is codified and articulated *via* its "Twelve Principles". Similarly, the Green Engineering domain, provides a "green" framework that approaches sustainability from an eco-effective design perspective by proposing a "conceptual shift away from current industrial system designs, which generate toxic, one-way, 'cradle-to-grave' material flows, toward a 'cradle-to-cradle' system powered by renewable energy in which materials flow in safe, regenerative, closed-loop cycles" (McDonough *et al.*, 2003: 434A).

> "Green Engineering, defined as the design of systems and unit processes that obviate or reduce the need for the use of hazardous substances while minimizing energy usage and the generation of unwanted by-products, is the next generation of environmental protection in chemical engineering." (Anastas *et al.*, 2000b: 1)

Green Engineering is governed by twelve principles, *The Twelve Principles of Green Engineering* (cf. Table 2.4), and provides a framework that advances beyond baseline engineering quality and safety specifications to encompass environmental, economic and social factors (Anastas and Zimmerman, 2003). The Twelve Principles, proposed by Paul Anastas and Julie Zimmerman (2003), are applicable, effective, and appropriate to a wide spectrum of design architectures in the various industrial sectors "otherwise these would not be principles but simply a list of useful techniques that have been successfully demonstrated under specific conditions". (*ibid*: 95A)

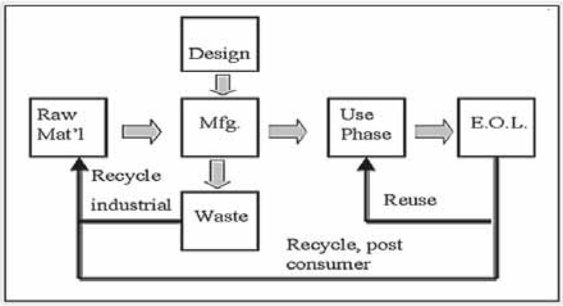
Within this framework, designers and engineers can use the principles of GE to create and select safe materials (Principle 1) whose inputs are renewable (Principle 12). In addition, these principles can be the base for the design of products, processes, and systems that are integrated and interconnected with available energy and materials flows (Principle 10) and are designed for performance in a commercial "afterlife" (Principle 11) (McDonough *et al.*, 2003).

With this in mind, engineers who design products and systems must begin the process by analyzing the chemistry of materials to determine which are inherently safe and which should be avoided. A material should not only be nonhazardous but also provide nourishment for something after its useful life—either "food" for biological systems or high-quality materials for subsequent generations of high-tech products (Principle 11)

Designers guided by the "Twelve Principles of Green Engineering" are challenged to design processes that operate at a maximum eco-effectiveness [39], and efficiency[40] (Principle 4) so as to avoid the waste of materials throughout the manufacturing and product life cycle (Figure 2.6) (Anastas and Zimmerman, 2003). They are encouraged to design processes that are not based on the worst case scenario and operate without the use of excess capacity (Principle 8) in order to avoid excessive use of materials and energy (*ibid*).

Efficient synthetic pathways are at the heart of GCE principles: reducing the use of non-renewable materials, eliminating waste, and reducing emissions.

Figure 2.6- Manufacturing and the product life cycle: a closed systems view of production, use and end-of-life management of products



Note: E.O.L = end-of-life phase
Source: WETC (2001)

Products should be designed to not last beyond their commercial life (Principle 7) so as to avoid problems that can range from solid waste disposal to persistence and bioaccumulation (Anastas and Zimmerman, 2003). In order to allow for recycling, reusing and to reduce energy requirements in recycling processes, "embedded entropy and

[39] According to Braungart et al. (2007: 1337), the concept of **eco-effectiveness** is "a positive agenda for the conception and production of goods and services that incorporate social, economic, and environmental benefit, enabling triple top line growth (...) The concept of **eco-effectiveness offers a positive alternative** to traditional **eco-efficiency** approaches for the development of healthy and environmentally benign products and product systems. It involves the design of things that considers the interdependence with other living systems. **Eco-efficiency** strategies focus on maintaining or increasing the value of economic output while simultaneously decreasing the impact of economic activity upon ecological systems. Zero emission, as the ultimate extension of eco-efficiency, aims to provide maximal economic value with zero adverse ecological impact" (bold added).

[40] The concept of efficiency is also a factor of importance in the green chemistry domain. It establishes the conceptual foundation for assessing the efficiency of the synthetic pathways that are fundamental to the green chemistry principles: e.g. reducing the use of non-renewable materials, eliminating waste, and reducing emissions (Anastas and Beach, 2007). A good example of efficiency metrics is the concept of "Reaction Mass Efficiency" (RME) that takes into account a calculation of atom economy as well as the stoichiometry and yield of each step. "Atom economy and RME calculations typically do not account for use of hazardous reagents, or solvents, which may constitute the primary source of waste in a synthesis" (ibid: 2007: 10). Atom economy (atom efficiency) describes the conversion_efficiency of a chemical process in terms of all atoms involved (desired products produced).
Note 72: continued

$$\text{Atom economy (efficiency)} = \frac{\text{Molecular Weight of desired products}}{\text{Molecular Weight of all reactants}} \text{ X } 100$$

complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition" (Principle 6) (*ibid*: 96A).

Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency. "Appropriate up-front designs, permit the self-separation of products using intrinsic physical/chemical properties, such as solubility and volatility rather than induced conditions, decrease waste and reduce processing times" (Principle 3) (*ibid*: 97A).

It is important to highlight the systemic nature of GCE. They are interrelated and interdependent. In practice, the redesign efforts (eco-innovation) of products and processes, *via* the use of all of the CGE principles simultaneously, is likely to not be achievable since "like all multi-parameter systems, tradeoffs and balances will have to be made in striving toward optimization based on the specific circumstances of the application" (Anastas and Kirchhoff, 2002: 686).

Table 2.4- The Twelve Principles of Green Engineering

1. Inherent Rather Than Circumstantial	• Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible
2. Prevention Instead of Treatment	• It is better to prevent waste than to treat or clean up waste after it is formed.
3. Design for Separation	• Separation and purification operations should be designed to minimize energy consumption and materials use.
4. Maximize Efficiency	• Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
5. Output-Pulled Versus Input-Pushed	• Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials.
6. Conserve Complexity	• Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
7. Durability Rather Than Immortality	• Targeted durability, not immortality, should be a design goal.
8. Meet Need, Minimize Excess	• Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.
9. Minimize Material Diversity	• Material diversity in multicomponent products should be minimized to promote disassembly and value retention.
10. Integrate Material and Energy Flows	• Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
11. Design for Commercial "Afterlife"	• Products, processes, and systems should be designed for performance in a commercial "afterlife."
12. Renewable Rather Than Depleting	• Material and energy inputs should be renewable rather than depleting.

Source: Anastas and Zimmerman (2003).[41]

[41] Extracted from the American Chemical Society Internet site at: http://portal.acs.org/portal/acs/corg/content?_nfpb=true&_pageLabel=PP_ARTICLEMAIN&node_id=1415&content_id=WPCP_007505&use_sec=true&sec_url_var=region1&__uuid=f2d57341-84f9-4cb0-88aa-5f7950f34ba7, accessed in December, 2010.

In the previous sections, the GCE frameworks were presented at the depth required by the objectives of this research. The idea was to introduce their main underpinning tenets and concepts in order to justify their importance for designing the next generation of environmentally benign technologies that will support a more sustainable chemical enterprise and a more sustainable society.

The examples presented in table Table 2.3 and those contained in the cited literature, related to how *GCE Principles* can be employed to address technological sustainability in the chemical industry, represent a small part of the possibilities to be explored. Although the prospects for the creation of a more sustainable chemical enterprise, through the utilization of GCE principles seem to be promising, it is always prudent to emphasize that the challenges are enormous. The development of the next generation of environmentally benign chemical technology based on these principles is still at its infancy not only in technical terms but also fundamentally in what is related to their dissemination and adoption by the industry.

> "While Green Chemistry is receiving significant attention in the business and academic communities, efforts to encourage its adoption in practice are slow, piecemeal, and encounter resistance". (Lowell Center for Sustainable Production, 2008: 10)

Once the resistance to acceptance of GCE is overcome, much is still to be done and the envisioned advancements depend fundamentally on research and innovation (Anastas and Beach, 2007; Horváth and Anastas, 2007).

Although it is not within the objectives of this section, it is advisable and appropriate to complement this reasoning by calling attention to and by emphasizing the importance of the role played by the social and economic factors that are determinants of the acceptance of and underpin GCE-based innovation processes (cf. Chapters 2 and 6).

So far the discussions on GCE have revolved around the conceptual aspects related to the design of more environmentally benign materials, products, processes and systems for the development of a more sustainable chemical enterprise. Section 2.3 addresses the importance of innovation in the development of GCE-based technological solutions and establishes a link to Chapter 3 where eco-innovation was discussed more deeply.

2.3 Green Chemistry, Green Engineering and their Relation to Innovation

It has been broadly argued that the current technological regimes and trajectories in the chemical industry do not fulfill the demanded level of environmental protection. It has also been agreed upon that in order to overcome the environmental and technological challenges and achieve more advanced states of sustainability, new knowledge and new technological regimes and trajectories will be necessary. The need for technological changes can be translated as a need for eco-innovation.

> "According to the Organization for Economic Cooperation and Development (OECD), industrial sustainability is defined as the **continuous innovation**, improvement and use of clean technologies to reduce pollution levels and consumption of resources. In practical terms, industrial sustainability means employing technologies and know-how to use less material and energy, maximizing use of renewable resources as inputs, minimizing generation of

pollutants or harmful waste during product manufacture and use, and producing recyclable or biodegradable products" (Jenk *et al*., 2004: 544, bold added)

According to Manley *et al.* (2008), Green Chemistry is about continued improvement and innovation. "The Principles of Green Chemistry must become the core for tomorrow's chemistry, by integrating sustainability into science and its innovations" (*ibid*: 748). On the other hand, Anastas and Beach (2007:20) reinforced this view on the importance and the dependence of Green Chemistry on innovation by arguing that "innovation is the lifeblood of Green Chemistry".

This suggests that for successful advancements in GCE to take place, favorable conditions for innovation should be created and supported. Furthermore, the theoretical grounds of innovation and innovation systems play a fundamental role in promoting the development of technological solutions based on GCE, and in creating more support, demand and opportunities for them in society.

This section briefly explored the eco-innovative character of GCE in the sense of how they can contribute to and can be integrated into processes of technological transitions towards the development of innovative and more environmentally benign chemical processes, products and systems.

2.3.1 Green Chemistry, Green Engineering and Technological Transitions

As stated in Section 2.2, in the effort of converting the chemical industry, as well as the industrial development as a whole, to more environmentally and economically sustainable states, the GCE principles provide the conceptual fundamentals for the creation of a new class of technological solutions. "Industry leaders recognize that technology transitions are inevitable and they are, in fact, the driving force of innovation and new growth. Many industry leaders, along with labor and community leaders, also recognize that *proactive* transition strategies provide a margin of protection to the economic security of workers and communities" (Wilson *et al.*, 2006: 55)

Such solutions are conceived, guided and designed based on environmental and socio-economic paradigms that have not previously been taken into account. The new paradigms establish new challenges and require changes, both incremental and radical, to the dominant technological paradigms and regimes presently used in the chemical industry.

According to Green *et al.* (1994), this scenario depicts circumstances, whereby innovation becomes necessary and is induced by pressures exerted by the environmental and socio-economic domains. Drawing on the "Evolutionary Theory of Economic Change" developed by Nelson and Winter (1982) (cf. Chapter 2); Green *et al.* (*ibid*) provided an analysis on the relationship of these pressures and the subsequent technological eco-innovations.

According to the evolutionary economics, the technological regime followed by a specific firm or a sector is dictated by the conditions and influences of the environment within which it operates. This space, located off the corporate (or sector) activities domain, represents what Nelson and Winter called the "selection environment" (Green *et al., ibid*).

"The selection environment is comprised of the factors that are external to a firm, which influence which products and/or processes it chooses to innovate" (*ibid*: 1049). Green *et al.*

(*ibid*) also acknowledged the importance of internal factors and pressures in the understanding of technological innovation in firms. This view was also shared and explored by Montalvo Corral (2002) who expanded this "selection environment" to include factors internal to the firms in order to provide a better understanding and to explain the processes of willingness formation, within the firm´s domain, regarding organizations´ engagement in innovation activities (cf. Chapter 6).

According to Green *et al.* (*ibid*: 1050), this "selection environment" includes:

- The prices of raw material inputs;
- The prices of capital equipment;
- The demand for the firm's products;
- The competitive pressures from rival firms, and
- All the laws, regulations and public-political pressures, which bear on a firm's products, processes and organizational routines.

Although this list is not inclusive of every factor of relevance to influence innovation and technological change, it depicts some that are important and capital. The development of a comprehensive general list of the possible "selection environments" would be difficult due to its context dependent characteristics.

Another view that may allow for a good understanding of why new GCE-based technological solutions are largely dependent on innovation processes can be obtained by the use of the theoretical fundamentals proposed by Geels (2002). By conducting an evolutionary and integrative multi-level analysis (micro, meso and macro levels) on socio-technological transitions (changes), he provided a theoretical approach that explained the overall pathways through which technological transitions and innovation processes can develop. Drawing on these theoretical fundamentals, it is possible to show how the onset and the evolution of eco-innovation processes and the emergence of new technological paradigms, regimes and trajectories, based on GCE, can occur (cf. Figure 2.7).

According to Geels (*ibid*), at the macro-level, in the domain of technological transitions, the conditions and influences of the environment within which firms operate and that are located off the corporate (or sector) activities domain are exerted upon companies by the socio-technical "landscape". He argued that the macro-level socio-technical "landscape" consists of "slow changing external factors, providing gradients for the trajectories" (*ibid*: 1261). In addition, it refers to the wider external (to firms and sectors) factors containing a series of heterogeneous social, economic, political, cultural and normative values and environmental variables that provide the structure and the context for the interactions of actors (*ibid*).

The meso-level is the territory of socio-technical "regimes". It accounts for the stability of existing technological development and represents the level where incremental innovation based on existing technologies is generated.

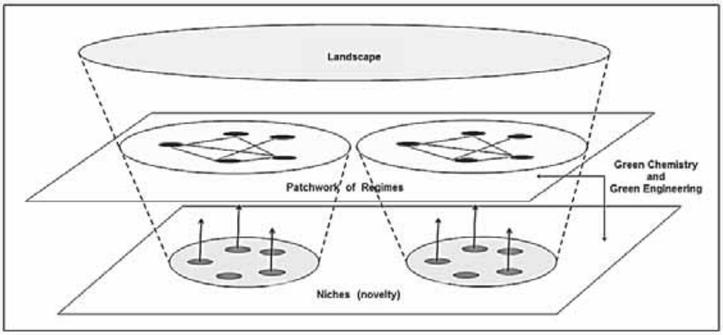
The micro-level of technological transitions acts as an incubation area and represents the domain where the technological novelties (radical innovations) are generated and arise initially as "niches" that are protected or insulated from "normal" markets (*ibid*). "Niches also provide spaces to build the social networks, which support innovations, e.g. supply chains, user–producer relationships" (*ibid*: 1261).

This multi-level perspective establishes the hierarchical relationships between the levels. Changes at the macro-level (“landscape”/“selection environment”) may exert pressures and influences on the meso-level (“regimes”) creating openings for new technologies. The introduction of new elements at the meso-level may influence further changes if changes at the “landscape” create new opportunities. The “landscape” and “regimes”, in turn, exert influence on the micro-level creating opportunities for the emergence of niches of new technologies (dotted lines in Figure 2.7) (*ibid*). Openings for technological change at the meso and micro levels can represent opportunities for GCE to flourish and prosper (cf. Figure 2.7). “The nested character of these levels means that regimes are embedded within landscapes and niches within regimes” (*ibid*: 1261).

> “The important point of the multi-level perspective is that the further success of a new technology is not only governed by processes within the niche, but also by developments at the level of the existing regime and the socio-technical landscape” (Geels, 2002: 1261). “It is the alignment of developments (successful processes within the niche reinforced by changes at regime level and at the level of the sociotechnical landscape) which determine if a regime shift will occur” (Kemp *et al*., 2001,: 277).

A graphical representation of Geels´ (2002) multilevel (macro, meso and micro) perspective of evolutionary technological transitions and its hierarchical relationships is presented in (Figure 2.7).

Figure 2.7- The nested hierarchy of the multilevel perspective of evolutionary technological transition



Source: adapted from Geels (2002)

According to Freeman and Perez, (1988, *apud* Geels, 2005), the emergence of niches occur in the context of existing “regimes” and “landscapes”. Their socio-technological characteristics and novelties are initially developed based on the knowledge base and upon the capabilities within the existing framework. Geels (*ibid*) added that the evolution of a radical innovative technology from the “niche” to “regime” level does not happen in a fast pace, it occurs gradually and after it is “used in subsequent application domains or market ‘niches’” (*ibid*: 1271).

A more elaborate discussion on the mechanisms governing the interactive relations between the micro, meso and macro levels of the technological transitions is beyond the objectives of this research. The simplified view and arguments presented in the foregoing paragraphs suffice to provide the argumentation that the decay in the quantity and quality of ecological systems and nonrenewable matter and energy, due to overexploitation and pollution, have produced changes in the way society and industry perceive the sustainability of society upon the planet.

Consequently, new responsibilities arise for corporations. The changes at the macro level are beginning to produce environmental and socio-technical pressures on companies in the petrochemical sector thereby creating conditions and opportunities for technological changes (transitions) to take place.

Once the existing technological regimes demonstrate that they are not in balance with the socio-environmental domains and that their lack of competitiveness produce economic and opportunity losses, the development of new technological paradigms and regimes become essential. These symptoms indicate the existence of pressures exerted by the "landscape" and suggest that new innovative solutions may be needed.

The GCE concepts and principles emerge as a result of these pressures. When applied in technological innovation processes they can generate radical and innovative technologies that are developed in and for specific "niches". On the other hand, incremental innovative technological solutions can evolve and can be used as a means to reconfigure the existing technologies in a more environmentally sound fashion (cf. Figure 2.7).

It is very important to highlight that innovation processes involve far more elements and concepts than the ones taken into account above. This simplified view on technological transitions represents an effort to place GCE into the eco-innovation domain. Above all, this approach is important to demonstrate that the development of GCE-based solutions is strongly bonded to processes of incremental and radical eco-innovation. Not least, it is fundamental to state that innovation is a complex process. In innovation processes, social, personal, corporate, political, financial, economic, technical etc. elements interact in complex dynamics that may develop nonlinear dynamic patterns of relationships (Deneke, 1998) making them profoundly context dependent.

2.4 Integrating Green Chemistry and Green Engineering into the Industrial Sustainability and Eco-innovation Domains

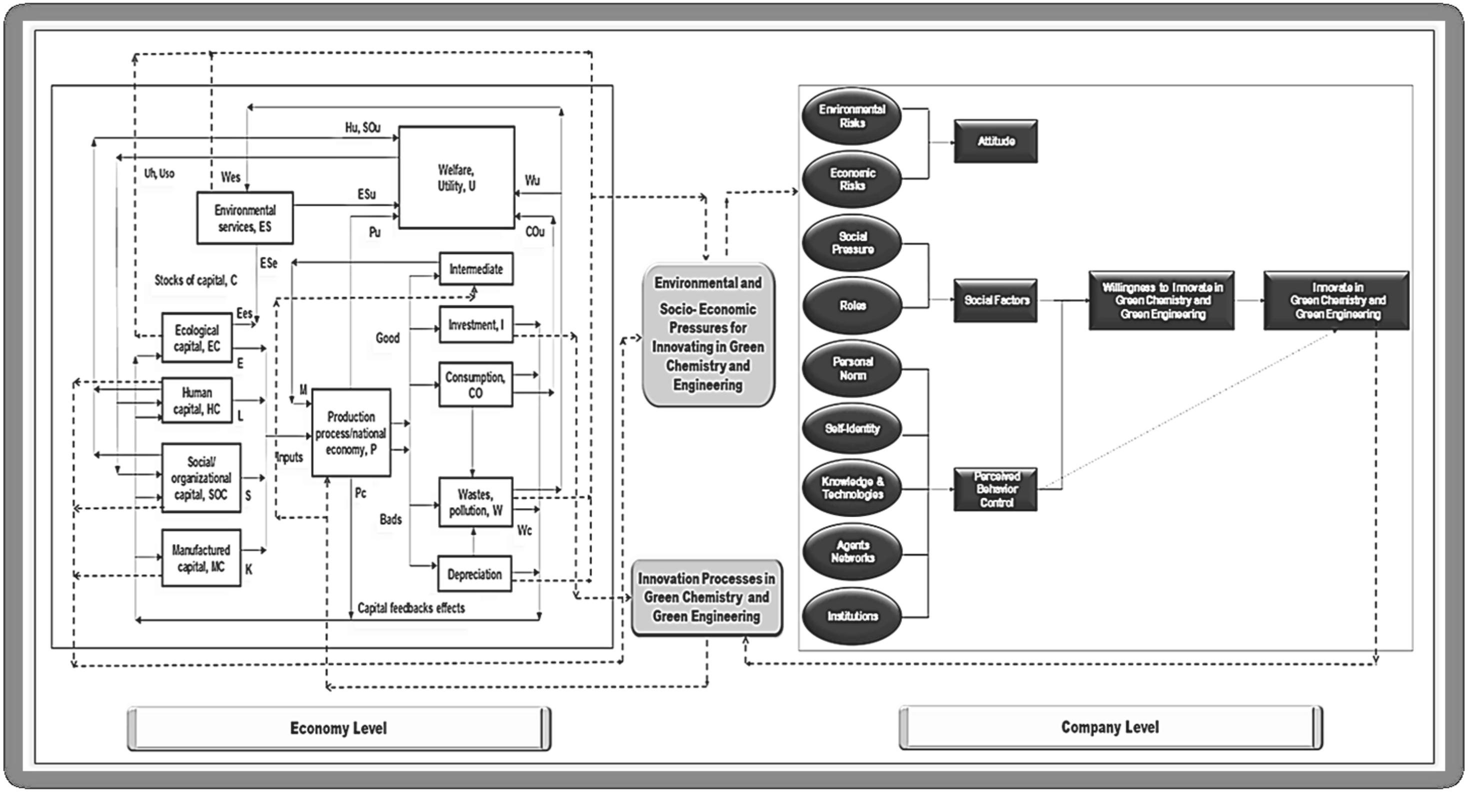
This thesis research does not focus on the dynamics of innovation nor on specific technological paradigms and trajectories. Its main interest is devoted to the behavioral aspects of innovation. It explores the motivational determinants for that companies´ intention (willingness) to engage in GCE-based eco-innovation processes. Section 2.4 represents an effort to integrate and connect GCE with the other overarching key theoretical pillars of this study: industrial environmental sustainability, innovation and eco-innovation (Chapter 2) and behavioral aspects of innovation (Chapter 6).

In a more detailed perspective, the goal of this thesis author was to establish a link between:

- The pressures and demands exerted on companies by: (a) attitudinal elements associated with environmental and economic risks regarding innovating in GCE, (b) GCE innovation-inducing socio-economic agents, and (c) requisites and opportunities associated with companies adoption of GCE and their engagement in GCE-based eco-innovation processes;
- The intention (willingness) of companies to engage in GCE eco-innovation processes, and
- The implementation of the developed greener solutions.

Figure 2.8 shows a diagrammatic representation of these relations.

Figure 2.8- Pressures for innovating in Green Chemistry and Green Engineering and their relation to sustainability in the industrial domain



Sources: Ekins (1999) and this thesis author

Figure 2.8 is composed by the integration of two major models. The first, to the left of the figure, represents Ekins´ (1999) model of economic and social welfare and utility creation process by the industrial production processes. A full explanation of Ekins´ model is provided in Section 1.1.1. of Chapter1. The model shows the relations and the interdependence of the industrial production processes, their *inputs* and *outputs* and the welfare and utility creation.

The other diagram depicts this thesis research´s structural descriptive behavioral model. This model was custom designed to predict and explain Brazilian petrochemical companies' willingness to perform a specific behavior and to identify its important determinants. In the case of this research, the behavior under study was the engagement of companies in GCE-based technological eco-innovation activities.

The models were merged by this thesis author who used as his main theoretical approaches: (a) the Montalvo Corral´s (2002) Theory of Planned Behavior-based structural behavior model for innovation, (b) Malerba´s (2002, 2004) Sectoral Systems of Innovation (SSI) and other complementary theories (for details cf. Chapter 5). As noted in Chapter 2, the model functions as a meta-theoretical model that takes into account influences from the wider environmental end socio-economic "landscape" within which the companies in the Brazilian petrochemical sector operate (macro level), the petrochemical sector (meso level) and from variables that were associated with companies´ internal domain (micro level) (cf. Chapter 5).

As a starting point, this thesis author considered the welfare and utility creation process, which places the industrial production processes (P) at the center of the analysis. According to Ekins (1999), the creation of welfare and utility by (P) is a function of its inputs and outputs. Inputs were represented by different environmental, socio-economic, organizational and manufactured capitals and by their respective services and intermediates from other production processes:

- Ecological capital (*EC*) and environmental services (ES)
- Human capital (*HC*) and human capital services (*L*)-
- Social/organizational capital (*SOC*) and services (*S*)
- Manufactured capital (*MC*) and services (*K*)-
- Intermediates (*M*),

These *inputs* have direct influence on (P). On the other hand, (P) produces *outputs* that are, classified as *goods* (I, CO and intermediates) and *bads* (W and depreciation), which have direct and indirect influences on welfare and utility creation as well as on the production processes *inputs* (for more details cf. Section 1.1.1 of Chapter 1).

The model shows that these relations establish direct and indirect circular relations that produce reinforcing feedback loops between *inputs*, *outputs*, the production processes and societal welfare and utility. Based on Eking´s (*ibid*) model, it can be argued that production processes that are intensive in non-renewable materials and energy sources (*inputs*) and whose emissions to the environment (*bad outputs*) of their products and production processes are polluting and generate harm to the environmental and to the socio-economic capitals that support the economy. This represents an unsustainable way of production and consumption.

When these capitals are threatened and run the risk of decaying or collapsing, pressures are expected to become stronger towards the adoption of cleaner and more sustainable technologies. In the context of this research these cleaner and more sustainable technologies are proposed and are represented as those that are developed under the guidance and by following the principles of GCE.

Once the pressures for the adoption, by companies, of cleaner and more sustainable technologies are generated, the next step represents the challenges associated with the acceptance and the adoption of GCE by the industrial sector. As stated in Section 2.2, GCE represent a more sustainable way of doing chemistry and of designing production processes.

For the cases in which GCE-based technologies are not included in the dominant technological regimes, a shift towards a technological paradigms and regimes that could develop GCE-based products and processes can present not only benefits (drivers) but also risks (barriers).

This represents the main issues that the structural behavioral model to the right of Figure 2.8 proposed to study. A company will not adopt and invest in GCE innovation processes unless its managers and decision-makers perceive that the benefits of doing so surpass the perceived involved risks and that the expected social and environmental advanced states of corporate sustainability can contribute to the company economic success.

The behavioral model represents the domain where the pressures for innovating in GCE are processed and decisions are made. These influences, pressures and requirements comprise *inter alia* a set of environmental, attitudinal, social, personal, technical, organizational, institutional elements that could generate favorable conditions that allow for the development of corporate willingness to accept GCE and promote the deliberate engagement of organizations in GCE-based innovation processes.

Since willingness is an immediate pre-condition for the engagement of a person or a group of persons (e.g. a company) in the performance of a specific behavior (Ajzen, 1991). If a company's willingness is strong enough to promote its engagement in GCE-based eco-innovation, the next step to be taken is to provide the necessary conditions to establish such processes. If technological eco-innovation processes are successful, strategies for technological transitions can take place[42].

[42] For further reading on technological transitions refer to Geels (2002), Loorbach and Rotmans (2006), Rotmans (2005).

3. Theoretical Framework

3.0 Introduction

As noted in Chapter 1, achieving advanced states of environmental, social and economic sustainability has become the greatest challenge of the industrial sector in the short and long- term perspective. In the particular case of the relations between societies and the chemical and petrochemical industry, environmental issues and pressures have been at the center of a long-standing debate that was initiated in the late 1960s and that is still ongoing today.

In this study, this author highlighted evidence that indicates that the petrochemical industry has initiated a transition process to more sustainable performance, environmentally, socially and economically. This perception was based upon the author's insights, which were strongly influenced by personal work experiences, upon the broad scientific and corporate literature that has been reviewed and finally upon the broad media coverage,

This view was also grounded on reports from some companies and on the perceptions of interviewed managers (cf. Section 7.4.1) of this sector that stated that sustainability is a matter of business competitiveness and survival. Currently, the petrochemical industry's diverse initiatives towards S can be identified both in their corporate sustainability reports and in their trade association's sustainability initiatives such as the *Brazilian Chemical Industry Association*´s (ABIQUIM) "Responsible Care Program" (cf. Section 7.4).

Chapter 3 presents and examines the theoretical framework that supports and represents the scientific pillars of this thesis research. It contributes to the studies of the behavioral aspects of innovation as it draws on behavioral and innovation theory to identify behavioral determinants of innovation.

It has been a common view in the academic, business and non-business realms that making the transition to more sustainable performance is not an easy task. As highlighted in the following paragraphs, such a transition involves structural changes of technological and organizational aspects of the industrial sector and of the surrounding social, business and institutional contexts. Additionally, changes in the perceptions, beliefs and behaviors of industrial and societal players, towards environmental preservation, is one of the important determinants of the reconciliation of industry´s interests and the broad societal expectations and demands (Montalvo-Corral, 2002).

It is often argued that there is no agreement on the physical limits of the environment. Despite this view, there are strong societal appeals and demands for new kinds of development (Jiménez Herrero, 2001) based on innovative visions and approaches, and on new forms of organization. Such development forms are perceived to be effective ways to foster the development and utilization of new technologies for helping to ensure more sustainable processes, products and services.

Due to its unique character of producing and releasing vast amounts and types of hazardous and toxic substances into the environment and being largely dependent on nonrenewable[43] natural resources, as the source of raw materials and energy[44], the Brazilian petrochemical industry[45] is basically an environmentally unsustainable business.

For the petrochemical manufacturing companies to be sustainable, it is essential for them to disconnect from their present raw materials and energy sources and from the current manufacturing practices. In addition, it is important to promote changes towards new and innovative technologies that produce non-toxic and recyclable products made from renewable raw materials and using renewable energy sources. More sustainable manufacturing processes ought to increasingly be non-polluting and require less energy input/unit of product/service yielded. This will require new innovative technological, management and accounting regimes.

In this thesis, the interest of the author focused upon eco-innovative processes related to the chemical synthesis and production processes as they represent the heart of the petrochemical industry. In this regard, this study tested the propensity of industries in the Brazilian petrochemical sector to engage in eco-innovative processes based upon the Green Chemistry and Green Engineering (GCE) frameworks.

As noted in Chapter 7, the GCE principles were not entirely known by the surveyed Brazilian petrochemical companies. In this regard, this thesis research was designed to contribute to promote GCE as viable baseline frameworks for directing companies present technological systems towards “greener” approaches; thereby creating commitment to working to create a more sustainable (petro)chemical industry.

In this research, the author interpreted the need for structural changes in the petrochemical industry sector, as well as in the broader societal context, as a need to find new and unprecedented solutions to our environmental sustainability challenges. In another words, there is a strong need to innovate. This requires innovative technological solutions and innovative visions, attitudes, values, policies and approaches in the social, business and institutional environment that support them.

Innovative processes have to be developed and implemented to replace the present petrochemical industry technological, organizational and institutional regimes with those that can increasingly fulfill the industries and societal sustainability requirements and expectations within the context of a sustainable eco-systems.

Innovation is a collective and socially constructed process with interactions of interlinked social and economic agents (Christ, 2007; Fagerberg, 2006; Edquist, 2005). Agents can be individuals and organizations, which are, in the end, comprised of humans. Corporate willingness to perform specific innovative behavior is intrinsically connected to human perceptions and beliefs (Ajzen, 1991, Beckenbach and Daskalakis 2008, Montalvo-Corral, 2002).

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[43] Natural resources are considered to be nonrenewable due to the short time frames required by the economic processes.

[44] For figures on consumption of raw materials and energy sources by the Brazilian chemical sector refer to *Brazilian Energy Balance Report 2009*, Brazilian Ministry for Mines and Energy and Empresa de Pesquisas Energéticas (EPE), https://ben.epe.gov.br/downloads/Relatorio_Final_BEN_2009.pdf.

[45]Petrochemical: Any compound obtained from petroleum or natural gas (http://www.websters-online-dictionary.org/definition/petrochemical), accessed in December, 2009.
Petrochemicals: Chemicals made from oil, natural gas or other fossilized hydrocarbons .
http://www.greatlakesbioenergy.org/research/bioenergy-glossary/, accessed in December, 2009.

It can be argued that beliefs are strongly associated with the processes of behavioral change. "(…) almost always, there will be a set of understandings or beliefs associated with a particular routine, which explicates or rationalizes why it is appropriate in a particular context, and often, which provides an explanation of why and just how it works" (Nelson and Nelson, 2002: 267).

This thesis researcher established a relation between eco-innovation and corporate behavioral aspects. It pursued the identification of the relevant agents, significant determinants and mechanisms that are likely to act as incentives and disincentives for the companies, in the Brazilian petrochemical sector, to engage and invest in projects using the GCE principles as technological orientation.

In addition, this study searched for evidence that indicated that companies have advanced beyond intentionality (willingness) and effected technical and non-technical initiatives that promoted advancements towards higher states of S of their products, processes and services.

Another important point covered in this research was the identification of the relationships and influences of important sector level actors and mechanisms in the acceptance, dissemination and implementation of the GCE frameworks at the company level.

The research questions highlight the theoretical framework supporting the research objectives:

Research Questions

a) Are Brazilian petrochemical companies **willing** to **innovate** in **Green Chemistry** and **Green Engineering** as a viable option to more sustainable corporate behavior?

b) How can their **willingness** be explained and what are the main determinants?

c) What are the sector´s agents, mechanisms and actions, which are integral to their implementations of **Green Chemistry** and **Green Engineering**?

The following objectives were addressed in seeking to answer the research questions:

- To help to ensure innovative progress within and among the companies in the Brazilian petrochemical sector *via* a sound theoretical framework grounded on innovation theory with a specific focus on its behavioral aspects and on its systemic nature;
- To utilize this theoretical framework to study significant preconditions for the onset of GCE-based eco-innovation processes;
- To assess the willingness[46] of Brazilian petrochemical company leaders to incorporate Green Chemistry and Green Engineering into their companies' environmental governance;

[46] The behavioral intention (willingness) is the immediate pre-condition for the engagement in and the performance of a specific behavior. This issue is fully explored in Chapter 2.

- To assess the variables that emerged as the determinants of companies´ willingness to engage in GCE-based eco-innovation processes;
- To assess the extent to which companies have advanced beyond intentionality and made progress towards S *via* SD-based technical and non-technical initiatives;
- The identification of the relationships and influences of important sector level actors and mechanisms in the acceptance, dissemination and implementation of the GCE frameworks at the company level.

This thesis research was developed based on a theoretical background that was supported by two fundamental and interrelated pillars. The first one was represented by the theoretical fundamentals of the theory of innovation and, more specifically, upon its systemic nature. In this respect, due to the research focus on companies that pertain to the petrochemical sector, the Sectoral Systems of Innovation (SSI) framework was one of the main theoretical elements in the study of eco-innovative processes in this domain. Considerations on the relevant aspects of SSI were discussed in Section 3.1.

The argumentation, presented in Section 3.1 was supported by Appendix H where background considerations on technical change and innovation processes were discussed. In this respect, and in order to stress and highlight the importance of innovation in the economy, Appendix H showed the relations of innovation to competitiveness in the economic sphere. In addition, it highlighted the evolutionary aspect of innovation and the relation to technological and economic change. Complementarily, relevant theoretical aspects of the structure of technological changes such as technological paradigms, trajectories and regimes were introduced.

In parallel, Appendix H presented and discussed the systemic nature of systems of innovation as supporting elements for a better understanding of the origins and application of the SSI framework. Finally, as eco-innovation possesses characteristics that are different from "normal innovations", aspects regarding eco-innovation were presented at the last part of Appendix H.

The second pillar was related to behavioral aspects of innovation. Section 3.2 addressed the aspects and the determinants of innovative behavior *via* the presentation of the theoretical elements that constitute Icek Ajzen´s (1991) Theory of Planned Behavior (TPB).

Although there is a "somewhat strange neglect of the behavioral aspects related to the innovation process" (Beckenbach and Daskalakis 2008: 181), these aspects are central, much valued and important components in the evolutionary approach to innovation. In this thesis research, *"willingness"* was represented by the willingness (intentionality) of the firms´ managers and important decision-makers to engage in GCE-based eco-innovation activities.

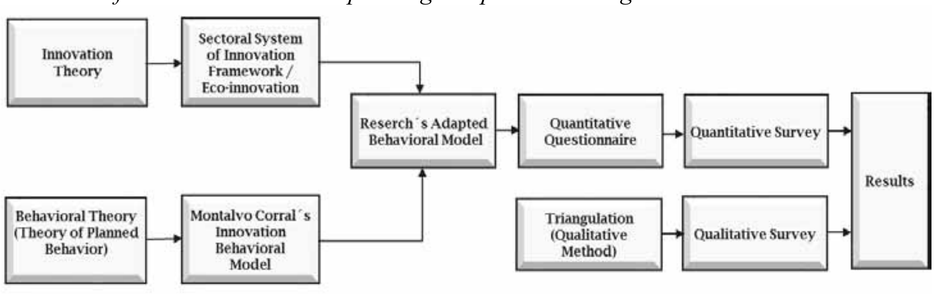
The behavioral hypotheses proposed by this study´ behavioral model were tested against empirical data collected *via* a customized quantitative questionnaire. The behavioral model was used as the basis upon which the questionnaire was developed (cf. Chapter 5 and Appendix E).

This researcher's modified model, put the firm at the center of the innovation system and introduced and merged the theoretical principles underpinning Franco Malerba´s (2002, 2004) Sectoral Systems of Innovation (SSI) framework to Montalvo-Corral's (2002) model. Figure 3.1 depicts schematically the research's theoretical backgrounds and their relations.

In addition, in order to have a deeper view and a better understanding of the results obtained in this thesis researcher's qualitative survey, further investigations were conducted using a qualitative triangulation method (cf. Section 4.7).

Diagrammatic representation of the overall structure of this research´s theoretical framework is presented in Figure 3.1.

Figure 3.1- Diagrammatic representation of the overall structure of this research´s theoretical framework aimed at explaining companies' willingness to eco-innovate



Source: author

Section 3.3 discusses the choice of companies´ managers and key decision-makers as the thesis research´s unit of analysis.

3.1 Sectoral Systems of Innovation

As noted in Section 3.0 and in Appendix H the "Sectoral Systems of Innovation" (SSI) framework represents one of the major theoretical foundations in the context of this research. The merger of the SSI framework and the behavioral foundations provided by the "Theory of Planned Behavior" (TPB) provided the theoretical grounds for identifying important determinants for and explaining companies´ behavioral intention (willingness) to engage in GCE-based eco-innovation activities.

Before making considerations on the motivations underpinning the merger of the SSI framework and the TPB, for development of this thesis research´s operational behavioral model, it is important beforehand to discuss and to provide information on the foundations (concepts, definitions and framework) of the SSI framework.

3.1.1 Differences Across Sectors and Heterogeneity of Firms Within a Sector: the Justification for the Use of the SSI Framework

The systemic nature of innovation can be studied at various levels of aggregation. It is left to the researcher to select the option of configuring the level of aggregation, which best fits, the research's objectives. In the case of this thesis research", in which the study of the determinants of pro-innovative environmental behavior in the firms' domain is the ultimate objective, the adoption of the SSI as a suitable framework and analytical base was a plausible choice for reasons that are related to its conceptual and theoretical formulation as explained later in this section.

According to Malerba (2004: 9), “a sector is a set of activities, which are unified by some related product groups for a given or emerging demand and which share some basic knowledge. In a sector, firms have commonalities and at the same time are heterogeneous”.

This definition suggests that firms in a sector share communalities that are not shared with others belonging to other sectors. This makes a given sector a system with unique characteristics across the economy. These exclusive characteristics are reflected in the differences in sectors’ structures, dynamics and innovation processes. “Innovation processes greatly differ across sectors in terms of characteristics, sources, actors involved, the boundaries of the processes and the organization of innovative activities” (Malerba, 2005b: 380). The adoption of SSI, as a framework and analytical tool for the study of environmental innovation focused on the petrochemical sector, in the Brazilian context, is then fully justified.

Two other important factors associated with the theoretical and conceptual foundations of SSI have central influence upon the structure and content of this thesis research. The first is based upon the fact that SSI places firms as the key actors at the same time that it examines other types of agents. Firms are key elements in SSI as “they are involved in the innovation, production and sale of sectoral products, and in the generation, adoption and use of new technologies.” (Malerba, 2002: 255).

The second factor is associated with the heterogeneity presented by firms within a sector. In a sector’s domain, firms (organizations and individuals), at various levels of aggregation, although sharing communalities, have their own individual “personalities” and interests expressed by their specific learning processes, competencies, organizational structure, beliefs, objectives and behaviors (Malerba, 2005a).

These different “personalities” and interests are ultimately of significant importance and influence the outcomes of firm’s organization and decision-making processes. They can influence the emergence of specific determinants of a firm’s willingness to engage in environmental innovation endeavors in specific contexts (Montalvo Corral, 2002).

As presented in Section 3.2, firm’s willingness to perform a specific behavior is dependent on the belief system and perceptions of their key individuals on the factors that may represent incentives and disincentives for them to adopt specific behaviors. For objectives of policy design and strategic planning for the micro and meso levels, a diagnosis of these incentives and disincentives for eco-innovating across the companies in the sector is of high value. This diagnosis is the ultimate objective of this thesis research.

3.1.2 The Sectoral System of Innovation Framework

> “A sectoral system of innovation and production is a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products. Sectoral systems have a knowledge base, technologies, inputs and demand. The agents are individuals and organizations at various levels of aggregation, with specific learning processes, competencies, organizational structure, beliefs, objectives and behaviors.” (Malerba, 2002: 248)

The sectoral system of innovation (SSI) framework examines the factors that influence innovation in sectors. According to Malerba (2002), it presents a multidimensional, integrated and dynamic view of innovation in sectors.

Stemming from diverse theoretical, intellectual and analytical traditions
(cf. Tabel 3.1)

Intellectual and Theoretical Traditions/Authors	Relevant Aspects/Concepts of the SSI Framework
Case studies	- Evidences on the features and working of sectors, on their technologies, production, innovation and demand and on the type and degree of change
Sectoral taxonomies (Joseph Schumpeter, Keith Pavitt)	- Differences across sectors in innovative activities
Change and transformations in sectors: Industry life cycle literature (James Utterback and Steven Klepper) Analyses of long-tem evolution of industries (Joseph Schumpeter, Simon Kuznets and Colin Clark)	- Laws of motion; - Dynamics; - Emergence and - Transformation
Links and interdependencies and sectoral boundaries Concept of development blocks (Erik Dahmen)	- Relationships between boundaries of sectors and their interdependencies and links among related industries; - Changes of boundaries of sectors in time; - Dynamic complementaries among artifacts and activities.
Innovation systems approach (Bengt-Åke Lundvall, Bo Carlsson, Charles Edquist)	- Innovation as an interactive process among a wide variety of actors; - Firms do not innovate in isolation. Innovation as an collective process; - In innovative processes firms interact with other firms and non-firms organizations; - Firms and non-firms actions are shaped by institutions; - Emphasis on interdisciplinarity and historical perspective; - Learning as a key determinant of innovation.
Economic evolutionary theory (Richard Nelson, Sidney Winter, Giovanni Dosi, J. Stanley Metcalfe)	- Dynamics, processes and transformation (et the center of analysis); - Knowledge and learning are key elements in the change of the economic system; - Agents' bounded rationality and uncertain and changing environment; - Relations between competencies, knowledge and organizational content; - Learning, knowledge and behavior relations with agents heterogeneity in experience, competencies and organization; - Emphasis on cognitive aspects such as beliefs, objectives and expectations, which are affected by previous learning and experience and by the environment in which agents act; - Economic processes driving economic change: • processes of variety creation in technologies, products, firms and organizations; • processes of replication; • Processes of selection. - Aggregate phenomena are emergent properties of interaction far from equilibrium.

the SSI concept follows the concepts of the theory of evolutionary economics, whereby learning, knowledge, competencies and a major focus on dynamics are central. In parallel, SSI is also solidly grounded on the studies of the systems of innovation, in which cooperation networks and the relationships between agents are key elements to the innovative processes. The SSI approach is complementary to other systemic innovation approaches and concepts such as national systems of innovation, regional/local systems of innovation and technological systems of innovation (Malerba, 2004).

As noted in Malerba´s definition of SSI, five key points are highlighted:

- Focus on the supply as well as on the demand side;
- Examines other types of agents in addition to firms;
- Places considerable emphasis on non-market as well as on market interactions;
- Pays attention to institutions, and
- It focuses on processes of transformation of the system and does not consider the sectoral boundaries as given or static.

The structure and the functioning of a SSI are context-specific and are a result of the interaction of the elements that belong to the domains associated with the three main dimensions of sectors. These dimensions represent the SSI building blocks (Malerba, 2002, 2004, 2005a and 2005b):

- Knowledge, technological domain and boundaries;
- Actors, interactions and networks;
- Institutions.

The following paragraphs explore the core concepts encompassed in these SSI building blocks based fundamentally upon the work of Franco Malerba (2002, 2004, 2005a and 2005b). For a better and easier understanding, they are presented in a synthetic form. A more elaborate examination is presented in Chapter 5.

Table 3.1- Theoretical and intellectual traditions supporting the SSI framework

Intellectual and Theoretical Traditions/Authors	Relevant Aspects/Concepts of the SSI Framework
Case studies	- Evidences on the features and working of sectors, on their technologies, production, innovation and demand and on the type and degree of change
Sectoral taxonomies (Joseph Schumpeter, Keith Pavitt)	- Differences across sectors in innovative activities
Change and transformations in sectors: Industry life cycle literature (James Utterback and Steven Klepper) Analyses of long-tem evolution of industries (Joseph Schumpeter, Simon Kuznets and Colin Clark)	- Laws of motion; - Dynamics; - Emergence and - Transformation
Links and interdependencies and sectoral boundaries Concept of development blocks (Erik Dahmen)	- Relationships between boundaries of sectors and their interdependencies and links among related industries; - Changes of boundaries of sectors in time; - Dynamic complementaries among artifacts and activities.
Innovation systems approach (Bengt-Åke Lundvall, Bo Carlsson, Charles Edquist)	- Innovation as an interactive process among a wide variety of actors; - Firms do not innovate in isolation. Innovation as an collective process; - In innovative processes firms interact with other firms and non-firms organizations; - Firms and non-firms actions are shaped by institutions; - Emphasis on interdisciplinarity and historical perspective; - Learning as a key determinant of innovation.
Economic evolutionary theory (Richard Nelson, Sidney Winter, Giovanni Dosi, J. Stanley Metcalfe)	- Dynamics, processes and transformation (et the center of analysis); - Knowledge and learning are key elements in the change of the economic system; - Agents' bounded rationality and uncertain and changing environment; - Relations between competencies, knowledge and organizational content; - Learning, knowledge and behavior relations with agents heterogeneity in experience, competencies and organization; - Emphasis on cognitive aspects such as beliefs, objectives and expectations, which are affected by previous learning and experience and by the environment in which agents act; - Economic processes driving economic change: • processes of variety creation in technologies, products, firms and organizations; • processes of replication; • Processes of selection. - Aggregate phenomena are emergent properties of interaction far from equilibrium.

Source: author

Knowledge, Technological Domain and Boundaries

Knowledge and learning are increasingly important at all levels of the economy (learning economy) and it is no longer valid to theoretically consider technologies, skills preferences and institutions as exogenous (Lundvall, 1996). In the technological domain, a "technological regime is a particular combination of some fundamental properties of technologies: opportunity and appropriability conditions; degrees of cumulativeness of technological knowledge and characteristics of the relevant knowledge base" (Malerba, 2005a: 64). Knowledge is, therefore, at the base of technological change and plays a pivotal role in innovation. It is highly specific at the firm level, it does not diffuse automatically and freely and it is absorbed by the firms, through differential abilities accumulated by them overtime (Malerba, 2002: 251).

In a SSI, the sectoral borders of the system are not fixed and change overtime because of the dynamic links and complementarities (interdependencies and feedbacks) between artifacts, technologies and activities at the production and demand sides.

Actors, Interactions and Networks

With regard to agents, interactions and networks, firms are the key actors in a sectoral system as they are involved in the innovation, production and sale of sectoral products and services; and in the generation, adoption and use of new technologies (Malerba, 2002 and 2004). Firms also include users (demand side) and suppliers (*ibid*). According to Malerba (*ibid*), the SSI framework views agents on the demand side as heterogeneous elements that hold their own specific attributes knowledge and competencies. They interact with producers in a variety of ways. On the supply side, agents' attributes, knowledge and competencies possess affinities and close relationships with firms within a sector.

Agents in a sector are heterogeneous. They can be organizations (firms and non-firms) and individuals. They are characterized by specific learning processes, beliefs, expectations, competencies, organization and behaviors. Agents are engaged in processes of learning and knowledge accumulation. Lundvall (1996) argued that skills are included in the knowledge domain and that learning is basically a process of competencies building. He also highlighted (*ibid*: 1) that "learning is an interactive process and knowledge is a collective asset shared in networks and organizations" (Lundvall, 1996). Malerba (2002) argued that in uncertain and changing environments, the emergence of networks occurs due to the dissimilarities and complementarities of agents.

Agents interacting in a sectoral system are connected and relate to each other via market and non-market relationships and interact through processes of communication, exchange, cooperation, competition and command. They undergo changes and transformation through processes of co-evolution. Agents also relate to each other in formal cooperation and informal interaction. In SSI, the sense of structure is related to links among artifacts and to relationships among agents. This is different from the concepts used in industrial economics where structure is associated with market structure, vertical integration and diversification. Networks and agent's interactions are important elements behind the integration of complementarities in knowledge, capabilities and specialization.

Institutions

According to Malerba (2005b), in all sectoral systems, institutions play a fundamental role in influencing the rate of technological change, the organization of innovative activity and performance. The fundamental argument underpinning the importance of the institutions in a SSI is the fact that they shape agents cognition and actions and affect their interaction.

Institutions often have an informal character and reproduce the contents of common habits, norms, routines that regulate social and economic life. They hold a substantial "tacit knowledge"[47] as opposed to the formal institutions whose contents are basically comprised of "codified knowledge"[48] as laws, standards and specific regulations (Conen and Díaz Lopez, 2009).

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[47] Polanyi (1966) classified human knowledge into two categories: "Explicit" (cf. note 12) and "Tacit" knowledge. "It is generally accepted that tacit knowledge is non-codified, disembodied know-how that is acquired via the informal take-up of learned behavior and procedures" (Howells, 1996: 92). "Tacit knowledge has a personal quality, which makes it hard to formalize and communicate". (Nonaka, 1994: 16)

[48] "Explicit or codified knowledge refers to knowledge that is transmittable in formal, systematic language." (Nonaka, 1994: 16)

In the formal field, regulative institutions refer to the formal rules constraining and regulating behavior and are backed by sanctions. The informal institution's domain is mainly permeated by normative institutions, which encompass informal rules that follow from socialization processes and socially desirable expectations (*ibid*). Additionally, "cognitive rules constitute the nature of reality and the frames through which meaning or sense is made. Symbols (words, concepts, myths, signs, gestures) have their effect by shaping the meanings we attribute to objects and activities" (Geels, 2004: 904)

Institutions can emerge as a result of agents' intentional elaboration and as the result of planned decisions or can be an unpredicted result of agents' interaction. They can act upon agents' behavior and interaction both as binding and stimulating (Malerba, 2002). Depending on the context and on the specific case, institutions can exist in isolation or be part of a system of institutions whereby, its regulating character is rendered effective through the complementarities and influence of a number of different institutions (*ibid*).

They can be national and sectoral and vary across countries and sectors. It is also important to highlight the crucial influences of national institutions on sectors and *vice versa.* National institutions affect different sectors in different manners by favoring sectors that fit their specificities better and by limiting innovation processes in other sectors. In the opposite direction, sectoral institutions can evolve and occupy the national level (Malerba, 2002, 2004, 2005a, 2005b).

3.2-The Theory of Planned Behavior: Background and Theoretical Aspects

As stated previously, innovation theory and its behavioral aspects are important theoretical pillars that support and form the structure for this thesis´s research. In this respect, Appendix H was entirely devoted to present the aspects, principles and relations that underpin technological change, innovation and eco-innovation that are of interest in this work.

Section 3.2 discussed the behavioral theoretical grounds that support eco-innovation processes. It builds upon the previous sections of this thesis research. The main objective of this section is to provide a testable theoretical body for conducting the micro to meso level study designed to gain an understanding of the determinants of eco-innovative behavior in the Brazilian petrochemical sector.

Social human behavior in the industrial realm, at the firm and sector levels or at the supply and demand sides, plays a fundamental role in the innovation processes. At the firm level, owing to its evolutionary heritage, innovation studies establish a primary dependence of innovation on individual and organizational behavior. This is illustrated by Nelson and Winter (1982: 72) who addressed concerns "with the behavioral aspects of firms and other organizations". They explored the connections between routines and innovations and clarified how innovative activities relate to the general image of firm's behavior that is governed by its routines.

This view was shared and reinforced by (Meeus and Oerlemans, 2000) who argued that innovative activities were understood as a component of behavioral routines, which determine the competitive edge of firms.

As noted in Appendix H, innovations and routines are not produced unexpectedly. Firms deliberately innovate and dedicate financial, material and cognitive resources to that purpose. Cognitive resources can be traced back to the individual level (Beckenbach and Daskalakis, 2008). "Investigating the reason why a firm's agents leave well-established routines and switch to a highly uncertain innovation process, is a further important aspect of a behavioral foundation of innovation processes" (*ibid*, 182).

In this regard, the study of determinant factors that can influence companies to change their behavior towards the environment and promote their deliberate engagement in eco-innovative activities, is the most important contribution of this thesis research to innovation studies.

By providing an understanding on and an explanation of these influences on the development of companies´ intention (willingness) to engage in pro-environmental behaviors, it is expected that this work contributes to diminish the "somewhat strange neglect of the behavioral aspects related to the innovation process" (Beckenbach and Daskalakis, 2008: 181).

Innovating means undergoing processes of change. As these processes are socially induced and constructed, it seems plausible that any human social activity is molded and mediated by factors that determine and shape human behavior.

Explaining why and how innovative behavior takes place at the firm level and identifying the elements that determine and influence (incentives and disincentives) innovation processes has been a major challenge in theoretical and empirical innovation studies (Montalvo, 2006). According to Montalvo (*ibid*: 312), these studies and challenges have been historically adversely influenced by some shortcomings that reside in "three fundamental concerns about the current state of the innovation literature (…) concerning the capacity of current models to explain and predict innovative behaviors":

a) A commonality of current theories and studies is that they tend to put emphasis on individual factors as determinants of the innovative behavior and much of the knowledge is still rather fragmented due to the lack of the unification of diverse insights;
b) No models have been provided to facilitate the quantitative empirical test of the influences of these individual factors;
c) The literature does not propose methodologies to assess the origin of such dissonance between cognition and behavior.

This vision of fragmented, dissimilar factors influencing behavior was also shared by Bamberg and. Schmidt (2003: 265):

> "(…) many of these studies were exploratory in nature. As such, many of them examine variables without providing a strong theoretical basis for doing so. Often it remained unclear how these factors relate to each other when studying environmental behavior".

In order to overcome these shortcomings, Montalvo (*ibid*) emphasized the need for the provision of a single theoretical body that could unify the many fragmented insights, individual determinants and dissimilar factors[49] attributed to the occurrence of innovative behavior in organizations by current theories and studies (*ibid*).

This was translated as a need for the development of a theoretical and methodological approach that enabled the integration of insights from diverse areas of innovation studies towards the explanation of innovative behavior of the firm in specific contexts.

According to Bamberg and Schmidt (*ibid*: 265) "a great advantage of theory-driven models is that they contain precise operationalization of the theoretical constructs used and specify the causal processes through which they affect behavior".

As a consequence, Montalvo Corral (2002) proposed a behavioral structural descriptive model (cf. Chapter 5) that:

> "Compared to previous models that explain the innovative behavior of firms, the structural model proposed (…) not only enables to comprehensively explore the internal and external operating contexts of the firm. In addition, it allows assessing the influences between the predictors and the propensity of the firm to innovate and explore what type of relationship could exist among variables". (Montalvo, 2006: 320)

Following Montalvo Corral´s (2002) seminal work, this thesis research was designed to contribute to behavioral sciences and innovation research fields. It developed insights and reflections designed to help to reverse the historical neglect related to the behavioral aspects of innovation. In addition, this research can contribute to the field of innovation economics as "analyzing the behavioral foundations of innovation should be viewed as a one main topic of innovation economics" (Beckenbach and Daskalakis, 2008: 181).

In addition, this thesis research contributes to the field of behavioral economics[50], which "uses evidence of psychology and other disciplines to create models of limits to rationality, will-power and self-interest, and explores the implication in economic aggregates" (Camerer, 2006: 181).

> "(…) economic theory is more than an analogy to behavioral psychology; economics is also a science of behavior, albeit that of highly organized human behavior" (Hursh, 1984: 435).

The need for a unifying theoretical body for predicting and explaining human social behavior has produced a variety of social-psychological theories used for the explanation and prediction of social behavior. They cover different grounds and incorporate many diverse insights, approaches and theoretical formulations. Such theories have been applied to a variety of different contexts producing many different results (cf. Bamberg and.

[49] "e.g. institutional arrangements, entrepreneurial or risk taking behaviors, economic opportunities, organizational learning, technological and organizational capabilities, etc." (Montalvo, 2006: 312).

[50] Behavioral Economics: "a method of economic analysis that applies psychological insights into human behavior to explain economic decision-making. Source: Oxford Dictionaries" (http://www.oxforddictionaries.com/us/definition/american_english/behavioral-economics) accessed in August 2013). It studies the effects of emotional, social and cognitive factors on the economic decisions of individuals and institutions and their impact on economic aggregates.

Schmidt, 2003). Additionally, behavioral theories and models harbor the analytical problem related to the level of analysis.

> "Notably, for more than a hundred years, economics (…), sociology (…) and the philosophy of science (…) have witnessed a debate as to whether individuals ('micro') or social collectives ('macro') have explanatory primacy. This debate has raged under the label of 'methodological individualism' versus 'methodological collectivism'. The issue and debate carry very substantial theoretical and explanatory implications; for example, what are the relations between micro and macro levels? Do we always need to invoke micro-level explanatory mechanisms when trying to explain some macro-level phenomenon? Is it legitimate to rely on aggregate constructs as part of the *explanans* – or, are these only present in the *explanandum* of an explanatory structure?" (Felin and Foss, 2006: 2).

In this respect, because this research work focused upon firms as the central object of study, the choice of the most appropriate level of analysis, which can best explain innovative behavior at the firm level, was of extreme relevance.

According to Staw (1991: 815), "many rather universalistic tendencies on the part of the individuals will aggregate into organizational level behavior". Additionally, he argued that psychological models are of relevance under circumstances in which individual behaviors and individual-level processes influence and mediate organizational actions, and theories of human behavior serve as a metaphor for the actions of organizations.

In the same line of argumentation, Beckenbach and Daskalakis (2008) called attention to the importance of agent-related surveys in the innovation research. According to them, the usefulness of such surveys resides in their capability of enabling a disaggregated assessment of observable innovation elements. In parallel, they allow for taking into consideration innovation determinants, which cannot be observed with the usual methods.

They further emphasized that this kind of survey is able to capture agent-related micro-foundation topics that have often been neglected. This includes the agents´ cognitive processes in terms of knowledge, memory, attitudes and beliefs involved in the process of novelty creation. Such processes depart from the development of agents' perceptions on market processes up to their transformation into courses of action. Although this issue is fundamentally important in the study of firms' behavior, it is more appropriately dealt with in Chapter 5 in which it is addressed in detail.

Based on the foregoing paragraphs, and in line with this thesis researcher's objectives, Ajzen's (1991) "Theory of Planned Behavior" (TPB) and Montalvo Corral´s (2002) TPB based structural descriptive behavioral model (cf. Chapter 5) are referred to as the behavioral theoretical body, organizing framework and analytical tool for the study of the determinants of the eco-innovative behavior of companies. Following the work of Montalvo Corral (*ibid*), this study was conducted at the individual level as a proxy to infer the planned behavior of the firm. The TPB is presented in Section 3.2.1 in the depth required for this research.

3.2.1- Theoretical Aspects of the Theory of Planned Behavior

The "Theory of Planned Behavior" (TPB) is a social psychology based behavioral theory in which the "true goal of the theory is explaining human behavior, not merely predicting it" (Ajzen, 1991: 189). It has been applied as a framework in the studies of explanation and prediction of a large number and a wide variety of social behaviors in a broad spectrum of social activities in different contexts (for examples of the TPB applicability, cf. Ajzen, 1991 and 1996, Montalvo-Corral, 2002 and When de Montalvo, 2003).

Despite the existence of TPB-based empirical studies, for a vast set of environmental behaviors (e.g. Bamberg 2003, Bamberg and Schmidt, 2003; Beckenbach and Daskalakis, 2008, Harland *et al.*, 1999; Kalafatis *et al.*, 1999; Manetti *et al.*, 2004), according to Beckenbach and Daskalakis (2008), not much attention has been dedicated to behavioral aspects related to the eco-innovation process. In this regard, "only few empirical studies have been influenced by the findings of modern cognitive psychology" (*ibid*, 2008: 181) (e.g. Beckenbach and Daskalakis, 2008; Montalvo-Corral, 2002; Montalvo, 2005 and 2006; When de Montalvo, 2003; Sartorius, 2008, Zhang *et al.*, 2011).

The following sections explore the theoretical aspects of the TPB that are relevant to this thesis research and provide a foundation for a better understanding of the development of its behavioral model (cf. Chapter 5). Such behavioral model was empirically tested in the context of the Brazilian petrochemical sector (cf. Chapter 6 and Appendices A, B and C).

The Contributions from the Decision-Making Theory to the Development of the Theory of Planned Behavior

When an individual decides to engage or simply not to engage in a behavioral mode, he or she is actually making a choice (Ajzen, 1996). Human decision-making is a socio psychological process that is influenced and constructed by the interaction of a number of interdependent social, personal and environmental aspects that pose a host of challenges to decision-makers. This argument was synthetically explored by Ajzen (*ibid*: 297):

> "Most important perhaps, is the problem structuring occurring prior to making a decision, in which she or he becomes aware of the problem that requires decision, specifying the possible courses of action, collecting information about the possible alternatives, identifying likely future events and other circumstances relevant to the decision and considering the possible outcomes on the chosen action and prevailing circumstances. After structuring the problem needs to estimate the probabilities of the outcomes associated with the different alternatives, the appraisal of the subjective values or utilities of the outcomes, integrate these outcomes to choose a preferred course of action and then implement the decision at an appropriate opportunity."

For each of these noted aspects, there are various subjacent processes and influencing mechanisms. According to When de Montalvo (2003: 34), "research into factors that influence human judgment and decision-making provides a basis for deriving the necessary theoretical constructs". She also called attention to the multidisciplinary character of the decision-making domain. Decision-making domain undergoes influences and contributions from different areas of knowledge as diverse as economics, political sciences, organization and management studies and social psychology.

The field of behavioral decision-making is vast and multidisciplinary. Covering all aspects and the many theoretical contributions related to it is out of the boundaries of this work. In this thesis research, for the sake of providing a good understanding of the TPB, the interest resided in covering conceptual and theoretical aspects that can exert influence on its conception and that can provide theoretical support for the theory.

According to Bamberg and Schmidt (2003: 265), "the development of models for explaining and predicting environmental behaviors has become a key issue of social science environmental research". Additionally, they stated that the application of well-established social-psychological theories for explaining and predicting environmental behavior provides the advantage of allowing for the development of theory-driven models containing "precise operationalization of the theoretical constructs used and specify the causal processes through which they affect behavior" (*ibid*: 265).

In the field of the social psychology, research on decision-making explores attitude formation as a central research field (*attitude-behavior* models). In this regard, much of the decision-making research has been based on the Rational Choice Theory (RCT). According to the RCT, "actors are assumed to anticipate and evaluate the consequences of what they do. As a result, behavior is construed as a decision that is based on what people expect as a result of what they do and on their beliefs if this is good or bad" (Strack and Deutsch, 2007: 408).

Additionally, according to Opp (1999)[51], the RCT took into consideration the following important assumptions in explaining human behavior: (a) the cognitive limitations of the decision-makers (bounded rationality); i.e. "(…) failure of knowing all existing alternatives, uncertainty about the relevant exogenous events, and inability to calculate consequences" (Simon, 1979: 502), (b) that all kinds of preferences may be explanatory factors, (c) that all kinds of constraints may govern human behavior, (d) that perceived (subjective) and objective constraints may be relevant, and (e) that constraints and preferences taken together may explain behavior. These assumptions are present in the theoretical aspects that support TPB.

The RTC influenced the work of Martin Fishbein and Icek Ajzen in the development of their *attitude-behavior* theories and models. Their well-known, "Theory of Reasoned Action" (TRA)[52], the predecessor of the TPB, is a prominent example of a RCT influenced theory. In the TRA, Fishbein and Ajzen (1975: 29), stated that "a person´s attitude toward any object is a function of his beliefs about the object and the implicit evaluative responses associated with these beliefs"; i.e. people´s decision on what they do is conditioned and determined by their attitude toward the behavioral outcome (Strack and Deutsch, 2007). It can be argued that, in general terms, any given decision is associated with a target behavior (Montalvo Corral, 2002).

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[51] Opp (1999) explored the RCT in its diverse aspects by making comparisons of its "narrow" and "wide" versions. The assumptions explored in that text were extracted from RCT´s "wide" version. This choice was based mainly on the fact that factors such as bounded rationality and the other assumptions that are present in the RCT "wide version" are in line with the underlying aspects of the TPB.

[52] The "Theory of Reasoned Action" (TRA) postulates that besides attitudinal factors, social or normative factors are two major factors that determine behavior (Fishbein and Ajzen, 1975). Since the TRA is the predecessor of the TPB, from which it inherited its theoretical formulation and the attitudinal and normative constructs, the TRA is not covered in detail in this section but it is indirectly considered in the discussions related to the TPB.

In regard to beliefs, Fishbein and Ajzen (1975: 218) argued that "although a person may hold a large number of beliefs about any given object, it appears that only a relatively small number of beliefs, no more than five to nine, serve as determinants of her or his attitude at any given moment". These are called "salient beliefs". Salient beliefs tend to correlate more strongly with an independent measure of attitude than non-salient beliefs (Ajzen, 1996: 191). "The source of beliefs can be logical processes as well as emotions and desires" (When de Montalvo, 2003: 35 *apud* Ajzen, 1996).

Complementary to the discussions regarding the attitude forming beliefs, it is important to underscore the role of behavioral intention in the attitude-behavior domain.

According to Ajzen, (1991), Fishbein and Ajzen (1975) and Triandis (1977), the decision to engage in a behavior is mediated by the behavioral intention and that the attitude construct is a central social psychological concept used to predict and to explain behavioral intention and actual behavior (Ajzen, 1996).

According to Eagly and Chaiken (1993), it is mostly agreed among social psychologists that attitude is the tendency to respond to an object with some degree of favorableness. At the core of a person's attitude, dwells her or his evaluative reaction to the attitude object. This evaluative reaction is attributed to the beliefs that this person holds towards to the attitude object (behavior) (Ajzen, 1996).

In order to operationalize their *attitude-behavior* theoretical formulations, and to measure the beliefs-attitudes relations, Fishbein and Ajzen proposed a descriptive model (TRA) "that is applicable to any set of beliefs, salient and non-salient, new or old" (Fishbein and Ajzen, 1975: 222).

The model was developed based on the theoretical grounds of the expectancy-value theories (or expectancy-value models - EV). Expectancy value theories stem from the argument that people would learn to perform (or increase their probability of performing) a behavior that they expected to lead to positive outcomes (*ibid*). "According to the expectancy-value model, a person´s evaluation of the attitude contributes to his attitude in the proportion of the strength of his belief" (*ibid*: 222).

Consistent with the assumptions made by the RCT, in explaining human behavior, the EV models make no assumptions on rationality and rely on the internal consistency[53] between the model´s constructs instead (Ajzen, 1996). Additionally, they are not limited to the use of cognitive elements only, their formulation also include non-cognitive factors (*ibid*, 1996). The model is not based upon assumptions on causality, but deals with the relations between beliefs and attitudes (Fishbein and Ajzen, 1975).

Expectancy value models are considered the ones that better support this approach of attitude formation as they are based on the relations between beliefs about an object and the attitudes towards this object. In EV models, the predisposition to engage in a behavior is also directly related to the decision-maker's evaluation of each outcome and to the subjective probability that the behavior will produce that outcome.

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[53] Internal consistency refers to the degree of interrelatedness among the items (Cortina, 1993). It measures whether several items that propose to measure the same general construct produce similar scores.

Stated differently, each belief is associated with a specific outcome. A person's overall attitude towards the behavior is determined by the subjective values or evaluations of the outcomes associated with the behavior and the strengths of these associations. The basic analytical representation of the EV model is:

$$A \; \alpha \; \sum_{i=1}^{n} b_i e_i \quad \text{(Eq. 3.1)}$$

Where A is the attitude towards the behavior A, b_i is the strength of the belief (subjective probability) that the behavior will lead to outcome *i*, e_i is the evaluation of outcome *i*, and n is the number of outcomes.

As stated earlier, EV models do not make assumptions about rationality. They rely on the internal consistency of beliefs with the constructs within the model and these constructs with intentions and intentions with behavior. In this chain of consistency along the descriptive behavioral models underlie the "principle of compatibility", formulated by Ajzen and Fishbein.

> "According to this principle, attitudes predict behavior only to the extent that the two refer to the same underlying evaluative disposition. Because they reflect a general evaluation of the attitude object, behavioral aggregates (multiple-act criteria) are compatible with attitudes toward the target of the behaviors, whereas, a specific action performed in a particular context is compatible only with the evaluation of the specific behavior in question". (Ajzen and Fishbein, 2000: 17)

Behavioral Definition

The "principle of compatibility", clarifies the conditions under which strong attitude-behavior correlation can be expected. This implies that, when applying the TPB, the first step towards understanding a behavior is to define the behavior under study (Montalvo Corral, 2002).

According to the "principle of compatibility", the TPB established four criteria for a behavior definition. Behavioral entities may be viewed as being defined by four different elements (a) the ***action*** (a given action is always performed with respect to a given target), (b) the ***target*** at which the action is directed, (c) the ***context*** in which the action is performed, and (d) the ***time*** at which the behavior is performed[54] (Ajzen and Fishbein, 1977). The generality or specificity of each element depends on the measurement procedure employed (*ibid*).

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[54] Although intention determines behavior, it should not be considered to be an accurate predictor of behaviors. According to Montalvo Corral (2002), a reliable prediction is contingent on two factors: (a) the degree of correspondence between the measure of intention and the behavioral criterion: action, target, context and time. "Intentions and behaviors correspond only to the extent that their elements are identical (…) Changing any of the four elements that define behavior can call out completely different (…) beliefs" (*ibid*, 39), and (b) the stability of behavior over time.

> "A clear definition of each of these four behavioral criteria is essential for the accurate measurement of any behavior under study". (Montalvo Corral, 2002 *apud* Ajzen, 1991)

The behavioral definition for this thesis research is presented in Chapter 4.

The Structure of the Theory of Planned Behavior

The Theory of Planned Behavior (TPB) is a social psychology based theory concerned with predicting and explaining human social behavior. It is claimed to be a general theory of social behavior. Its formulation takes into account that most human behavior is goal-directed implying that social behavior can be depicted as moving along paths of more or less well formulated plans (Montalvo Corral, 2002).

Owing to its theoretical heritage from the decision-making theory in the social psychological domain, the TPB postulates that intention is the immediate predecessor determinant of an action (behavior). Ajzen (2005: 113) defined intention as:

> "Intentions are assumed to capture the motivational factors that have an impact on a behavior, they are indications of how hard people are willing to try, or how much of an effort they are planning to exert in order to perform a behavior. These intentions remain behavioral dispositions until, at the appropriate time and opportunity, an attempt is made to translate the intentions into action."

The Theory of Planned Behavior (Ajzen, 1991) is an expansion of the "Theory of Reasoned Action" (TRA) Fishbein and Ajzen (1975) whereby, behavioral intention is predicted and explained for cases when the behavior under study is completely under volitional control. According to the TRA (*ibid*) behavioral intentions are a function of the weighted sum of two constructs: (a) the actors´ attitude toward performing the behavior under a given set of circumstances, and (b) the person´s perception of the social influence exerted by important referents for the performance of a given behavior.

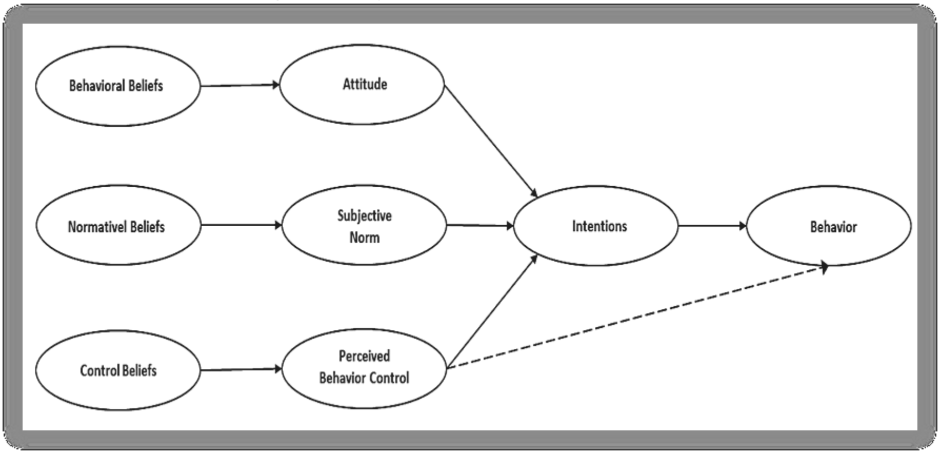
The TPB was designed to predict behaviors that are not entirely under volitional control. This was achieved *via* an expansion of the TRA. Such expansion included of a third construct that took the measures of the perceived control over the behavior (*PBC*) into consideration. The relationship of the *PBC* with the actual behavior is based on two rationales:

- "Holding intention constant, the likelihood that a behavior will be carried out increases with greater perceived behavioral control, and
- Perceived behavioral control will influence behavior directly to the extent that perceived control reflects actual control. In addition, perceived behavioral control works in parallel with attitudes and subjective norms as a determinant of intentions." (Armitage and Conner, 1999; 36)

The inclusion of the volitional control element in the TBP, made explicit that the behavior intentions of individuals, in most situations, can be explained and predicted by their attitudes, subjective norms and behavioral control towards a specific behavior, in specific contexts (Montalvo Corral, 2002).

These elements are hierarchically structured in the descriptive structural model presented in Figure 3.2.

Figure 3.2- The hierarchical structure of the Theory of Planned Behavior descriptive behavioral model according to Icek Ajzen



Source: Armitage and Conner (2001)

From Beliefs to Behavior: Predicting and Explaining Behavior

As previously noted, at its most general level of explanation, the TPB framework postulates that performing a specific behavior is mediated by the behavioral intention. The behavioral intention is, in turn, directly influenced by three behavioral constructs: attitudes (*A*), subjective norm (*SN*) and (*PBC*) perceived behavior control. A specific behavior is considered explained once its determinants have been traced back to underlying beliefs (Montalvo Corral, 2002). The examination of the three constructs that influence intention-behavior is fundamental for reaching the predictive reliability and the understanding of any behavior (*ibid*).

From Beliefs to the Determinants of Intentions

As previously noted, in the EV-based TPB models the predisposition to engage in a behavior is directly related to the decision-maker's evaluation of each outcome and to the subjective probability that the behavior will take to the outcome in question. These evaluations rely on the internal consistency along the different hierarchical levels of explanation proposed by the theory spanning from beliefs through the behavior performance.

Stated differently, the constructs of behavioral intentions (attitude, subjective norm and perceived behavioral control) are associated with their underlying beliefs. A person's overall attitude, subjective norm and perceived behavior control over the behavior are determined by the subjective evaluation of each belief and its respective strength.

In respect to beliefs, Ajzen (Ajzen, 1996) argued that three classes are identified:

- **Behavioral beliefs**: are assumed to influence attitudes toward the behavior;
- **Normative beliefs**: constitute the underlying determinants of subjective norms, and
- **Control beliefs**: provide the basis for perceptions of behavioral control.

Attitude Formation Towards the Behavior

Attitude formation and its relationships to the behavioral beliefs are theoretically based upon Fishbein and Ajzen's (1975) expectancy-value model (EV) of attitudes. According to the EV model, attitudes develop reasonably from the behavioral beliefs people hold about the object of the attitude" (Ajzen, 1991).

Montalvo Corral (2002) argued that attitudes are indices of the degree to which people like or dislike, approve or disapprove, agree or disagree with any aspect of her or his life. It is the positive or negative evaluation of performing a behavior (Wehn de Montalvo, 2003). "A person's attitude towards performing a specific behavior is proposed to be a function of the perceived consequences of performing that behavior and of the person's evaluation of those consequences." (Fishbein and Ajzen, 1975: 301)

At the theoretical level, each behavioral belief is associated with an outcome, which is valued positively or negatively. Analytically, it is expressed by Equation 3.1, which depicts how, under the TPB, attitudes are expressed as indexes that are proportional to the results obtained by multiplying the subjective evaluation (*e)* of each behavioral belief attribute and the strength (*b)* of each belief. The final index is obtained by the summations of the products over the "*n*" beliefs. That is: a person's attitude (*A)* is directly proportional (*α*) to this summative belief index (Ajzen, 1991).

$$A \; \alpha \sum_{j=1}^{n} b_i \, e_i \qquad \text{(Eq. 3.1)}$$

Where:

A	is the individual's attitude towards performing a behavior;
b_i	is the belief (subjective probability) that performing the behavior will lead to the outcome i;
e_i	is the evaluation (strength) of outcome i;
n	is the number of behavioral salient beliefs, and
Σ	is the sum of the n salient behavioral beliefs.

Normative Beliefs and Their Influence on Subjective Norms

The subjective norm deals with the influence of the social environment on human behavior (Fishbein and Ajzen, 1975). The subjective norm measures the perception that one has on the degree to which important referents, individuals or groups, in her or his social environment, think he or she should or should not perform the behavior. The subjective norm index reflects both the perceived social pressure to perform a given behavior and the subject's motivation to comply with those pressures and expectations.

In the TPB, the subjective norm index calculation, as any other index that provides indirect measures of the constructs of behavioral intentions formation, follows the Fishbein and Ajzen's (1975) expectancy-value model. In the social normative domain, the strength of each normative belief (*b*) is multiplied by the person's motivation to comply (*m*) with the referent in question. The subjective norm (*SN*) is directly proportional to the sum of the resulting products across the "n" salient referents (Ajzen, 1991) as expressed in Equation 3.2.

The subjective norm index calculations it takes the following form:

$$SN \; \alpha \sum_{j=1}^{n} b_j \, m_j \quad \text{(Eq. 3.2)}$$

Where:

SN	is the subjective norm;
b_j	is the normative belief *j*;
m_j	is the motivation to comply with referent *j*;
n	is the number of normative salient beliefs, and
Σ	is the sum of the n salient normative beliefs.

Control Beliefs and the Perceived Behavioral Control

According to Ajzen (1991), in the TPB domain, among the beliefs that ultimately determine intention and action, there are the ones that deal with the presence or absence of requisite resources and opportunities. They are called control beliefs that may be based on past experiences related to the behavior, or on other factors that may increase or reduce the perceived difficulty of performing the behavior in question.

This concept of perceived behavioral control has its roots in concept of self-efficacy developed by Albert Bandura. This concept "is concerned with judgments of how well one can execute courses of action required to deal with prospective situations" (Bandura, 1982: 122). The more resources and opportunities individuals believe they possess, and the fewer obstacles or impediments they anticipate, the greater should be their perceived control over the behavior (Ajzen, 1991). The stronger the perception of behavior control, the higher the behavior is under volitional control.

> "Thus, just as beliefs concerning consequences of a behavior are viewed as determining attitudes toward the behavior and normative beliefs are viewed as determining subjective norms, so beliefs about resources and opportunities are viewed as underlying perceived behavioral control." (Ajzen, 1991).

The theory of planned behavior (Ajzen, 1991) is an expansion of the "Theory of Reasoned Action" (TRA) whereby, behavioral intention is predicted and explained for cases when the behavior under study is completely under volitional control and are only subjected to the influences of attitudes and subjective norms. The addition of the perceived behavioral construct introduces the possibility to predict and explain behaviors whose performance is not under volitional control. The perceived behavioral control is considered to contribute to the prediction of both behavior and intention. (cf. Figure 3.2).

Equation 3.3 shows how the perceived behavioral control index can be estimated by multiplying each control belief (*c*) by the perceived power (*p)* of the particular control factor to facilitate or inhibit performance of the behavior. The resulting products are summed across the "*n*" control beliefs to produce the perception of behavioral control (*PBC*).

$$PBC \; \alpha \sum_{j=1}^{n} c_i \, p_i \quad \text{(Eq. 3.3)}$$

Where:

PBC	is the perceived behavioral control;
c_i	is the control belief strength;
p_i	the perceived particular control factor to facilitate or inhibit performance of the behavior, and
n	is the number of control salient beliefs, and
Σ	is the sum of the n salient normative beliefs to produce the perception of behavioral control.

Linking Beliefs to Behavior: the Relations between Intentions, Attitudes, Subjective Norms and Perceived Behavioral Control

According to Montalvo Corral (2002), the TPB is essentially a system of hypotheses linking beliefs to behavior with each hypothesis requiring empirical verification. Predicting and explaining a behavior is contingent on:

- The weight the selected beliefs hold;
- The empirical correlation of the beliefs and their respective indices (*A*, *SN*, and *PBC*) and
- The empirical correlation that *A*, *SN*, and *PBC* hold with intentions.

Not least, the TPB makes clear that global attitudes towards a broad target cannot be expected to predict specific behavior associated with that target (*ibid*). The measures of attitude-behavior are expected to strongly correlate and to be compatible with each other to extent that they address the same behavior, directed to the same target, and in the same context (Ajzen, 1996) as postulated by the "principle of compatibility" (Fishbein and Ajzen, 1975).

As stated earlier in this section, the TPB established that behavior is ultimately determined by beliefs, which influence the variables that determine intention and intention ultimately determines behavior. Therefore, explaining the variance associated with the determination of intention is fundamental for the prediction and explanation of the behavior under study.

According to Montalvo Corral (2002), the variance in intention is proportional to the contributions of each of the constructs in the model and the mathematical form of the relationships of attitudes, subjective norms and perceived behavioral control must be determined empirically. In its simpler form, it is expected to find the following linear relationship between intention and its determinants (Montalvo Corral, 2002):

$$B \sim I \; \alpha \; (w_o + w_1 A + w_2 \, SN + w_3 PBC) \quad \text{(Eq. 3.4)}$$

Where:

B	is the behavior of interest
I	is the individual's intention;
A	is the attitude toward performing the behavior;
SN	is the individual's subjective norm concerning the performance of the behavior;
PBC	is the individual perceived behavioral control;
w_n	are weighting parameters empirically determined, and
~	suggests that intention is expected to predict behavior only if the intention has not changed prior to the performance of the behavior.

3.2.2 Additions and Extensions to the TPB: The Contributions from Other Theories to Enhance the Explanatory Power

Due to its popularity and its proposal to be a general theory to predict and explain human social behavior, the TPB has been widely used and tested in many different fields. This high exposure brought not only criticisms but also a variety of suggestions and claims for the incorporation of additions and extensions that could enhance the TPB's behaviors prediction and explanation power (e.g. Ajzen, 1991; Beck and Ajzen, 1991; Armitage and Conner, 1999; Conner and Armitage, 1998; Manstead and Parker1995).

For a variety of behaviors, these diverse inputs improved the usefulness of the model. Conner and Armitage, (1998), quoting Fishbein (1997), admitted that a good indicator of the usefulness of models such as the TPB is their power to help design effective interventions that produce behavioral changes. Ajzen (1991: 199) made it clear that the TPB is not a closed system and that there is room for improvements and further constructs:

> "The theory of planned behavior is, in principle, open to the inclusion of additional predictors if it can be shown that they capture a significant proportion of the variance in intention or behavior after the theory's current variables have been taken into account. The theory of planned behavior, in fact, expanded the original theory of reasoned action by adding the concept of perceived behavioral control."

These additions and extensions derived from a variety of different theories and other behavioral models from the social and social psychology sciences. According to Bamberg and Schmidt (2003: 280), they "should not be viewed as alternatives but as supplementary models".

Under the same optics, Conner and Armitage (1998) suggested that a good way to achieve the enhancement of the explanation power of the TPB is to examine different combinations of the variables depending on the nature of the behavior and the purpose of the study.

With regard the study of the determinants of the intention (willingness) of the companies in the Brazilian petrochemical sector, to engage in GCE-based eco-innovative activities, a further elaboration of the social construct of the TPB was proposed.

Therefore, it seemed plausible to propose, as an expansion of the TPB´s social construct, the introduction of personal normative variables. This introduction was intended to expand the options of social and personal determinants in the study of this specific environmental behavioral intention formation. This proposal was designed to enhance the explanatory and predictive power of the model by capturing the underlying social and personal pressures for the performance of the behavior under study.

It was supported by a number of studies (e.g. Ajzen, 1991; Beck and Ajzen, 1991; Armitage and Conner, 1999; Conner and Armitage, 1998; Manstead and Parker, 1995). Although they were directed to other contexts and behaviors, they found relevant evidence of the contributions, of these variables, to the prediction and explanation of the behavioral intentions.

Furthermore, these extensions to the TPB were supported by the line of argumentation that predicates the need for a "re-conceptualization of the mechanism by which normative pressure is exerted" (Armitage and Conner, 2001: 486).

According to these authors, this re-conceptualization was required to overcome the weaknesses presented by the TPB´s normative component as it was found to be the weakest predictor of intention in the TPB. Such weakness had attracted criticism for their narrow conceptualization (Armitage and Conner, 1999; Conner and Armitage, 1998). Therefore, in this thesis research, the use of the previously highlighted variables as extensions of the normative construct of the TPB was expected to contribute to overcoming the "growing criticism of the subjective norm component as a limited representation of social influences on behavior" (White *et al.*, 2008: 486).

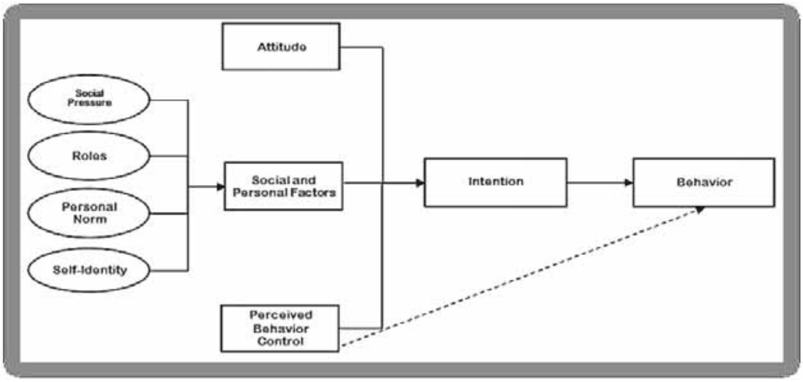
In order to expand this research´s behavioral model´s explanatory power, this proposal incorporated to the TPB´s normative construct: (a) the social normative and self-identity concepts, proposed by the "Theory of Interpersonal Behavior" (TIB) (Triandis, 1977) and (b) the concept of the personal moral norm (Schwartz, 1977).

According to the TIB, perceived social norms are formed by normative and role beliefs.

Social factors include norms, roles and self-concept. Similarly to the TPB, social normative beliefs in the TIP, refer to the internalization by an individual of the opinions of important referents about the realization of the behavior. *Role beliefs* reflect the extent to which an individual thinks someone of his or her age, gender and social and professional position should or should not behave (Gagnon *et al.*, 2003; Jain and Triandis, 1997). *Self-identity* (self-concept) refers to the degree of congruence between the individual's perception of himself or herself and the characteristics that he or she associates with the realization of that behavior (Jain and Triandis, 1997).

The *personal normative beliefs* reflect commitment with internalized values and are experienced as feelings of personal (moral) obligation to engage in a certain behavior (Schwartz, 1977). Moral norms are regarded as an individual's perception of the moral correctness or incorrectness of performing a behavior (Ajzen, 1991). Further elaborations on this issue are presented in Chapter 5. The proposed social factors construct is presented in Figure 3.3.

Figure 3.3- This thesis researcher's proposed social and personal factors construct to predict and explain companies' intentions to engage in eco-innovation activities



Source: author

3.3 Managers as the Unit of Analysis for Organizational Behavior

From a general perspective, the main objective of this research is to predict and to explain companies´ willingness to engage and invest in GCE-based eco-innovation activities as a means to achieve advanced states of environmental and economic sustainability.

Two basic and fundamental challenges that arises and that represent a sensitive point for the success of the research are: (a) the choice of the level of analysis and (b) the appropriate agents that can satisfactorily reflect, express and be responsible for the company's notions of "organizational behavior" and "organizational willingness".

The choice of the appropriate level of analysis can be found in the work of authors on decision-making theory. Hambrick and Mason (1984: 194), in their analyses on the human limits to choice and citing Cyert and March (1963), argued that "complex decisions are largely the outcome of behavioral factors rather than a mechanical quest for economic optimization".

They found that bounded rationality, multiple and conflicting goals, myriad options, and varying aspiration levels are limiting factors to the extent that complex decisions can be made on a techno-economic basis. In the realm of decision-making processes within organizations, Hambrick and Mason (*ibid*: 193) in their studies on the "Organization as a Reflection of Its Top Managers" argued that "organizational outcomes, both strategies and effectiveness, are viewed as reflections of the values and the cognitive bases of powerful actors in the organization". This directs the choice of the appropriate levels of analysis, when studying organizational behavior, to these powerful actors in the organizations. In this thesis research, they are the organizations´ managers and key decision-makers.

Based on these arguments and on Montalvo Corral´s (2002) work, this researcher made a simile between the "perception" of the entity "the firm" with the perceptions of the managers and important decision-makers (*ibid*).

Based on numerous authors, Montalvo Corral (*ibid*) and Montalvo (2006) argued that the reason for this choice stemmed from the fact that decision-making within the firm is socially constructed and that in this process managers are considered to be the primary decision-makers.

They are, therefore, best positioned to express the preferences of their organization as they are the trustees of the strategic vision of the firm and the hub of information, communication, control and decision-making. Managers are considered to be the best informed about the internal and external contexts in which their organization operates. Therefore, "the assessment of managers' (or CEOs) perceptions (…) is considered to be the appropriate proxy to infer the planned behavior of the firm." (Montalvo, 2006: 315)

3.4 Summary

This chapter introduced the theoretical framework that is the base for this thesis research. It showed the relevant topics that were required for the study of the determinants of GCE-based eco-innovative behavior in companies in the Brazilian petrochemical sector. It is of uppermost value to stress that this thesis researcher's findings can significantly contribute to eco-innovation policy formulation at the corporate, sector and governmental levels.

Innovations do not come from the blue. Firms deliberately innovate through complex processes that involve a series of interrelated and interdependent variables and agents (individuals and organizations) relationships.

Agent's engagement, or not, in these eco-innovative processes is contingent on their behavioral intention (willingness) to participate in such processes. In this thesis research, the TPB was adopted as the main theoretical body and organizing framework, to predict and explain the degree to which firms, in the Brazilian petrochemical sector, are willing to engage in the aforementioned behavior. In order to extend the predictive and explanatory power of the TPB its social construct was reinforced with elements of its analogous construct in the "Theory of Interpersonal Behavior".

The SSI framework provided the theoretical contribution regarding innovation to thy study.

The set of theoretical domains depicted in this chapter provide the required base for the formulation of an operational structural descriptive model that was constructed, and empirically tested, based upon Montalvo Corral's (2002) TPB-based structural descriptive behavioral model for innovation behavior.

This thesis research was built upon the argument that "analyzing the behavioral foundations of innovation should be viewed as one main topic of innovation economics" (Beckenbach and Daskalakis, 2008: 181). It was designed to contribute to the behavioral and innovation study fields by eliciting insights and inducing reflections to help to reverse the "somewhat strange neglect of the behavioral aspects related to the innovation process" (*ibid*: 181).

In parallel, if eco-innovation is seen as an economic activity, this research can contribute to the fields of innovation economics and behavioral economics. Behavioral economics "uses evidence from psychology and other disciplines to create models of limits on rationality, will-power and self-interest and to explore their implication in economic aggregates" (Camerer, 2006: 181). This perspective is supported by Hursh´s (1984: 435) argument that "economic theory is more than an analogy to behavioral psychology; economics is also a science of behavior".

4. Research Design and Implementation Methods

4.0 Introduction

Chapter 3 defined the theoretical grounds and provided the organizing framework for this research. Chapter 4 is an extension of Chapter 3 wherein an in-depth view of the methodological issues was presented.

In this regard, Section 4.1 presented the definition of the case study of this thesis research. Departing from this presentation, Section 4.2 introduced key contributing theoretical elements for the research design.

Section 4.3 presented the fundamentals of the development of the research´s Theory of Planned Behavior (TPB)-based structural behavioral model. In a natural sequence, Section 4.4 presented the foundations that underpinned the construction of this research´s qualitative questionnaire, which was applied to companies' managers and decision-makers in order to collect empirical data.

Complementarily, Section 4.5 provided a detailed view into this thesis research´s qualitative survey by discussing methodological issues of the questionnaire application and data collection. It was followed by a theoretical discussion on the empirical confirmation of the research´s supporting theory *via* the measurement of the statistical reliability of the qualitative questionnaire and the statistical validity of the behavioral model (Section 4.6).

In order to provide a deeper view and a better understanding of the results obtained in this thesis research´s qualitative survey, a quantitative survey was conducted by the researcher. This survey was composed by in-depth interviews with agents who were found to be important actors for the introduction of GCE at the sector and at the company levels. The quantitative survey and its results are presented and discussed in Section 4.7.

Finally, and concluding Chapter 4, the salient limitations of the TPB based method were presented (Section 4.8).

4.1 Definition of the Research´s Case Study

Defining and framing a research study is surely a particular case regardless if it has individual or collective motivations. Motivations exist in as large a number as the number and characteristics of individuals´ perceptions, beliefs, contexts and interests on a given subject.

In this thesis research, the motivations underpinning its framework and objectives were related to the prospective environmental and economic sustainability of the Brazilian petrochemical industry. Such motivations had strong links to the author´s personal views, perceptions and beliefs on the current unsustainable connections and dependency of the current mainstream products and production technologies with the environment (cf. Rand Corporation, 2003; Vision 2020, 1996).

Complementarily, the author had a strong interest in understanding the main determinants of behavioral changes in Brazilian petrochemical companies that could lead them to engage in GCE-based eco-innovation processes. It is expected that this engagement will lead to the development of the next generation of chemical technologies that are more environmentally benign and more competitive.

Secondly, the author was convinced that the current time is propitious for this research. It was justified by the Brazilian chemical and petrochemical sectors´ ambitious plans for expansion. Such plans encompass expansions in size and diversification as a means to make Brazil to rank fifth in the list of world´s largest chemical industries by the year 2020 (ABIQUIM, 2010) (cf. Chapter 1).

According to the *Brazilian Chemical Industry Association* (ABIQUIM, 2010a), among the commitments made by the sector, increasingly higher standards of environmental responsibility, the promotion of the sector´ sustainability, the development of solutions aimed at the development of a renewables-based chemistry and a strong commitment to innovation are central elements.

These arguments indicated a window of opportunities for technological change and eco-innovation to develop. They also suggest that it is a good occasion for the introduction of new and effective frameworks, such as the GCE frameworks, for the design of more sustainable products and processes.

This context provided a favorable scenario for the application of the findings of this research and help companies to develop policies and technological development eco-innovation plans. These contributions can represent substantial contribution for the promotion of transition processes aimed at environmentally and economically GCE-based more sustainable states at the company and the sector levels.

4.2 Key Contributing Theoretical Elements for the Research Design

> "Scientific method refers to a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge." (Goldhaber and Nieto, 2010)

> "To be termed scientific, a method of inquiry must be based on gathering observable, empirical and measurable evidence subject to specific principles of reasoning." (Newton, 1999)[55]

In addition to these considerations, it can be argued that the choice of the scientific method, under which to conduct research, is a function of what is objectively and specifically researched. Under this principle, the research methodology for this thesis research was developed based on its underpinning theoretical grounds.

The choice of the methodological approach was guided by the nature and the objectives posed by the research´s questions. As noted in Chapters 1 and 3, this thesis research's questions focused upon understanding and explaining the key determinants and motivational factors that could support and promote behavioral changes, in the Brazilian basic and intermediate petrochemicals manufacturing companies, as a means to develop the GCE-based next generation petrochemical enterprises.

[55] Newton, I. (1999), *Rules for the study of natural philosophy*, from Book **3**, *The System of the Word,* pp.794–796 (cf. references).

Research Questions

a) Are Brazilian petrochemical companies **willing** to **innovate** in **Green Chemistry** and **Green Engineering** as a viable option to more sustainable corporate behavior?

b) How can their **willingness** be explained and what are the main determinants?

c) What are the sector´s agents, mechanisms and actions, which are integral to their implementations of **Green Chemistry** and **Green Engineering**?

In these three research questions the keywords marked in bold print, underscore specific universes of research under which this thesis was developed:

a) "**Willing" (willingness-intention):** according to the *Webster´s Online Dictionary*, willingness connotes "the quality or state of being willing; free choice or consent of the will; freedom from reluctance; readiness of the mind to do or forbear"[56]. These definitions go hand in hand with Montalvo Corral's (2002) work on behavioral aspects of innovation that, based on the work of Icek Ajzen (cf. Ajzen, 1991; Ajzen and Madden, 1986), associated willingness with behavioral intentions. These intentions, in turn, represent preconditions for one to perform a specific behavior in specific contexts and time frames.

   In this respect, this thesis research was designed to investigate behavioral aspects of innovation, which, according to Beckenbach and Daskalakis (2008), have been, in general, neglected in innovation studies. It proposed the TPB (cf. Chapter 3) (Ajzen, 1991, Ajzen and Madden, 1986) as the behavioral theoretical framework that can integrate several bodies of theory. In addition, it provided a method to search systematically for those bodies of theory that might offer insights into the factors that explain behavior in specific situations. It also rendered "a guidance to search for the belief systems that might determine the planned behavior of the firm" (Montalvo Corral, 2002: 111)

   When a given behavior is the object of interest, it can be argued that any individual holding that will to perform this behavior acquires an immediate and central importance. In the present case, a direct relation between the willingness of the company as an entity with the willingness of its manager is proposed. Firms are inanimate entities. They do not have the sense of willing anything. Their lifelike characteristics are given and are a response to what the people that lead them and those that are responsible for their administration and operations (managers, directors and other influential decision maker) perceive and believe to be the right option to conduct the business (cf. Chapter 3).

[56] http://www.websters-online-dictionary.org/definitions/willingness?cx=partner-pub-0939450753529744:v0qd01-tdlq&cof=FORID:9&ie=UTF-8&q=willingness&sa=Search#922

These arguments supported the metaphor "the companies´ willingness" as a function of the perceptions and beliefs of their leaders´ (the managers as the unit of analysis), which was grounded on the following three factors:

- **The first factor** stemmed from the fact that the research questions and the methodological approach used by this thesis author, relied on the usage of self-reporting questionnaires, which, in turn, characterized the individual as the unit of analysis. It represented the use of individuals´ perceptions and beliefs "to capture the collective vision of the organization´s strategy within a sample of organizations" (Montalvo Corral, 2002: 114);
- **The second factor** was grounded on the literature of organizational studies whereby, it was argued that senior managers or CEOs: (a) ought to have a vision of the future of their companies and (b) have a clear mental image of the firm´s present state and a realistic and attractive vision of the future for their organization. "Empirical evidence shows that the managers themselves believe that articulating a vision and formatting a strategy are their key roles within organizations" (*ibid*: 114); and
- **The third factor** addressed the social aspects associated with the decision-making processes. Strategic decisions within the firm are socially constructed and managers usually make their decisions in conjunction with other actors (*ibid*).

  Firms´ managers, can be considered to be positioned, to best express the preferences of their firms. Their strategic position enables them to be the hub of information, communication control and decision-making. Managers are the trustees of the strategic views of the firm, which is equivalent to the fact that they are the drivers of the company´s planned behavior (*ibid)*.

b) **Green Chemistry and Green Engineering**: provided this thesis author's with the supporting frameworks based on which technological change can develop. Such technological represents "the design of systems and unit processes that obviate or reduce the need for the use of hazardous substances while minimizing energy usage and the generation of unwanted by-products, which is the next generation of environmental protection in chemical engineering." (Anastas *et al.*, 2000b: 1).

   In the specific case of this research, technological changes represented those that are based on the principles established by (a) the Green Chemistry framework proposed by Paul Anastas and John Warner (1998) (cf. Section 2.2.1 of Chapter 2) and (b) the Green Engineering framework proposed by Paul Anastas and Julie Zimmerman (2003) (cf. Section 2.2.2 of Chapter 2).

c) **Innovation theory**: represented this thesis author´s belief and perception of the importance of innovation in promoting environmentally driven technological changes. Eco-innovation is supported by a number of organizations such as the Organization for Economic Cooperation and Development (OECD), which views industrial sustainability as the continuous innovation, improvement and use of clean technologies to reduce pollution levels and consumption of resources (Jenk *et al.*, 2004). In addition, they argued (*ibid:* 545) that "innovation is critical: the challenge for business is not only to provide service to our consumer society, but to innovate new ways of doing so with markedly lower reliance on materials, energy, and waste". On the other hand, Anastas and Beach (2007:20) reinforced this view on the importance and the dependence of Green Chemistry on innovation by arguing, that “innovation is the lifeblood of Green Chemistry”.

Innovation theory provided a theoretical complement to the main theoretical framework that supported this thesis research. Therefore, since innovation covers many issues in industrial firms, it is crucial to specify which aspects of innovation the research was designed to investigate.

Because companies seldom innovate in isolation (Fagerberg, 2005 and Edquist, 1997, 2005b), this thesis´ author focused upon the systemic nature of innovation (cf. Chapter 3). Companies interact with other economic agents (firms and non-firms) in multiple ways. Putting it in a simple way, Lundvall (2007) stated that, in the process of innovative economic and technological change, these connections and interactions between elements are as important as the elements themselves and that the whole is more than the sum of the parts.

Within the systems of innovation theory, and due to the characteristics of this thesis research, which focused on the petrochemicals manufacturing sector, the Sectoral Systems of Innovation (SSI) framework of (Malerba, 2002, 2004, 2005b) was the chosen option.

According to Malerba (2002: 250) “a sectoral system of innovation and production is a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products. A sectoral system has a knowledge base, technologies, inputs and an existing, emergent and potential demand

As a result, behavioral theory, Green Chemistry and Green Engineering frameworks and innovation theory constitute the main theoretical pillars upon which this research was built.

4.3 The Structural Custom Behavioral Model Development of this Research

As stated in Chapter 3 and in Section 4.2, the main theoretical foundations upon which this research evolved was comprised of theories that belong or have significant connections to the behavioral, innovation and GCE domains.

Within the universe of theories in each of these domains, the choices of theories that (a) fit the researcher´s objectives, and (b) promote their integration, represented the first stage of the research strategy (cf. Chapter 3). Both elements were central for the construction of the thesis research´s custom structural descriptive behavioral model (cf. Chapter 5).

The empirical data were collected *via*:

a) The participation of companies´ managers and decision-makers in completing a self-administered, structured quantitative questionnaire. This questionnaire was comprised of closed questions, which were developed and guided based on the elements of the custom structural behavioral model developed for this research (c.f. Chapter 6 and Appendix E) and
b) The performance of a series of in-depth interviews via a qualitative survey, to explore the perceptions of important agents, at the sector and at the company levels, regarding the qualitative survey´s results. In addition, the qualitative survey was

very useful to have a deeper knowledge on these agents´ motivational factors, which underpinned their answers and their perceptions of GCE and their implementation in the Brazilian petrochemical context.

Behavioral Definition

As previously noted in Section 3.2.1 of Chapter 3, the explanation and the prediction of a subject´s planned behavior is the overall objective of the TPB. According to this theory, this prediction can be achieved by unveiling the subject´s belief system that determines her/his behavioral intention, which is ultimately the immediate precursor of the behavior performance (cf. Chapter 3).

The hierarchy that was established for behaviors and intentions implies that, when applying the TPB, the first step towards understanding a behavior is to develop its definition (Montalvo Corral, 2002). Following the "principle of compatibility" (cf. Chapter 3) the TPB established four criteria for the definition of a behavior (*ibid*).

Behavioral entities may be viewed as being comprised of four complementary elements: a given (a) ***action*** (behavior performance) is always performed towards a given (b) ***target***, within a given (c) ***context*** in which the action is performed, and (d) the ***time*** dimension within which the action takes place. The generality or specificity of each element depends on the measurement procedure employed (Ajzen and Fishbein, 1977). Table 4.1 depicts the behavior definition for this research according to the ***action***, ***target***, ***context*** and ***time*** criteria.

The behavioral definition criteria established this research behavior specification based on which the proposed behavioral model was developed, the research hypothesis system was conceived and the structured questionnaire for obtaining the empirical data was constructed.

At this point, it is important to highlight that the time criterion was defined for this research as the next five years starting from the year of 2012. This does not constitute a random choice but it is associated with the Brazilian Chemical Industry´s expansion plans for the second decade of this century (cf. Chapter 1). As noted in Section 1.3.2 of Chapter 1, the Brazilian Chemical sector plans to invest in expansion and innovation in order to rank fifth among the largest chemical industry in the world by 2020. It was assumed that the next five years would be adequate and propitious for initiating the investments in the development of innovative and more environmentally sustainable solutions based in GCE provided that GCE are properly diffused, adopted and implemented.

Table 4.1- Thesis research behavior definition is based upon the criteria established by the Theory of Planned Behavior

Action	• Engagement in eco-innovation activities based on Green Chemistry and Green Engineering
Target	• Companies in the petrochemical sector
Context	• Brazilian petrochemical sector
Time	• Within the next five years

Source: author

Modifying Montalvo Corral´s Model

Although this research largely evolved from Ajzen´s TPB (Ajzen, 1991, Ajzen and Madden, 1986), its development was based upon the work of Montalvo Corral (2002) whose seminal work *Environmental Policy and Technological Innovation: Why do Firms Adopt or Reject New Technology?* provided the fundamentals for the utilization of the TPB as a theoretical platform for the study of behavioral aspects of innovation.

As this researcher adopted a different behavioral definition (*action*, *target*, *context* and *time* criteria) and a different innovation theoretical approach (the SSI framework), modifications to Montalvo Corral´s structural behavioral model were necessary to provide adaptations to the peculiarities of this thesis research (cf. Chapter 5).

In this case, although the researcher´s model´s structure was kept in its original form, its content has undergone substantial changes (cf. Chapter 5). The modifications were made at the following levels:

- **Determinants of intention:** although the TPB specifies three constructs that determine behavioral intention (attitude towards the behavior, perceived social norms and control over the behavior), for the purpose of this thesis research, this author identified an opportunity to expand the study. This expansion introduced personal and additional social normative variables that were expected to enhance the knowledge and the understanding of the influence that they could exert on willingness formation. This approach was inspired by previous research by Ajzen, 1991; Beck and Ajzen, 1991; Armitage and Conner, 1999; Conner and Armitage, 1998; Manstead and Parker, 1995.

- **Behavior domains:** according to Ajzen (1988), behavioral domains were defined as the specific areas of experience and knowledge from which salient beliefs arise. As many and diverse areas of experience and knowledge are required to frame the behavior under study, in this thesis research, the model´s behavioral domains were elicited from various relevant bodies of literature. Such a procedure was possible due to the *meta* theoretical characteristics of the TPB.

  Although this research holds commonalities to Montalvo Corral´s original work, it bears substantial differences. Differences were introduced in the definition of behavior and in the theoretical bodies used to construct the behavioral domains of the research´s structural behavioral model. This explained the modifications to the behavioral domains associated with the model´s social factors and the perceived behavioral control constructs as compared with Montalvo Corral´s model.

- **Beliefs:** as in the definitions of the behavioral domains, the elicitation of their associated beliefs was accomplished *via* insights and from the relevant literature. This was reviewed in detail in Chapter 5.

  These beliefs emerged as the result of the incorporation into the behavioral model of Triandis´s (1977) social factor construct elements (roles and self-identity), Schwartz´s (1977) concept of personal moral norms, and the building blocks of the SSI framework (knowledge and technology; agents and networks and institutions) (Malerba, 2002, 2004 and 2005b).

In this regard, the beliefs of this thesis researcher associated with: (a) the attitude construct, (b) "perceived social pressures" in the perceived social factors behavioral domain, and (c) those related to "strategic alliances with external actors" (within the actors and networks behavioral domain) were identical to Montalvo Corral´s model for reasons that were clarified in Chapter 6.

Figure 4.1- The adapted empirical, behavioral model based on the Theory of Planned Behavior and the "Sectoral System of Innovation" framework for predicting and explaining companies' engagement in eco-innovation activities in green chemistry

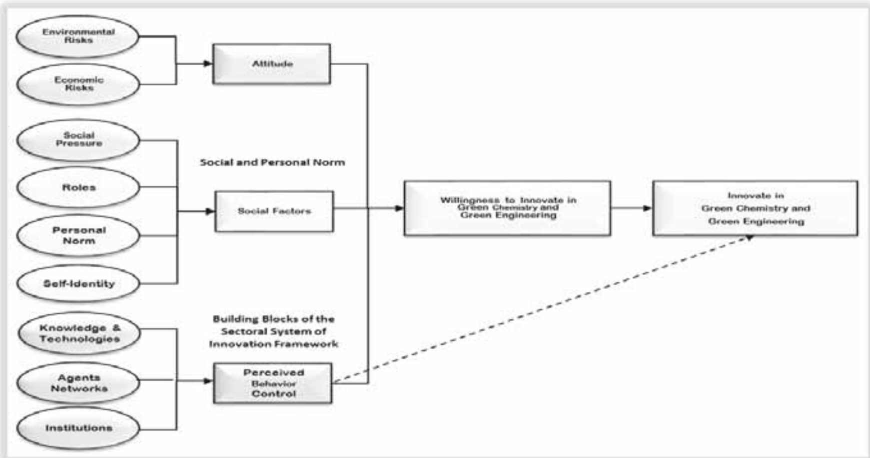


Figure 5.2, in Chapter 5, depicted the modified structural behavioral model custom developed for this research. Note that the model is partially depicted and only showed the levels of explanation that supports this section´s argumentations related to the modifications introduced at the model´s behavioral domains and beliefs levels. Both the development of the custom structured behavioral model and its full diagrammatic representation were presented in detail in Chapter 5.

4.4 Research´s Quantitative Questionnaire Construction

As noted in Section 3.0 of Chapter 3, this thesis research was related to the behavioral aspects of innovation. In this respect, and in order to accomplish the research objectives of measuring and explaining the willingness of Brazilian petrochemical companies to engage in GCE-base eco-innovation processes, four basic research steps were developed.

First, a structural behavioral model was developed. This model possesses meta-theoretical characteristics that integrate insights from various bodies of theory. This allowed for a deeper understanding of the importance and contributions of a set of variables that are related to the behavior under study (to eco- innovate in GCE) (c.f. Chapters 3 and 5).

Second, in order to measure the degree of influence (quantitative approach), which each of these variables exerts upon companies´ engagement in GCE-based eco-innovation activities, a structured quantitative questionnaire was constructed. The application of this questionnaire served as the vehicle to collect the empirical data. On the one hand, this was instrumental for measuring the company respondent's intention to engage in the eco-innovation processes and, on the other hand, the data were essential for testing/validating the model.

In the third step, the application of a structured questionnaire was performed. This included various methods such as those related to its application, the definition of the sampling method, the choice of the questionnaire application instrument, the questionnaire response follow-up, data collection, analysis and interpretation. These issues were covered in detail in Section 4.5.

The fourth step was the administration of qualitative research based on semi-structured, in-depth, face-to-face interviews (cf. Sections 4.3 and 4.7).

4.4.1 Fundamentals Underpinning the Thesis Research Questionnaire Development

A questionnaire is an evaluation instrument that is employed to obtain information aimed at the assessment of specific subjects that are under study. Therefore, the construction of the research questionnaire, besides being based on theoretical approaches that evolved from questionnaire development methods, it was essential that the measurement technique was strongly grounded on the theoretical foundations that were used in the development of the behavioral model and the system of hypothesis (cf. Chapters 3 and 5).

Measurement Principle used in the Questionnaire

The theoretical foundations underpinning the measurement principle used in this thesis research´s questionnaire were based upon the attitude-behavior measurements theory upon which the TPB was developed.

According to this theory, at a basic level "all measurement involves observation of one or more responses made by a subject, whether they are verbal (e.g., a questionnaire response) or overt behavioral responses". Fishbein and Ajzen (1975: 53)

Fishbein and Ajzen (*ibid*) called attention to the importance of single-response measures to infer beliefs, attitude and intentions. They emphasized that even if more complex indices of beliefs, attitudes and intentions are developed and used, such indices are always derived from single-response measures in structured questionnaires (verbal in nature).

They added that responses in this domain involved three different aspects: (a) the concept, (b) the judgment, and (c) the format (*ibid*). In the process of responding to question *stimuli*, an individual using a certain response **format**, makes a **judgment** about a given **concept** (*ibid*).

- **Response format:** in this thesis research´s quantitative questionnaire, although many response formats were available and applicable, the one that was used was the type that has been mostly used in attitude-behavior research. He used an Osgood scale on which the respondent was invited to place a check mark on the scale containing discrete and nominal categories.
- **The concept:** according to Fishbein and Ajzen (1975: 54), "much more than the response format, however, the diversity of judgment was introduced by variations in the concept being judged and the nature or content of the judgment that was required (…). Judgment can be made with respect to any concept". Following Fishbein and Ajzen's (*ibid*), concepts were represented in this thesis researcher´s questionnaire mainly by organizations, institutions, persons, attributes and behaviors that are related to the research´s theoretical constructs and variables. In some cases, concepts, were represented by statements linked to an object or to an attribute.
- **Nature of judgment:** the content of a judgment was defined by the labels (adjectives). Labels can be associated with judgmental categories or dimensions (*ibid*). *Unlikely-likely*, *disagree-agree, difficult-easy* etc. illustrate some of the labels used in the questionnaire. In this research, priority was given to labels that have been previously and successfully used in related research, and that had been proven to be applicable to this research´s behavior definition (c.f. Montalvo Corral, 2002; POPA-CDTA Project, 2005a, 2005b, 2006a, 2006b; When de Montalvo 2003).

"By the variation of concepts, formats and judgment contents, an infinite number of single-response measures can be generated" (Fishbein and Ajzen, 1975: 55).

The Use of Semantic Differential as a Rating Technique

Osgood´s semantic differential technique was the standard technique used to measure the degree of influence that the perceptions and beliefs have on the intention to perform the behavior under study. This choice was based on two interrelated points: (a) the use of semantic differential in various similar previous successful TPB-based research (c.f. Montalvo Corral, 2002; POPA-CDTA Project, 2005a, 2005b, 2006a, 2006b; Wehn de

Montalvo, 2003), and (b) on the work of Fishbein and Ajzen (1975) in which an evaluative study on measurement techniques[57] in the attitude-behavior domain was done.

As noted in Chapter 3, at the most basic level of explanation, the TPB postulates that behavior is a function of the beliefs or the information relevant to the behavior (Montalvo Corral, 2002). Beliefs are formed when we associate a connotative meaning to the characteristics, qualities and attributes associated with an object. This generates an attitude towards this object (Ajzen, 1991).

Attitudinal beliefs in conjunction with those related to social and personal determinants and those associated with the control over the behavior (the availability of skills, resources, time etc.) represent the base of behavioral intention formation (cf. Chapter 23. Therefore, the identification and the measurement of these elements are of upmost importance in explaining and determining behavioral intention (willingness) and, consequently, in performing a given behavior.

In line with the generation of connotative meanings, Osgood´s semantic differential measurement technique "was developed not for the purpose of assessing attitudes but rather as an instrument for the measure of meaning" (Fishbein and Ajzen, 1975: 73).

The semantic differential is a psychometric technique that is designed to measure the traits, abilities, and attitudes by arriving at single attitude based on responses to questions or statements of beliefs or intentions. It is based on the premise, according to Osgood´s argumentation (1952), that "since the basic function of ordinary language was assumed to be the communication of meaning, ordinary language could be used to differentiate between concepts and to measure their meaning" (Fishbein and Ajzen, 1975: 73).

According to Fishbein and Ajzen (*ibid*), the major aim in developing the semantic differential was to identify the major dimensions of meaning. Osgood (1964) analyzed a large number of different scales and concepts and found three basic factors and dimensions underlying semantic differential ratings. He categorized meaning into three major dimensions: (a) evaluation, (b) potency and (c) activity. In this respect, "Osgood argued that a person´s attitude toward an object is equivalent of the object´s evaluative meaning for the person" (Fishbein and Ajzen, *ibid*: 76).

Fishbein and Ajzen (1975) provided examples of these three dimensions:

Dimension	Scales
Evaluation	**good-bad, clean-dirty, beautiful-ugly**
Potency	**strong-weak, large-small, thick-thin**
Activity	**fast-slow, active-passive, hot-cold**

The semantic differential technique consists of providing the respondent with one or more concepts and a set of bipolar adjectives. Based on such elements, the respondent can make his or her judgment by rating each concept on each scale. Scales are scored from +3 to -3 (seven point scale).

57 In their work, Fishbein and Ajzen (1975) conducted a comparative study on four standard attitude scales: Guttman´s Scalogram, Thurstone´s Equal-Appearing Interval Scale, the Likert Method of Summated Ratings and Osgood´s Semantic Differential Technique.

In harmony with the TPB definition of attitude, social norm, and perceived behavior control, the scores were summed across all evaluative scales and this value was taken as indices that represent the connotative meaning of this thesis research´s elements.

> "The semantic differential is constructed by making a statement regarding the concept to be ranked, coupled with a seven point scale linked to opposed adjective pairs" (Montalvo Corral, 2002: 120 *apud* Carlsmith *et al*., 1976)

In this respect, the use of the semantic differential technique to estimate the indices of attitude, perceived social/personal norms, perceived behavioral control and behavioral intention as a function of their respective accumulated semantic loads, captures the cognitive and the evaluative components proposed by Ajzen (cf., Chapters 3 and 5).

Osgood (1952) reported the following positive evaluation of the method:

a) **Objectivity:** the semantic differential yielded quantitative data, which are presumably verifiable, in the sense that other investigators can apply the same sets of scales to equivalent subjects and obtain essentially the same result;
b) **Reliability:** in his studies, the method produced high reliability coefficients and minimum variation, which was interpreted as indications of the stability of the method, and
c) **Validity:** all data collected on several problems displayed convincing face-validity.

The theoretical foundations that underlay the use of the semantic differential method for measuring an ample diversity of meanings, associated with the elements of this thesis research´s behavioral model, provided the essential support for its use in this thesis research.

Questionnaire Construction: Wording, Format and Context

> "Evaluation researchers frequently obtain self-reports of behaviors, asking program participants to report on process and outcome-relevant behaviors. Unfortunately, reporting on one's behavior poses a difficult cognitive task, and participants' reports can be profoundly influenced by question wording, format, and context." (Schwartz and Oyserman, 2001: 127)

Complementary to the definition of the measurement method employed in this thesis, the aspects related to survey structure, questions and statements wording and format were central for the construction and application of a successful self-report questionnaire.

Although it may seem so, questionnaire construction is not an obvious task. It does not simply involve asking questions regarding specific issues of interest. If not properly designed (structure and wording), self-report surveys can produce enormous distances between the evaluators' hopes about the question-answering process and the reality experienced by participants attempting to answer these questions.

Psychologists and survey methodologists, "drawing on theories of language comprehension, memory, and judgment, formulated models of the question answering process and tested these models in laboratory experiments and split-sample surveys"

(Schwartz and Oyserman, 2001: 128). They produced a significant body of literature that support scientifically based questionnaire construction[58].

Because explaining these theoretical aspects is not the object of this thesis research, and due to the fact that they are covered elsewhere (cf. Duckworth, 1973; Rea and Parker, 2005; Schwartz and Oyserman, 2001), this topic is not included in this thesis. They were used and built upon, in this research, in the form of principles and guidelines that were used for the development of the questionnaire.

As initial guidelines, it can be argued that a "good" questionnaire should possess some basic characteristics, which according to Duckworth (1973) are:

a) **Validity:** "a questionnaire must accomplish the purpose for which it is designed" (*ibid*: 8). In respect to this thesis research's objectives, in which beliefs related to attitudes, social/personal influences, behavior control, and behavioral intention are the objects of the survey, "it was considered valid if there is statistical proof that the respondents expressed their true opinions at that particular time and that the particular sample of respondents was representative of the population" (*ibid*: 8);
b) **Reliability**: "questionnaire reliability is measured in terms of accuracy or consistency of agreement of both the respondent and the rater.
    - Respondent reliability is achieved if respondents reply in the same fashion when a questionnaire is submitted to them a second time, or if they respond in much the same way to an alternate form of a questionnaire, which is equivalent to the first one.
    - Rater reliability is achieved if two independent raters score the questionnaire in the same way or if one rater scores it in much the same way at different times." (*ibid*: 8), and
c) **Administration and scoring**: administration and scoring are basic elements in questionnaire design. Questionnaires must be easy to use. This depends on a number of factors such as physical appearance of the form itself, the arrangement, the order of the questions, clarity of directions, and the form or type of questions or statements (free-answer, multiple choice, open or close-ended questions, etc.) (*ibid*).

    The length of the questionnaire is also a topic that can facilitate or hamper respondents' interest. Although long questionnaires can pose some difficulties, however fairly extensive questionnaires, if they are carefully constructed and laid out receive very satisfactory returns (*ibid*).

    Easy scoring or rating is another factor of importance. In addition, Duckenworth (*ibid*) argued that a questionnaire is much more manageable if possible answers are arranged in accordance with a coding system decided upon in advance.
d) **Face value (validity)**: the questionnaire designer, taking full consideration of the questionnaire's development and strategy in obtaining a level and quality of responses that are in accordance with his or her expectations, must be concerned

[58] For references on comprehensive reviews on theoretical aspects of question answering processes and research examples refer to: Schwarz, N. and Oyserman, D. (2001), *Asking questions about behavior: cognition, communication, and questionnaire construction*, American Journal of Evaluation, Vol. 22, No. 2, pp. 127–160.

with face value[59]. Sometimes, for some specific reason, it is of interest of the questionnaire designer to conceal the questionnaire's face validity (for examples cf. Duckesworth, 1973). In this thesis research, making clear the questionnaire's face value was a constant preoccupation.

Questionnaire Structure

The foundations for the understanding of the importance of a questionnaire's structure can be traced to Guttman´s definition of theory. He defined a theory as an "hypothesis of a correspondence between a definitional system for a universe of observations and an aspect of the empirical structure of those observations, together with a rationale for such a hypothesis" (Gratch, 1973: 35).

According to Bar-on and Perlberg (1985), Guttman´s definition of theory established the requirement for a correspondence between a definitional system for the observations and the empirical structure of those observations. This is well exemplified by Guttman´s elaboration in respect to behavioral studies.

According to him, in behavioral studies, which usually involve complex issues, the conceptualization and the definition, in substantive terms, of what is really studied, precede the design of tests and questionnaires, data collection and elaborate statistical analyses (Guttman and Greenbaum, 1998). That is, "after a definitional system for the observation has been established, it is possible to test its correspondence to the empirical structures" (Bar-on and Perlberg, *ibid*: 100).

In this thesis research, the questionnaire design and structure followed and incorporated the theoretical structural relationships proposed in the TPB and in its custom behavioral model. This approach produced a questionnaire structure that was highly applicable for TPB-based research as it has been successful tested and reported in a number of works (e.g. Montalvo Corral, 2002; POPA-CDTA Project, 2005a, 2005b, 2006a, 2006b; Wehn de Montalvo 2003).

Complementarily, in order to ensure the correspondence between the definitional system for the observations and the empirical structure, the Facet Theory (FT) (Guttman, 1959) helped this researcher to develop the structure of the questionnaire based on the "Principle of Contiguity" (Montalvo Corral, *ibid*).

> "Facet Theory (is) a systematic approach to facilitating theory construction, research design, and data analysis for complex studies, that is particularly appropriate to the behavioral and social sciences." (Guttman and Greenbaum, 1998: 13, note added)

According to Shye *et al.* (1994: ix), "facet theory (FT) represents a research theory that truly integrates content design with data analysis". In this respect, they further highlighted that the FT calls attention to the inappropriateness of an overdue attention to sophisticated data analysis without due attention to the substantive content aspects of the research (*ibid*). "Substantive content can and should be formalized, structured and reliably communicated" (*ibid*: ix).

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[59] A test can be considered to have face value (or face validity) if it measures what it is supposed to measure.

By using the FT, researchers are able to identify and explain the theoretical constructs of the research and the kind of observations needed in a simultaneous fashion (Guttman and Greenbaum, 1998). Facet analysis also allows for testing whether a facet design produces similarity in patterns that are confirmed by empirical data. In parallel, the conceptual structure of variables may indicate hypotheses about their expected statistical relationships (Foa, 1965). "The hypotheses are to be formulated according to the lawfulness of the empirical structure of the variables" (Hildebrandt, 1986: 524 *apud* Guttman, 1959). For a more elaborated view on this thesis research´s system of hypotheses refer to Section 5.3.

According to Foa (1958), FT offers an opportunity for the application of the concept of contiguity in the construction of behavioral models, as it proposes "a possible relationship between the conceptual and empirical structure of the variables" (Foa, 1965: 264).

The Principle of Contiguity states that variables, which are more similar in their facet structure (i.e. their conceptual definition), will also be more related empirically. Therefore, it provides the link between the conceptual and empirical structures making it possible to predict these relationships.

"Facet elements can be classified into specific and nonspecific to the set of variables and that variables containing specific elements tend to be related to the set of variables more than variables containing nonspecific elements" (Foa, 1965: 262).

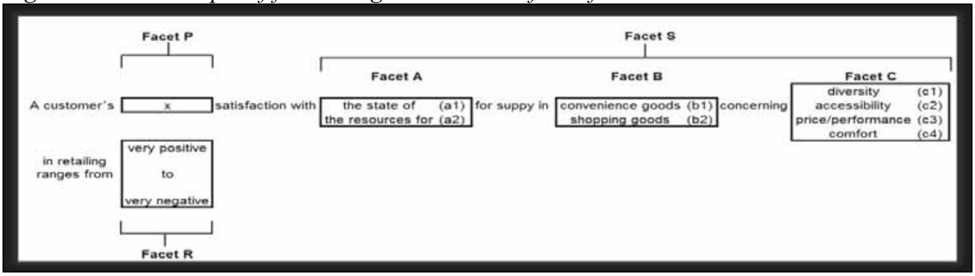
As a deeper study of FT and the Principle of Congruity is beyond the objectives of this thesis research, they were reviewed in this work at a superficial level both in terms of conceptual grounds and in terms of examples. It is this thesis author´s belief that considerations at this level suffice for a good understanding of the theoretical principles upon which this researcher´s quantitative questionnaire structure was developed. For more detailed reading on these topics refer to Bar-on and Perlberg, 1985; Guttman, 1959, Guttman and Greenbaum, 1998, Foa, 1958 and 1985; Shye *et al.* 1994, Hidebrandt, 1986. A good illustration of the similarities and the empirical relatedness of variables, in light of the FT and the Principle of Contiguity, was provided by Hildebrandt (1986) from which the following exposition was extracted:

In relation to the FT, the definitional basis for the measurement of the theoretical constructs provided by the facet design consists of three basic facets:

a) The population facet (P): describes the characteristics of the population;
b) The content facet (S): defines the content of the variables under investigation (a set of *stimuli* or variables), and
c) The answers facet (R): specifies the categories of the answers (a set of responses).

Figure 4.2 presents an example of the use of facet. This example was extracted from the satisfaction research and the construct under investigation is the consumer's satisfaction with different aspects of retailing in the consumer's area (cf. Hildebrandt, 1986).

Figure 4.2- An example of facet design in the area of satisfaction research



Source: adapted from Hildebrandt (1986)

In this example, "x" represents the population facet (P), facets A, B and C represent a set of content facets (S), which define the *stimuli*, and answer facet (R) represents the response range.

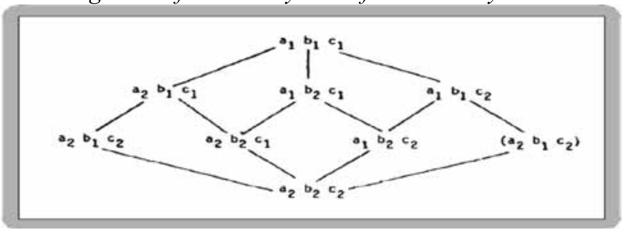
> "The cartesian product of the defined content facets A x B x C provides all possible combinations of the facet elements which may be relevant to the domain under investigation. However, not all structuples[60] (facet combinations) in general make sense (…) The system may serve as a basis for constructing items, but it can as well be used to select items from former empirical research. Using this approach, the researcher assures that also different types of studies are comparable on the general level, even if the focus of each single study may be different" (Hidelbrandt, 1986: 524).

"Using the principle it is possible to derive an ordering from the variables which in the simplest case is linear" (Hildebrandt, 1986: 524). Variables are arranged according to their contiguity with each one being different to its neighbor by one element (*ibid*).

[60] "A structuple is defined as an element of the Cartesian set; it is a profile composed by selecting an element of each element from the facet. Each structuple represents one possible item of observation in relation to the domain facet. A structuple is constructed by drawing one, and only one, element of each and all domain facets in the mapping sentence" (Godwin, 1999: 46).

In this respect, in the previous example, the linear combination of the three “S” facets, containing two elements each, produces eight combinations that define the variables that can be arranged in an orderly way according to the principle of contiguity as shown in Figure 4.3.

Figure 4.3- The ordering in a definitional system of three binary items



Source: Hidelbrandt (1986)

Note that if all eight variables are ordered in such way that each one is contiguous with its neighbor and it is differentiated from each other by one element, then the first variable becomes similar again with the last one (*ibid*) as it is shown by variable $a_2b_1c_2$ in Figure 4.3.

As an illustration, according to Hidebrandt (*ibid*), on the semantic level, the expected similarity relations of the following variables are:

var 1	• $a_1\ b_1\ c_1$
var 2	• $a_1\ b_2\ c_1$
var 3	• $a_1\ b_2\ c_2$
var 4	• $a_2\ b_2\ c_2$

Similar	Less similar	Dissimilar
var1 and var2	var1 and var3	var1 and var4
var2 and var3	var2 or var4	
var3 and var4		

In this thesis research, these theoretical grounds helped this thesis author “to design the structured questionnaire based on the premise that the theoretical constructs that comprise the questionnaire should be semantically linked to the main variables that they were intended to measure” (Montalvo Corral, 2002: 119). Therefore, the produced questionnaire held the following sequence that fits the TPB based custom developed structural behavior model:

1. **General level:** asked general questions about the firm and the respondent;
2. **Direct measures[61] of intention:** asked questions about firms′ intention of engaging in GCE-based eco-innovation (in the next five years);
3. **Direct measures of the theoretical constructs:** asked questions about attitudes, perceived social factors and perceived behavioral control:

[61] “A direct measure refers to the single item (or questions) that intend to capture the overall connotative load held by the respondent regarding a specific behavioral domain” (Montalvo Corral, 2002: 109) (eg. knowledge and technologies), See the wording of the items (direct measures) in Appendix E.

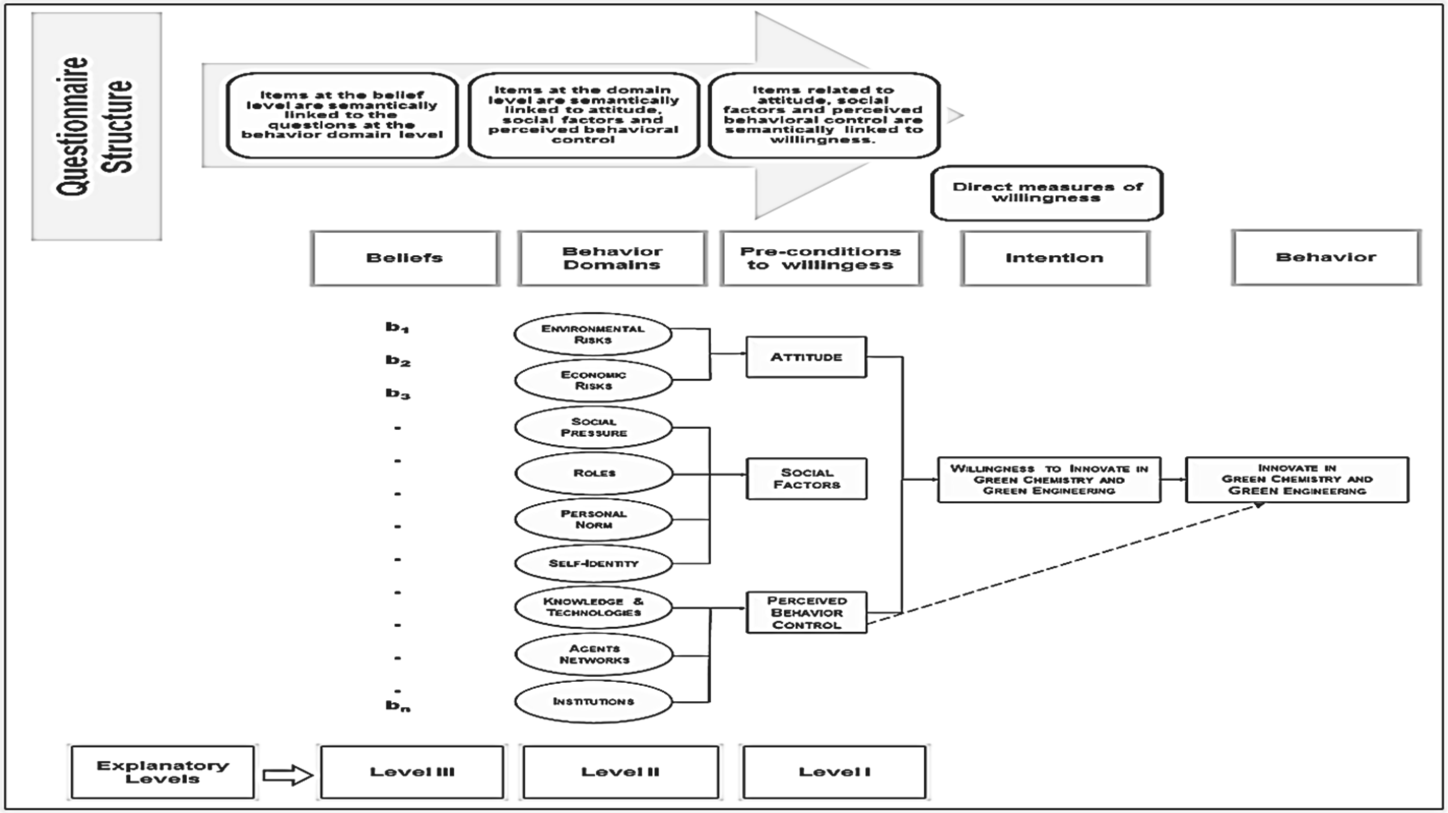
4. **Direct measures of the model´s behavioral domains:** asked questions about environmental risks, economic risks, roles, personal norms, self-identity, knowledge and technology, agents and networks and institutions, and
5. **Beliefs scales:** intended to measure the beliefs associated with each behavioral domain.

This questionnaire sequence provided a semantic link of each item to the next explanatory level. In a hierarchical sequence:

1. Items at the belief level were semantically linked to the questions at the domain level;
2. Items at the domain level were semantically linked to attitude, social factors or perceived behavioral control constructs, and
3. Items within the attitude, social factors and perceived behavioral control constructs were semantically linked to willingness.

The questionnaire structure and its relations to this thesis researcher's behavioral model are shown in Figure 4.4.

Figure 4.4- Thesis research´s questionnaire structure and its relation to the thesis researcher´s behavioral model



Source: author

4.5 Quantitative Questionnaire Application and Data Collection

Researchers in the pursuit of empirical information collection are confronted with a wide variety of methods ranging from the experimental designs used in the physical sciences through surveys that are more common in the social sciences.

As this thesis research relied on survey based data collection, upon the conclusion of the questionnaire construction (Section 4.4), two major challenges appeared along the natural path that linked its development and the analysis of the results produced by its application:

a) What would be a suitable sampling method that could produce results that make it possible to make estimates in respect to the target population[62] under study?
b) What would be the appropriate means and strategy that could be employed in respect to the application of the questionnaire, in order to improve the response rate?

4.5.1- Defining the Survey´s Sampling Method

In the surveys domain, due to a variety of factors (e.g. territorial extent, survey costs, lack of knowledge on the number of possible respondents etc.), in most cases the impossibility of approaching every single person in the surveyed population (census) is a real fact. In order to overcome these limitations, "researchers often use sample survey methodology to obtain information about a large population by selecting and measuring a sample from that population" (SAS Institute Inc. 1999: 149)

In this respect, as researchers work with a small part of the population, the use of samples that represented the population under study has long been a preoccupation in sampling methods development (Kosnick, 1999).

Sampling methods represent a vast scientific domain that evolved during the past decades as is attested to the work of various scientists such as Babbie (1990); Kosnick (1999); Lavrakas (1993); Weisberg *et al*. (1996).

Since the study of sampling methods is beyond the objectives of this thesis research, the focus of this section is limited to providing an explanation of the selection of the sampling method that was chosen by this thesis author.

Among the existing sampling methods, this thesis author initially faced the challenge of identifying one that could overcome the difficulties presented by the specificities of the research.

As a key initial difficulty, the author faced the fact that he had no information on the identity and on the number of elements that composed the population from which the sampling should be conducted (i.e. managers and decision-makers in the Brazilian basic and second generation petrochemicals manufacturing companies). This aspect, coupled with the difficulties in

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[62] "The target population can be viewed as the set of persons one wishes to study or the population to which one wants to make inference" (Couper, 2000: 467).

promoting this identification, such as the access to individuals, territorial coverage of the research, time requirements and cost, challenged this thesis author to identify a sampling method that could overcome these barriers.

This lack of information on the identities and on the number of potential surveyed individuals did not allow for the establishment of a sampling strategy as it did not make it possible to define the sampling (or population) frame[63]. A sampling frame had, therefore, to be constructed.

In this research, the construction of the sampling frame was difficult because it fell in the case in which "for a number of populations this frame construction is made impractical or impossible by, first, the small size of the target population and second, the difficulty of locating members of the target population" (Salganik and Heckathorn, 2004: 194).

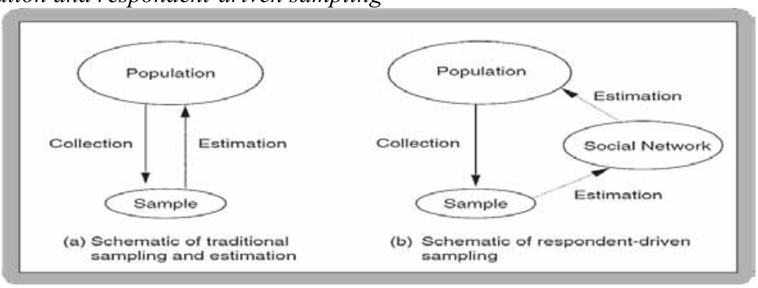
These populations are named "hidden populations" (Atkinson and Flint, 2001; Heckathorn, 2002; Salganik and Heckathorn, 2004; Thompson, 1997) and cannot be studied using standard sampling and estimation techniques (*ibid*).

Therefore a sampling method was required that could penetrate the companies′ borders and reach elements of this "hidden population".

These factors influenced this thesis author to consider a chain referral sampling method as a suitable method for this thesis research. The chosen method, was introduced by Coleman (1958) under the name *snowball* sampling.

Snowball sampling is a method that takes advantage of the (social) network perspective to conduct estimations (Figure 4.5).

Figure 4.5- Schematic representations showing the differences between traditional sampling and estimation and respondent-driven sampling



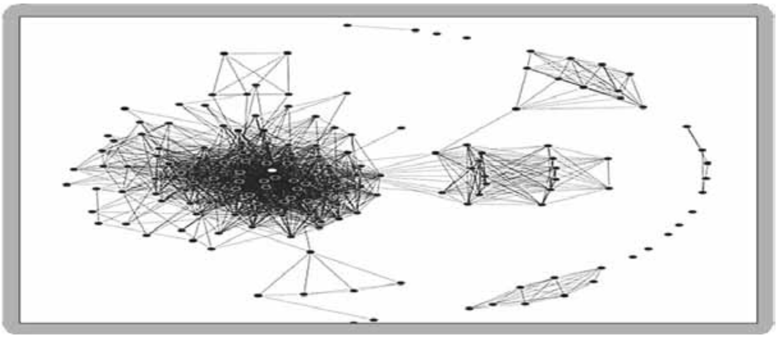
Source: Salganik and Heckathorn, 2004

It explores individuals′ *intra* and *inter* relationships in social networks (cf. Figure 4.6). "Using the extra information that is available in the social network allows one to design a sampling

[63] Sampling frame is a list of all members of the population (cf. Salganik and Heckathorn, 2004). According to Groves (1989: 82), the frame population is defined as "the set of persons for whom some enumeration can be made prior to the selection of the sample."

and estimation scheme that, in many cases, is both cheaper and more accurate than existing methods commonly in use" (Salganik and Heckathorn, 2004: 196).

Figure 4.6- Example of a social network showing the linkages between/among people in a group



Source: United States Geologic Survey. *Snowball sampling.*
http://www.fort.usgs.gov/landsatsurvey/SnowballSampling.asp. Accessed in January, 2012

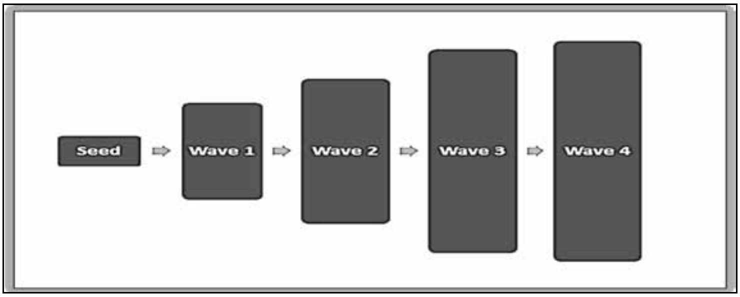
One inspirational point for the use of *snowball* strategy in the context of this research, came from Atkinson and Flint (2001). According to them, the main importance of this method resides on the fact that it allows the researcher to identify potential respondents where they are few in number or where some degree of trust is required to establish a contact. Complementarily, they added that "under these circumstances, techniques of 'chain referral' may imbue the researcher with characteristics associated with being an insider or group member and this can aid entry to settings where conventional approaches may be difficult to succeed" (*ibid*: 2)

Snowball sampling can produce in-depth results and can produce them relatively quickly. In addition, it has been found to be economical, efficient and effective in various studies (*ibid*). This method can be applied as an informal method to reach target populations and it is frequently used to conduct qualitative research primarily *via* interviews (*ibid*). It is used as a more formal methodology for making inferences about a population of elements, which have been difficult to enumerate through the use of other methods (Atkinson and Flint, 2001; Coleman, 1958; Goodman, 1961; Spreen, 1992).

It is a method for finding hidden and atomized subjects. In its simplest formulation, the *snowball* sampling method consists of identifying respondents who are then used to refer researchers on to other respondents (Atkinson and Flint, 2001).

According to Vogt (1999), *snowball* sampling starts with a set of respondents who serve as *seeds*. These *seeds* then recruit individuals in their social networks (personal, professional etc.) who, in their perception, are eligible to participate in the study. These *seeds'* initial choices form the *first-wave* respondents. *First-wave* respondents then recruit the *second-wave* and so on. A diagrammatic representation of the strategy employed by the *snowball* sampling is presented in Figure 4.7. The ideal number of links in a referral chain will vary depending on the purpose of the study (Atkinson and Flint, *ibid*).

Figure 4.7– Representation of the Snowball sampling process wherein each wave increases the sample size



Source: United States Geologic Survey. *Snowball sampling.* http://www.fort.usgs.gov/landsatsurvey/SnowballSampling.asp. Accessed in January, 2012

In some way, *snowball* sampling provides results that coincide with the ones obtained *via* the use of the *quota*[64] sampling method:

> "The key idea in quota sampling is to produce a sample matching the target population on certain characteristics (e.g. age, sex) by filling quotas for each of these characteristics. The assumption is that if the sample matches the population on these characteristics, it may also match the target population on the quantities we are trying to measure" (Doherty, 1994: 22)

From Theory to the Real World

The strategies used to translate these conceptual and theoretical formulations into actions evolved in accordance to the specificities and context of this research and followed these rationale and steps:

a) **Approaching the companies**: this research was developed within the industrial context where trust is required as a *sine qua non* condition. In such cases, chances of success can be improved if the researcher is viewed as an insider or as a group member. This can aid entry to settings where conventional approaches may not succeed.

   In addition, because this thesis research was conducted within the industrial domain, having previous "knowledge of insiders" facilitated the identification of initial respondents. Coinciding with what was reported by Atkinson and Flint (2001), such knowledge was not readily available to the researcher and it would have been very time consuming and labor intensive to acquire.

[64] Quota: (a) the share or proportional part of a total that is required from, or is due or belongs to, a particular district, state, person, group, etc., (b) a proportional part or share of a fixed total amount or quantity. Source dictionary.com (http://dictionary.reference.com/browse/quota) accessed in January, 2012.

Under these circumstances, the approach that was adopted followed the one addressed by Groger *et al.* (1999). They suggested that engagement of people in positions of relative authority or proximity may provide a route into the required population.
In order to overcome these difficulties, and to construct a route into the Brazilian petrochemical sector, this thesis author obtained official support from the *Brazilian Chemical Industry Association* (ABIQUIM)[65]. ABIQUIM´s support was of uppermost importance for the success of the application of this research´s qualitative survey. It was fundamental for the generation of awareness, the creation of legitimacy and for encouraging commitment and responsiveness in relation to the survey.

ABIQUIM was a key element in promoting contacts with key people in the companies´ realm (*seeds*) who facilitated the proper articulation for the initiation of the sampling and survey application processes.

b) **Establishing contact with companies**: being a trade association and a central member of the petrochemical sector social network in the Brazilian context, ABIQUIM held the required credibility and legitimacy to permeate the sector´s boundaries and to establish a bond, between this thesis researcher and the companies. This provided a good environment for the application of the questionnaire.

   By giving its official support to the research and introducing the researcher to one representative in each company, ABIQUIM in addition to providing access of the researcher to the study domain it took the first step in the *snowball* sampling process. This move identified the *first-wave* respondents (the *seeds*) in the sampling and questionnaire response chain (cf. Figure 4.7). The seeds, were represented by one representative in each company.

c) **Constructing samples and identifying respondents**: subsequently, the *seeds,* in turn, recruited further questionnaire respondents that he or she considered suitable to respond the questionnaire.
d) **Information collection**: upon the identification of the *seeds* and the recruitment of additional respondents, the questionnaire response and data collection was performed.

Due to the characteristics of this thesis research, which specifically focused on managers and on influential decision-makers within the company domain, only one wave in the *snowball*-

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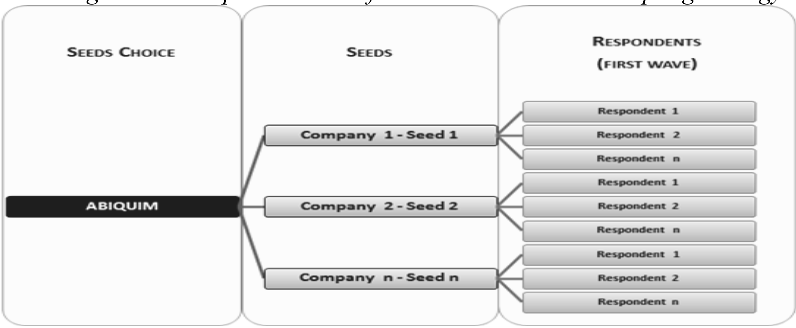
[65] ABIQUIM is an acronym for Associação Brasileira da Indústria Química, which can be translated into English as the ***Brazilian Chemical Industry Association***. ABIQUIM represents the Brazilian manufacturers of chemical products and deals with a wide variety of issues, including the coordination of *Atuação Responsável*® (Brazilian version of Responsible Care®); quality, environment and safety related issues; human resources development; statistics; economic studies; product advocacy; free trade agreements; tariff negotiations; and others.

ABIQUIM also represents the Brazilian Chemical industry in the Mercosur Chemical Industry Council - CIQUIM and in the International Council of Chemical Associations - ICCA. Its membership includes 160 companies. These companies produce basic and intermediate chemicals, petrochemical commodities, specialties, fine chemicals and other industrial chemical products. Among the members there are also transporters and distributors of chemical products committed to the Chemical Manufacturer's "Responsible Care Program".
Source: http://www.abiquim.org.br/english/content.asp?princ=wwa&pag=whowe. Accessed in January, 2012.

sampling *wave* was required. A diagrammatic representation of this research thesis´ sampling strategy is presented in Figure 4.8.

Figure 4.8- Diagrammatic representation of this thesis research´s sampling strategy



Source: Author

4.5.2 Survey Implementation: Methodology and Tools

As an exercise of simplification, survey processes (conception, development and implementation) can be understood as being composed by the interactions of a series of sub-processes that are supported by a significant number of theories. This produces a variety of methods that can be applied according to the objectives, context, and limitations of the research.

Examples of some of these theories, their application and their contribution to the quantitative survey associated with this thesis research were presented in this Chapter. Complementary to previous sections in this Chapter, Section 4.5.2 presented and discussed the implementation of this research´s qualitative survey, the questionnaire pretest methods and the instruments that were employed to make the survey implementation viable.

Definition of the Survey Method

According to Couper (2000), survey types are a function of their stated goals and the context of the various sources of survey measurement errors. In self-administrated surveys, errors could be a result of the respondents´ lack of motivation, comprehension problems, deliberate distortion, etc. and from the survey instrument poor wording or design, technical flaws, etc.

Identifying a suitable method and instruments for the implementation of a survey that can overcome the limitations imposed by these sources of measurement errors is case specific and of prime importance.

Couper (*ibid*: 464) further stated that, “the rubric ‘web survey’ encompasses a wide variety of methods, with different purposes, populations, target audiences, etc. (…) In order to judge the quality of a particular survey (be it Web or any other type), one needs to do so within the context of its stated aims and the claims it makes”.

Based on the research goals and on the aforementioned context limitations, the self-administrated web survey method was selected as a suitable method that could fulfill this thesis researcher's needs.

In the opinion of this thesis author, the combination of the self-administrated web survey method, the ABIQUIM supported implementation strategy, and the use of the appropriate tools could:

a) Promote the territorial coverage of the survey in a cost effective way (Brazil is a vast country and the petrochemical sector is spread throughout different regions),
b) Reach the respondents in an easier way than contacting companies in the absence of this kind of sponsorship,
c) Collect information in an accessible and cost effective manner,
d) Provide the tools that allow for data collection and analysis in an easy, reliable and effective way, and
e) Allow for an easier follow-up of the progress of the survey process and closer interaction with the respondents.

In order to comparatively place this thesis web survey relative to the many existing methods, the typology of web survey design proposed by Couper (*ibid*) was used as a reference. Among the non-probability and probability types of web surveys proposed by him, the method adopted for this research is similar to the one described as "list-based samples of high-coverage populations" (LBHCP) (Couper, *ibid*).

The choice of this method was supported by Couper´s (*ibid*) argumentation that web surveys are useful for a subset of the population with very high or complete coverage. In this case, very high coverage was interpreted as managers and decision-makers full access to Internet. Additionally, he stated that, "the basic approach to this type of web survey is to begin with a frame or list of those with web access. Invitations are sent by e-mail to participate, and access is controlled to prevent multiple completions by the same respondent" (*ibid*:485).

It is important to underscore the fact that while coverage does not represent a concern in this type of survey, nonresponse remains a key concern (Couper, *ibid*). Many factors, which are dependent on the type, objectives and context of the research, are influential to obtaining a low or a high nonresponse rate, (Atkinson and Flint, 2001; Couper, 2000; Kronsick, 1999; Linsky (1975); Porter and Whitcomb 2003).

An in-depth study of factors that can influence response rate in surveys is beyond the scope this thesis research. Therefore, only factors found in the literature that were assumed, by this author, to have relevance to this specific thesis research were taken into account in the design and implementation of this thesis´ survey. They are discussed in the following paragraphs.

One interesting approach for explaining the influences on the questionnaires' response rates was published by Linsky (1975). According to him, two major classes of factors contribute to survey response rates: (a) perceptual and mechanical, and (b) broad motivational factors.

Based on Atkinson and Flint (2001), it is this thesis researcher´s opinion that in the perceptual domain, survey response rates can be associated, with the degree of legitimacy, bonding and awareness of the salience of the survey that the researcher/survey generates with the respondents. The mechanical factors are represented by techniques that are “intended to increase response rates either by making it mechanically easier for the respondent to reply or by making recipients more aware of having received the questionnaire” (Linsky, 1975: 83).

Broad motivational factors involving elements, such as anonymity, presentation letters, phone contacts, arguments of social importance and relevance of the research etc., were explored in the following paragraphs.

According to Krosnick (1999: 549), “factors influencing a respondent´s motivation to optimize[66] include the need for cognition, the personal importance of the question’s topic to the respondent, the beliefs about whether the questionnaire will have useful consequences, the behavior of the interviewer, and fatigue.”

These aspects were taken into account and precautions were taken to develop a questionnaire that could enhance the interest and willingness to participate in the survey and to complete the answering process. At the same time, suitable techniques and tools were identified, which could make the survey implementation easier and fluid.

In order to show how these precautions were incorporated they are organized and presented in the following order: questionnaire pretest and survey implementation.

Questionnaire Pretest

The questionnaire pretest represented the proving grounds upon which the proposed questionnaire was tested under actual survey conditions before it was submitted for full-scale implementation. According to Rea and Parker (2005: 27), “during the course of the pretest, poorly worded questions will be identified and the overall quality of the survey instrument will be refined. Based on actual pretest experience, the questionnaire is fine-tuned for use in actual survey process”

Questionnaire pretesting aims at the identification of questions that are difficult to be comprehended by the respondents and those questions that are interpreted differently than the original researcher´s intention (Krosnick, 1999). Besides that, the pretest constitutes an excellent opportunity to identify the existence of moral and ethical violations, and motivational factors that could introduce barriers for the response process and, therefore, could diminish the willingness of the respondent to participate (Rea and Parker, 2005).

For pretest purposes, only companies that were in close territorial proximity to the thesis author were contacted. This proximity facilitated the process and the enhancement of the pretest quality through the easiness of communication with professionals, some of whom were acquaintances of the researcher.

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[66] According to Krosnick (1999), an optimizing respondent is the one who under a series of motives (e.g. desires for self-expression, interpersonal response, intellectual challenge, self-understanding, feelings of altruism, or emotional catharsis) feels inspired to perform the necessary cognitive tasks in a thorough and unbiased manner.

Since this thesis survey was conducted *via* a web-based, self-administrated questionnaire, the pretest scope included the assessment of the survey instruments by verifying if it was sufficiently able: (a) to promote a good and steady communication between the researcher and the respondents, (b) to convey the questionnaire to the respondents in an easy, secure and efficient manner, and (c) to collect the information generated by the questionnaire respondents in a format that facilitated easy data assessment.

In this qualitative research survey, the e-tools used for the questionnaire development and application were: (a) a web-based survey dedicated application which was accessed by the respondents *via* a custom password protected web link that was sent to each *seed* (cf. Section 4.5.1) (b) e-mails that followed an introductory phone call.

After a series of contacts, three companies at the *Camaçari Petrochemical Complex,* northeast Brazil*,* volunteered and cooperated in the questionnaire pretest. They agreed to review, assess and comment upon the e-questionnaire wording and design elements such as the placement of the questions, the flow of the questionnaire, its typographical features, technical flaws, etc. (cf. Couper, 2000) as well as on the adequacy, performance and efficiency of the survey´s e-tools.

Following Couper (2000), Kosnick (1999) and Rea and Parker (2005), the following guidelines for the draft questionnaire pretest (Table 4.2) were used:

Table 4.2- Guidelines developed for pretesting the web survey´s questionnaire content and the e-instruments used for its implementation

Assessement of the Web Survey e-Tools	• Verification of the suitability and efficiency of the use of e-mails as a communication tool and their capability to deliver to the respondents the weblink and password for accessing the questionnaire on tne web; • Verification of the suitabulity and efficiency of e-mails in forwarding the weblink and the password to the questionnaire to other respondents; • Verification of the capability of the web survey instrument to be accessed via the weblink embodied on the survey´s invitation e-mails; • Verification of the efficiency and easiness of the use of the websurvey instrument to answering the questionnaire, and • Verification of the capability of the websurvey instrument to provide data collection in an way that allows for easy and reliable data assessment.
Questionnaire Clarity and Understanding	• The degree of understanding of the questions; • The existence of ambiguities; • The provision of clear questions and response options that allow for a good interpretation and response easiness; • The use of a simple and direct language that allow for easy understanding and interpretation of what is being asked; • The existence of specific words or expression that can make it difficult for the questions to be understood; • The clarity and the sufficiency of information of the questionnaire introductory pages with regard the instructions for the use of the e-tool used for the questionnaire answering, and • The clalrity and the efficiency of the introductory and guiding texts, at the beginning of each section, in promoting a good understanding of the objectives of the section´s questions..
Questionnaire Acceptability	• Violation of personal, functional or organizational privacy; • Violation of moral or ethical standards; • Questionnaire length, and • Overall questionnaire acceptability

Source: author

Under the guidelines shown in Table 4.2 and based upon reactions and suggestions of the volunteer respondents, the test produced good results and also provided suggestions for improvements that were incorporated into the final version of the questionnaire.

After the pretest was completed, the survey implementation and the questionnaire application were performed.

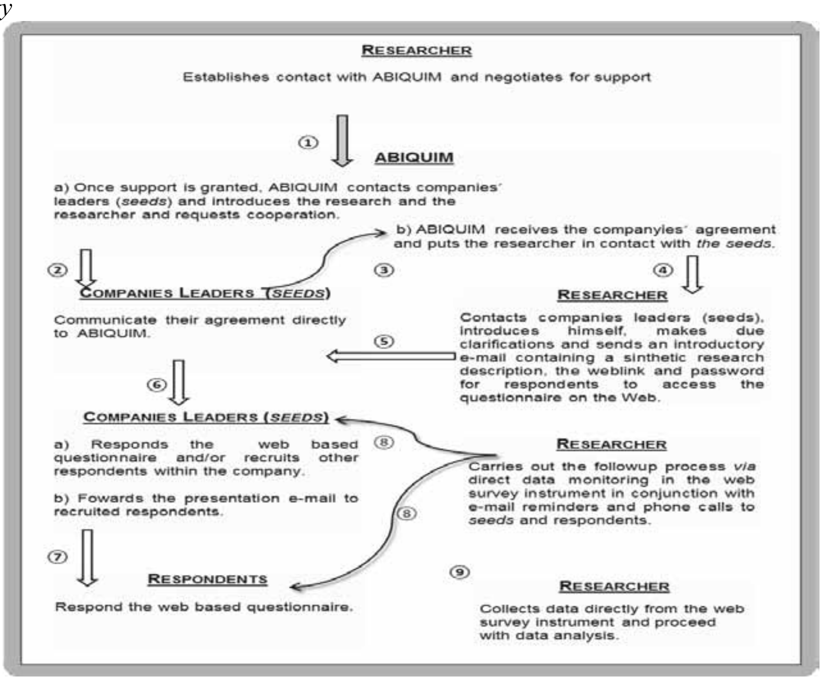
Survey Implementation

One interesting aspect of this thesis´ survey is that, due to the factors explained in Section 4.5.1, the strategy for its implementation embedded the research´s sampling process, which was done concomitantly to the questionnaire application.

This section presented a more detailed and consolidated dynamic representation of the issues presented in the foregoing sections and presented the theoretical grounds based on which key stages of this research´s implementation process were designed.

As a complement to Figure 4.8, Figure 4.9 shows a detailed diagrammatic representation of the implementation strategy of the quantitative survey questionnaire.

Figure 4.9- Diagrammatic representation of the thesis questionnaire survey implementation strategy



Source: Author

This thesis research´s survey implementation strategy was conceived not only to promote a fluid and efficient questionnaire application, but it was also designed to use motivational elements that could enhance the questionnaire respondents´ willingness to engage cooperatively in the survey process.

Although Figure 4.9 is self-explanatory, further explanation is required for a deeper view and a better comprehension of which motivational theoretical elements were employed and how and why they were introduced in the steps 1, 2, 5 and 8 of the survey implementation strategy:

a) **Step 1**: was related to the process of legitimacy and bonding building in a realm (industrial sector) in which trust is required as a *sine qua non* condition for cooperation and engagement. Once legitimacy and bonding are achieved and the research and researcher are viewed as reliable and trustful, the chances of cooperation and response rate to the questionnaire are likely to increase. According to and Heberlein and Baumgartener (1978), Linsky (1975) and Sheenan, (2001), studies showed that the use of an **influent sponsoring organization** can give researchers the right support to achieve these objectives.

   In this respect, this thesis author appealed to and negotiated for required support, for the survey implementation, with ABIQUIM (cf. Section 4.5.1). ABIQUM´s support was granted based on an array of factors that included:
   - The thesis research objectives;
   - The credibility of the supporting educational organization (**research affiliation and/or university sponsorship;** cf. Fox *et al*. 1988 and Sheenan, 2001);
   - **The arguments for social utility** (cf. Linsky, 1975) of the research and
   - The analysis of the degree of congruence between the researcher´s aims and the petrochemical sector´s interests.

b) **Step 2**: was taken based upon the previous argumentations. By attesting to the reliability and credibility of the study, ABIQUIM appealed to leaders (*seeds* - cf. Section 4.4.1) in the companies in the Brazilian petrochemical companies to help the researcher to conduct the study. Appeals were made via **introductory and personalized e-mails.** The decision to send personalized e-mails was made based on studies conducted by Linsky (*ibid*) in which this approach produced higher response rates.

c) **Step 5**: pre-contacting each *seed* in every company that demonstrated interest in participating in the survey was considered to be another key element for increasing the questionnaire response rate. According to Linsky (ibid: 83-84) "pre-contacting respondents before they receive the questionnaire appears to increase response rates (…). Generally, such pre-contacts identified the researcher, discussed the study's purpose, and requested cooperation". In the same direction, Fox *et al*. (1988) and Klapowitz *et al.* (2004) called attention to the impacts of pre-notification contacts in the response rate.

   This approach also allowed the researcher to come into closer contact with the companies' leaders (*seeds*) and provided him with the opportunity to render detailed information on the survey. This generated legitimacy and helped o positively influence them to fill in the questionnaire. Pre-contacting also generated awareness about the reception of the e-mail from the researcher with the survey invitation. This e-mail contained detailed information about the survey as well as a web link and the password for the questionnaire.

   Metha and Sivadas (1995) made a strong point over the indispensability of pre-notification for e-mail surveys and emphasized that the practice of sending unsolicited e-mail surveys is unacceptable.

This is a very significant point because, normally unsolicited survey e-mails are trashed or they go directly into spam. "Spam has become a ubiquitous feature of the web, and many people are used to receiving countless unwanted e-mails from marketers (…). It will become increasingly important for survey researchers to distinguish themselves from spammers and to do so in creative ways". (Porter and Whitcomb, 2003: 586-587)

At this point, it was expected that the researcher promised anonymity and acquired a closer level of intimacy with the respondents thus allowing for the development of stronger bonding and trust.

d) **Step 8**: the last step of this thesis survey implementation strategy harbored motivational elements aimed at enhancing willingness to cooperate in the questionnaire response is represented by the survey follow-up process.

Post-notification or follow-up has been found to have positive influence on response rates in the different types of survey (Comer and Kelly, 1982; Heberlein and Baumgartner, 1978; Jobber, 1986; Murphy, *et al.*, 1990, 1991; Linsky, 1975; Yammarino *et al.*, 1991).

In the specific case of electronic surveys, Kittleson (1997: 196) made a strong point on the importance and efficiency of follow-up notices to electronic survey emphasizing that "one can expect between a 25 and 30% response rate from an e-mail survey when no follow-up takes place. Follow-up reminders will approximately double the response rate for e-mail surveys".

In the same direction, Heberlein and Baumgartner (1978), in addition to noting the potentiality of follow-ups to promote higher response rates, they emphasized that, although many types of follow-up contacts can be and have been employed, the use of multiple follow-ups has been found to produce higher response rates than single reminders.

Based on these previous arguments, and on previous experiences of this thesis author, the incorporation of tight and close follow-up was implemented. The follow-up process was conducted via e-mails and/or phone calls in accordance with the degree of accessibility and availability of the respondents for conversations. Although it was not measured, this practice provided significant improvement in the response rate.

In respect to Step 9, this author reported that data generated in the questionnaire response were easily and reliably collected by the web survey instrument. This instrument had a perfect integration with statistical software packages and allowed for proper data analyses (Chapter 6). The statistical analyses provided the resources to test the research´s questionnaire reliability and the validity of this thesis research´s behavioral model. The theory supporting the verification of the reliability and the validity are presented in Section 4.6 and the related results are shown in Chapter 6 and in Appendices A, B and C.

4.6 Empirical Confirmation of the Research´s Supporting Theory: the Reliability of the Measurements and the Validity of the Research´s Behavioral Model

As noted in Chapter 3 and in Section 4.3, the TPB occupies a central place in this thesis research and functions as the meta-theory that integrates various theories in the process of human behavior explanation and prediction. As a result, a TPB-based structural behavioral model was developed (cf. Chapter 5) through which the relative importance of the behavioral determinants in explaining and influencing GCE eco-innovative behavior of the Brazilian petrochemical companies could be assessed. "This assessment implies the measurement of the behavioral correlates involved" (Montalvo Corral, 2002: 198). The validation process of these measurements provided the grounds upon which their supporting theories could be tested and verified in respect of its empirical confirmation (Montalvo Corral, *ibid apud* Loewenthal, 1996; Kline, 1986; Ghiselli, 1981).

The validation of abstract constructs is intimately related to the adequacy of the measurement method. According to Korzybsky (1994: 259), "a measurement represents nothing else but a search for empirical structure by means of extensional, ordered, symmetrical and asymmetrical relations".

"Measurement is mostly viewed as the process of linking abstract concepts to empirical indicants" (Carmines and Zeller, 1979: 10). In the psychometric research, it is widely accepted that methods that are used for the measurement of abstract constructs are considered good or scientific if the instrument used to measure is based on at least one interval scale and it is reliable and valid (Montalvo Corral, 2002). This corroborates Duckworth´s (1973) (cf. Section 4.4.1) and Carmines and Zeller´s (1979) arguments that reliability and validity are basic and fundamental characteristics required for a psychometric measurement instrument to be considered scientifically useful.

> "Measurement focuses on the crucial relationships between empirically grounded indicator(s), that is, the observable responses, and the underlying unobserved concept(s). When this relationship is a strong one, analysis of empirical indicators can lead to useful inferences about the relationships among the underlying concepts. In this manner, social scientists can evaluate the empirical applicability of the theoretical propositions". (Carmines and Zeller, 1979: 10)

Complementarily, it can be argued that inferences that are made from empirical results that are obtained from measurement instruments whose reliability and validity are weak and faulty can show to be incorrect and produce misleading conclusions as well as a poor understanding of the concepts under investigation. Therefore, they are deemed to be of no scientific value and deserve low confidence. "(…) validity (and reliability) of measurement qualify our interpretation of scores (and of observed relations among measured variables)" (Hoyt *et al.*, 2006: 770).

Reliability and validity of measurements are translated as the measurement's capability to provide consistent results with repeated measurements and to reflect its intended theoretical concepts (Carmines and Zeller, 1979).

In the following sections, a more elaborate view on these two concepts is presented.

4.6.1 Reliability of Measurements (questionnaire)[67]

Measurement reliability is related to the extent to which repeated measurements of the same phenomenon produce consistent results (Aronson *et al*., 1990; Carmines and Zeller, 1979). According to Hair *et al*. (2005), reliability represents the degree to which the measurements of a set of latent construct[68] indicators are consistent.

"Construct indicators that are highly reliable are highly inter-correlated, indicating that they are all measuring the same latent construct" (Hair *et al*., *ibid*: 467)[69].

Higher reliability levels of a measurement procedure are achieved when the results obtained by repeated measurements show high degree of consistency (Carmines and Zeller, *ibid*). When measurements reliability decreases, indicators become less consistent and represent poor indicators of the latent constructs (Hair *et al*., *ibid*)

In the use of questionnaires as a measuring instrument, reliability "refers to the extent to which the outcome of a test remains unaffected by variations of the conditions and procedures of a test" (Montalvo Corral, 2002: 200, *apud* Loewenthal, 1996). A reliable test (or scale) is expected to be consistent, internally and overtime (*ibid*).

Internal consistency can be expected to exist, if each item in the scale measures attributes of the same variable (Litwin, 2003; Montalvo Corral, 2002). It represents a *sine qua non* condition for testing measurement reliability. It indicates how well the different indicators measure the same variable, based on the correlations between the different items of the same test. Internal consistency in the reliability domain concerns individual constructs, one at a time, as opposed to measurement validity, which is related to the relationships of individual constructs with the other constructs that are present in the proposed nomological network[70].

The concept of nomological networks "refers to the interlocking system of laws which constitute a theory" (Cronbach and Meehl, *ibid*: 290). Nomological research involves internal and external examinations of the construct. According to Byrne (1984), the analysis of the

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[67] This section discusses the concept of reliability of measurement as used in social sciences (but not in industrial statistics or biomedical research). The term reliability used in industrial statistics denotes a function describing the probability of failure (as a function of time).

[68] Latent construct (or latent variable): in the operationalization of a construct in Structural Equation Modeling (SEM), a latent construct or variable cannot be measured by direct measures. It can be only represented or measured through one or more variables (indicators) (cf. Hair *et al*., 2005).

This statement reflects the case of this thesis research in which willingness of companies to engage in eco-innovation activities cannot be measured directly. It is represented by and measured *via* a set of constructs and variables (indicators) comprised in a structural behavioral model.

[69] Free translation from Portuguese by this thesis researcher.

[70] According to Cronbach and Meehl (1955), the concept of nomological networks refers to the interlocking system of laws, which constitute a theory. Nomological network is intended to connect the theoretical and the observable domains. "The laws in a nomological network may relate (a) observable properties or quantities to each other; or (b) theoretical constructs to observables; or (c) different theoretical constructs to one another. These 'laws' may be statistical or deterministic." (*ibid*: 290).

relationships of the different variables of a construct, allows for the examination of its internal structure with the possibility of determining its dimensionality.

"External examination of a construct, on the other hand, focuses on relationships between the construct under study and other constructs, presumed to be mutually exclusive" Byrne (1984: 428).

In reliability analysis, the dimensionality of a test is a crucial factor because achieving acceptable one-dimensional measures is a necessary condition for assigning meaning to estimated constructs (Anderson and Gerbing, 1988). A set of indicators is one-dimensional if it has characteristics that have only one underlying trait or concept in common (Hair *et al*. 2005). Internal consistency represents, therefore, a necessary condition in assessing one-dimensionality (Anderson and Gerbing, *ibid*).

In this thesis research, the questionnaire scales were selected to provide measurements that are internally consistent and one-dimensional in acceptable levels. This was expected to render estimates of the connotative load of the attitudes, of the perceived social factors and of the perceived capabilities to engage in GCE-based eco-innovation activities.

Reliability statistics of tests are expressed by indices. Hoyt *et al*. (2006: 793), based on Schmidt *et al*. (2003), highlighted that "when scores to be correlated are derived from self-report measures, two types of reliability coefficient are commonly considered". These two coefficients were proposed by Cronbach (1951) in order to cover reliability in different timespans:

a) **"Coefficient of stability (CS):** estimates the stability (replicability) of scores over time (i.e., test-retest reliability) and is computed as the correlation between scores on the same measure administered on two different occasions (longitudinal studies);
b) **A coefficient of equivalence (CE)**: "estimates the replicability of scores across different samples of items from the same content domain and is computed as the correlation between scores on different measures of the same construct, administered on the same testing occasion" (Hoyt et al., 2006: 793). It shows how nearly two measures of the same tract agree (Cronbach, 1951).

These two statistical approaches make it possible to determine if a measurement instrument fulfills the previously noted characteristics required for it to be reliable, to be consistent internally and overtime.

The calculation of reliability of measurements in longitudinal studies requires multiple application of the questionnaire to a control group in different times. In the case of this thesis research was virtually impossible due to time constraints and willingness limitations of the respondents in answering the questionnaire a second time. Only the coefficient of equivalence (CE) was considered in calculating this thesis research questionnaire's reliability.

This choice was supported by the arguments published by Loewenthal (1996). He emphasized that one test suffices to test the reliability of a battery of items. In addition, Bryman (1992) reported the tendency of multi-indicator measures to exhibit greater internal than external[71] consistency thereby, reflecting a tendency for coherence (internal consistency) to be a more exacting requirement than stability (test re-test) overtime (cf. Montalvo Corral, 2002: 218, note 4).

The most widely accepted coefficient of equivalence statistics to estimate replicability of scores (internal consistency) is the Cronbach *Alpha* (α) coefficient (Gardner, 1995; Hair *et al*. 2005; Hoyt *et al*., 2006; Montalvo Corral, 2002). It represents the ratio of the sum of the variances of the individual scores to the variance of the scale score.

Cronbach *alpha* (Cronbach, 1951) is a general coefficient that can be "applied to essays tests and attitude scales where responses to individual items could be given a range of scores" (Gardner, *ibid*: 285). According to Hoyt *et al*., (*ibid*: 793)," researchers use coefficient *alpha* (Cronbach, 1951), which can be computed based on a single test form, to estimate the CE, so they do not need a second, equivalent test form.

Alpha values can range from zero to one. It is maximized when every item in a scale shares common variance with at least some other items in the scale (Gardner, 1995). In practical terms the higher the correlation among items the higher the alpha value.

In this thesis research, the levels of reliability coefficients values that were accepted for the scales follow those accepted by Cronbach (1990) and Kline (1986) who consider values that range from 0.6 to 0.8 as acceptable while aiming to obtain values close to or above 0.7.

The results of the evaluation of the reliability of the statistics of this thesis research are presented in Appendix A.

4.6.2 Validity Statistics

Although reliability is an important and basic element in providing confidence regarding accurateness of measurement of an abstract concept, it does not suffice by itself. In this respect, in addition to being reliable, a measurement must also be valid (Carmines and Zeller, 1979). In psychometric and in social sciences, an indicator of any abstract concept is considered to be valid if it measures what it is intended to measure (Carmines and Zeller, 1979; Hair *et al*., 2005; Kline, 1986).

Validity is the extent to which a concept, conclusion or measurement is well-founded and corresponds accurately to the real world. In the area of scientific research design and experimentation, validity refers to whether a study is able to scientifically answer the questions it is intended to answer[72].

A validity judgment can be looked at as an "integrative evaluation of cumulative evidence of internal structure and external correlates, considered in light of an evolving theoretical framework" (Hoyt *et al*., 2006: 769).

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[71] "External consistency refers to the degree to which a measure is consistent over time." (Bryman, 1992: 55)
[72] Source: http://en.wikipedia.org/wiki/Validity_(statistics)#Criterion_validity, accessed in January, 2013.

While reliability focuses on the extent to which empirical indicators provide consistent results in repeated measurements, validity is related to the relationship between a concept and the indicators (*ibid*).

> "Validity is an integrated evaluative judgment of the degree to which empirical evidence and theoretical rationales support the *adequacy* and *appropriateness* of *inferences* and *actions* based on test scores and other modes of assessment". (Messick, 1989: 13; original italics)

These statements represent another way to emphasize, that "there are always theoretical claims being made when one assesses the validity of social sciences measures" (Carmines and Zeller, 1979: 12).

They further added that the assessment of the validity of an indicator is actually the assessment of the use to which it is being put. "One validates not a test but an interpretation of the data arising from a specified procedure" (Cronbach, 1971: 447).

One instrument can be valid for measuring one type of phenomenon and be invalid for assessing other phenomenon (Carmines and Zeller, *ibid*). This is a view that was also shared by Hoyt *et al.* (2006: 771):

> "The nature of validity evidence will vary depending on the construct being measured and even depending on the population and setting to which the researcher plans to apply this construct".

While reliability is intrinsically related to random measurement error, non-random error is at the heart of validity by producing systematic biasing effects on the measuring instrument (Carmines and Zeller, *ibid*).

In the psychometric research, five types of validity were identified: face, concurrent, predictive, content and construct (Carmines and Zeller, 1979; Cronbach and Meehl, 1955, Hoyt *et al.*, 2006; Kline, 1998).

Based on Carmines and Zeller (*ibid*) and following Montalvo Corral (2002), for this thesis research, content and construct validity were of primary interest. This choice stemmed from the fact that they "intrinsically demonstrate or falsify the quantitative nature of the constructs of interest. In addition, in establishing these types of validity it can be said that the theory supporting the production of the tests (constructs) can be considered as empirically confirmed" (Montalvo Corral, *ibid*: 206 *apud* Loewenthal, 1996; Kline, 1986 and Ghiselli *et al.*, 1981).

The Content Validity of this Thesis´ Behavioral Model

According to Carmines and Zeller (1979: 20), content validity is related to "the extent to which an empirical measurement reflects a specific domain of content". Content validity reflects the degree that a measurement reflects the meaning associated with the domains and sub-domains of the concept that is under study.

> "Content validity is established by showing that the test items are a sample of a universe in which the investigator is interested. Content validity is ordinarily to be established deductively, by defining a universe of items and sampling systematically within this universe to establish the test". (Cronbach and Meehl, 1955: 282)

Montalvo Corral (2002), quoting Ghiselli *et al*. (1981), noted that content validity of a set of measurement operations considers two aspects. According to him, "the extent to which each scale of the test pertains to the variable of interest as it is defined, and the extent to which the entire set of scales represent all aspects that the designated model intends to capture" (ibid: 206). Cronbach and Meehl (*ibid*) corroborated this view.

According Hoyt *et al.* (2006: 776), in the evaluation of existing measures, researches are advised "to pay close attention to instrument-development strategies and content-validity evidence and to consider the match between instrument content and current construct theory as they consider the basis for interpreting scores (and the empirical findings based on these scores)."

In this thesis research, the content validation was accomplished by means of multivariate statistical confirmatory principal components analyses. The analyses theoretical foundations are presented in the next section and the results are shown in detail in Appendix B.

Statistical Foundations of the Content Validity

The results of the statistical analyses regarding this thesis research´s behavioral model´s content validity, presented in Appendix B, supported the discussion, the explanations and the conclusions, presented in Section 6.6.2 of Chapter 6.

Montalvo Corral (2002: 206 *apud* Ghiselli *et al*., 1981: 274, original italics), emphasized that the "*content validity* of a set of measurement operations refers to the degree to which those operations measure the characteristics we wish to measure, as *judged* from the appropriateness of the content of those operations"

The principles and concepts underpinning content validity that were presented in this section were used as guidelines for the content validation of this thesis research´s behavioral model. As aforenoted in this section, content validation was conducted *via* confirmatory principal components factor analyses as it makes it possible the definition of the subjacent structure of the data in a series of observations.

It "addresses the problem of analyzing the structure of the interrelationships (correlations) between a large number of variables (e.g. test scores, test items, questionnaire answers) defining a set of common latent dimensions (factors) (Hair *et al.*, 2005: 91).

The choice of performing a confirmatory principal components analysis bears two interconnected elements that are fundamental in achieving the objectives of the content validation process:

a) **Confirmatory factor analysis**: it is a multivariate technique that is used to test (to confirm) a pre-specified relationship. A confirmatory analysis is performed when one tests the statistical significance of the predictor variables and the non-significance of the other variables. It "is used to confirm the hypothesized model" (Wehn de Montalvo, 2003: 225)
b) **Principal components analysis**: this technique is considered to be appropriate for its application to this thesis research due to its capability to determine the minimum number of factors that are required to explain the largest part of the variance represented by the original set of variables

   According to Wehn de Montalvo, (*ibid*, 225), "in confirmatory factor analysis, the loading of each variable on a particular factor(s) is compared to the expected solution. If the variables that load high on one factor fit together conceptually, this factor can be named according to the underlying concept that was theoretically proposed. These interpretations of the outcomes establish the extent to which the results confirm or fail to confirm the hypothesized structure".

In this thesis research, a confirmatory factor analysis was performed using the SPSS statistical software package´s principal components extraction option. In accordance with the underlying behavior model, the analyses were conducted by setting the number of factors at three in order to represent the models three constructs: attitude (*A*), perceived social factors pressures (*PSFP*) and perceived behavior control (*PCB*).

The analyses were conducted at two levels. The first level analysis analyzed the scores of the behavioral domains scales (∑evr, ∑ecr, ∑sp, ∑rlp, ∑pn, ∑si, ∑ktc, ∑an and ∑inst). The second level of analysis regarded the scores of the direct measures of the behavioral domains overall perceptions (EVR, ECR, SP, RLP, PN, SI, KTC, AN and INST). The behavioral domains and their associated scales were discussed in Chapters 5, 6 and 7).

In order to enhance the interpretability of the factor analysis, a rotated[73] orthogonal solution of the component matrix[74] was adopted. Due to its extensive and common use, in this thesis research, the Varimax rotation (with Kaiser Normalization) was employed[75].

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73 In the factorial rotation, the factors´ reference axes are rotated around their origin until a new position is obtained. The final effect produced by the rotation of the component matrix is to distribute the variance of the first factors to the last ones in order to achieve a factorial pattern that is simpler and more significant (Hair *et al.*, 2005). The rotation maximizes the loadings of some variables and thereby assists in identifying the underlying concept (When de Montalvo, 2003, *apud* Bryman and Cramer, 1999).

74 A component matrix is the table of all variable's loads on each factor in a factor analysis.

75 "Varimax, (…) is indubitably the most popular rotation method by far. For varimax a simple solution means that each factor has a small number of large loadings and a large number of zero (or small) loadings. This simplifies the interpretation because, after a varimax rotation, each original variable tends to be associated with one (or a small number) of factors, and each factor represents only a small number of variables. In addition, the factors can be often interpreted from the opposition of few variables with positive loadings to few variables with negative loadings. Formally varimax searches for a rotation (i.e., a linear combination) of the original factors such that the variance of the loadings is maximized". Source: *Factor Rotations in Factor Analyses*. Hervé Abdi, The University of Texas at Dallas. (http://www.utdallas.edu/~herve/Abdi-rotations-pretty.pdf). Accessed in September, 2012.

Another important point in factor analysis is the verification of the adequacy of the dataset to this kind of analysis. That is, does the dataset have enough correlations that justify the employment of a factor analysis? In this research, this was answered in two complementary ways:

a) **The Kaiser-Meyer-Olkin measure of sampling adequacy (MSA)**: it tests whether or not the partial correlations among variables are small. The MSA criterion indicates the degree to which the variables are related. Therefore, it helps in evaluating if using a factor analysis makes sense. This measure varies between zero and one. The values closer to one are an indication that each variable can be predicted by the other variable without errors. A value of 0.6 is a suggested minimum (Hair *et al.*, *ibid*).
b) **The Bartlett test of sphericity**[76]: this test assesses the statistical probability that the correlation matrix has significant correlations, at least, between some variables (Hair *et al.*, *ibid*).

Influences of the Sample Size on the Statistical Significance of the Content Validity

Small sample sizes represent a problem in determining the significance of the correlation between variables in factor analyses. According to Hair et al. (*ibid*), preferably, factor analyses should be performed by using sample sizes that contain one hundred or more observations.

In respect to the significance criteria for factor loads, Hair *et al*. (*ibid*) provided the following guidelines: (a) the larger the sample size, the lower are the loads to be considered significant, (b) the larger the number of variables to be analyzed, the lower are the loads to be considered as significant, and (c) the larger the number of factors, the larger are the loads in posterior factors to be interpreted as significant.

Since the sample size obtained in this thesis research´s empirical data collection was low, thirty-six observations, in a dataset with a large number of variables, it was considered that this is a case that can be considered as falling into the "b" category of these guidelines.

This raised the question about the criteria for the acceptance of the analyses´ factor. The answer was provided by the concept of "Practical Significance" analysis. Practical significance is a practical norm frequently used as a means to conduct a preliminary examination of the component matrix (Hair *et al*, *ibid*).

In this domain, factor loadings with values that are above ± 0.30 are considered to be at a minimum level, factor loadings of ± 0.40 are considered more important and factor loadings with values equal or are greater than ± 0.50 are considered to have practical significance. Since the factor loading represents the correlation between the variable and the factor, the squared value of the load signifies the total variance of the variable that is explained by the

[76] "This tests the null hypothesis that the correlation matrix is an identity matrix. An identity matrix is a matrix in which all of the diagonal elements are 1 and all off the diagonal elements are 0. You want to reject this null hypothesis". (http://www.ats.ucla.edu/stat/SPSS/output/principal_components.htm). Accessed in June, 2012.

factor. Therefore, loadings of 0.30 and 0.50 denote that approximately ten and twenty five percent respectively of the variable variance can be explained by that factor.

In respect to the content validity of a measurement, Hoyt *et al.* (2006) and Carmines and Zeller (1979) called attention to the fact that although it is important and necessary, it is not a sufficient condition for valid inferences. In addition, construct validity is, therefore, a necessary and complementary assessment in order to assure an acceptable degree of confidence in respect to the conclusions that are based on the measurement results.

The Construct Validity of this Thesis´ Behavioral Model

> "We have suggested that both criterion validity and content validity have limited usefulness for assessing the validity of empirical measures of theoretical concepts employed in the social sciences. It is partly for this reason that primary attention has been focused on construct validity". (Carmines and Zeller, 1979: 22)

According to Hoyt *et al.* (2006), the reason for the importance given to construct validity arises from the recognition that many constructs, and many measures, in psychology had no valid criterion measure and no adequate specification of the content domain. In order "to validate interpretations of scores on this type of measure, investigators must adopt an indirect and usually multifaceted approach (…) *construct validation*". (*ibid*: 777, original italics).

Construct validity is defined broadly as the extent to which an operationalization measures the concept it is supposed to measure (e.g. Cook and Campbell, 1979; Ghiselli *et al.*, 1981).

At a basic level, "construct validity is concerned with the extent to which a particular measure relates to other measures consistent with theoretically derived hypotheses concerning concepts (or constructs) that are being measured" (Carmines and Zeller, *ibid*: *23*).

Carmines and Zeller (*ibid*) also emphasized and called attention to the theory-laden aspect of the processes of construct validation. According to them, it is impossible to validate a measure of a concept in the absence of a theoretical network that supports the concept. The absence of this theoretical support makes it impossible to generate theoretical predictions, which lead directly to the empirical tests associated with the measures of the concept.

In this respect and in accordance with the previous paragraphs, this thesis researcher proposed a structural behavioral model (cf. Chapter 5), represented by a TPB theory-supported system of hypotheses, which linked beliefs to willingness (intention) to perform a specific behavior (cf. Section 5.3). In such a hypothesis-based system, each hypothesis required empirical verification.

According to Cronbach and Meehl (1955), construct validation is applicable to a test whenever it is considered as an interpretation of a measure of attributes and quality that are not operationally defined and the researcher aims at identifying which constructs account for variance in test performance. On the other hand, they emphasized that construct validation is usually valuable when the tester has no direct criterion to measure the quality that he is concerned with and must use indirect measures.

Carmines and Zeller (1979) noted that construct validation involves the specification of theoretical and empirical relationships involving concepts and measures of the concepts. It involves the interpretation of empirical evidence. In this respect, they noted that construct validation is comprised of three distinct steps: (a) the specification of the theoretical relationships between the concepts themselves, (b) the examination of the empirical relationships between the measures of the concept, and (c) the interpretation of the empirical evidence in terms of how it clarify the construct validity of a particular measure.

In this thesis research, these steps were accomplished as follows:

a) The specification of the theoretical relationships between the concepts was done *via* the proposal of a hypotheses system (cf. Section 5.3) that linked and established the theoretical relationships between beliefs to willingness to perform the behavior under study. These relationships were established across the research model´s explanatory levels (cf. Chapter 5);
b) With regard to the examination of the empirical relationships between the measures of the concept, it was conducted *via* a multivariate statistical test (multiple regression analysis) of the hypothesized relationships between the constructs and variables in the model. The construct validation statistics consisted of a set of multiple regressions upon the data set pertaining to the three levels of explanation of the behavior model. Appendix C presented the results of these analyses.
c) The interpretation of the empirical evidence was done in light of the concepts under study and were presented in Chapters 6 and 7.

Statistical Foundations of the Construct Validity

The results of the statistical analyses, presented in Appendix C, supported the discussion, the explanations and the conclusions, presented in Section 6.6.3 of Chapter 6, related to the content validity of this thesis research´s structural descriptive behavior model.

The analyses provided basic and fundamental elements for the development of Chapter 7. In these analyses, the process of willingness formation, in the context of this thesis research, was fully explored, explained and discussed. Therefore, it was possible to identify key elements based on which recommendations regarding eco-innovation policies and strategies could be made. These recommendations were expected to help organizations, in the private and governmental domains, to develop efficient and effective policies that can facilitate and promote the engagement of Brazilian petrochemical companies in GCE-based eco-innovation processes.

As noted in the previous section, validity judgments can be understood as “integrative evaluations of cumulative evidence of internal structure and external correlates, considered in light of an evolving theoretical framework” (Hoyt *et al*., 2006: 769). Validity is associated with the relationships between a concept and the indicators (*ibid*).

In this thesis domain, these relationships were proposed *via* an hypotheses system that was constructed based on the principles specified by the TPB. They provided the theoretical links that explained the influences that the beliefs exert on the formation of willingness to perform the behavior under study.

It was hypothesized that the beliefs in each of the behavioral domain scales[77] can explain the overall perception in their respective domains. This was followed by the hypotheses that the perceptions at the domain level can explain willingness. Finally, at the model´s highest level of explanation, it was proposed that willingness was equally explained by the direct measures of attitude (*A*), perceived social factors pressures (*PSFP*) and perceived behavioral control (*PBC*).

Statistical Examination of the Relationships Between the Empirical Results

A key concept underpinning the (construct) validation of this thesis research´s behavioral model was derived from Montalvo Corral´s (2002) work, which established that people´s behavior, can be expressed in the form of the following mathematical expression (cf. Eq. 3.4 in Section 3.2.1 of Chapter 3):

$$B \sim I\, \alpha\, (w_o + w_1 A + w_2\, SN + w_3 PBC)$$

Where:

B	is the behavior of interest
I	is the individual's intention;
A	is the attitude toward performing the behavior;
SN	is the individual's subjective norm concerning the performance of the behavior;
PBC	is the individual perceived behavioral control;
w_n	are weighting parameters empirically determined, and
~	suggests, that intention is expected to predict behavior only if the intention has not changed prior to the performance of the behavior.

For the purposes of this thesis research, this mathematical expression can be expressed in the form:

$$B = w_o + w_1 A + w_2\, PSPF + w_3 PBC \qquad \text{(Eq. 4.1)}$$

This made it possible to use multiple linear regressions to test each proposed hypothesis. According to Montalvo Corral (*ibid*), in the postulate of each hypothesis a null ($H_{1,0}$) and an alternative ($H_{1,1}$) were generated. They were related to the acceptance or rejection of the existence of a linear relationship of dependence between the dependent and the independent variables that were proposed, in Chapter 5, by the system of hypotheses.

$$\mathbf{H_1, 0}\text{: } wo = w1 = w2 = w3 = w4 = 0 \text{ (null hypotheses)}$$
$$\mathbf{H_1, 1}\text{: } wo \neq w1 \neq w2 \neq w3 \neq w4 \neq 0 \text{ (alternative hypotheses)}$$

[77] "Behavioral domain scales refer to scores obtained with the addition of several items to obtain a composed single score" (Montalvo Corral, 2002: 109).

A null hypothesis was accepted if the degree of influence of the independent variables, weighted by their respective coefficients, upon the dependent variable was zero. On the other hand, the alternative hypothesis states that the influence of the independent variables on the dependent variable must be different from zero.
The test of hypotheses had the objective of verifying the existence of linear relationships of dependence between the dependent and independent variables. The existence of such relationships was conditioned to if, and only if, the null hypothesis was rejected.

In order to assess the chain of causalities between the perceptions and beliefs held by the managers and the firms´ planned behavior of engaging in GCE-based eco-innovation activities the following sequence was adopted:

a) **The Behavioral model´s first level of explanation**: this higher and more general level of explanation of the model proposed that willingness (*W*) can be explained by attitudes towards the behavior (*A*), by the perceived social factors pressure (*PSFP*) and by the perceived control one has over the requisites, resources and opportunities to innovate (PBC). The existence of these relationships and their strength was tested by the regression of willingness (*W*) against (*A*), (*PSFP*) and (*PBC*) (cf. Section C1 of Appendix C).
b) **The Behavioral model´s second level of explanation:** at this level, the behavioral model specified that willingness can be explained by the behavioral domains that influence managers´ *A*, *PSFP* and *PBC* regarding the behavior under study. These relationships were tested by the regression of *W* against the model´s behavioral domains (*ENV*, *ECR*, *SP*, *RLP*, *PN*, *S*I, *KTC*, *AN* and *INST*)[78] (cf. Section C2 of Appendix C);
c) **The Behavioral model´s third level of explanation:** this level explained the influence of each variable in the scales on its respective behavioral domain. These relations were tested by regressing each behavioral domain against their respective scales (cf. Section C3 of Appendix C).

Influences of the Sample Size on the Construct Validity Statistics

According to Hair et al. (2005), the effects of the sample size are more directly seen on the statistical power of the significance test of a multiple regression. "The power of a multiple regression refers to the probability of detecting, as statistically significant, a certain level of R^2 (coefficient of determination)[79] at a significance level that was specified for a given sample size" (*ibid*: 148).

[78] Behavioral domain's nomenclature: environmental risk (EVR), economic risk (ECR), social pressure (SP), roles (RLP), personal norms (PN), self-identity (SI), knowledge and technologies (KTC), actors and networks (AN) and institutions (INST).
[79] Coefficient of determination (R^2) "is the measure of the proportion of the variance of the dependent variable that is around its mean that is explained by the independent variables (or predictors). The coefficient can vary between 0 and 1. If the regression model is properly applied and estimated, one can assume that the higher the R^2 value, the greater the explanation power of the regression equation". (Hair et al, 2005, 132, free translation by this thesis research´s author).

The samples size affects the tests of statistical significance sensibility in the sense that: (a) samples sizes that are too small allow for the test to detect only very strong relations with a certain degree of confidence, and (b) samples sizes that are too large make the tests of statistical significance too sensitive indicating, many times, that almost any relation as statistically significant (*ibid*).

Table 4.3 below illustrates the effect between the sample size, the chosen significance level (α) and the number of independent variables in the detection of a significant R^2. The values in the table are the minimum R^2 that the sample size detects as statistically significant at the specified α at a probability (power) of 0.8.

Based on this table, it can be seen that in a sample size of 20 observations, if five independent variables were used in an analysis to which a 0.05 significance and a statistical power of 0.80[80] were specified, the minimum R^2(coefficient of determination) value that could be statistically significant would be 0.48 (48%).

Table 4.3- The minimum R^2 that can be considered statistically significant at a power of 0.80 for diverse number of independent variables and sample sizes

	Significance level (α) = 0.01				Significance level (α) = 0.05			
	Number of Independent Variables				Number of Independent Variables			
Sample Size	2	5	10	20	2	5	10	20
20	45	56	71	Not applicable	39	48	64	Not applicable
50	23	29	36	49	19	23	29	42
100	13	16	20	26	10	12	15	21

Source: Hair *et al.* (2005: 148)

In this research, in the analysis of the extent to which the behavioral domains explained willingness, the regression of the dependent variable "*W*" against the nine independent variables (the behavioral domains *EVR, ECR, SP, RLP, PN, SI, KTC, AN* and *INST*) produced a R^2 of 0.724 (or 72.4%). According to the aforementioned table, the value found for R^2 can be considered statistically significant for a sample size of 36, nine independent variables, for α= 0.05 and a power of 0.80.

For the case of this thesis research (with a sample size of thirty-six observations), although the statistical results showed that the model explained a major part of the variance and captured relevant relationships between variables, this thesis researcher believes that, based on the theory, weaker relationships could have been captured if the sample size had been larger.

Criteria for the Construct Validation of the Thesis Research´s Behavioral Model

Multiple regression analysis was the statistical method used to assess the relationships between the dependent and independent variables that were proposed by this thesis research´ system of hypotheses. In this regard, the following criteria were considered when deciding for the rejection of the null hypothesis and for explaining how well the regression equations fit the data:

[80] The specification of a 0.80 statistical power in detecting a R^2 signifies that one is satisfied to detect R^2 at 80% of the time that it occurs.

a) **Verification of the coefficient of determination (R^2)**: the coefficient of determination represents the percentage of the total variance of the dependent variable (*Y*) that is explained by the independent variables (*X*). It expresses the gain in variance explanation that is obtained by the use of multiple independent variables as compared with the sole use of the mean of *Y* to predict the dependent variable;

b) **The dimension of the standard error of the estimate (SEE)**: the SEE is a measure of the precision of the estimates. "It represents an estimate of the standard deviation of the dependent real values around the regression line. It is a measure of the variation around the regression line" (Hair et al. 2005: 173). SEE should not be much greater than one unit of measurement (When de Montalvo, 2003);

c) **Examination of the statistical significance of the model**: this statistical test was performed in order to identify if the regression model can represent the population from which the data were sampled. It tests the predictive ability of the model. This test is conducted *via* the use of the F-ratio statistical test (F statistic). It tests the hypothesis that the amount of the variation that is explained by the regression model is greater than the amount of the variation explained by the mean (that is, R^2 is greater than zero) (Hair *et al.*, 2005). The F-ratio corresponds to the ratio of the means square of the regression to the means square residual[81].

   The F-ratio was calculated and compared with the F statistics table for the assessment of the significance of the model and the consequent rejection of the null hypotheses. If the test was significant, it can be concluded that at least one of the coefficients is not zero;

d) **Significance test for the regression coefficients**: this test provided a probability based estimate that the coefficients, from samples of a given size, are different from zero (Hair *et al. ibid*). The significance of the regression coefficients were tested for their statistical significance *via* a *t*-test[82].

   The coefficient significance was verified by comparing the *p*-value[83] with the significance level for the test (α), which is the degree of confidence that the coefficient is not zero. In this thesis research, the regressions coefficients were significant, and therefore accepted, for *p*-values that are lower than a significance level of 0.05;

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[81] The mean square of the regression was computed by taking the sum of the squares of the errors for the regression and dividing it by the degrees of freedom for regression. The mean square residual was computed by taking sum of the squares of the errors (total) and dividing it by the degrees of freedom for residual.

$$F-ratio = \frac{\dfrac{\text{Sum of squares of the erros (regression)}}{\text{Degrees of freedom (regression)}}}{\dfrac{\text{Sum of squares of the errors (total)}}{\text{Degrees of freedom (residual)}}} = \frac{\dfrac{SSE(regression)}{df(regression)}}{\dfrac{SSE(total)}{df(residual)}}$$

SEE = standard error of the estimate
df = degrees of freedom

[82] A *t*-test is a statistical hypothesis test in which the test statistic follows a Student's *t* distribution . It is a test to assess the statistical significance of the difference between two samples means for a single dependent variable (Hair *et al.*, 2005).

[83] The *p*-value is the probability that observations as extreme as the data would occur by chance in a given single null hypothesis.

e) **Assessment of the impact of the multicollinearity in the regression model**: this assessment was conducted *via* two interrelated measures: (1) the tolerance values calculation, and (2) the variance inflation factor (VIF).

The tolerance is the amount of the variability of the selected independent variable that is explained by the other independent variables. It equals one minus the proportion of the variance that is explained by the other independent variables. Values of the tolerance range from zero to one. Low tolerance values signifies high collinearity. On the other hand, tolerance values that were close to zero indicated that the variable was almost totally explained by the other variables (Hair *et al.*, *ibid*).

The VIF is the reciprocal of the tolerance. According to Cohen *et al*. (2003, 423), VIF "provides an index of the amount that the variance of each regression coefficient is increased for a situation in which all of the predictor variables are uncorrelated". Values close to one indicate that the interpretation of the coefficients of the statistical variable of the regression should not be unfavorably affected by multicollinearity. As a "cut-off" criterion, Daniel J. Denis[84] suggested that the one should consider the parsimony of the model for the cases when VIF values are above five;

f) **Assessment of the normality of the distribution of the residuals**: this assessment was performed via visual inspection of the normal probability plots of the residues.

Final Considerations Regarding the Behavioral Model´s Construct Validity

Based in the confrontation of the results presented in the Appendix C and the criteria for the behavioral model construct validation, it can be argued that:

a) for every proposed hypothesis, there is a linear relationship of dependence between the dependent and independent (predictors) variables;
b) the system of hypotheses was not rejected and, as a consequence, the links of causality that were proposed can be accepted.

This supports the conclusion that the behavioral model is valid, that it measured the concept it was intended to measure and that the measures relate to other measures consistent with the theoretically derived hypotheses proposed in Chapter 5. Therefore, it can be used to explain and predict willingness in the context for which it was designed.

In addition, the multiple regression analyses identified significant coefficients that represented the beliefs that were statistically relevant. Therefore, they can be taken into consideration in the development of eco-innovation policies. An in-depth analysis of this argumentation was presented in Chapters 6 and 7.

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84 Psyx 521 – Multiple Linear Regression Using SPSS Part II - Copyright 2011, Daniel J. Denis, University of Montana.
(http://psychweb.psy.umt.edu/denis/datadecision/front/stat_II_2011/psyx_521_multiple_regression_part_II.pdf). Accessed in June, 2012.

4.7 Promoting a Deeper Understanding on this Thesis Research´s Findings

This thesis research´s behavioral model covered a broad spectrum of elements that are likely to be important determinants of companies´ willingness, in the Brazilian petrochemical sector, to engage deliberately in GCE-based eco-innovation processes. Despite that array of relevant elements, the statistical analyses demonstrated that, in the context of this thesis research, a reduced number of those variables actually have that significance (cf. Chapters 6 and 7).

In order to obtain a deeper understanding of the implications of the results obtained from this thesis research´s quantitative survey, further investigations were conducted using a complementary qualitative, in-depth, face-to-face, interview method. This approach was expected to produce the following outcomes:

a) To overcome the problem of the relatively small sample-size through triangulation (cf. Hussein, 2009);
b) To check on the consistency of the findings generated by both methods (convergence of results of both quantitative and qualitative methods);
c) To elicit new and complementary insights in respect to managers´ willingness to eco-innovate in GCE;
d) To elicit information on companies´ existing or planned initiatives that represent an indication that they have already moved from willingness to concrete GCE actions. In parallel, it was predicated by the thesis author that the existence of such initiatives can be interpreted as a further indication of the companies' leaders capacity to go beyond expressions of willingness to appropriate and relevant GCE corporate actions.

The chosen approach

The selected methodological approach for this phase of the research is commonly known, in the social sciences domain, as triangulation. It is generally agreed that triangulation is "the combination of methodologies in the study of the same phenomenon" (Jick, 1979: 602). Triangulation refers to the use of more than one approach for investigation of a research question in order to enhance confidence in the resultant findings. In the case of this thesis research, the triangulation method used was the classical type of combining qualitative and quantitative methods.

As the research initially applied a quantitative method, a qualitative method was used in a complementary fashion for:

- **Confirmation purposes:** in this case, the confirmatory insights were obtained *via* qualitative in-depth face-to-face interviews (open questions interviews) and
- **Completeness purposes:** the researcher used the triangulation approach to enlarge and deepen the understanding of the research findings. "The use of the complimentary approach was grounded on the extensive use of triangulation to increase the researchers´ understanding of the phenomena under investigation by combining multiple methods and theories" (Hussein, 2009).

According to Patton (2001), this approach is called “Methods Triangulation”. “Methods Triangulation involves comparing and integrating data collected through some kind of qualitative methods with data collected through some kind of quantitative methods” (Patton, 2001: 556). Such an approach to employ mixed methods analysis provided potential compatibility in ways that are designed to help the researcher to discover the degree and nature of such compatibility. It also helped to provide a single, well-integrated picture of the situation (*ibid*).

By conducting in-depth interviews with a sub-set of leaders from the companies that participated in the thesis research´s quantitative survey, the interviewees had the opportunity to review and reflect upon the researcher’s findings from that survey. They also reflected upon the changes, actual or planned, that their companies have made or are committed to make to transform their operations to be more in agreement with the environmental and socio-economic requirements of the sustainability journey.

According to Patton (*ibid*: 560), “having those who were studied review the findings offers a second approach to analytical triangulation. Researchers and evaluators can learn a great deal about the accuracy, completeness, fairness and perceived validity of their data analyses by having the people described in the analysis react to what is described and concluded”.

This approach provided an opportunity for the participants in the study to relate to the findings and the analysis based upon the quantitative survey. Because this thesis researcher’s quantitative survey results revealed that, in the context of this study, the pressures and influences exerted by the chemical and petrochemical sector’s Trade Association and the State Environmental Agencies represented important determinants of companies´ willingness to engage in GCE-based eco-innovation processes, representatives of these two organizations were also included among those who were interviewed.

The results of the in-depth interviews as well as the interview guides were presented in Appendix F and were discussed in Section 7.4, of Chapter 7.

4.8 Salient Limitations of the TPB Based Method

The presentation of the salient limitations of the TPB based method used in this thesis research was thoroughly conducted by Montalvo Corral (2002). It is this thesis author´s belief that emphasizing such limitations, and placing them in the context of this thesis research, is of extreme relevance for the reader to be informed and acquainted of the limits of applicability of the method.

As noted in Section 3.3 of Chapter 3, the performance of a specific behavior by individuals is goal oriented, it is immediately preceded and it is a function of people´s intention to perform that behavior. Intentions, on the other hand, are assumed by the TPB framework to be associated with individuals´ motivations and cognition.

The first limitation of the method arose from the fact that since intention can change over time. This imposes limitations to the predictive capability of the method.

> "The longer the time interval, the greater the likelihood of unforeseen events will produce changes in intentions. It follows that accuracy of prediction will usually be an inverse function of the time interval between measurement of intention and behavior" (Montalvo Corral, 2002: 122)

This thesis researcher´s time reference was based on the strategic plans of the Brazilian chemical industry for this decade (cf. Chapter 1). They require short-term engagement of the companies in expansion and modernization initiatives. Therefore, a time span of five years was adopted for this research, in such a slow changing paced sector, it is believed to be adequate for the use of the method.

As a second limitation, according to Montalvo Corral (*ibid*) is associated by the provision of inaccurate answers by the respondents to the survey. He pointed out that it can occur in situations in which the requirements or available resources have changed or when new and unfamiliar elements have entered into the situation.

One final limitation arose from a major objection in studies based on self-reports, which is related to cross-sectional design where all data are collected at one point at time (*ibid*). Although cross-sectional design is in harmony with the time dimension criteria established by the TPB for a behavior definition (cf. Chapter 3 and Section 4.2), "a longitudinal design would allow for more reliable conclusions about casual relationships, which are difficult to document in cross-sectional design, regardless of the measurement method used" (*ibid*: 122). Due to the time constraints associated with the finalization of this thesis research, longitudinal design can be applied as an extension of this study in the future.

5. The Development of a Behavioral Model and a System of Hypotheses of Willingness to Eco-Innovate

5.0 Introduction

Chapter 3 provided this thesis with the main theoretical foundations required for the development of a framework for the investigation of the behavioral determinants related to the deliberate engagement of companies in eco-innovation activities. Specifically, for the context of this thesis, eco-innovation activities were considered to be those that are based on the principles dictated by Green Chemistry and Green Engineering (GCE) (cf. Chapter 2). Additionally, in Chapter 3 this thesis author postulated the chosen methodological approach and theoretical grounds required the development of a behavioral model through which they could be empirically tested (cf. Section 3.3 of Chapter 3).

As noted in Chapters 3 and 4, such a behavioral model was conceived and built as an organizing framework that was developed on the grounds proposed by Ajzen´s (1991) "Theory of Planned Behavior" (TPB) and represented a modified version of Montalvo Corral´s (2002) TPB-based structural descriptive behavioral model for predicting and explaining environmentally innovative behavior (eco-innovation).

The model aggregated elements of the behavioral realm, and those belonging to innovation in industrial sectors. It placed the firm at the center of the innovation system and introduced and merged, into Montalvo Corral's TPB based behavioral model, the theoretical principles underpinning the "Sectoral Systems of Innovation" (SSI) approach developed by Malerba (2002, 2004, 2005) (cf. Chapters 3 and 4).

The model helped to organize knowledge generated in diverse areas of innovation studies to explain and predict the conditions upon which innovative behaviors of organizations in specific contexts could occur (Montalvo, 2006). Additionally, in an effort to enhance the explanatory power of the TPB and to study the influences other than the social norms prescribed in the TPB on companies' willingness to engage in innovation activities, personal and additional social factors were included in the model´s social construct (c f. Section 3.2.1. of Chapter 3)

Departing from the presentation of Montalvo Corral´s model (Section 5.1), Chapter 5 highlighted the development of the TPB based structural descriptive model custom modified for the objectives of this research (Section 5.2). Section 5.3 presented the system of hypotheses, which was used to test and to empirically validate the theoretical approach and the behavioral model of this thesis. Section 5.4 presents the summary of this chapter.

5.1 The Starting Point: Montalvo Corral´s Behavioral Model

> "Although analyzing the sources of innovation should be at the core of innovation economics, up till now there has been a somewhat strange neglect of the behavioral aspects related to the innovation process. This neglect is a shortcoming of conceptualizations as well as of empirical investigations of the innovation process" (Beckenbach and Daskalakis, 2008: 181)

In the field of eco-innovation, this gap was significantly closed, by Montalvo Corral´s (2002) studies on the pre-dispositional factors influencing companies, in the “In-Bond Industry”, which is located along the United States-Mexico border, to adopt cleaner technologies (eco-innovative behavior).

In his studies, the TPB (Ajzen and Madden, 1986; Ajzen, 1991) was instrumentally used as a definitional system and an organizing framework to test the determinants of firms´ innovative behavior in cleaner technologies. Upon it, an empirical model, providing a test to the causal links and relations between agents´ cognition and behavior, was developed. Such causal links and relations represented the base upon which behavioral intentions regarding specific behaviors could be explained and predicted. Montalvo Corral´s model has been positively accepted and used in a number of researches in which the study of the determinants of eco-innovative behaviors were the main interest (e.g. POPA-CDTA 2005a, 2005b, 2006a, 2006b; Sartorius, 2008; When de Montalvo, 2003; Zhang *et al.*, 2011)

Although the TPB has been widely employed to predict and explain a variety of behaviors in many contexts, Montalvo Corral’s (2002) study represented a major contribution regarding the application of the TPB to eco-innovative behavior at the same time that he introduced an empirical model for decision-making analysis regarding innovation and resistance to change.

5.1.1 Montalvo Corral´s Modifications to Ajzen´s Model

Montalvo Corral´s model modification to the TPB´s original form was concentrated on three aspects:

a) **Estimation of the indices of attitude, perceived social norms and perceived behavioral control**

In Montalvo Corral´ model, the indexes of attitude (*A*), perceived social norms (*SN*) and perceived behavioral control (*PBC*) were estimated as accumulated semantic loads[85]. “This was done by combining the wording and the differential semantic of a single item- the notion of outcomes and the evaluation of its likelihood of occurrence” (*ibid*, 112). They include the cognitive and the evaluative components proposed by Ajzen. This was a modification to Ajzen´s original proposition for the use of expectancy value models to create the scales of attitude ($A \alpha \sum b_i e_i$), perceived social norms ($SN \alpha \sum b_i m_i$) and perceived behavioral control ($PBC \alpha \sum c_i p_i$) (cf. Section 3.2.1 of Chapter 3).

[85]The accumulated semantic load regarding a construct represents the overall meaning that is produced by the sum of the connotative meaning of the items that compose such construct. It captures in a single item the accumulated connotative load that the scale in a particular domain contains For example, in this research, the accumulated semantic load of attitude is given by A=A(EVR, ECR). EVR and ECR are expressed as EVR = EVR($\sum evr_b$) and as ECR = ECR($\sum ecr_b$). The sum indicate that the connotative meaning of the items evr and ecr accumulate to shape the perception of environmental (EVR) and economic risks (ECR), which, in turn, form attitude.

This modification was introduced based on Ajzen's (1991) statements that "the application and the appropriateness of the expectancy value model, for example, multiplying an outcome by its perceived likelihood of occurrence, was subject of an unresolved debate" (*ibid*: 112). A second reason emerged from Shapira's (1994) argument on the insensitiveness of managers to estimate outcome probabilities as opposed to their ability to access detailed descriptions of particular events such as outcomes scenarios. Additionally, according to Montalvo Corral (*ibid*: 112) "using two separate items to access one belief, as proposed by Ajzen, would have doubled the number of items in the questionnaire, making its application impractical."

b) Perceived Social Pressure – motivation to comply with important referents

Ajzen´s (1991) definition of the perceived behavioral control stated that the perceived social pressure is a function of the normative belief in question and the motivation to comply with important referent (cf. Section 3.2.1 of Chapter 3). In Montalvo Corral´s model, this was modified in the sense that that the motivation to comply with important referent(s) was not generally included for each item suggested by Ajzen. Instead, it was included only in those domains of the perceived social pressure where it was considered appropriate.

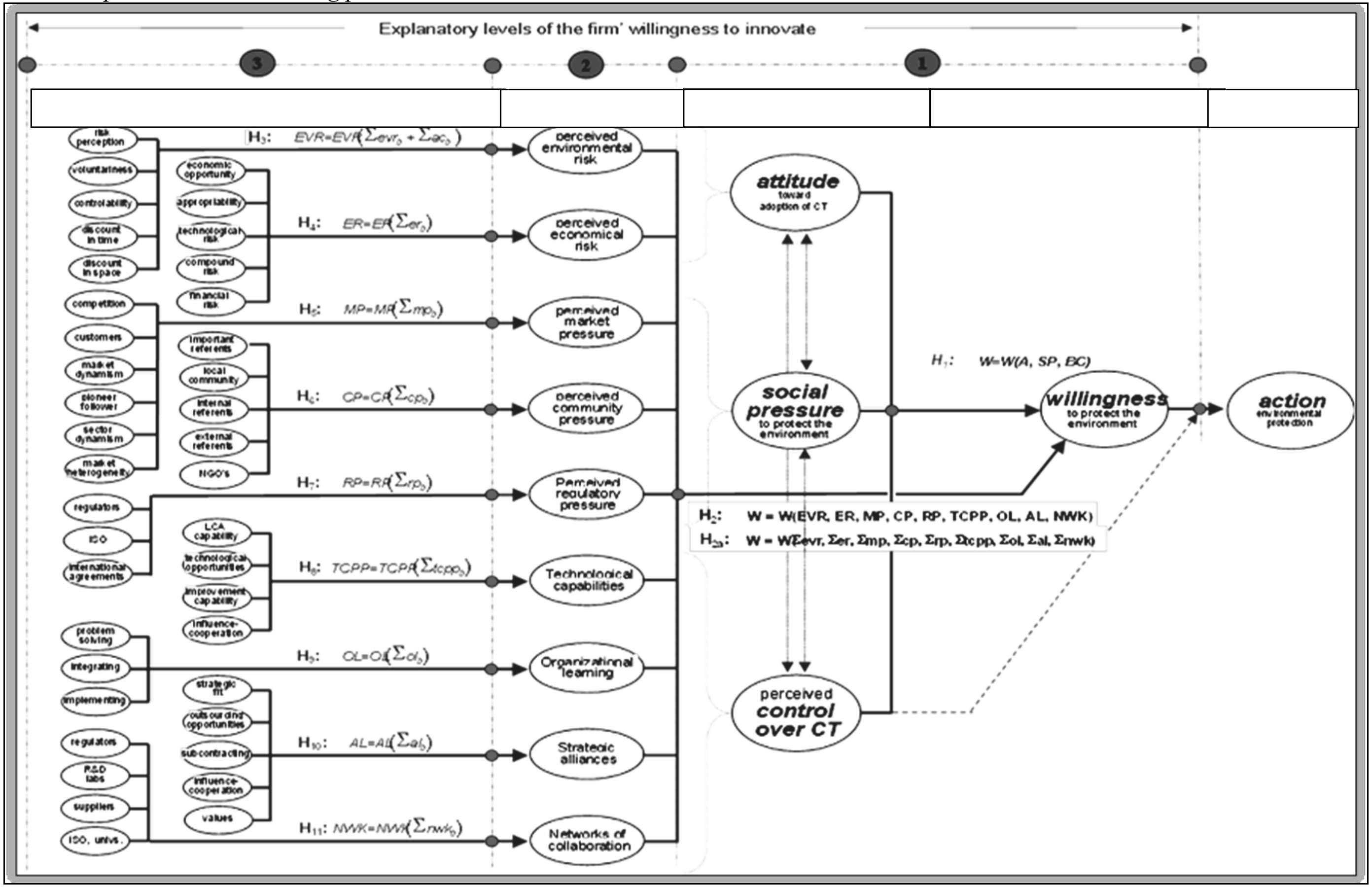
c) Levels of explanation of intention and behavior

With regard the levels of explanation of the behavioral intention and the behavior, Montalvo Corral´s model introduced one additional level as compared with Ajzen´s original proposition.

According to Montalvo Corral (2002), Ajzen's model did not include items assessing the overall perception of the behavioral domains that underlie studies of (*A*), (*SN*) and (*PCB*) in a single item. Grounded on the fact that "behavioral domains represent the specific areas of experience and knowledge from which the salient beliefs arise" (Ajzen, 2008: Ch. 1), he further explained that the justification underpinning this modification was that this inclusion had the objective of capturing, in a single item, the accumulated connotative load that the scale in a particular domain contains. In parallel, he noted that the inclusion of this extra level of explanation allowed for the integration of different theoretical bodies into a single model and built a coherent and robust set of causal links between beliefs and the behavioral intention.

Figure 5.1 depicts Montalvo Corral´s descriptive structural TPB based model with the representation of its levels of explanation and hypotheses system.

Figure 5.1- Montalvo´s empirical behavioral model for the engagement in environmental innovative behavior (eco-innovation) within corporate decision-making processes



Source: Montalvo (2002)

Finally, at the end of this section, it is important to highlight that the modifications introduced great flexibility to the use of the TPB in the sense that "it could be modified according to the needs of the study, instead of requiring the study to be molded according to the possible rigidities of the models" (Montalvo Corral, 2002: 112).

5.2 The Development of the Research´s Behavioral Model of Willingness to Eco-Innovate in Industrial Sectors

As stated in the concluding lines of Section 5.1.1, Montalvo Corral's model introduced more flexibility to the use of the TPB as a methodology for predicting and explaining specific behaviors in specific contexts. The fact that the methodology could be modified according to the needs of the study enlarged the spectrum of possibilities of the ways the behavioral studies could be performed using the TPB as an instrumental methodology.

Making use of the principles postulated by the TPB and drawing on Montalvo Corral's model, an adapted model was constructed in order to fulfill this researcher´s objective, i.e. to predict and explain the engagement of companies, in the Brazilian petrochemical sector, in innovation activities that are based in the principles of GCE.

5.2.1 Adaptations to the Montalvo Corral Model

In this research, adaptations to the Montalvo Corral´s model became necessary and were driven by the necessities dictated by the nature and objectives of the research as well as by the approach that was adopted. In this case, the necessity for merging the behavioral theory fundamentals of the TPB and the theoretical approach aimed at innovations in (industrial) sectors induced modifications in relation to both its contents and behavioral intentions constructs. As stated in Chapter 3, two main factors induced these changes:

1) The interest of this thesis author to amplify and expand the TPB explanatory power. This was conducted *via* the incorporation of personal and other social factors in addition to the social factors that were originally used in Montalvo Corral´s model´s social norm construct. These additional elements comprised (a) the social factors (roles and self-identity) obtained from Triandis´ "Theory of Interpersonal Behavior" (TIB) (Triandis, 1977; Jain and Triandis, 1997), and (b) the personal moral norm as predicated by Schwartz (1977).

   The merger of Tiandis´ TIB social factor construct, into the TPB´s model provided a good fit to the structure of this researcher´s model due to considerable similarity between both theories.

> "Both claim to be general theories of social behavior. Both include expectancy-value and normative belief constructs, and both attempt to explain the intention to perform a specific behavior and the actual performance of that behavior. The main distinction between the models lies in the relative importance attributed to the level of consciousness in explaining and predicting a given social behavior. Whereas the TPB stated that social behavior is under the individual's conscious control, the TIB proposed that the level of consciousness decreases as the level of habit in performing the behavior increases." (Bamberg and Schmidt, 2003: 268)

Another important characteristic of the TIB´s social construct is the fact that it shares the TPB´s normative beliefs. In addition, it includes role beliefs about the appropriateness of the behavior for one's perceived professional role, the interpersonal agreements, and self-definitions (*ibid*).

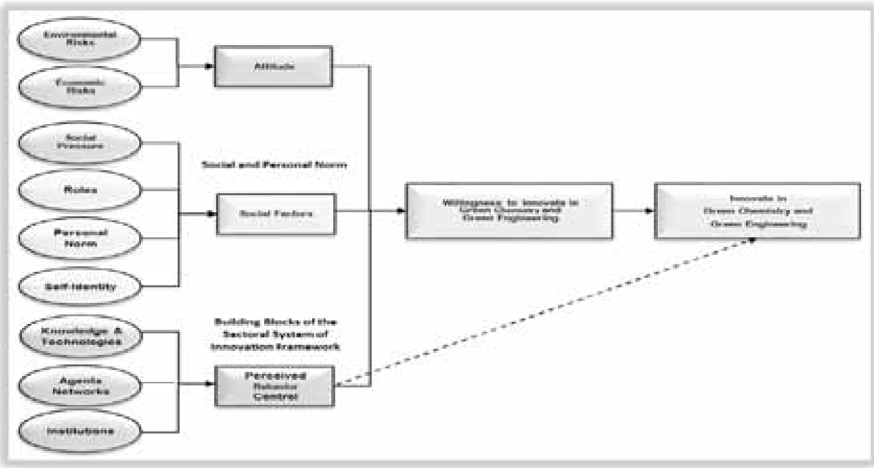
2) Because this thesis research was focused upon innovation in a specific industrial sector, the theoretical framework postulated by the concept of "Sectoral Systems of Innovation (SSI)", proposed by Malerba (2004, 2005), was considered to be appropriate (cf. Chapter 3). The SSI postulated that innovations in sectors emerge as a result of dynamic processes and are supported by three building blocks (cf. Section 3.1.2):

- Knowledge, and technological domains;
- Actors, interactions and networks and
- Institutions

As shown in
Figure 5.3 and in more detail in Section 5.2.2, in this thesis research, these building blocks constituted the behavioral domains associated with the TPB´s perceived behavior control construct. Based on the TPB, it is proposed that the stronger the organization's managers and key decision-makers judge that their companies have access to the opportunities and possess the requisite resources associated with these building blocks, the more strongly they will be inclined to engage in GCE-based eco-innovation activities. The stronger the perception of behavioral control, the more the behavior is under volitional control (Ajzen, 1991; Ajzen and Maden, 1986; Montalvo Corral, 2002).

These adaptations were limited to the model´s contents since the structure, fundamentals and methodological aspects of Montalvo´s original model remained intact (cf. Chapter 3).
Figure 5.3 depicts a schematic illustration of this thesis' operational model for explaining and predicting the engagement in eco-innovation activities based upon the principles predicated by GCE using the TPB and the SSI framework.

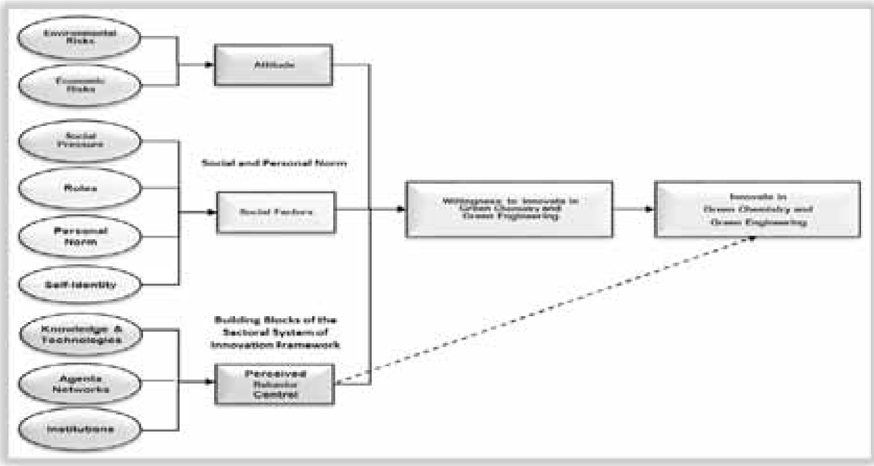
Figure 5.2- The adapted empirical, behavioral model based on the Theory of Planned Behavior and the "Sectoral System of Innovat ion" framework for predicting and explaining companies' engagement in eco-innovation activities in green chemistry



Note: The elements presented in darker color are the original elements in Montalvo Corral´s model. The ones depicted in lighter print represent the modifications that were introduced by this thesis author.
Source: Author

These adaptations corroborated the argumentation in Section 5.1 about the flexibility of Montalvo Corral´s model to be modified according to the needs of this research.

Figure 5.2- The adapted empirical, behavioral model based on the Theory of Planned Behavior and the "Sectoral System of Innovat ion" framework for predicting and explaining companies' engagement in eco-innovation activities in green chemistry

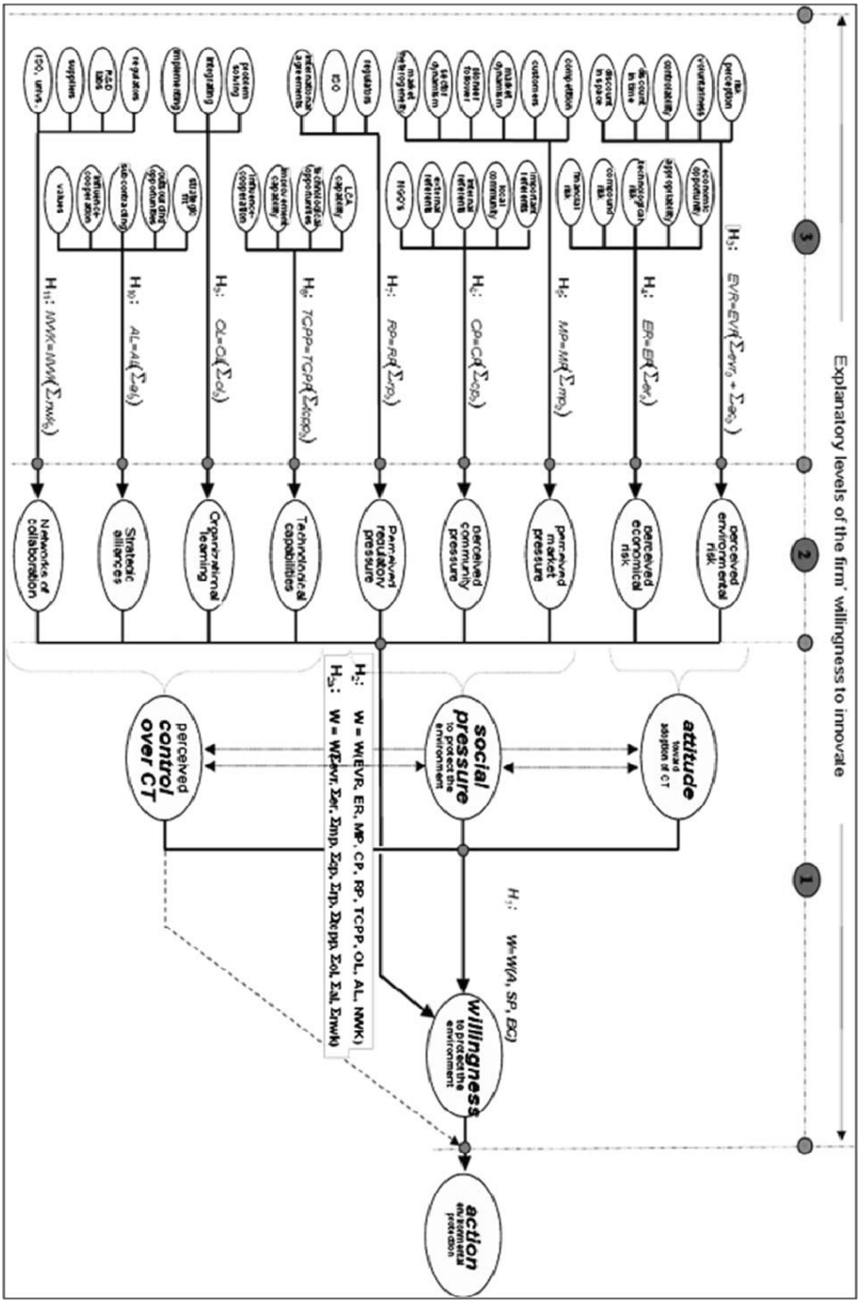


Note: The elements presented in darker color are the original elements in Montalvo Corral´s model. The ones depicted in lighter print represent the modifications that were introduced by this thesis author.
Source: Author

It is important to note the following points regarding the model presented in Figure 5.3.

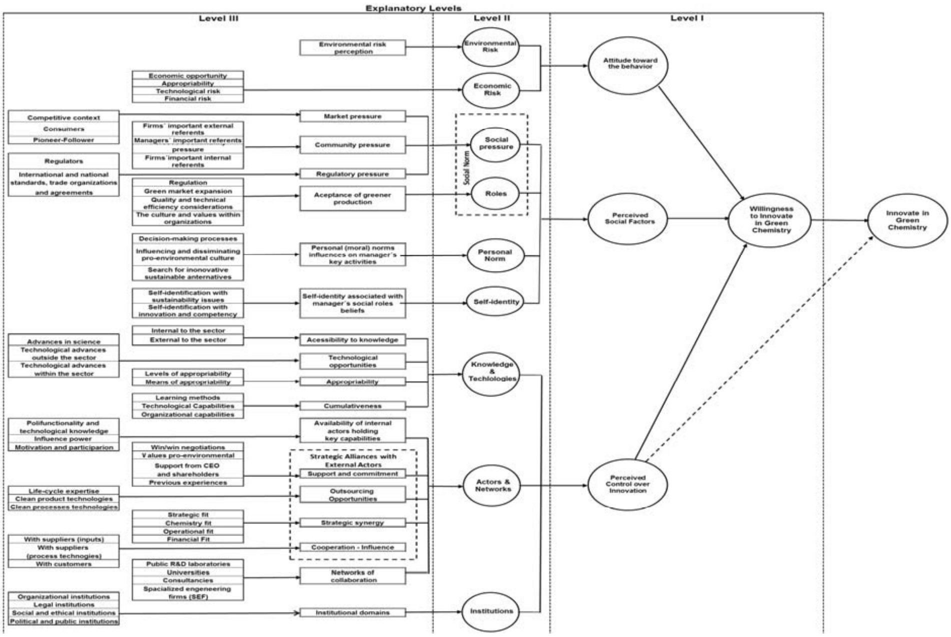
a) The issues involving the behavioral domains: Environmental Risks, Economic Risks and Social Pressures and Agents and Networks and their associated beliefs represent a direct application of Montalvo Corral´s (2002;
b) The remaining behavioral domains and beliefs were developed by this thesis author by taking into consideration a number of different theoretical elements associated with the behavioral domains under study.

Figure5.1(see page 136)



It is important to highlight that the model represented in
Figure 5.3 is a partial representation of the full model. This representation reached as far as the second level of explanation (behavioral domains). The third level of explanation (i.e. beliefs) required a more elaborate and labor-intensive approach as it captured a variety of beliefs related to specific behavioral domains that stem from various theoretical fields. The full model is explained in Section 5.2.2 and its schematic representation is presented in Figure 5.9. The full development of the model represents the basis for the construction of the quantitative questionnaire used in the empirical research.

figure 5.8 (see full scale on page 202)



5.2.2 The Development of the Full Research´s Operational Behavioral Model

Section 5.2.2 builds on the previous sections and objectives the full development of this thesis' empirical model. With regard to the structural aspects, the development of the model maintained Montalvo Corral´s model TPB structure and hierarchical and causal relationships between the three levels of explanation: i.e. intentions (willingness), behavioral domains and beliefs (cf. Figure 5.8 and Figure 5.9).

This section sequentially explores the behavioral domains associated with the model´s behavioral intention constructs and additionally, based upon consultation of the relevant literature, a criterion is chosen for the selection of the beliefs connected to each behavior domain. This reinforced the meta-theoretical character of the TPB models. The beliefs are then listed for inclusion in the questionnaire.

The Attitude Construct as a Determinant of Eco-Innovation in Green Chemistry and Green Engineering

Before proceeding with the development of the theoretical constituents of the attitude construct it is important to highlight that this research utilizes the "attitude" component and its associated beliefs in the same way proposed by Montalvo Corral (2002). They were, however, applied to a different behavioral, context, target and time. Due to the nature of this research, this required modifications to the wording of the questionnaire

Attitude was defined in Section 3.2.1 as a function of the perceived consequences (outcomes) of performing the behavior and the person's evaluation of those consequences. The willingness to perform, or not perform, a specific behavior is dependent on a favorable or unfavorable evaluation a firm's manager has about the expected outcomes.

In this thesis research, managers´ and important decision-makers´ attitude towards their companies´ engagement in GCE-based eco-innovation processes was interpreted as a function of their subjective evaluation of the expected outcome associated with such engagement.

According to Montalvo Corral (2002: 55), in the eco-innovation realm "the main concept behind this evaluation is risk". The perception of risk is assumed to stem from two domains":

- The **possible environmental impacts** (perceived environmental risk) generated by the firm's operation and the perceived environmental relevance of the environmental improvement introduced by the development of cleaner and more sustainable products, processes, raw materials and energy sources, and
- The **possible economic consequences** in terms of perceived possible capital losses or gains (business opportunities) arising from firm's GCE-based innovative activities, be they incremental or radical, under risk or uncertainty.

figure 5.7 (see full scale on page 196)

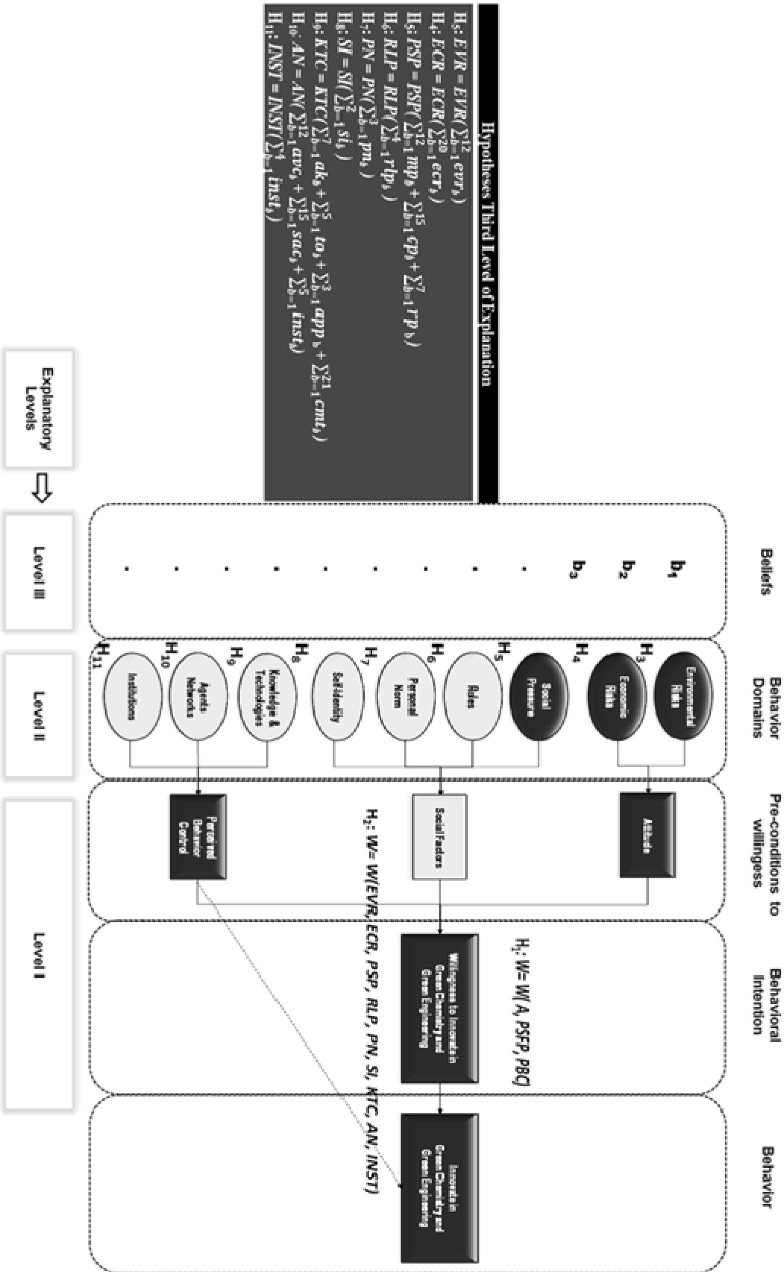
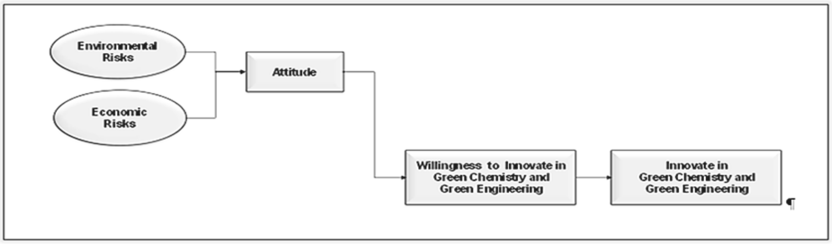


Figure 5.3 depicts the model structure related to the attitude construct.

Figure 5.3- Attitude behavioral domains that predict and explain firm´s willingness to innovate in Green Chemistry and Green Engineering



Source: adapted from Montalvo Corral (2002)

The model´s structure and its relationships guided the author in the development of the questionnaire for the attitude construct. Table 5.1- presents a sample of an item of the research questionnaire for the direct measurement of attitude.

Table 5.1- The statement used, in the questionnaire as a direct measure pertaining to the attitude towards innovation in Green Chemistry and Green Engineering. (The complete questionnaire is in Appendix E)

The engagement of our company in eco-innovation activities, related to our products and processes, that are based on the principles predicated by the Green Chemistry and the Green Engineering will produce, relative to the local, regional and global environment:						
-3 very bad consequences	-2 significant	-1 slight	0 uncertain	1 slight	2 significant	3 very good consequences

Attitude Behavioral Domain 1: Environmental Risk

According to Montalvo Corral (2002), the main premise supporting the environmental risk domain is that managers who perceive an environmental risk, produced by his/her firm´s operations, that is beyond its subjective and objective acceptance level, will be more likely to engage in eco-innovative behaviors.

For this reason, the objective of this section was to develop a better understanding of manager's perceptions of the risky or safe character of operations of their firms. This included their perceptions respective to the hazards that their firms may produce for themselves, the surrounding communities and the broader environment and of what they take into account in accepting or avoiding the generation of environmental risks.

Montalvo Corral's (2002) approach to address risk perception was based on the "psychometric approach" originated from the cognitive psychology. This approach is focused on the attributes of risk in order to infer its acceptability. Its main propositions are: (1) perceived risk is determined by a variety of quantitative and qualitative risk attributes, (2) risk perception is quantifiable and predictable and (3) risk means different things to different people in different situations. The choice of this approach resides on its coherence with the TPB method as it "focuses on individuals and functions by assessing expressed preferences via responses to self-reporting questionnaires" Montalvo Corral (2002: 63).

Environmental Risk Perception

For the purposes of this research, the environmental risk perception concept is expressed by "how and why individuals perceive technologies and activities as (environmentally) risky or safe and, as a consequence of such perception, accept or reject that risk" (Montalvo Corral, 2002: 63).

According to Slovic *et al.* (1984:187), in relation to risk assessment, some generalizations can be made:

(1) "Perceived risk is quantifiable and predictable. Psychometric techniques seem well suited for identifying similarities and differences among groups with regard to risk perceptions and attitudes;
(2) Risk means different things to different people. When experts judge risk, their responses correlate highly with technical estimates of annual fatalities. Laypeople can assess annual fatalities if they are asked to (and produce estimates somewhat like the technical estimates). However, their judgments of risk are sensitive to other factors as well (e.g., catastrophic potential, threat to future generations) and, as a result, may differ from their own (or experts') estimates of annual fatalities;
(3) Even when groups disagree about the overall riskiness of specific hazards, they show remarkable agreement when rating those hazards on characteristics of risk suck as knowledge, controllability, dread, catastrophic potential, etc."

In this respect, Montalvo Corral (2002) based on the work by Slovic *et al.* (1984), stated that one's sense of safeness related to any activity or technology emerges when the possible hazards associated with it are: (1) meant to be controllable, (2) not dreaded, (3) not catastrophic, (4) the benefits and social costs are equally distributed, (5) of low risk for future generations, (6) voluntarily exposed, (7) do not affect the observer, (8) observable, (9) known to those exposed, (10) of delayed effect, (11) old and familiar and (12) known to science.

Table 5.2 depicts the scales to assess the environmental risk perception.

Table 5.2- Behavioral beliefs and the questionnaire item used to assess organization leader's perceptions related to the environmental risks associated with their companies´ activities

Question: The environmental hazards generated by the operations of our company for this region are likely to be:

evr1	Controllable	1 2 3 4 5 6 7	Uncontrollable
evr2	Do not have global impacts	1 2 3 4 5 6 7	have global impacts
evr3	Consequences not fatal	1 2 3 4 5 6 7	Fatal consequencesl
evr4	Evenly distributed	1 2 3 4 5 6 7	Unevenly distributed
evr5	Low risk to future generations	1 2 3 4 5 6 7	High risk to future generations
evr6	Voluntary for those exposed	1 2 3 4 5 6 7	Involuntary for those exposed
evr7	Does not affect me	1 2 3 4 5 6 7	Affects me
evr8	Not observable	1 2 3 4 5 6 7	Observable
evr9	Known for those exposed	1 2 3 4 5 6 7	Unknown for those exposed
evr10	Delayed effects	1 2 3 4 5 6 7	Immediate effects
evr11	Old risks	1 2 3 4 5 6 7	New risks
evr12	Risks known to science	1 2 3 4 5 6 7	Risks unknown to science

Source: Montalvo Corral (2002)

Attitude Behavioral Domain 2: Economic Risk and Business Opportunities

According to Montalvo Corral (2002), the nature of the manager's behavioral beliefs[86] regarding the economic risks associated with the processes of innovation gravitates around two central elements: uncertainty and risk.

Such argumentation was grounded on the very nature of innovation processes of exploring previously non-exploited opportunities in many areas of human activities such as the ones in the technological and economic domains.

According to Brown and Damery (2009), as it focused on the negative impact of being exposed to harm, the concept of risk is usually associated with loss. "It extended the concept of uncertainty to decision-making where the potential for loss is known (…) but the precise nature of loss, whether it will occur, or even how probable it is, is unclear" (…) risk implies uncertainty about costs and benefits of a decision (*ibid*: 83).

"Discussions about uncertainty and risk are complicated by the varying ways these concepts are defined and applied, both within and between disciplines" (*ibid*: 82). Based on the risk literature, Montalvo Corral (2002) posited that uncertainty is regarded as situations and events in which each action generates a set of consequences whose outcomes are unknown. On the other hand, risk refers to the possibility of gains as well as the threat of losses in situations in which each action leads to a few known outcomes associated with specific probabilities of occurrence.

> "(…) uncertainty leads to hazard, and hazards have a probability of occurrence". (Montalvo Corral, 2002, 70)

These definitions provided a good fit for innovation studies (*ibid*) and corroborated Dosi's (1988b) argument that uncertainty in innovative activities emerges from the lack of knowledge on the solution for techno-economic problems and on the impossibility to foresee the consequences of actions.

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[86] Behavioral beliefs are the beliefs that are assumed to influence attitudes towards the behavior. (Montalvo Corral, 2002)

In order to define and operate the concept of economic risk within the context of eco-innovative activities and to provide a framework that enables the identification of the sources of uncertainty and risk, in the organizational set, Montalvo Corral (2002) highlighted four main areas of possible gains and losses from which eco-innovative technologies may arise:

1) **Economic and business opportunities:** in the literature of innovation, business and economic opportunities are regarded as the primary factor driving technological innovation in clean products and manufacturing processes (*ibid*). Eight behavioral beliefs emerged as highly contributing to the perception of economic and business opportunities (cf. Table 5.3). In this domain, three were related to the firm/consumers relations that influence the conquest of new market niches as a response to consumers' environmental expectations. Four additional beliefs were related to the opportunities generated by the notion of the timing of market entry and the benefits and novelty effects originated from it. Finally, one was related to the economic risk imposed by future new and more restrictive environmental regulation;
2) **Appropriability:** appropriability is acknowledged as the benefits of R&D and/or the investment in innovative new technologies, which is secured by various mechanisms such as patents, licensing and transfer of technology. In this respect, the perceived economic risks associated with appropriability were considered to be associated with companies´ loss of control over their own knowledge and technology due to outsourcing processes via alliances or subcontracting;
3) **Technological risk**: "technological Risk refers to the uncertainty of discovery regarding the feasibility of the concept of clean technologies as perceived by managers" (*ibid*: 73). In the context of this research, it is perceived to be the amount of R&D required, its costs, the time required to develop new technologies (both developed by the company itself or through alliances), the availability and opportunity of economic resources and the compound uncertainty that is associated with new products and processes, and
4) **Financial risk**: "financial risk refers mainly to what is perceived by managers as downside risk as it connotes mainly with the possible losses of profits and capital" (*ibid*: 74). Three behavioral beliefs emerged in this domain. The first concerned the timing of resources availability followed by the possibility of the loss of sums of capital investment on R&D and the reduction of competitiveness due to the increase in fixed costs.

Table 5.3 lists the beliefs, referred to in the foregoing paragraphs that may be held by managers in the industrial organization in relation to the economic risks associated with innovating in GCE.

Table 5.3- Behavioral beliefs used to assess organization's leaders´ perceptions related to the economic risks associated with innovating in Green Chemistry and Green Engineering

Economic Opportunity	Market niche opportunity loss Regulatory risk Distribution and novelty effects Entry timing Pioneer vs. Follower Customers expectancies (predisposition to pay) Growth opportunities Market uncertainty	Technological Risk	R&D requirements R&D costs Economic resources availability Project life time Uncertainty of achievement and discovery Compound risk
Appropriability	Appropriability conditions Subcontracting risks Alliance risk (loss of technological control)	Financial Risk	Management uncertainty Resources uncertainty Capital risks

Source: Montalvo Corral (2002)

Table 5.4 contains a statement of the questionnaire related to economic risk perception.

Table 5.4- The statement used in the questionnaire pertaining to the perceived economic risk. (The complete questionnaire is in Appendix E)

The predisposition of our clients to pay higher prices for products that are environmentally more sustainable is:						
-3 very high	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 very low

The Social and Personal Factors Construct as a Determinant of Innovation in Green Chemistry and Green Engineering

The theoretical foundations underpinning the TPB (Ajzen and Madden, 1986 and Ajzen 1991), as well as its predecessor the “Theory of Reasoned Action” (Fishbein and Ajzen, 1975) postulated that the social environment exerts strong influence on one’s intention to perform a given behavior (cf. Section 3.2.1). Consistent with it, the TPB proposed the use of a social construct as one of the main determinants of behavioral intention that established a causal link between the social normative beliefs and the intention to perform a given behavior in specific contexts (cf. Figure 3.2). As noted in Section 3.2.1, social norm, in the TPB domain refers to:

> “(…) the person’s perception that most people who are important to him think he should or should not perform the behavior in question. According to the theory, the general subjective norm is determined by the perceived expectations of specific referent individuals or groups and by the person´s motivation to comply with those expectations” (Fishbein and Ajzen, 1975: 302).

On the other hand, the TPB has been criticized for not including other social dimensions and extensions to the model. Consequently, other theoretical behavioral predictors have been proposed under the “increasing empirical evidence that the TPB is not a sufficient model for explaining all kinds of social behaviors” (Bamberg and Schmidt, 2003: 269). Ajzen made it clear that the TPB is not a closed system and that there is room for improvements and for the introduction of further constructs:

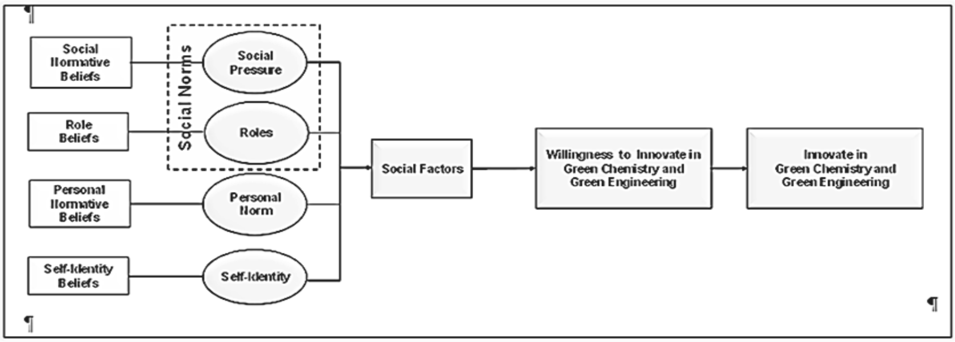
"Perhaps of greater importance is the possibility of making further distinctions among additional kinds of beliefs and related dispositions. The theory of planned behavior is, in principle, open to the inclusion of additional predictors if it can be shown that they capture a significant proportion of the variance in intention or behavior after the theory´s current variables have been taken into account. The theory of planned behavior in fact expanded the original theory of reasoned action by adding the concept of perceived behavioral control." (Ajzen, 1991: 199)

Despite the emphasis placed by the TPB on the influence of the social norm as a determinant of behavioral intention, other influences are also claimed to be determinants of behavioral intentions in diverse contexts (Ajzen, 1991; Armitage and Conner, 1999; Bamberg and Schmidt, 2003; Conner and Armitage, 1998; Guagnon *et al.*, 2003; Jain and Triandis, 1997; Kaiser *et al*., 2005; Manstead and Parker1995; Triandis, 1977; White *et al*., 2008).

These theoretical arguments on the sufficiency of TPB coincide with the interests of this researcher with regard to the extent of the influence of social and personal normative factors on the willingness of companies´ leaders to engage in GCE-based eco-innovation processes. In this regard, as noted in Section 5.2.1, Montalvo Corral model´s social pressure construct was extended to incorporate personal moral and additional social factors.

Figure 5.4 represents the structure of the expanded social construct of this research's operational model following the introduction of additional social and personal normative and identity beliefs.

Figure 5.4- Social factors behavioral domains to predict and explain firm´s willingness to innovate in Green Chemistry and Green Engineering



Source: author

Table 5.5. contains a question of the questionnaire regarding a direct measure to assess managers´ perceptions of the social and personal pressures associated with innovating in GCE.

Table 5.5- The question in the questionnaire used as a direct measure of the perceived pressures arisen from the social factors domain. (The complete questionnaire is included as Appendix E)

In your perception, the degree to which social factors such as market, community, regulatory organizations; the social and professional responsibilities; together with moral obligations, in relation to the environment, can positively influence the decision-making process related to the engagement of your company in eco-innovation activities that are based on Green Chemistry and Green Engineering is:						
-3 very low	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 very high

Social Factors Behavior Domain 1: Perceived Social Norm (Social Pressure)

Drawing on the foregoing paragraphs, on Section 3.2.1 and following Triandis (1977) and Gagnon *et al.* (2003), in this thesis research the perceived social norms were interpreted as being composed by: (a) social normative beliefs and (b) role beliefs (cf. Figure 5.4).

Roughly, "norms" can be understood as social attitudes of approval and disapproval, specifying what ought to be done and what ought not to be done (Sunstein, 1996). There are social norms about nearly every aspect of human behavior. Individuals in societies are submitted to social judgment and behaviors that are inconsistent with contextual social norms may be submitted to public disapproval. Consequently, they may experience intense unpleasant feelings and substantial social consequences. (*ibid*).

According to Sunstein (*ibid*), social roles and social meaning are, in general, products of social norms. Social norms also affect personal choices and thus personal behaviors. He further stated that the relevance of a given social norm on personal choice is dependent on five factors:

1) "The intensity of the norm (exactly how much opprobrium attaches to a violation?);
2) The nature of the norm (what kind of attitude is signaled by a violation? what kind of attitude is provoked by violators?);
3) The agent's attitude toward the norm and the opprobrium occasioned by its violation (does the agent like to be seen as a defiant person? how does the agent react to social opprobrium?);
4) The possibility of social approval or forgiveness among relevant subgroups (will the agent's peer group support the norm-defying act?), and
5) The nature and weight of the other ingredients in choice, including competing norms, intrinsic value, and effects on self-conception (what must a norm-complier sacrifice?)" (*ibid*: 940).

In the context of this research, social normative beliefs (social norm) refers to the social pressure perceived by managers and key decision-makers regarding their pro-environmental behavior. More specifically, it regards their perceptions of the pressures from their important referents relative to the implementation environmentally sustainable products, process technologies such as those that are based on GCE.

According to Montalvo Corral (2002) the sources of social influence span a variety of agents and institutions such as competitors, customers, legal requirements, employees, shareholders, general public, NGOs, to cite a few. In the context of eco-innovation in the industrial sector, he proposed that the possible sources of social pressure can be classified in three groups: (1) the market, (2) the communities directly related to the firm and (3) the regulatory regime. The social influences of these groups on the manager's willingness to perform eco-innovation behaviors are discussed in the following paragraphs.

Perceived Market Pressures

> "A market is a group of buyers and sellers of a particular product or service. The buyers, as a group, determine the demand of a product, and the sellers, as a group, determine the supply of the product" (Mankiw, 2008: 66)

In a reinterpretation of the concept of market, it can be argued that, in the economic domain, groups of individuals in the pursuit of selling, buying or exchanging any type of goods, services and information promote social interactions within which they exert influences in terms of supply and demand. Presently, in the environmental sustainability domain, as a consequence of significant improvement of societal environmental awareness in industrial societies, there are ongoing societal demands (pressures) for a cleaner and more (environmentally) sustainable world. Among these sustainability-demanding pressures, the ones that are originated in the market may affect companies' business relations and interests, which are of upmost importance for their corporate sustainability (social, environmental and economic).

These pressures represent market demands towards a cleaner and safer environment. They are generated by the underlying social norms concerning the environment that mediate the relations between industry and market.

> "Market operates under well-institutionalized rules that have maturated as a result of a social development process (…) In these instances it can be said that market operation is guided by, and within the limits of the dominant social norms." (Montalvo Corral 2002: 76)

This section follows Montalvo Corral (2002) in the sense that it aims at assessing the perceived social pressure arising from the market. It intends to gauge market pressures related to the adoption (development or acquisition) by companies of eco-innovative products, processes and services such as those that are based on GCE.

In order to accomplish this objective and being faithful to and following the concept of normative beliefs, which underlie the perceived social pressures (subjective norm) to perform or not to perform a specific behavior, the primary motivation of this section was to identify the important market referents. The importance of these referents reside in their power to dictate objective and subjective social norms that can influence and induce companies to adopt and/or invest in the development of new GCE-based technological solutions that could fulfill the market´s needs.

In this thesis research, the motivational factors to engage in technological GCE-based eco-innovations activities could arise from market demands for new cleaner technologies that could be seen, by the firms, as a competitive advantage.

Montalvo Corral (*ibid*) argued that the market pressures exerted on the firm to develop cleaner technologies arise mainly from their competitors and from their customer's expectations regarding specific environmental qualities of products. By further investigating the origins of normative pressures from the market on manager's perceptions, he found evidence that if the competitive context motivates a company to behave as a pioneer or a follower in the technological development domain, then the competitive context is expected to be a referent that dictates social norms.

Montalvo Corral (*ibid*) proposed that the possible sources of perceived social pressure that might arise from the market can be classified in three groups: (1) The competitive context, (2) The customers' demands, and (3) the perception of the need to be a pioneer or a follower.

These three groups are explained as follows:

1) **The competitive context**: the first aspect concerning the competitive context was the way managers perceive market leaders and important competitors as adopters of clean technologies. In this regard, the actions of competitors´ environmental (and economic) behavior serve as a motivational driver for them to follow these referents. Market pressures can become stronger if managers perceive that cleaner and innovative technological solutions represent a universal trend in the sector.

   The other aspects are related to the three dimensions of firms´ competitive context[87] (i.e. dynamism, hostility and heterogeneity):
   - The sector dynamism-related aspects refer to the extent to which the rate of change in the industry's technological conditions could induce companies to perceive the incorporation of cleaner technological options as a viable way to pose barriers to competitors' entries;
   - The market hostility-related aspects regard the context of business climate with intense competition and limited market opportunities that may generate the need for the adoption of cleaner technologies, and
   - The heterogeneity of markets, serves as a source of market pressure in the sense that companies may need to introduce innovative cleaner products to match the diversity of customer needs;
2) **The customers' demands:** the market pressures originated at the customers' level stem from how firms perceive current and future customer demands regarding the development of cleaner products and processes;
3) **The need to be a pioneer or a follower:** being a pioneer or a follower relates to the competitive context in which a firm operates (Montalvo Corral, 2002). Companies are more likely to be pioneers in competitive contexts that are highly dynamic (i.e., highly

[87] According to Montalvo Corral (2002: 77), the three dimensions of the firms´ competitive contexts are as follows:

a) "Dynamism: refers to the unpredictability of consumers preferences, competitors´ behaviors, and the rate of technical change and growth opportunities in a specific industry (sector);
b) Hostility: refers to an intense competition accompanied with unfavorable business climate due to market saturation or recessionary conditions;
c) Heterogeneity: indicates the diversity and complexity of market segmentation in which the firm operates."

unpredictable consumers preferences and competitors behavior and high rate of technical change and growth opportunities), moderately hostile (i.e., moderate competition followed by moderately unfavorable business climate due to market saturation) and moderately heterogeneous (i.e., moderate diversity and complexity of market segmentation). The market pressures originated from the pioneer or follower characteristic of companies are related to firm's perception of its competitive context, its history and its experience as a pioneer or a follower of new products and production technologies.

Table 5.6 lists the beliefs, referred to in the foregoing paragraphs that may be held by managers in the industrial organization in relation to market pressures towards companies´ adoption of GCE-based cleaner products and production processes.

Table 5.6- Social normative beliefs used to assess organizations leaders´ perceptions regarding the market pressures associated with the adoption of cleaner products and production processes

Competitive Context	Pace of technical change Competitors' behavior Competition drive Market competition Sector dynamism Market heterogeinity	Pioneer-Follower	Pioneer in product technology Pioneer in process technology Follower in innovation
Consumers	Consumer expectations Future consumers pressure Motivation to comply with consumers		

Source: Montalvo Corral (2002)

Table 5.7 contains a statement of the questionnaire to assess managers´ perceptions of the market pressures associated with the adoption of GCE-based cleaner products and processes.

Table 5.7- The statement used in the questionnaire pertaining to the perceived market pressures. (The complete questionnaire is in Appendix E)

The pace of technological innovation in the petrochemical sector will soon induce our company to adopt or develop more sustainable Green Chemistry and Green Engineering based technologies for our products and processes.						
-3 very unlikely	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 very likely

Community Pressure

Industries are acknowledged as one of the important actors within the vast and heterogeneous socio-economic aspects of society. They exert influence upon and are submitted to influences and pressures from a number of social and economic agents regarding an immense variety of private and collective interests.

In the environmental realm, the idea of community pressure, concerning environmental protection in the industrial set, may be conceived and synthesized by the concept of "social license" under which companies should perform their activities. That is; companies are constrained to meet the expectations of society and to avoid activities that societies (or influential elements within them) deem unacceptable" (Gunningham *et al*., 2002).

Social pressures are as heterogeneous as the types of social and economic agents that exert them. Sometimes, they demand measures, on the part of the companies, that go beyond what is imposed by regulation even in circumstances where they are unlikely to be profitable (*ibid*).

Although the need for harmonizing industry´s private interests with those belonging to the broad societal environmental spectrum is acknowledged by organizations, it is perceived that this dispute generates tensions and that their accommodation is dependent on contextual factors. These factors influence managers´ perceptions on what the favorable or demanding conditions are for companies' engagement in technological eco-innovation activities.

Generally, perceptions on the need for corporate social responsibility that incudes firms´ pro-environmental behavior is often triggered "when the local community becomes proactive and attempts to protect the physical and social landscape" (Montalvo Corral, 2002: 79).

Guided by these perspectives, this section was designed to highlight the beliefs that may contribute to the manager's perceptions of community pressures towards cleaner and more sustainable products, processes and services.

Montalvo Corral (*ibid*), proposed that the sources of community influences related to the environmental social responsibility originate from four domains:

1) **The manager's personal important referents**- refers to the managers social obligations related to the community within which the company is inserted in and also to the social norm he is submitted to by his personal important referents (relatives, friends, his family, etc.);
2) **The firm's important external referents**- this domain refers to those important referents from segments belonging to domains outside the firm's realm who are considered important for the success of the company. This class of referents includes environmental experts from, *inter alia,* universities, research institutes and environmental consultants. Additionally, it is important to highlight manager's motivation to comply with these experts as a basic factor for the success of these referents pressures;
3) **The firm's important internal referents-** refers to how managers value the suggestions and the point of view of their staff with regard to the environment and to the implementation of GCE-based more sustainable technologies and organizational practices, and
4) **The perceived community pressures-** it refers to how managers perceive community pressures in terms of the environmental expectations, self-organization and lobbying capacity. It also refers to the extent to which local NGOs exert pressures on companies for the use of cleaner technologies. Finally, the manager's motivation to comply with the community pressures is the measure of success of these pressures;

Table 5.8 lists the beliefs, referred to in the foregoing paragraphs that may be held by managers in the industrial organization in relation to community pressures towards companies´ adoption of cleaner products and production processes

Table 5.8- Social normative beliefs used to assess organizations leaders´ perceptions related to the community pressures associated with the adoption of GCE-based cleaner products and production processes

Firm's important external referents	Outsiders social norms Outsiders pressure capabilities Environmental experts norm agreement Perceived pressure from experts Motivation to comply with experts	Perceived community pressure	Compliance with community demands Community lobying current capacity Community lobying future capacity NGO's pressure Motivation to comply with commmunity pressure
Manager's personal important referents	Manager's counciousness Managers close personal relationships	Firm's important internal referents	Important staff Staff capabability pressure Motivation to comply with staff pressure

Source: Montalvo Corral (2002)

Table 5.9 contains a question of the questionnaire to assess managers´ perceptions of the community pressures associated with the adoption of GCE-based cleaner products and processes.

Table 5.9- The question used in the questionnaire pertaining to the perceived community pressure. (The complete questionnaire is in Appendix E)

The pressures and lobbies from the local community on your company for the adoption and/or the development of cleaner and more sustainable products and processes such as those that are based on Green Chemistry and Green Engineering are:						
-3 very weak	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 very strong

Regulatory Pressures

In the industrial set, regulatory pressures in the environmental domain refers to how managers perceive that regulations affect their companies´ business. It also refers to the degree to which they are influenced by important referents, in the regulatory domain, regarding the performance of innovative eco-environmental behaviors.

Montalvo Corral (2002) argued that the enforcement of environmental legislation is widely recognized as the major driver of environmental protection (eco-behavior) in industry. According to Grabowski and Vernon (1979), two streams of legislation influence the chemical industry: (1) the economic regulation that addresses economic relationships and norms and (2) the social regulation that concerns the protection of the society against the negative impacts produced by the chemical industry's operations. Mahdi *et al.* (2002) highlight Davies´ (1983) observation that at least three types of social regulations have impact on industrial chemical innovation:

1) Environment oriented regulations (oriented to reduce the negative impacts of the chemical industry),
2) Product registration regulations (governmental approval before product manufacturing or launching in the market), and
3) Product oversight regulations (focus on specific types of product but do not require government approval for new products).

This exemplifies the importance and the significant dimension that the environmental regulatory forces occupy in the chemical industry space. Regulation enforcement by governments as well as other nongovernmental agents seek to express through social norms what is expected from firms, in terms of corporate environmental behaviors, by the broad societal spectrum.

These two-sided relationships and social pressures involving companies and their multiple referents are assumed to make fundamental contributions to the adoption by companies of eco-innovative behavior.

In this regard, López-Gamero *et al.* (2002: 964 *apud* Berrone and Gomez-Mejia, 2009) emphasized that “managerial perceptions of the importance of environmental regulations as a competitive opportunity are associated with a more proactive stance on environmental commitment”.

Within this context, it is proposed that the environmental demands embedded in regulatory social norms, may arise from a significant array of societal organizations in the governmental and nongovernmental domains. They are represented by organizations in the domains of environmental regulations, industrial standards, international environmental trade norms, and international treaties for environmental protection.

For the purposes of this thesis research, these organizations represent important referents that push or demand companies to perform of eco-behaviors such as those regarding the engagement of GCE-based eco-innovation processes. These processes are expected to develop the next generation chemical products, processes.

Table 5.10 lists the beliefs, referred to in the foregoing paragraphs, which may be held by managers in the industrial organization in relation to regulatory pressures towards companies´ adoption of cleaner products and production processes.

Table 5.10- Social normative beliefs used to assess organizations leaders´ perceptions related to the regulatory pressures associated with the adoption of cleaner products and production processes

Regulators		National and international standards, trade organizations and agreementss	
	Environmental agency Risk of future regulation Regulators' enforcement capability Motivation to comply with regulators		Influence exerted by ISO, ICCA, and ABIQUIM Motivation to comply with ISO and ICCA/ABIQUIM National and international agreements

Notes: ISO- International Organization for Standardization
ICCA- The International Council of Chemical Associations
ABIQUIM- Brazilian Chemical Industry Association
Source: adapted from Montalvo Corral (2002)

Table 5.11 contains a statement of the questionnaire to assess managers´ perceptions of the regulatory pressures associated with the adoption of GCE-based cleaner products and processes.

Table 5.11- The statement (or question) used in the questionnaire pertaining to the perceived regulatory pressures. (The complete questionnaire is in Appendix E)

Environmental authorities have the enforcement capability to force us to develop clean products and adopt clean and more sustainable production processes.						
-3 strongly disagree	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 strongly agree

Social Factors Behavior Domain 2: Perceived Social Norm (Role Beliefs)

The TPB does not prescribe roles (roles beliefs) as a central motivational factor that may influence and underlie the formation of behavioral intentions. Harry C. Triandis, in his studies on human behavior in varying situational contexts, agreed with the TPB on the importance of the perceived social norm and the behavioral intention, in predicting and explaining a given behavior performance. Despite this agreement, he stated that that in the social normative beliefs domain, “role beliefs” are of equal and of fundamental relevance (cf. Jain and Triandis, 1997 and Triandis, 1977).

As noted in Section 3.2.1 of Chapter 3, in this research, the assessment of managers’ and important decision-makers perceptions was considered as an appropriate proxy to infer of companies´ innovative behavior. As such, manager’s role beliefs appear to be strong and convincing motivational factors for companies to engage in GCE-based eco-innovation processes and, therefore, deserve attention and to be tested.

Social roles are intrinsically related to social norms in the sense that roles are a product of social norms and social norm can be a product of roles as some norms are intensely *role-specific* (Sunstein, 1996). According to Lopopolo (2001), the role incorporated by individuals in a group is formed by a reoccurring exchange of expectations between societal groups’ members and role incumbents.

In this regard, “the role of any individual member of the work group reflects that person’s perceptions and beliefs as well as those held by the group” (*ibid*: 1318). According to Sunstein (*ibid*) the internalization by people of the social norms about their roles occurs rapidly and violations of the role-specific norms can produce prompt social punishments or rewards.

This research builds upon the concept of professional roles in organizations as defined by Jain and Triandis (1997: 100):

> “The roles concept, holds the ideas about the correct behavior for a specific position that a member of the organization holds”.

In this research, the role beliefs are those associated with managers’ engagement in eco-innovative activities (eco-behavior) in the field of cleaner and more sustainable products, process technologies, materials and energy sources. They reflect his or her perceptions of the correctness of the performance of such behavior by someone occupying his or her position, or function, in the company.
As roles are a product of social norms emerging from the dynamics of the social relationships (Sunstein, 1996), it can be argued that they are vulnerable and are influenced by changes that occur in the societal environment. “In the organizational set, organizational roles are never static because they are modified as those who occupy the roles (role incumbents) adapt to changes occurring within the organization” (Lopopolo, 2001: 1318) and to the environment within which they are inserted.

Because this research was designed to elucidate the motivational factors for the performance of a specific behavior in the short and medium term, it represents a snapshot of the role beliefs of managers in this context and is not intended to expand it to behavioral predictions within long-term future.

Lopopolo (2001) explained the significance of roles as contributors to the behavioral intention formation and actual behavior performance. According to him, it represents the degree to which societal expectations are harmonious with the role incumbent’s perceptions, beliefs and experience.

> “If the role expectations of the work group are perceived as congruent with the person’s perceptions, beliefs, and experience, it will influence and motivate her or his behavior in a manner consistent with the work group’s intent. However, if the role expectations of the work group are perceived to be incongruent, illegitimate, or coercive, the individual may strongly resist meeting the work group’s expectations” (*ibid*: 1318).

Due to the multitude of roles that can be associated with managers’ positions in the company, for the purpose of this research, it seemed to be plausible, to consider as significant the eco-innovative roles that have the potential to develop manager’s intentions to catalyze activities that can contribute to companies’ engagement in eco-innovation activities in cleaner production[88] in manufacturing firms.

Based on the definition of the roles concept, which underscores the importance of the sense of behavior correctness that a member of the organization holds for his or her position, a proposal for managers´ pro-environmental roles beliefs could be made. This proposal had its foundations on the work by Vickers and Cordney-Hayes (1999) on innovation and cleaner

[88] Jackson (1994) defined Cleaner Production as: “An operational approach to the development of the system of production and consumption, which incorporates a preventive approach to environmental protection”.

production, which highlighted the following factors as the main motivational forces behind the adoption of cleaner production:

1) **Regulation:** according to Cordney-Hayes (*ibid*), empirical studies tend to confirm the importance of legislation and regulatory pressure as the main motive force behind the adoption of cleaner technology, especially those involved in environmentally sensitive activities;
2) **Green market expansion**: due to the expansion of the green market in industrial societies many businesses are seeking to use environmental issues as an opportunity for growth;
3) **Quality and technical efficiency considerations:** considerations of cost, efficiency and quality are important stimulants to technical improvement and conservation in the use of materials and energy with their associated environmental benefits; and
4) **The culture and values within organizations:** refers to the great importance that the role of values and culture assume in the potential commitment of people within organizations to social and environmental responsibility. Changes in the organizational culture and values towards greener consciousness may foster the perception of the interconnectedness of economic success and the health of the ecosystem.

It is proposed that managers, who believe that to be supportive to these elements is part of the position or function that he or she occupies in the company, are expected to be more inclined to develop stronger intentions towards the performance of pro-environmental behaviors such as eco-innovating in GCE

Table 5.12 lists the beliefs, referred to in the foregoing paragraphs that may be held by managers in the industrial organization in relation to their professional role regarding the adoption of GCE-based eco-innovation behaviors a means to develop or acquire cleaner products and production processes.

Table 5.12- Normative beliefs used to assess organizations leaders´ perceptions related to their professional role associated with eco-innovation behaviors that are based on the principles of GCE

Acceptance of cleaner production	Regulation Green market expansion Quality and technical efficiency considerations The culture and values within organizations

Source: author

Table 5.13 contains a statement of the questionnaire to assess managers´ perceptions of their professional role associated with the adoption of cleaner products and processes (based on Green Chemistry and Green Engineering).

Table 5.13- The statement used in the questionnaire pertaining to the organizations leaders´ perceived professional environmental role. (The complete questionnaire is in Appendix E)

Being environmentally responsible and being favorable to cleaner and more sustainable products

and processes, such as those that are based on the principles predicated by the Green Chemistry and Green Engineering, are expected from someone that occupies my current professional functions and position at the company.						
-3 strongly disagree	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 strongly agree

Social Factors Behavior Domain 3: Perceived Personal Norm (Moral Obligation)

Personal normative beliefs are related to a person's own expectations about his or her behaviors. They are based on internalized values (Schwartz, 1977) as opposed to social normative beliefs, which are related to other people's expectations about one's behavior. Personal normative beliefs "measure what the person feels he or she should do, and form part of the general normative pressure, which influences their behavior" (Budd and Spencer, 1985: 300). They take account of personal, rather than societal values (Connor and Armitage, 1998).

Although personal normative beliefs are not a constituent part of the TPB structure, it is important to note that they were taken into account in Fishbein's original model of the attitude-behavior relationship. They were dropped from the model in subsequent revisions that shaped the development of the TPB's predecessor: the "Theory of Reasoned Action". According to Ajzen and Fishbein (1970), personal norms were dropped because they correlated highly with intentions and were considered to be an alternative measure of a subject's behavioral intention.

Many authors refuted this view and researchers such as Budd and Spencer (1985), Conner and Armitage (1998) and Harland *et al*. (1999) documented that personal norms improved the behavioral predictive power for behaviors where personal normative beliefs are relevant. Although the conceptualization of personal norms relates to a person's own values involved with a certain behavior, which may encompass moral and other values, they appeared to be closely related to the concept of individual self-identity (cf. next section) as proposed by Cialdini *et al.* (1991).

> "The link between personal norm and self-identity is clear, but personal norm differs in that it takes account of personal, rather than societal values". (Conner and Armitage, 1998: 1443)

In this research, the concept of personal norms followed Schwartz (1977), whereby personal norms, when activated, reflect commitment with internalized values and are experienced as feelings of personal (moral) obligation to engage in a certain behavior.

The reason for this choice was grounded on this thesis researcher's interest in: (a) testing the extent to which personal norms can influence and explain managers' behavior associated with the support to pro-environmental actions within their companies' domains, and (b) examining the degree of stimulus that personal norms provide to foster the introduction of GCE-based innovation activities.

In order to study the influence of the personal normative beliefs in the realm of this research, two points should be observed. The first regards that personal norms have been found to be relevant in explaining a wide variety of behaviors (i.e. Budd and Spencer, 1985; Conner and Armitage, 1998; Harland *et al*, 1999). Therefore, "the crucial question, then, was whether personal norms also play a role in the domain of environmentally relevant behavior, where possible beneficial consequences of one's behavior for others are less obvious" (Harland *et al.*, 1999: 2508).

The second relates to the degree of confidence one has that personal norms do not overlap with some constructs of the TPB as indicated by previous studies such as those conducted by Budd & Spencer (1985); Raats *et. al* (1995) and Harland *et al*. (1999).

In general, the explanation for the compliance with these two points can be found, among others, in the work by Stern (2000) and Harland *et al.* (1999). These studies provided a solid basis for justifying the study of the influences of personal norms on this research's domain and objectives.

Many authors embraced the research line focused on establishing the influence of personal norms on environmentally relevant behavior (e.g., Black *et al.*, 1985; Heberlein and Black, 1981; Hopper & Nielsen, 1991; Vining & Ebreo, 1992). In this respect, Stern (*ibid*) developed an interesting approach. He related his work to Heberlein (1972) and Schwartz (1977) to demonstrate that altruistic personal (moral) norms can explain environmentalism.

According to Heberlein (*ibid*), because the environmental quality is a public good, in the domain of the personal (moral) norms, it requires altruistic environmental behavior for an individual to engage in pro-environmental actions. On his side, Schwartz (*ibid:* 227), in his moral norm-activation theory of altruism, postulated that:

> "altruistic behavior is influenced by the intensity of moral (personal) obligation that an individual feels to take specific helping actions (…) feelings of moral obligation are generated in particular situations by the activation of the individual's cognitive structure of norms and values".

In relation to the moral norm-activation theory, Stern (2000: 412) argued that:

> "The theory holds that altruistic (including pro-environmental) behavior occurs in response to personal moral norms that are activated in individuals who believe that particular conditions pose threats to others (awareness of adverse consequences, or AC) and that actions they could initiate could avert those consequences (ascription of responsibility to self, or AR)".

Additionally, by citing a number of authors, he stated that "substantial evidence supporting the theory's applicability to a range of environmental issues has accumulated over two decades" (*ibid*: 412)

Based on these and other considerations, Stern and colleagues developed the "Value-Belief-Norm" (VBN) theory of environmentalism (Stern *et al.*, 1999) that offered explanatory account of a variety of behavioral indicators of non-activist environmentalism in which personal values (especially altruistic values) and personal norms for pro-environmental action play a significant role (Stern, 2000).

Harland *et al* (1999) provided a demonstration of the applicability of personal norms to explain pro-environmental behavior. Differently from Stern (2000), they tested the explanation power of the personal (moral) norms *via* the use of the TPB. Both issues are important to this research. In their study, the influence of personal normative considerations on behavioral intentions, in the domain of environmentally relevant behavior, was captured *via* the use of Schwartz's (1977) personal-norm construct as an extension to the TPB. They concluded that:

> "The results of this study suggest that, in this domain, personal norms are of importance. It appears that, while the usual constructs of the TPB explained five specific behavioral intentions to a considerable extent, personal norms improved their explanation significantly (…). Additionally, our results imply that decisions to behave pro-environmentally are based partly on moral considerations (…). This suggests that what we found may be a fairly general relation between personal norms and environmentally relevant behavior." (*ibid*: 2522)

The foregoing theoretical grounds inspired and provided the author of this thesis with confidence to justify the inclusion of personal norms in this research. Personal norms were proposed as determinants of managers' behavioral intention (willingness) to engage in eco-innovation activities based on the principles of Green Chemistry and Green Engineering.

Such interest was focused on managers´ perceived personal moral obligations related to key fundamentals and activities within the organization that can promote pro-environmental changes by:

a) Providing support and defense of pro-environmental technological changes at the upper management level decision-making processes;
b) Influencing people and disseminating pro-environmental culture, and
c) Taking active and objective actions to identify new (short and long-term) alternatives and innovative solutions for the firm's environmental and economic sustainability challenges.

These beliefs are depicted in Table 5.14. They represent a set of beliefs that may contribute to the perception of managers with regard to his or her moral obligation relative to the environment. They may be influential factors with regard their engagement in GCE-based eco-innovation activities as a means to search for solutions for their companies´ environmental sustainability challenges.

Managers whose personal moral norms regarding the environmental preservation are activated are more likely to engage in pro-environmental behaviors.

Table 5.14 lists the beliefs, referred to in the foregoing paragraphs that may be held by leaders in the industrial organization in relation to their moral (personal) obligations towards the environment.

Table 5.14- Personal normative beliefs used to assess organizations leaders´ perceptions related to their moral obligations associated with eco-innovation behaviors that are based on the principles of GCE

Personal (moral) norms	Influence on managers´ key activities	Decision-making processes Influencing people and disseminating pro-environmental culture Active and objective actions to to identify new alternative and innovative environmental solutions

Source: author

Table 5.15 contains a statement of the questionnaire item related to organization's´ leaders´ moral personal norms related to their obligations towards the environment.

Table 5.15- The statement used in the questionnaire pertaining to the organization´s leaders´ perceived moral personal norms towards the environment. (The complete questionnaire is in Appendix E)

The degree of moral obligation that I feel in relation to my active engagement in influencing individuals, in all hierarchical levels of my company, favoring pro-environmental behaviors and innovative and more sustainable technologies is:						
-3 not responsible	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 very responsible

Social Factors Behavior Domain 4: Perceived Self-Identity

Despite the broad and intensive worldwide use of the TPB as a reliable theory to predict and explain different behaviors in a wide variety of contexts, there are criticisms directed to the theory's normative component as being the weakest predictor of behavioral intentions (Ajzen, 1991, Armitage and Conner, 1999; Conner and Armitage, 1998, Terry and Hogg, 1996). As a consequence, it has been the object of many researcher's investigations designed to supplement it with new elements that could increase its predictive and explanatory power.

As illustrative of the search for alternatives to overcome the TPB's social construct shortcomings, researchers have integrated the construct "self-identity". It has been found to be valuable and distinctive predictor of intentions (Armitage and Conner, 1999, Jain and Triandis, 1997; Terry *et al*., 1999, Triandis, 1977).

The concept of "self-identity" can be defined "as the salient part of an actor's self[89] which relates to a particular behavior. "It reflects the extent to which an actor sees him or herself as fulfilling the criteria for any societal role". (Conner and Armitage, 1998: 1444)

[89] Self: the personality or character that makes a person different from other people: the combination of emotions, thoughts, feelings, etc., that make a person different from others. Source: Merriam-**Webster** Online **Dictionary** and Thesaurus (http://www.merriam-webster.com/dictionary/self), accessed in June 2012.

Identifiable social roles are, in turn, known to drive intentions (Armitage and Conner, *ibid;* Jain and Triandis, 1997; Triandis, 1977). Self-identity is influenced both by personal motivations (for self-esteem, self-enhancement, and self-understanding) as well as by social interactions (Whitmarsh and O'Neill, 2010). "Self-identity serves both to differentiate oneself from others and to conform to the values, beliefs and behaviors of the social groups to which one belongs (Whitmarsh and O'Neill, *ibid*: 2).

It is important to underscore that, in the context of this research, the use of social-identity as a social pre-conditional, motivational factor underpinning the behavior intention, was inspired by the Triandis´(1977) "Theory of Interpersonal Behavior" (cf. Section 3.2.1).

In the domain of environmentally significant behavior, Fielding *et al*. (2008), Fekadu and Kraft (2001), Sparks and Shepherd (1992), Sparks *et al.* (1995), Terry *et al.* (1999) and Whitmarsh and O'Neill (2010) corroborated the findings of these aforementioned studies and reinforced the existing evidence of the importance of self-identity as a significant determinant in predicting environmentally-significant behavior.

According to Terry *et al.* (1999), the link between self-identity and behavioral intentions is predicated on the basis of Identity Theory (IT). The theory conceives of the self not as a distinct psychological entity, but as a social construct.

"Identity theory, thus, provides a clear justification for the inclusion of self-identity as a predictor of intention, given that, in both the theories of reasoned action and planned behavior, intention is regarded as the most proximal predictor of behavior (Terry *et al.,* 1999: 227).

The ID explained social behavior in terms of the reciprocal relations between self and society (Hogg *et al*., 1995).

> "(…) identity theory, (…) views the self not as an autonomous psychological entity but as a multifaceted social construct that emerges from people's roles in society; variation in self-concepts is due to the different roles that people occupy" (Hogg *et al*., 1995: 256).

For every societal role an individual occupies, he or she attributes and associates specific meaning to the self (Burke and Tully, 1977). The distinct components of the self, as proposed by Stryker, are called role identity and are associated with the roles one occupies in society. (Hogg *et al*., 1995).

> "Role identities are self-conceptions, self- referent cognitions, or self-definitions that people apply to themselves as a consequence of the structural role positions they occupy, and through a process of labeling or self-definition as a member of a particular social category" (Hogg *et al*., 1995).

A central facet in the relation between role identity and behavioral outcomes is the concept of identity salience. The meaning of identity salience, stems from the principle that for any individual, some identities have more self-relevance than others and are hierarchically organized in the self-concept.

The higher ranked ones in the salience hierarchy are more likely to be invoked in a specific situation, are more self-defining and are more preponderant in the determination of a specific behavior. "Identity salience is conceptualized (and operationalized) as the likelihood that the identity will be invoked in diverse situations" (Hogg *et al*., 1995: 257)

In this regard, López-Gamero *et al.* (*ibid*: 964), citing Drumwright (1994) and Fineman (1997), stated that:

> "Research has shown that management commitment to environmental causes is a powerful internal political force that reflects that managers' ideals, values, and even lifestyle are bound to have a direct effect on their degree of commitment to the environment, which will eventually determine the development of environmental orientation and strategies."

For the purposes of this research, the self-identities of managers, in the Brazilian petrochemical sector, which may contribute to eco-innovation behaviors, were assessed regarding their social role identities associated with the following characteristics: (1) manager's identification with environmental sustainability issues and (2) managers who are innovative are seen as responsible and competent.

Managers that see themselves as environmentally responsible, innovative and competent are likely to to be more prone to engage in eco-innovative activities.
Table 5.16 lists the beliefs, referred to in the foregoing paragraphs that may be held by managers in the industrial organization in relation to their self-identity associated with the environment and innovation.

Table 5.16- Self-identity beliefs used to assess organizations leaders´ perceptions related to their positive identification with environmental causes and with eco-innovative behaviors

Self-identity roles associated with managers role beliefs	Self identification with environmental sustainability issues Self identification with innovativeness and competency

Source: author

Table 5.17 contains a statement of the questionnaire item related to organizations leaders´ self-identity perceptions associated with the environmental causes and with innovative behaviors.

Table 5.17- The statement used in the questionnaire pertaining to the organizations leaders´ perceived self-identity towards the environment and innovation. (The complete questionnaire is in Appendix E)

I identify myself with and I believe in the importance of the environmental preservation of our planet. Therefore, I am favorable that innovative and more environmentally sustainable solutions, such as those that are based on the Green Chemistry and Green Engineering, should be sought in the industrial domain.						
-3 strongly disagree	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 strongly agree

The Perceived Behavioral Control Construct as a Determinant of Innovation in Green Chemistry and Green Engineering

As noted in Section 3.2.1, the TPB gravitates around the theoretical concept that the individual's intention to perform a behavior is the immediate antecedent of the actual behavior performance. Intentions are assumed to capture the motivational factors that influence the performance of behavior.

Section 3.2.1 stated that control beliefs are, according the TPB, among the beliefs that ultimately induce an individual to develop behavioral intention and action.

The concept of behavioral control (control beliefs) relates to the extent to which the performance a given behavior is dictated by individuals' perceptions of the availability of opportunities and resources.

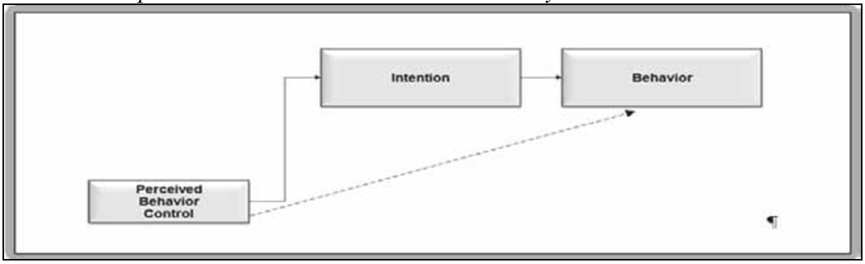
> "(…) perceived behavioral control (…) refers to the perceived ease or difficulty of performing the behavior and it is assumed to reflect past experience as well as anticipated impediments and obstacles" (Ajzen, *ibid*: 188)

In the case that these opportunities and resources are held by individuals or organizations, it is argued that the behavior in question is under volitional control (i.e. there is actually control over the performance of a behavior).

The more resources and opportunities an individual perceives that he or she possesses and the fewer obstacles and impediments are anticipated, the greater should be their perceived control over their behavior (Ajzen and Madden, 1986)

The hierarchical relations that the perceived behavioral control construct assumes with behavioral intention and behavioral performance, within the structure of the TPB, are presented in Figure 5.5. Their theoretical foundations are originated in the notion that behavioral intentions can be effective as a behavior precursor only if the behavior in question is under volitional control (Ajzen, 1991). This is reflected in the TPB´s postulation that the perceived behavioral control can be used to influence the performance of a behavior in direct fashion or indirectly by helping to develop behavioral intention (*ibid*).

Figure 5.5- The Hierarchical relations between behavioral achievement and behavioral intentions and the perceived behavioral control as stated by the TPB



Source: author. Based on Ajzen (1991)

According to Ajzen (1991: 184) at least two rationales support this argument:

- “First, holding intention constant, the effort expended to bring a course of behavior to a successful conclusion is likely to increase with perceived behavioral control, and
- The second reason for expecting a direct link between perceived behavioral control and behavioral achievement is that perceived behavioral control can often be used as a substitute for a measure of actual control.”

The concept of *perceived* behavioral control (PCB) is centrally relevant and significant for the TPB. In fact, Ajzen (*ibid*) concluded that the perception of behavior control and its impacts on intentions and actions are of greater psychological interest than actual control (*ibid*).

In this thesis research, the perceived behavioral control is interpreted as the managers´ perception of how easy or difficult it is to engage in GCE-based eco-innovation processes. Such perception is contingent on managers´ degree of control over the opportunities and resources that are needed to engage in such behavior.

The theoretical universe associated with eco-innovation indicates that these resources have a multidimensional character and are associated with a large number of dissimilar variables. They can become confusing and unmanageable if not properly selected and organized. This underscored the need for a specific and testable framework that could help this researcher to organize and guide this study.

The Integration of the "Sectoral System of Innovation" Framework into the TPB´s Perceived Behavior Control Construct

As the focus of this thesis research was directed to companies in the Brazilian petrochemical sector, it became necessary to adopt a plausible framework that was able to represent the resources and opportunities for companies to engage in eco-innovation activities.

The proposed framework should also provide the theoretical grounds under which manager's and decision-makers´ perceived control over these resources and opportunities could be identified and measured. This was a necessary condition for helping the researcher to express and explain the strength of managers´ willingness (behavioral intention) to engage in eco-innovation processes.
For this purpose, the "Sectoral Systems of Innovation" (SSI) framework, proposed by Franco Malerba (2002, 2004, 2005a and 2005b) (cf. Section 3.1.2), was considered adequate for this thesis research and it was, consequently, integrated into the TPB´s perceived behavioral control construct. This choice was based on the fact that the SSI framework provided a multidimensional and integrated approach for innovation in sectors.

The SSI framework is based, theoretically and analytically, on evolutionary theory. It emphasizes cognitive aspects such as beliefs and expectations, which are in turn affected by the learning processes, experiences and by the environment in which the agents act (Malerba, 2005b).

According to the SSI, although a sector is composed by heterogeneous agents (organizations or individuals), "firms are the key actors in a sectoral system. They are involved in the innovation, production and sale of sectoral products, and in the generation, adoption and use of new technologies" (Malerba, 2002: 255). This coincides with the structure of this study, in which firms are the central elements in the analysis.

In order to provide a better understanding of how this integration was conducted, it is helpful to briefly go back to some important theoretical aspects of the role of *beliefs* and *behavioral domains* in the TPB (for an overview, refer to Section 3.2.1).

The first point to consider is the fact that at its most basic level of explanation, the TPB postulates that behavior is a function of the beliefs or information relevant to the behavior (Montalvo Corral, 2002). Beliefs are formed when we associate a connotative meaning to the characteristics, qualities and attributes associated with an object or with a behavior. This generates an attitude towards this object or behavior within us (Ajzen, 1991) at the same time that "we associate our skills, resources, time etc., with the control over our own and/or the others´ behavior" (Montalvo Corral, *ibid*: 38).

The generation of these beliefs is then of uppermost importance in determining behavioral intention (willingness) and in performing the behavior under study. Montalvo Corral (*ibid*) further argued that the first step in the identification of beliefs is the definition and mapping of the behavioral domains that underlie the TPB constructs. According to Ajzen (1988, Ch.1), "behavioral domains are defined as specific areas of experience and knowledge from which the salient beliefs arise".

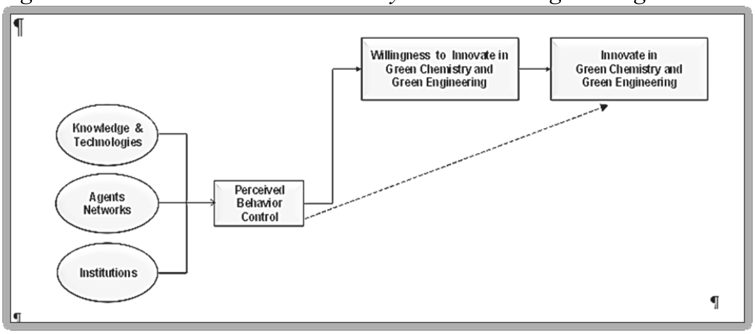
For this thesis research, the basic characteristics of sectors were considered when mapping the behavioral domains that may be justifiably associated with the control beliefs in innovation processes in sectors. The control beliefs associated with these behavioral domains were elicited from relevant literature.

In this regard, three dimensions compose the SSI framework. They are the building blocks of the SSI and constituted the behavior domains associated with the perceived behavioral construct of the behavioral model of this thesis research:

a) knowledge and technological domain;
b) Actors and networks, and
c) Institutions.

Figure 5.6 depicts the structure of the perceived behavioral control construct of this thesis research´s behavioral model.

Figure 5.6- Perceived behavior control behavioral domains that may predict and explain firm´s willingness to innovate in Green Chemistry and Green Engineering



Source: author

The model´s structure and its relationships, guided the construction of the questionnaire entry for the perceived behavioral control. Table *5.18* presents the sample questionnaire statement for the direct measure of managers´ perceived behavioral control in the Brazilian petrochemical sector.

Table 5.18- The statement used, as a direct measure, in the questionnaire pertaining to the perceived control over innovating in Green Chemistry and Green Engineering. (The complete questionnaire is in Appendix E)

For our company, the engagement in eco-innovation activities based on Green Chemistry and Green Engineering is:						
-3 very difficult	-2 significantly	-1 slightly	0 uncertain	1 slightly	2 significantly	3 very easy

Building upon the foregoing emphases, the following sections explore each of the behavior domains by discussing the beliefs associated and exploring how they contribute to assess managers´ perceived behavioral control within the scope of this thesis research.

Perceived Behavioral Control Behavior Domain 1: Knowledge and Technological Domain

As has been strongly emphasized within the evolutionary literature, knowledge is at the base of technological changes and plays a central role in innovation and production processes (Malerba, 2002, 2004, 2005a, 2005b). Knowledge and technologies in different sectors vary dramatically. Consequently, "knowledge becomes highly idiosyncratic at the firm level, does not diffuse automatically and freely among firms and it has to be absorbed by firms through their differential abilities accumulated over time" (Malerba, 2002: 251).

From the SSI framework, another important concept concerning knowledge emerge that help to explain differences in innovative activities in sectors. In sectors, knowledge differs in terms of domains. One knowledge domain refers to specific and technological fields that underpin the innovative activities in sectors. The other one relates to the applications, users and demands for sectoral products (Malerba, 2002, 2004).

Besides acknowledging these characteristics of knowledge and technologies in innovation processes in sectors, one question emerges. It regards the requisites for knowledge and technology to be developed and incorporated by firms in a given sector or by a sector itself.

Once these requisites are identified, two questions remain. The first is related to the degree of control companies' leaders perceive to have over these requirements (perceived behavior control). The second is associated to the existence of opportunities for innovation processes to be implemented so that company managers feel confident and willing to invest and engage in innovative activities.

For this behavior domain and from the SSI framework (Malerba, 2002, 2004, 2005b) four groups of beliefs related to the key dimensions of knowledge and technologies were identified: (a) accessibility to knowledge, (b) technological opportunities, (c) appropriability and (d) cumulativeness.

Accessibility to Knowledge

In innovation processes, knowledge occupies a central place and represents a powerful pre-condition for successful innovation achievements.

At the firm level, the construction of a solid knowledge base is a pre-requisite for its sustainability and for innovation. Firms need new knowledge, and their perception and belief that they have access to it represents a factor that can contribute to their deliberate engagement in eco-innovation activities.

Knowledge may have different degrees of accessibility (Malerba and Orsenigo, 2000). The idea of degrees of accessibility is related to the extent to which companies have access to knowledge from sources internal and external to their corporate environment. The combination of factors related to the easiness or difficulty of knowledge availability, together with the *locus* of their existence may influence the intention (willingness) of firms to engage in eco-innovation processes. From this, two aspects of control over this belief emerge:

1) **Internal to the sector-** knowledge that is easily accessible within the sector implies lower appropriability. Competitors may gain knowledge about new products and processes and, if they are competent, they may imitate them (Malerba, 2002, 2004, 2005b). In addition to having access to knowledge, firm's leaders should also take into account if the available knowledge can help them to make progress towards environmental sustainability and increase the business competitiveness of their firms. Considerations related appropriability are made further ahead.
2) **External to the sector-** according to Malerba (2005b: 388), "accessibility of knowledge which is external to the industry may be related to scientific and technological opportunities, in terms of level and sources. The external environment may affect firms through human capital with a certain level and type of knowledge or through scientific and technological knowledge developed in firms or non-firms organizations such as universities or research laboratories."

Table 5.19 lists the beliefs, referred to in the foregoing paragraphs that may be held by leaders in the industrial organization in relation to their companies´ control over the access to knowledge that can help them to engage in eco-innovation activities in Green Chemistry and Green Engineering.

Table 5.19- Behavior control beliefs used to assess organizations leaders´ perceptions related to the accessibility to knowledge

Accessibility to knowledge	Internal to the sector External to the sector

Source: author

Table 5.20 presents the statement from the questionnaire related to managers´ perceptions related to the control over the accessibility to knowledge.

Table 5.20- The statement used in the questionnaire pertaining to the organizations leaders´ perceived control over the accessibility to knowledge. (The complete questionnaire is in Appendix E)

Currently, the degree of access that your company has to new knowledge that is associated with Green Chemistry and Green Engineering via purchase processes, cooperation agreements and other means of knowledge acquisition, within the petrochemical sector is:						
-3 very low	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 very high

Technological Opportunities

Technological opportunities comprise the set of possibilities for technological advance and differ strongly among sectors (Malerba, 2005b). According to Klevorick *et al*. (1995), one relevant and substantial characteristic of industries that are reputed to be rich in technological opportunities is that high R&D intensities and high rates of technical advances tend to be sustained over time. In addition, they stressed that a key feature distinguishing industries with high rates of technological opportunities from those where these opportunities are limited resides on the fact that in the former those opportunities are augmented, or renewed, at a higher rate. Opportunities reflect the easiness of innovating for any given amount of resources invested in research (Malerba and Orsenigo, 1993).

It is important restate the fact that all these aspects related to the SSI are fully dynamic and interdependent. They are treated within this thesis as pre-conditional factors that may influence the establishment of these dynamic processes. Again, the interest in this specific topic resides upon the assessment of the managers´ perception of the availability of technological opportunities so they feel willing and have the intention to innovate.
The higher the existence of technological opportunities, the more the companies are expected to invest in innovative solutions to their environmental and competiveness problems. Following Klevorick *et al*., (1995) three control beliefs are distinguished as different sources of new contributions to an industry's pool of technological opportunities:

1) **Advances in scientific understanding and technique**: "the most powerful and, over the long run, almost certainly the most important source of new technological opportunities has been the advance of scientific knowledge" (Klevorick *et al*., 1995: 189). Science plays two different roles in shaping technological opportunities: one as a stock of knowledge and the other as a flow of often directly relevant knowledge. Additionally, it expands the opportunities for technological advances and establishes the basis for other factors that offset diminishing returns to technological opportunities (*ibid*). Science is employed as a set of tools and a stock of knowledge in the problem-solving processes by most scientists and engineers engaged in industrial R&D (Gibbons and Johnston, 1974).

   It is expected that the higher the access to scientific developments that induces and underpins the development of eco-innovative technologies, the greater the interest on the part of firms in investing in the development and/or acquisition of innovative solutions for their environmental and competiveness challenges.

2) **Technological advances originating in other industries and in other private and governmental organizations**: this group of technological opportunities is underpinned by the dynamic interconnectedness and interdependency of industry to the business environment they ate inserted in. Technological opportunities in one industry can be enriched by technological advances that are achieved in others. Technological opportunities may emerge from the supply and demand sides of the production chain. Other external sources, outside the vertical chain of production, also contribute to the technological opportunities in some industries. These may comprise government laboratories, universities, professional and technical societies, and independent inventors. "The contributions that external sources make to technical advances in an industry almost surely increase the industry's technological progress" (Klevorick *et al.*, 1995: 191). If external sources of knowledge are easily accessible and transformed into new greener and more competitive manufacturing processes and new artifacts readily to be offered to a variety of actors (e.g., customers and suppliers) innovative entry may take place (Malerba, 2005b).

   It is expected that the more opportunities a company has to access new technologies, generated by external agents, the more powerful are the incentives to undertake innovative activities either by acquiring or developing technologies.

3) **Feedbacks from an industry's own technological advances-** technological opportunities with this characteristic evolve and are supported by feedback mechanisms. In these processes, new knowledge and technological advances generated by a firm or an industry in a certain point in time are starting points for future new technological opportunities. It represents reinforcing learning process in which the knowledge and technology developed by firms are augmented via feedback on their products and processes from users along the production and consumption chains.

   It is expected that the more feedback information firms have on new knowledge and technological developments related to the technologies and products they generate and/or use, the greater the innovation possibilities are and the more willing to innovate companies are expected to be.

Table 5.21 lists the beliefs, referred to in the foregoing paragraphs that may be held by leaders in the industrial organization in relation to their companies´ control over technological opportunities that can help and influence them to engage in eco-innovation activities in Green Chemistry and Green Engineering.

Table 5.21- Behavior control beliefs used to assess organizations leaders´ perceptions related to technological opportunities

Technological opportunities	Advances in scientific understanding and technique Technological advances from other industries and other private and governmental organizations Feedbacks from an industry's own technological advances

Source: author

Table 5.22 presents the question from the questionnaire related to perceptions about the control over the technological opportunities

Table 5.22- The question) used in the questionnaire pertaining to the organizations leaders´ perceived control over technological opportunities. (The complete questionnaire is in Appendix E)

To what degree the diverse product and process technologies, currently available in other sectors and organizations external to the petrochemical sector, can contribute and facilitate the engagement of your company in eco-innovation activities that are based on Green Chemistry and Green Engineering?						
-3 very low	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 very high

Appropriability

In the innovation domain, appropriability represents the possibility of protecting innovation from imitation and consequently absorbing the benefits and returns of innovation activities. High appropriability means the existence of ways to protect successfully innovation from imitation (Malerba, 2002). The appropriability of the profits generated by innovative activities may constitute a strong motivational factor for firms to engage in innovation processes. Additionally, it permeates, influences and it is a capital factor in decision-making processes related to innovation activities. High cumulativeness of knowledge, intensity in an industry's R&D and technological opportunities are not independent of appropriability conditions and differ markedly across industries (Klevorick *et al*., 1995).

In innovation processes, appropriability is part of a complex dynamics among a variety of variables. Its degree varies according the relationships and interactions of these elements and contextual factors (cf. Levin, 1988, Saviotti, 1998). For the purposes of this research, a thorough study of the appropriability, its dynamics, its relationships and interactions in innovations systems are beyond the objectives. The interest in this thesis was concentrated on the perception of mangers, in the Brazilian petrochemical sector, of the appropriability conditions of knowledge and technologies that may or may not be an incentive condition for them, and their companies, to engage in innovation activities. Following Malerba and Orsenigo (1997), it is possible to identify two elements of appropriability conditions based on which managers perceived control beliefs can be assessed:

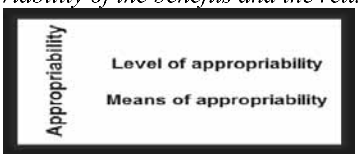
1) **Level of appropriability**- "high appropriability means the existence of ways to successfully protect innovation from imitation. Low appropriability conditions denote an economic environment characterized by widespread knowledge externalities (spillovers)" (Malerba and Orsenigo, 1997: 95).

   In terms of knowledge and technology appropriability conditions, companies may face the following the dilemma:
   a) to invest in efforts to acquire knowledge and technologies that are of low cost but of general and easy accessibility and therefore, are of low appropriability, and
   b) to invest in efforts to develop or acquire knowledge and technologies that are of highest cost but pose more conditions to its accessibility and therefore, are of higher appropriability
2) **Means of appropriability**- comprise a number of means to protect innovation by approaches such as patents, secrecy etc. "The effectiveness of these means of appropriability largely differs from industry to industry, thus affecting the level as well as the nature of knowledge externalities" (Malerba and Orsenigo, 1997: 95). Appropriability conditions must be present either to protect companies from imitation by the market and to prevent spillovers.

   It is expected that managers who perceive that the existing means of appropriability can provide him or her with the acceptable degree of protection against imitation and allow their companies to reap the profits from their investments in innovation, are expected to feel more prone (willing) to engage in innovation activities.

Table 5.23 lists the beliefs, referred to in the foregoing paragraphs that may be held by leaders in the industrial organization in relation to the control over the means of protecting their innovation from imitation. Such protection is expected to generate the adequate level of appropriability of the benefits and returns generated by innovation and to stimulate them to engage in GCE-based eco-innovation activities.

Table 5.23- Behavior control beliefs used to assess organizations leaders′ perceptions related to the control over the appropriability of the benefits and the returns generated by innovation



Source: author

Table 5.24 presents the question from the questionnaire related to perceptions about the control over the appropriability of the benefits and the returns generated by innovation

Table 5.24- The question used in the questionnaire pertaining to the organizations leaders′ perceived control over the appropriability of the benefits and the returns generated by innovation. (The complete questionnaire is in Appendix E)

According to your perception, the degree of availability of means outside your company domain, at the national and international levels, that can ensure the appropriability (confidentiality and benefits) of knowledge and technologies and prevent imitation is:						
-3	-2	-1	0	1	2	3
very low	quite	slightly	uncertain	slightly	quite	very high

Cumulativeness

Cumulativeness represents one of the key dimensions of knowledge in the sense that current knowledge is the base to the development of new knowledge. Cumulativeness conditions in innovation processes reflect the characteristic of innovation processes in which new innovation can be developed upon current innovations and innovative activities (Malerba and Orsenigo, 1997). Such processes are underpinned by evolutionary improvements that have self-reinforcing effect and contribute for companies to innovate in specific technological trajectories. This evidence is one of the factors why “today’s innovative firms are more likely to innovate in the future in specific technologies and along specific trajectories than non-innovative firms” (*ibid*: 95).

In the context of this thesis research, it is proposed that managers who perceive that his or her company controls (e.g. *via* their own resources, strategic alliances, technologies acquisition etc.) the processes that underpin knowledge cumulativeness are expected to feel more confident and willing to engage in eco-innovation processes.

Technological accumulation can be defined as the accumulation of “skills, knowledge and institutions that make up a country's capacity to generate and manage change in the industrial technology it uses (i.e. its technological capabilities)” (Bell and Pavitt, 1993: 159),

Technological cumulativeness and learning mechanisms, at the company level, is largely related to the technological capability building mechanisms required to promote technological change. The technological accumulation (learning) precedes technological capabilities, technological change, and the overall industrial capability (Díaz Lopez, 2003).

Technological accumulation relates to variables pertaining domains of the scientific and tacit knowledge, inter-firms relationships, discontinuities in the technical change, types of learning etc. (Díaz López, 2003). The same view was shared by Figueiredo (2002). He stated that companies that wish to advance towards technological frontiers have to engage in processes of technological learning in order to acquire the required knowledge to build up and accumulate their own technological capabilities.

According to Malerba and Orsenigo (1993) the following sources of technological accumulation can be identified. For the purposes of this thesis research, they were considered as cumulativeness control beliefs: (a) learning processes, (b) technological capabilities, and (c) organizational capabilities.

Learning Processes

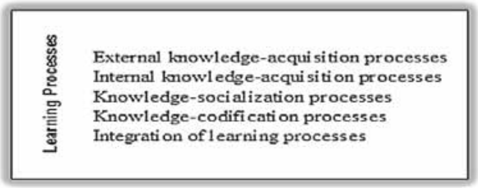
The cognitive nature of learning processes and past knowledge constrain current research, but also generate new questions and new knowledge (Malerba and Orsenigo, 1997). The importance of technological cumulativeness in the creation of new knowledge, was reinforced by Nonaka (1994). He stated that the continuous construction of new knowledge in organizations is done by reconstructing existing perspectives, frameworks, or premises on a day-to-day basis. Citing various authors, Díaz López (2003) stated that technological learning can be defined as the process by which firms create knowledge and technological capabilities.

For the purposes of this thesis research, technological learning processes were addressed as "the various processes by which knowledge is acquired by individuals and converted into the organizational level. In other words, the processes by which individual learning is converted into organizational learning" (Figueiredo, 2002: 686). Based on the work of Nonaka and Takeuchi (1995), Figueiredo (*ibid*) proposed that technological learning comprises the following modes of knowledge acquisition and knowledge conversion (cf. Figueiredo, 2002 for a complete view):

a) **External knowledge-acquisition processes:** it is the mode of knowledge acquisition by which individuals acquire tacit and/or codified knowledge from outside the company via, *inter alia*, pulling in expertise from outside, drawing on technical assistance, overseas training, systematic channeling of external codified knowledge, inviting experts for talks etc.;
b) **Internal knowledge-acquisition processes:** refer to learning processes by which the process of knowledge acquisition is carried out at the individual level by performing different activities inside the company (routine activities in various areas within the organization that may range from operations through research);
c) **Knowledge-socialization processes:** refer to learning processes by which individuals share their tacit knowledge (mental models and technical skills). It represents the knowledge transmission processes (formal and informal) by which tacit knowledge is transmitted from one individual or a group of individuals to another;
d) **Knowledge-codification processes:** refer to learning processes by which the tacit knowledge residing at the individual level is articulated in explicit concepts in organized and accessible formats, and
e) **Integration of the different modes of knowledge conversion**: in addition to the foregoing learning processes proposed by Figueiredo (*ibid*), Nonaka (1994) stressed that the dynamic interaction between the different modes of knowledge creation and conversion is a central theme in his model of organizational knowledge. "That is to say, knowledge creation centers on the building of both tacit and explicit knowledge and, more importantly, on the interchange between these two aspects of knowledge through internalization and externalization (…) A failure to build a dialogue between tacit and explicit knowledge can cause problems." (Nonaka, 1994: 20).

Table 5.25 lists the beliefs, referred to in the foregoing paragraphs that may be held by leaders in the industrial organization in relation to their companies´ control over learning processes, which can help them to engage in eco-innovation activities in Green Chemistry and Green Engineering

Table 5.25- Behavioral control beliefs used to assess organizations leader's perceptions related to the control over the learning processes that can help companies to engage in eco-innovation processes



Source: author

Table 5.26 presents the question from the questionnaire related to perceptions about the control over the learning processes.

Table 5.26- The question used in the questionnaire pertaining to the organizations leaders' perceived control over the learning processes. (The complete questionnaire is in Appendix E)

The learning mechanisms that your company currently holds that can promote the integration of the learning processes and knowledge acquisition (knowledge internalization and externalization) at personal and collective levels are:						
-3 very unsatisfactory	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 very satisfactory

Organizational Sources of Innovation Capabilities

According to Malerba and Orsenigo (1997: 95), in addition to learning processes, the other sources of knowledge cumulativeness reside in the organizational domain and refer to firm-specific technological and organizational capabilities, which "can improve only gradually over time and thus define what a firm can do now and what it can hope to achieve in the future" (*ibid*: 95).

Technological Capabilities

In the environmental domain, technological capability "is the ability to mobilize and apply knowledge related to diminishing the ecological impact of existing production and consumption processes, and the development of more sustainable products and services" (Baas and Huisingh, 2008: 411).

The development of technological capabilities, in the firms´ domain, can be understood, in a broad sense, by the learning and technological accumulation mechanisms within an organization (Díaz López, 2003). Technological change can be seen as determined partly by external inputs and partly by past accumulation of skills and knowledge" (Lall, 1992). Technological knowledge is strongly company-specific and it is not easily transferred from firm to firm (Lall, *ibid*; Malerba, 2005b).

As firms usually do not master technologies other than those that are related to their own products and processes technologies, technological knowledge acquisition and gaining mastership on new technologies requires skills, efforts and investment on the part of the receiving firm (Lall, *ibid*). This implies mandatory processes of learning due to the tacit character of technologies whose underlying principles are not always clearly understood (Lall, *ibid*). These processes are performed progressively in time and knowledge cumulativeness can convey companies to the development of technological capabilities (Díaz López, 2003).

Technological capabilities are related to the company's core and dynamic competences. Díaz López (*ibid*), quoting Prahalad and Hamel (1990) and Leonard-Barton (1992), argued that core competences comprise a set of differentiated skills, complementary assets and organizational routines specific to the firm, which allows for the creation of a technology based competitive advantage and determine the ability to survive and adapt to business environments of changing markets and contexts. Dynamic capabilities refer to:

> "(…) the firm's ability to integrate, to build, and to reconfigure internal and external competences to address rapidly changing environments. Dynamic capabilities thus reflect an organization's ability to achieve new and innovative forms of competitive advantage given path dependencies and market positions". (Teece *et al*., 1997: 516 *apud* Leonard-Barton, 1992))

In the studies of technological capabilities in the industrial domain, it is advisable to make the proper distinction between the technological capabilities related to the routine production and the innovation technological capabilities. The former refer to the technological capabilities required to use and operate the existing technologies and the latter are associated to the ones required to generate and to manage the technological change (Díaz López, 2003).

As this thesis research is focused on eco-innovation, the study of technological capabilities that may lead companies to engage in innovation activities and help to promote pro-environmental technological change, are the sole element of interest.

The behavior control beliefs used in this research (cf. Table 5.27) were derived from the work by Lall (1992) and additional elements extracted from the work by Durénit and Vera-Cruz (2001). As in the case of Lall (*ibid*), Durénit and Vera-Cruz (*ibid*) also developed a matrix of technological capabilities. In the latter case, in addition to using the Lall´s matrix as inspiration, the authors also used the taxonomy of technological capabilities developed by Bell and Pavitt (1995) in order to distinguish the main technological capabilities according to their degree of complexity in innovation.

Table 5.27 lists the beliefs, referred to in the foregoing paragraphs that may be held by leaders in the industrial organization in relation to their companies´ control over the companies´ technological capabilities that are necessary for them to engage in eco-innovation activities in Green Chemistry and Green Engineering

Table 5.27- Behavior control beliefs used to assess organizations´ leader's perceptions related to the control over the companies´ technological capabilities that can help companies to engage in eco-innovation processes

	Investment		Production			
Capabilities Level	Pre-investment	Project Execution	Process Engineering	Product Engineering	Industrial Engineering	Linkages Within Economy
Intermediate technological innovation capabilities (search based)	Search for technology source. Negotiation of contracts. Bargaining suitable terms. Info. Systems	Equipment procurement, detailed engineering, training and recruitment of skilled personnel	Equipment stretching, process adaptation and cost saving, licensing new technology	Product quality improvement, licensing and assimilating new imported product technology	Monitoring productivity, improved coordination	Technology transfer of local suppliers, coordinated design, S&T links
Advanced technological innovation capabilities (research based)	Development of new production systems	Basic process design and related R&D	In-house process innovation and basic research	In-house product innovation, basic research	Colaboration with suppliers and partners for technological development	Turnkey capability, cooperative R&D, licensing own technology to others

Sources: Díaz López (2003), Durénit and Vera-Cruz (2001) and Lall, (1992)

It is important to highlight that the basic level technological innovation capabilities originally proposed by Durénit and Vera-Cruz (*ibid*), were suppressed from this work. The reason for this suppression resides in the fact that innovations based on GCE may require radical innovation or the development of new technological paradigms and trajectories, which are not likely to be achieved via the proposed basic technological innovation capabilities.

Additionally, it is fundamental to highlight that, in accordance with the eco-innovation definitions presented in Table 16.1 of Appendix H, in this research, companies that are technology developers (research based innovators) and/or technology buyers (search based innovators) are considered to be innovators.

In this respect, it is important to highlight that, although some companies do not possess the required technological capabilities for the development of new technologies, they see the acquisition of innovative greener technologies as a means to be more sustainable and competitive. Therefore, it is required for them to hold (or to acquire) the required technological and organizational capabilities to absorb innovative technological eco-innovations.

Table 5.28 presents the question from the questionnaire related to perceptions about the control over the companies´ technological capabilities.

Table 5.28- The question used in the questionnaire pertaining to the organizations leader's perceived control over the companies´ technological capabilities. (The complete questionnaire is in Appendix E)

What is the degree of difficulty that your company faces in obtaining the required capabilities (inside and outside the company realm) if it decides to follow the path of developing eco-innovative processes and basic research?						
-3 very difficult	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 very easy

Organizational Capabilities

As previously noted in the foregoing sections, knowledge is central to innovation. Based on the framework of the SSI, this section explored important dimensions of knowledge required for the development of innovations. Under the optics of the behavioral model of this thesis research, these dimensions represent the control beliefs associated with the knowledge and technological behavior domain of the *perceived behavior control* (PCB) construct (cf. Figure 5.6 and Figure 5.8).

Central to this section, knowledge cumulativeness is intrinsically related to the companies´ learning processes and to organizational sources which, in turn, according to Malerba and Orsenigo (1997) comprise two domains: (a) technological capabilities (cf. previous section) and (b) organizational capabilities.

At this point, it is appropriate to refer to Dosi *et al*. (2000) who didactically explained that the notion of capability is associated with the sense of being capable of doing something. That is, "to have the capacity to bring that thing about as a result of intended action. Capability fills the gap between intention and outcome." Dosi *et al*. (*ibid*; 2).

To keep the focus on the object of this section (knowledge cumulativeness), it is argued that technological capabilities (cf. previous section) can be interpreted as the technological means through which companies effect the transformation of inputs into outputs. Figuratively, they represent a company's stocks of knowledge (tacit and explicit) accumulated throughout the years at both the personal and the organizational levels. They are dynamic, idiosyncratic and change overtime. "Production, the creation of value through transforming input into output, requires a wide array of knowledge, usually through, combining the specialized knowledge of a number of individuals" (Grant, 1996a: 377).

Following the principles for knowledge and capabilities integration proposed by Grant´s (*ibid*), technological capabilities can be viewed as a product of knowledge accumulation resulting from the integration of a wide spectrum of knowledge residing in the various knowledge strata within and outside an organization.

Knowledge obeys an integration hierarchy that is different from that associated with the administrative domain. It spans from the specialized knowledge held by individuals through knowledge that is integrated up to higher levels of integration, which requires wide-ranging cross-functional integration (e.g. new product development capability). This integration process also includes knowledge that is required to construct other levels of capabilities such as those specialized and broader functional capabilities (e.g. R&D, manufacturing etc.). "Although higher-level capabilities involve the integration of lower-level capabilities, such integration can only be achieved through integrating individual knowledge" (Grant, *ibid*: 378)

The concept of integration, is very useful in the processes of innovation, whereby, flexible integration is required. Such integration spans from the extension of existing capabilities to encompass new knowledge, through the reconfiguration of existing knowledge within new patterns of integration (Grant, 1996b).

At this point the question emerges of what organizational capabilities are necessary to integrate knowledge and thus to promote the development of technological capabilities. Certainly, a company should hold many organizational capabilities. To be faithful to the objectives of this section, this thesis author maintained the focus on the creation of technological capabilities *via* the integration (and accumulation) of knowledge present in the various strata and mechanisms within and outside the firms´ domains. These might not be the only contributing factors to the formation of capabilities but their absence can make it difficult to develop the essential knowledge and innovation.

To approach the subject of organizational capabilities in the knowledge domain, this thesis research built upon the premise of Grant (1996a: 377, original italics):

> "If knowledge is a critical input into all production processes, if efficiency requires that it is created and stored by individuals in specialized form, and if production requires the application of many types of specialized knowledge, then the primary role of the firm is the integration of knowledge. (…) Integration of specialist knowledge to perform a discrete productive task is the essence of *organizational capability*, defined as a firm's ability, to perform repeatedly, a productive task which relates either directly or indirectly to a firm's capacity for creating value through effecting the transformation of inputs into outputs."

Zander and Kogut (1995: 76) reinforced this view by stating that the capabilities of a firm are primarily related to "the organizing principles by which individual and functional expertise is structured, coordinated, and communicated."

Grant (1996b) proposed that knowledge integration for the formation of capabilities can be executed in organizations in three ways.

1) **Rules and Directives**: rules can be viewed as standards that regulate the interactions between individuals. Rules and directives represent a means through which tacit knowledge can be converted into readily comprehensible explicit knowledge (Grant, 1996b). They are comprised by a set of procedures, heuristics, and instructions developed through the articulation of specialists' tacit knowledge for efficient communication to (and application by) a large number of individuals that are non-specialists and specialists in another area (Alavi and Tiwana, 2002; Grant, 1996b);

2) **Organizational Routines:** "routines refer to organizational protocols, process specifications, and interaction norms through which individuals apply and integrate what they know without having to communicate it explicitly" (Alavi and Tiwana, 2002: 1031). The routines represent the accumulated knowledge of the organization that is developed via learning processes. They incorporate the organizations' skills, capabilities, culture and belief systems, and are transmitted through time. In Nelson and Winter's (1982) own words these processes constitute the "organizational genetics" or the "organizational memory.

   According to Grant (1996b,) routines possess the interesting ability to support complex patterns of interaction between individuals in the absence of rules and directives or even verbal communication. In this sense, they incorporate the notion of coordination by mutual coordination. "The advantage of routine in integrating tacit knowledge is in economizing upon communication and permitting flexible responses to changing circumstances." (Grant, 1996a: 385)

3) **Self-Management Teams:** refer to a knowledge integration mechanism for complex and non-routine organizational tasks especially when task uncertainty, novelty, and complexity preclude the use of existing routines or directives (Alavi and Tiwana, 2002). As opposed to the two other aforementioned mechanisms, self-management teams are employed in situations where there is the need for more personal and communication intensive forms of integration (Grant, 1996b).

   "Through a team structure, diverse knowledge and expertise of individuals at various locations in an organization can be assembled, integrated, and applied to the task at hand. Rich communication, collaboration, and creative conflict characterize knowledge integration in teams. Reconfiguration of distributed organizational knowledge using team structures facilitates innovation beyond that possible from using solely directives and routines" (Alavi and Tiwana, 2002: 1030).

In addition to the above mechanisms, and as part of organizational capabilities requirements for the promotion of the integration of knowledge, aiming at the construction and development of technological capabilities, Grant (1996a) put emphasis on the importance of existing correspondence between knowledge integration capabilities and the organizational structure. Based on the premise that the capabilities of the firm need to be hierarchically structured according to the scope of knowledge which they integrate, Grant (*ibid*) called attention to the importance of a close correspondence of the capabilities´ hierarchy to the hierarchic structures (authority-based) needed for managing their integration.

> "(…) if knowledge is to be integrated effectively by the firm, the architecture of capabilities must have some correspondence with the firm's structure of authority, communication, and decision making, whether formal or informal" (Grant, 1996a: 378).

For the purpose of this research, the mechanisms of integration of knowledge:

a) To promote the development of technological capabilities proposed by Grant (1996a and 1996b) (rules and directives, organizational routines and self-managed teams), and
b) The degree of correspondence between technological capabilities/knowledge with the organizational structure of authority, communication, and decision-making,

whether formal or informal represent the control beliefs associated with the organizational capabilities required to promote knowledge accumulation.

It is expected that managers who perceive that his or her company holds these organizational capabilities are likely to be more prone (willing) to engage in eco-innovation processes.

Table 5.29 lists the beliefs, referred to in the foregoing paragraphs that may be held by leaders in the industrial organization in relation to their companies´ control over the organizational capabilities that may represent incentives for them to engage in eco-innovation activities in Green Chemistry and Green Engineering

Table 5.29- Behavior control beliefs used to assess organizations leader's perceptions related to the control over the companies´ organizational capabilities that can help companies to engage in eco-innovation processes

Knowledge Integration mechanisms	Rules and directives Organizational routines Self-management teams	Capabilities/knowledge and organizational structure correspondence	Hierarchies of capabilities correspondence with authority-based hierarchies

Source: author

Table 5.30 presents the statement from the questionnaire related to perceptions about the control over the companies´ organizational capabilities.

Table 5.30- The statement used in the questionnaire pertaining to the organizations´ leaders´ perceived control over the companies´ organizational capabilities. (The complete questionnaire is in Appendix E)

Our company holds individuals that possess critical knowledge who can help our organization in successfully engaging in processes of acquisition and/or development of cleaner and more environmentally sustainable Green Chemistry and Green Engineering based technologies.						
-3 strongly disagree	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 strongly agree

Perceived Behavioral Control Behavior Domain 2: Actors and Networks

In the perception of the author of this thesis research, one important approach in trying to understand the SSI framework, as well as innovations systems, as a whole, is a metaphorical one. Innovations do not come out of the blue produced by spontaneous and inanimate generation processes. Innovations are a product of animate (living) processes whose driving forces for the creation of knowledge, technologies and artifacts reside on the social integration, cognitive capacity and learning capabilities of individuals or group of individuals gathered and interacting, in associations and organizations, *via* the establishment of relations of various types and strengths.

Metaphorically, it can be argued that human relationships and interactions are the powerhouse of the innovations in sectors. It is then comprehensible that actors and networks constitute one of the building blocks of SSI (cf. Malerba, 2002, 2004, 2005a and 2005b). The human element and the relationships that they constitute provide the driving force for the creation of innovative solutions for the challenges faced by societies.

According to Malerba (2002: 255), firm's behaviors follow evolutionary paths in the sense that "they are characterized by specific beliefs, expectations, competencies and organization and are engaged in processes of learning and knowledge accumulation". These characteristics are ultimately and fundamentally associated with the human individual and collective activities.

Malerba (*ibid*) also identified firms as the key actors in SSIs. This was grounded on the fact that in the spectrum of their activities, innovation, production and sale of sectoral products and the generation, adoption and use of new technologies occupy a central and fundamental place.

Although firms are central to SSI, no element (actor) innovates in isolation. Knowledge and innovation are produced amidst collective, systematic and interactive dynamic processes in the realm of interdependent and interdisciplinary network structures. Firms interact *through* market and non-market relations with a variety of heterogeneous actors (firms and non-firms organizations) holding complementary capabilities and knowledge "for the generation and exchange of knowledge relevant to innovation and its commercialization” (Malerba, 2005a: 66).

In SSI, networks types and modes of functioning can be as distinctive as sectors´ number of agents, extent and types of relationships; relevant knowledge base; learning processes; basic technologies; characteristics of demand; key links and dynamic complementarities. This produced the emergence of the concept of “sectoral structure”. The notion of “sectoral structure” is different from the one used in industrial economics, in which it is mainly related to the concept of market structure and of vertical integration and diversification. In the SSI domain, the sectoral structure concept is associated with the links among artifacts and relationships among agents (Malerba. 2002, 2004, 2005a).

With regard the chemical sector, according to Cesaroni *et al*. (2004), the most relevant actors are represented by the established chemical companies, which have a long tradition in innovation and R&D and constitute a science and technology intensive sector. They innovate *via* the establishment of dynamic interactions with academic organizations, individual firms, and government policies.

These authors emphasized the importance of the linkages between internal corporate capabilities, external sources of scientific knowledge (research institutes, universities, specialized engineering firms etc.) and the supply and the demand side (users) in innovation processes in the chemical sector.

As suggested by empirical evidence, knowledge creation and innovation are increasingly an outcome of formal and informal interaction among actors belonging to the same organization or from different market and non-market organizations (Cesaroni *et al*., *ibid*).

The dynamics of the relationships of interdependent agents are covered by a vast array of subjects, which are covered elsewhere. For the purposes of this research, the core interest resides on the extent to which the possession of capabilities, at personal and organizational levels, to form and participate in strategic alliances and networks of collaboration, can help to predict and explain firms´ willingness (intention) to deliberately engage GCE-based innovation activities.

Based on the arguments posed on the previous paragraphs, it is proposed that the determination and the measurement of the strength of the beliefs, associated with the actors and networks behavioral domains, can give a substantial contribution to explain and predict managers’ willingness to engage in such processes.

Based on Montalvo Corral (2002), such control beliefs arise from the following realms: (1) the availability of key actors holding the required capabilities (internal and external to the firm), (2) the capability of forming strategic alliances with external actors and (3) the capability of forming networks of collaboration.

1) **Availability of internal actors with key capabilities**: refers to actors that are part of the company staff who can influence the establishment and development of innovation processes. They contribute with knowledge, initiative power, leadership and supporting capacity. Key characteristics for agents in these processes may be

related to their polifunctionality and critical technological knowledge. This allows for good integration throughout the innovation network and a strong exploratory power in the search of new technological opportunities.

As communication and commitment are central to innovation processes, key influential agents are required to have strong potential of influence power and responsibility for defending, motivating and participating in cleaner technologies culture building as well as in supporting initiatives for the firm's engagement in innovation processes aiming at increasing states of corporate environmental sustainability and competitiveness (Montalvo Corral, *ibid*).

2) **Strategic Alliances with external actors**: refers to a relationship between two or more parties to pursue a set of agreed upon goals or to meet a critical business need while remaining independent organizations[90]. Montalvo Corral (*ibid*: 99) quoting Porter (1993) gave a definition of strategic alliances. He described "strategic alliances as informal business relationships characterized by tight operational linkages". These business relationships are organized around collaboration, not hierarchical power.

   Further, Montalvo Corral (*ibid*) proposed four aspects that are necessary to support firms´ strategic alliances: (a) strategic synergies, (b) availability of support and commitment from the top commitment, (c) the possibility to achieve influence via cooperation and (d) outsourcing opportunities. He discussed these issues in more details in his book from which this thesis author extracted the following paragraphs:

   a) **Strategic synergies** relate to the challenge to identifying the right partners in terms of:
      - **Strategic fit**: concerns the strengths and complementarities in innovative technical know-how;
      - **Chemistry fit**: relates to truth, honesty, common success commitment, good reputation, predictability under pressure and creativity in the face of adversity that prospective partnering may need to have;
      - **Operational fit**: relates to the reference framework upon which prospective partners operate their respective business (business strategies, communication methods, management styles, labor relations, technologies and business government relations)"
      - **Financial fit**: it is proposed by this thesis author and relates to the availability of prospective partners who share common interests and are interested in financing eco-innovative activities (development or acquisition of innovative products or production processes). Investment capital can take the form of venture capital or loan capital that is available and attractive to the company.

[90] http://en.wikipedia.org/wiki/Strategic_alliance. Accessed in September, 2012

b) **Support and commitment** relates to the support and commitment from key elements within the organization to the establishment of strategic alliances aiming at innovation activities:
   - CEO and shareholders support and commitment that the company may have to engage in the outsourcing of new environmentally benign technologies represent one of the main supportive elements for the establishment of strategic innovation alliances;
   - The perception of opportunities of the establishment of win/win relations between prospective partners may be a convincing element for support acquisition;
   - The same is valid when there is the existence of pro-environmental values;
   - Previous successful alliances experiences are also a significant factor for supportive behavior;

c) **Cooperation and influence** relates to the capability to influence suppliers (inputs and technologies) for the development of critical cleaner substitute inputs for and for new process technologies as well as customers for the development of cleaner consumer products.

d) In the topic of "**outsourcing opportunities**" regarding strategic alliances, Montalvo Corral (*ibid*) highlighted the view of diverse authors that cooperation between firms can provide leverage for off-the-shelf technological and know-how resources and opportunities specifically in the fields of life-cycle analysis expertise, cleaner products and cleaner processes technologies.

3) Networks of collaboration: is a network consisting of a variety of entities (e.g. organizations and people) that are largely autonomous, geographically distributed, and heterogeneous in terms of their operating environment, culture, social capital and goals, but that collaborate to better achieve common or compatible goals. "The discipline of collaborative networks focuses on the structure, behavior, and evolving dynamics of networks of autonomous entities that collaborate to better achieve common or compatible goals"[91]. The concept of networks captures essential characteristics of social structures made up of a range of agents, whether they are individuals or groups of individuals forming a wide variety of organizations. According to DeBresson and Amese (1991) the concept of networks is built upon important peculiarities in the supplier-user relationships, regional agglomerations, and international strategic technical alliances.

Montalvo (2002) argued that networks of collaboration were the routes through which knowledge and ideas about technology, products and environmental issues permeate into the firm. External networks of collaboration are particularly important in the understanding of global and large scale environmental problems. External collaboration with users and external sources of technical expertise has been identified to be of central importance in the development of innovations (Freeman, 1991).

In a complex and knowledge intensive sector, such as the petrochemical sector, one may find a profusion of collaboration networks for the development of innovative

[91] http://en.wikipedia.org/wiki/Collaborative_network. Accessed in September, 2012.

solutions for the multitude of environmental and economic sustainability challenges that firms currently have.

In this research, as an adaptation of the work by Cesaroni *et al*. (2004) on the processes of knowledge creation and diffusion in the chemical sector, this author identified the following actors as central for companies to promote collaboration GCE based eco-innovation networks:

- Public R&D laboratories;
- Providers of raw-materials and other inputs;
- Consultancies;
- Sectoral inter-firms collaboration, and
- Specialized engineering firms (SEF).

It is important to note that this small list does not necessarily define the borders of the collaborative networks focused upon eco-innovation in the petrochemical sector. Since it is a dynamic process, new and unprecedented possibilities may emerge according to the needs. "A network can be comprised of two companies at its core, but also may include their supplier networks and other firms, and a chain of linkages" (Clark and Staunton, 1989: 177).

It was proposed that manager's connotative accumulated belief of the perceived ease or difficulty to engage in eco-innovation strategic alliances and collaborative innovation networks is proportional to their perceived control over these beliefs.

Table 5.31 lists the beliefs, referred to in the foregoing paragraphs that may be held by leaders in the industrial organization in relation to their companies' control over the actors and networks that are required for the companies to engage in eco-innovation activities.

Table 5.31- Behavior control beliefs used to assess organizations leader's perceptions related to the control over the actors and networks that are required for the companies to engage in eco-innovation activities

Availability of Internal Actors holding key capabilities	Polifunctionality and technological knowle Influence Power and responsibility Culture building, motivation and participa	Networks of collaboration	Public R&D laboratories Providers of raw-materials and other inputs Consultancies Colaboration with companies within the sector Specialized engineering firms (SEF)
Strategic alliances with external actors			
Strategic synergy	Strategic fit Chemistry fit Operational fit Financial fit	Support and commitment	Win/win negotiations Values pro-environment Support from CEO and sharehorders Previous alliances experiences
Cooperation - influence	With suppliers (inputs) With suppliers (process technologies) With customers	Outsourcing opportunities	Life-cycle analysis expertise Clean product technologies Clean process technologies

Source: author and adapted from Montalvo Corral (2002)

Table 5.32 contains the statement from the questionnaire related to perceptions about the control over the actors and networks.

Table 5.32- The statement used in the questionnaire pertaining to the organizations´ leaders´ perceived control over the actors and networks. (The complete questionnaire is in Appendix XX)

Concerning the investments in new innovative technologies based in green chemistry and green engineering, finding partners for strategic alliances that ensure trust, honesty, win/win commitment, good reputation is:						
-3 very unlikely	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 very likely

Perceived Behavioral Control Behavior Domain 3: Institutions

In the previous section, the creation of knowledge, competences and the production of innovation were presented as a consequence of the dynamic interaction between socio-economic actors. Such interactions were considered to occur through the formation of networks in their many functional and structural forms. According to Nooteboom (2000), networks within and between firms generate social capital. Competence and knowledge are among the important elements of the firms´ social capital and are fundamental to innovation.

Although innovation processes are complex systems and hold a high degree of uncertainty, innovation systems are not uncontrollable. Social-economic agents in innovation systems interact under general and specific sets of social and economic behavioral control elements named institutions, which establish the required order for those systems and networks to function and to exist.

> "Just as social order cannot exist in the face of extreme uncertainty and requires customs norms and rules to reduce this, so does economic order" (van Waarden, 2001: 770).

Nooteboom (*ibid*) argued that the result of these inter-firm interactions is largely determined, coordinated and shaped by the institutions. They directly affect innovation outcomes. Institutions play a major role in sectoral systems. They affect the rate of technological change, the organization of innovative activity and performance (Malerba, 2005b). Institutions can be defined as:

> "(…) a set of common habits, norms, routines, established practices, rules or laws that regulate the relations and interactions between individuals, groups, and organizations. They are the rules of the game." (Edquist, 2005: 182).

> "(…) a 'more or less enduring sets of social *mutual expectations* crystallized in *rule systems*'. Rules — both formal and informal — define what is to be expected of social actors in a specific *role* and a specific *social situation*. Rules

> tell us something about the *intentions* others may have in a given situation and how they are likely to *behave*" (van Waarden, 2001: 770. Original italics)

Technical innovation is, by its nature, probably one of the most risk and uncertainty bearing activities in the economic order (Jorde and Teece, 2001; van Waarden, *ibid*). This stems from both the uncertainties surrounding the development of new knowledge and technologies and the risks and uncertainties inherent to the human relationships in the economic domain.

Rules express behaviors that are required from individuals and groups of individuals gathered in the form of organization in specific contexts and situations. Institutions (rules, norms, habits, conventions etc.) are seen as social, political and economic constructs whose major function is to regulate behavior and reduce risk and uncertainty "to manageable levels by decreasing the unpredictability of mutual social expectations and the arbitrariness of social behavior" (van Waarden, *ibid*: 770). They can be a product of deliberated planned decision or may emerge as an unpredicted result of agent's interactions (Malerba, 2005b).

On the one hand, the structure of a technical innovation network can be variable and may evolve through time and according to the needs and type of agents' interaction. On the other hand, the boundaries of institutions can expand and evolve *via* contributions from an ample spectrum of societal agents as it is remarked by Nelson, (1994: 57):

> "(…) the evolution of institutions relevant to a technology or industry may be a very complex process, involving not only the actions of private firms, but also organizations like industry associations, technical societies, universities, courts, government agencies, legislatures, etc."

As the evolution and dynamics of institutions in the innovation system's domain are not comprised within the scope of this thesis research, they were intentionally left out of the analysis.

This thesis research proposes that managers are likely to be more prone to engage in eco-innovation activities if they perceive that the current institutional set pertaining to the: (a) organizational, (b) legal, (c) economic, social and ethical, and (d) political and public realms provide their companies with satisfactory protection against imitation, facilitate and guarantee the appropriability of knowledge and innovation benefits and regulate and shape companies´ relationships with other actors (formal and informal and market and non-market).

In this thesis research, institutions are meant to regulate and coordinate agents' relations in the domain of eco- innovation processes.

Table 5.33 lists the beliefs, referred to in the foregoing paragraphs that may be held by leaders in the industrial organization in relation to their companies´ control over the institutional set that can support eco-innovation processes.

Table 5.33- Behavior control beliefs used to assess organization's leader's perceptions related to the control over the institutional set that can support innovation processes

Source: author

Table 5.34 presents the question from the questionnaire related to perceptions about the control over the actors and networks.

Table 5.34- The question used in the questionnaire pertaining to the organizations leaders´ perceived control over the institutional set. (The complete questionnaire is in Appendix E)

To what extent do the social and ethical institutions, that are present in your company´s commercial and non-commercial relationships, provide the required degree of confidence and protection for its engagement in Chemistry and Green Engineering based eco-innovation activities?						
-3 very low	-2 quite	-1 slightly	0 uncertain	1 slightly	2 quite	3 very high

It is proposed that the managers' perceived control over the beliefs presented above is proportional to their connotative accumulated belief of the perceived ease or difficulty to engage innovation activities. This perception was contingent upon the presence or absence of the required support from the current institutional structure at organizational, local, regional, national and international levels.

5.3 Behavioral Model Hypotheses System

In the industrial domain, technological changes to new paradigms represent a substantial challenge. Special emphasis can be placed on those changes towards new technological solutions that are based on novel knowledge and on approaches that deviate from companies´ established knowledge and technological bases. For such efforts to be successful, it may be required that substantial changes occur in the way companies see the challenges posed by the surrounding environmental, social and economic landscape in the short, medium and long-term.

Changes may implemented in a wide spectrum of interrelated and interdependent variables that comprise, *inter alia*, personal, broad social, technological, organizational and institutional factors that permeate companies´ technological, knowledge and organizational structures. These factors can give the firm an estimate or a vision of not only what it is today, but also what it may need to become in the future.

This thesis research was focused on technological changes related to the environmental sustainability challenges posed by the market and the society on the companies in the Brazilian petrochemical sector. These changes are, at a basic level, interpreted as changes on companies´ perceptions and on the belief system relative to their sustainability challenges.

In this respect, the adoption of novel knowledge and technological approaches is considered to be a result of changes in the company's behavior. In this thesis research, this behavioral change referred to the engagement of companies in eco-innovation activities that are based on the principles that are predicated by Green Chemistry and Green Engineering. As noted in Chapter 3, one of the main theoretical elements used to predict and explain the likelihood of companies to promote such behavioral change was extracted from the Ajzen´s (1991) "Theory of Planned Behavior (TPB)".

The TPB established a causal relation between beliefs and behavior. Beliefs influence attitudes, perceived social factors[92] and perceived behavioral control. They, in turn, determine behavior intention, which is the immediate determinant of the performance of a behavior. According to Montalvo Corral (2002), the TPB is essentially a system of hypotheses linking beliefs to behavior with each hypothesis requiring empirical verification.

The TPB based structural descriptive behavioral model of the likely determinants of the willingness to innovate in GCE, developed in this thesis research (cf. Figure 5.8), was used for the construction of this thesis´ underlying system of hypotheses presented in Table 5.35. Based on the hypothesized causal relations, the theoretical framework of the model was tested and validated using empirical data. The empirical validation of the model is presented in Section 6.6 and in Appendices B and C.

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[92] "Social factors" refer to the social construct that in the case of this research includes social norms, roles, personal norms and self-identity elements that may influence behavioral intention. It is the approach used for the purposes of this research and deviates from the original TPB social construct, which was comprised of only the "social norm".

The construction of the system of hypotheses was in agreement with the TPB's theoretical foundations, with the proposed relationships between direct and belief-based measures and followed the same structure, explanatory levels and hierarchical sequence proposed by Montalvo Corral (2002).

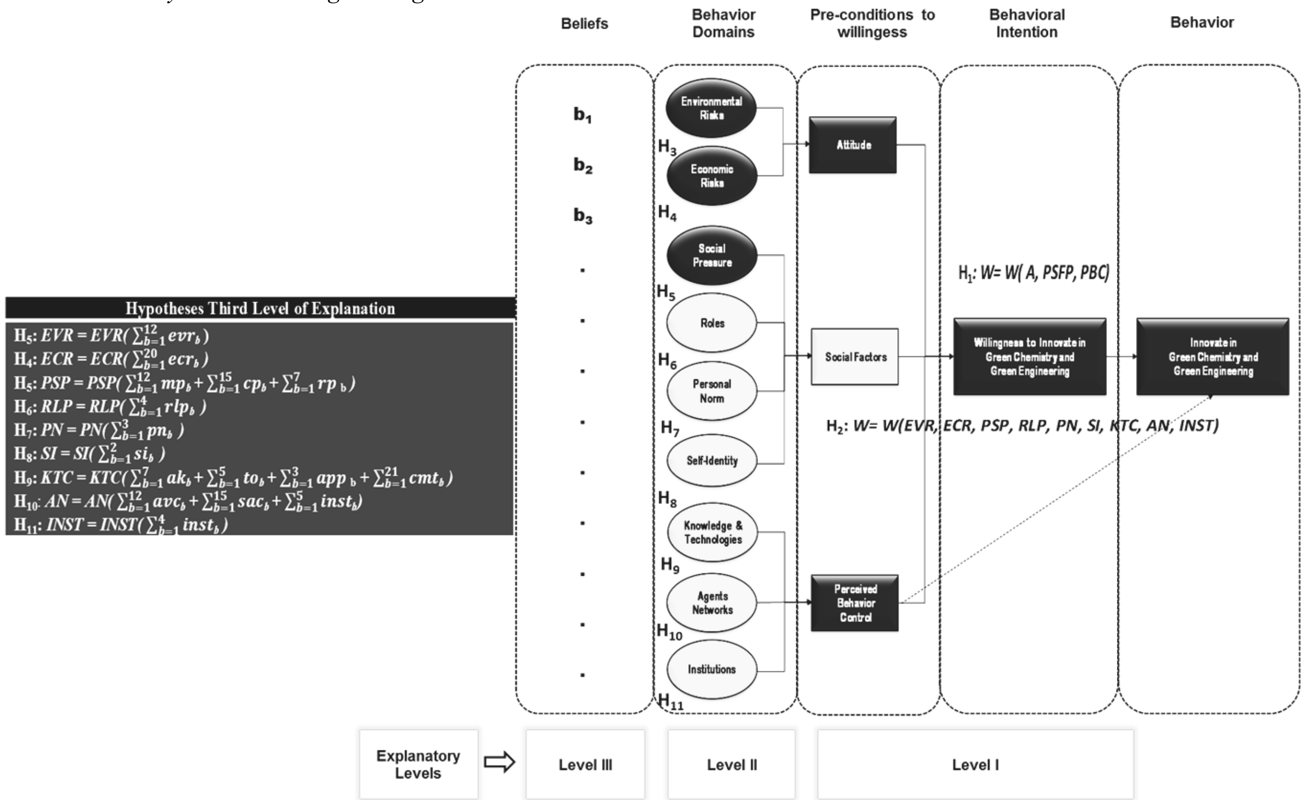
In this regard, the system of hypotheses just like this thesis researcher´s behavioral model was divided in levels of explanation of willingness to engage in eco-innovation activities (cf. Figure 5.7). According to Montalvo Corral (2002) these levels are three in number and are described in the following fashion:

a) In the first level of explanation it was proposed that willingness can be explained by attitudes towards the behavior (*A*), the perceived pressures originated from social factors (*PSFP*) and the perceived control over the requisites and opportunities regarding eco-innovation processes (*PBC*);
b) The second level of analysis was proposed that willingness can be explained by the nine behavioral domains (*EVR*, *ECR*, *SP*, *RLP*, *PN*, *SI*, *KTC*, *AN*, *INST*) pertaining to each of the three behavioral constructs (*A, PSP and PBC*), and
c) The third level of explanation was proposed that each behavioral domain captures, in a single item, the accumulated connotative load that the scale (beliefs) in this a particular domain contains.

> "The aim of the system of hypotheses was to test whether, within the environmental policy realm, it is possible to link salient beliefs to the perceptions at the domain level and, in turn, to be able to link these perceptions to the willingness to innovate. If the links are proven to exist, a chain of causality that connects the beliefs to willingness to innovate and ultimately to behavior would be established." (Montalvo Corral, 2002: 106)

These relations and their underlying hypotheses are presented in Figure 5.7 and Table 5.35.

Figure 5.7- Hierarchical levels and hypotheses system of the behavioral model to predict and explain firms´ willingness to innovate in Green Chemistry and Green Engineering



Notes: (a) The elements within the behavioral model´s structure showed in dark color represent the original elements that were present in Montalvo Corral´s model. (b) The ones depicted in light color represent the modifications that have been introduced by this thesis author. (c) It was agreed that, for the purposes of this thesis research, the acronyms representing the behavioral domains were written in capital letters and those representing the beliefs were written in lower case letter.

Source: author - adapted from When de Montalvo (2003)

Table 5.35- System of hypotheses that were used to test the links between beliefs and perceptions at the domain level and the perceptions to the willingness to eco-innovate at the firm level

HYPOTHESES	**PROPOSITION**	**EQUATION**	**REMARKS**
EXPLANATORY LEVEL I			
H_1	The firms´ willingness (***W***) to engage in eco-innovate activities based in GCE can be explained in terms of *attitudes* towards green chemistry and green engineering – GCE - (***A***), the *perceived social and personal pressures* and demands towards firms´ pro-environmental behavior (***PSFP***), and the *control over the requisites and opportunities* to eco-innovate based on GCE (***PBC***).	H_1: *W=W(A, PSFP, PBC)*	***A***, ***PSFP*** and ***PCB*** = direct measures of attitude, perceived social factors pressures and perceived behavior control.
EXPLANATORY LEVEL II – DOMAIN LEVEL			
H_2	The firms´ willingness (***W***) to innovate in GCE depends on the perceptions of the: *environmental risk* (***EVR***), *economic risk* (***ECR***), *social norm pressure* (***SP***), *roles* (***RLP***), *personal norm pressure* (***PN***) and *self-identity* (***SI***), *knowledge and technologies* (***KTC***), *agent and networks* (***AN***) and *institutions* (***INST***).	H_2: *W=W(EVR, ECR, PSP, RLP, PN, SI, KTC, AN, INST)*	***EVR, ECR, PSP, RLP, PN, SI, KTC, AN and INST*** = direct measures at the behavioral domains level of the perceived environmental risks, economic risks, social pressures, roles, personal norms, self-identity; and the perceived control over knowledge and technologies, agents and networks and institutions.
EXPLANATORY LEVEL III – BELIEFS LEVEL			
H_3	Managers´ attitude of *environmental risk* (***EVR***) is a function of the accumulated connotative load of the beliefs arising from *environmental risk perception* (***evr***).	H_3: $EVR=EVR(\sum_{b=1}^{12} evr_b)$	• ***EVR*** is the item that assesses environmental risk perception, • evr_b is the *b*th belief about risk perception,
H_4	Managers´ attitude of *economic risk attitude* (***ECR***) towards the engagement in eco-innovation activities based in GCE is a function of the accumulated connotative load of the beliefs arising from the perception of the positive and negative *economic*	H_4: $ECR=ECR(\sum_{b=1}^{20} ecr_b)$	• ***ECR*** is the item that assesses economic risk perception, • ecr_b is the bth belief about risk perception.

HYPOTHESES	PROPOSITION	EQUATION	REMARKS
	consequences for the firm that may result from the engagement in eco-innovation activities (***ecr***).		
H_5	Firms´ *perceived social pressure (**PSP**)* towards the engagement in eco-innovation activities based in GCE is a function of the managers´ accumulated connotative load regarding the perceived intensity and strength of the pressures exerted by the *market* (***mp***), the *community* (***cp***) and by the environmental *regulatory* domain (***rp***) on them and on the firm.	H_5: $PSP=PSP(\sum_{b=1}^{12} mp_b + \sum_{b=1}^{15} cp_b + \sum_{b=1}^{7} rp_b)$	•***PSP*** is the item that assesses social pressure perception, •$\boldsymbol{mp_b}$ is the *b*th belief about market pressure perception, •$\boldsymbol{cp_b}$ is the *b*th belief about community pressure perception, •$\boldsymbol{rp_b}$ is the *b*th belief about regulatory pressure perception.
H_6	Managers´ *perceived role pressure (**RLP**)* towards the engagement in eco-innovation activities based in GCE is a function of the managers´ accumulated connotative load regarding their perceived ideas about *the correct (environmental) behavior for his role as a manager or company leader* (***rlp***).	H_6: $RLP=RLP(\sum_{b=1}^{4} rlp_b)$	•***RLP*** is the item that assesses role pressure perception, •$\boldsymbol{rlp_b}$ is the *b*th belief about role pressure perception.
H_7	Managers´ *perceived personal (moral) norm pressure (**PN**)* towards the engagement in eco-innovation activities based in GCE is a function of the managers´ accumulated connotative load regarding their perceived personal moral obligation related to their engagement in eco-innovation activities and the promotion of pro-environmental changes in the firms´ policies and activities (***pn***).	H_7: $PN=PN(\sum_{b=1}^{3} pn_b)$	•***PN*** is the item that assesses personal (moral) norm perception, •$\boldsymbol{pn_b}$ is the *b*th belief about personal (moral) norm perception.
H_8	Managers´ *perceived self-identity pressure (**SI**)* towards the engagement in eco-innovation activities based in green chemistry and green engineering is a function of the managers´ accumulated connotative load regarding their social role identities associated with their personal identification with environmental sustainability issues and their self-perception as being innovative, responsible and competent (***si***).	H_8: $SI=SI(\sum_{b=1}^{2} si_b)$	•***SI*** is the item that assesses self-identity perception, •$\boldsymbol{si_b}$ is the *b*th belief about self-identity perception.

H_9	The perceived *control over the knowledge, technological*, capabilities and opportunities (***KTC***) required for firms´ engagement in eco-innovation activities based in GCE is a function of the managers´ accumulated connotative load regarding the perceived ease or difficulty of the *accessibility to knowledge* (***ak***), *technological opportunities* (***to***), *knowledge and technological appropriability* (***app***) and *knowledge cumulativeness* (***cmt***).	H_9: $KTC=KTC(\sum_{b=1}^{7} ak_b + \sum_{b=1}^{3} to_b + \sum_{b=1}^{4} app_b + \sum_{b=1}^{21} cmt_b)$	•***KCT*** is the item that assesses the control over knowledge and technologies perception, •ak_b is the *b*th belief about the accessibility to knowledge perception, •to_b is the *b*th belief about technological opportunities perception, •app_b is the *b*th belief about *knowledge and technological appropriability* perception, •cmt_b is the *b*th belief about *knowledge cumulativeness* perception
H_{10}	The perceived *control over the agents and networks* (***AN***) required for firms´ engagement in eco-innovation activities based in GCE is a function of the managers´ accumulated connotative load regarding the perceived ease or difficulty for their companies to have the *availability of internal actors with key capabilities* (***avc***), to establish *strategic alliances with external actors* (***sac***) and to *form or to join to networks of collaboration (innovation)* (***nwc***).	H_{10}: $AN=AN(\sum_{b=1}^{5} avc_b + \sum_{b=1}^{14} sac_b \sum_{b=1}^{5} nwc_b)$	•***AN*** is the item that assesses the control over the agents and networks perception, •avc_b is the *b*th belief about the availability of internal actors with key capabilities perception, •sac_b is the *b*th belief about establishment of strategic alliances with external actors perception, •nwc_b is the *b*th belief about the formation of networks of collaboration (innovation) perception
H_{11}	The perceived c*ontrol over the institutional requirements and opportunities* (***INST***) that may provide the incentives for firms´ engagement in eco-innovation activities, based in green chemistry and green engineering, is a function of the managers´ accumulated connotative load regarding the perceived ease or difficulty for them to have the institutional support from the institutional domains (***inst***) related to the companies´ innovation processes in green chemistry and green engineering.	H_{11}: $INST=INST(\sum_{b=1}^{4} inst_b)$	•***INST*** is the item that assesses the control over the institutional requirements (for innovate) perception, •$inst_b$ is the *b*th belief assesses the control over the institutional requirements (for innovate) perception.

Source:author

5.4 Summary

Chapter 5 provided a full description of the development of the behavioral operational model used in this thesis research. Currently, petrochemical companies are facing a multitude of challenges related to their environmental and business sustainability. According to this thesis author, understanding the processes of technological change towards eco-innovative, cleaner and more sustainable products, processes and services can help companies to steer their efforts to the right direction

It should be highlighted that the solutions for a sustainable chemical industry are yet to be created. Their creation is dependent on the processes by which society innovates. Innovation processes are fundamentally complex and socially constructed. They can be initiated and accomplished only if sufficient incentives and pressures are present and if societies perceive them as a need. Stated differently, no innovation can be produced or innovation processes cannot exist in the absence of willingness to innovate on the part of socio-economic agents.

In this regard, the behavioral model presented in Chapter 5 was designed to help to predict and to explain if/why the managers in the Brazilian petrochemical sector are or are not willing to engage in eco-innovation processes that are based on the principles that are predicated by the GCE frameworks.

Constructed under the theoretical framework of the "Theory of Planned Behavior (TPB)" (Ajzen, 1991), this research´s behavioral model is a modification to Montalvo Corral´s (2002) TPB based structural behavioral model. It was designed to explain and predict eco-innovative behavior, which extends the potential determinants of the organizations to engage in the innovation processes.

In regard to these extensions, and in relation to Montalvo Corral´s (2002) model, two theoretical domains were configured as central: (a) the modifications to the model´s social construct *via* the inclusion of roles beliefs, self-concepts (Triandis, 1977) and personal moral norms (Schwartz, 1977), and (b) the incorporation of the framework of the "Sectoral Systems of Innovation" (SSI) (Malerba, 2002, 2004, 2005a, 2002b) into the behavior control construct.

Regarding its contents, the elements of the model´s behavioral domain and their associated beliefs system were defined and mapped from the relevant literature. They include a variety of theoretical elements that supported the construction of the model and are in line with the objectives of this research.

As previously noted in Section 3.2.1 of Chapter 3, this clarifies and reinforces the model´s meta-theoretical character of the TPB as an organizing framework.

Following the TPB, this model can be interpreted as follows in a cause and effect relationship:

a) **The behavior** regarding companies engagement in GCE-based eco-innovation activities can be determined and explained by their intentions (**willingness**) to engage in such behavior;
b) Companies´ **willingness** to engage in such innovation activities is contingent on their managers´ **attitude**" towards innovating in GCE, on the pressures exerted by **social**

factors towards greener processes and products and on the perceived presence or absence of requisite resources and opportunities for innovating (**perceived control over innovation**);

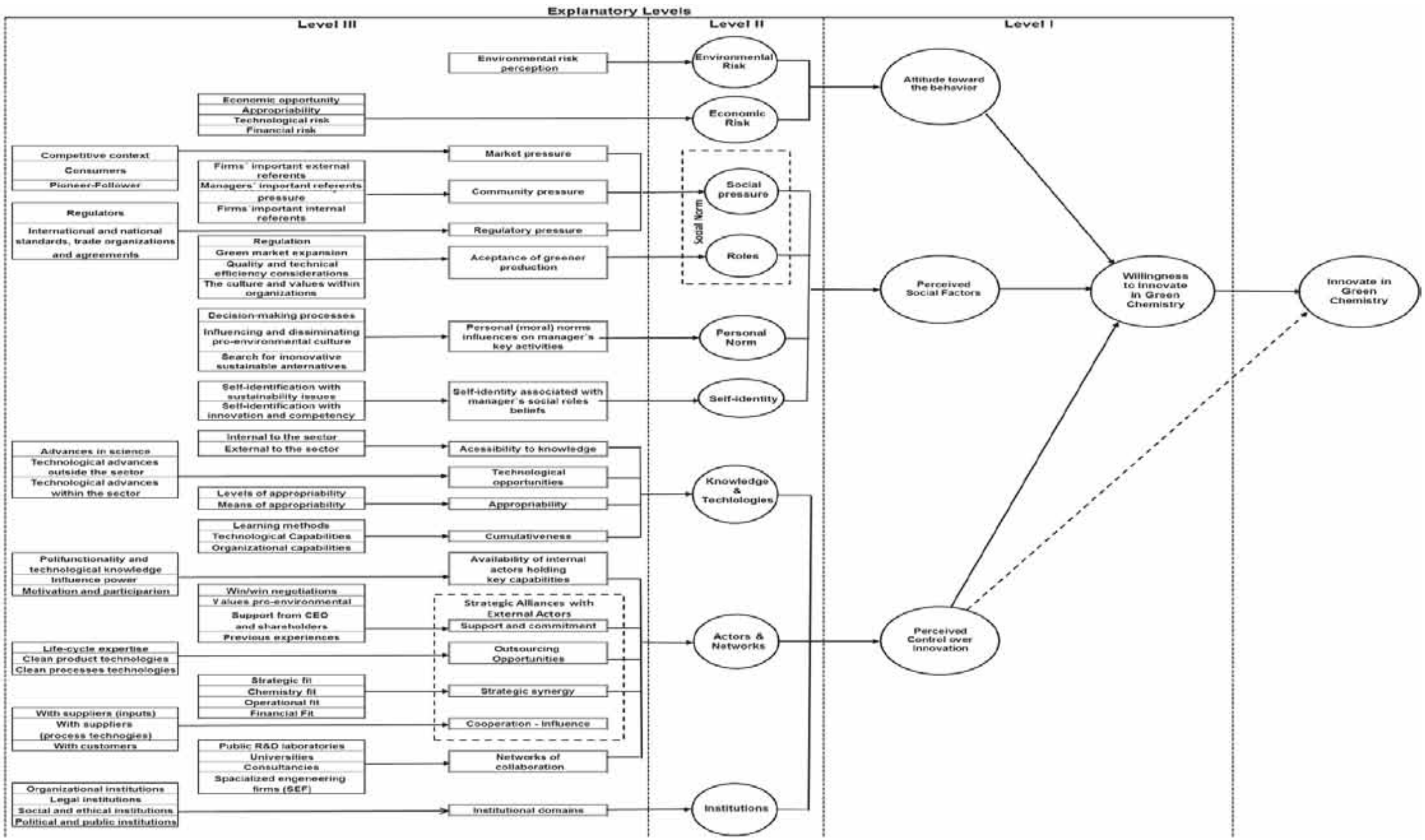
c) **Attitude, social factors** and **perceived control over innovation** are assumed to be constructed by the groups of **behavioral domains** and their underlying beliefs.
   a. "**Attitude**" refers to the degree to which managers´ beliefs have a favorable or unfavorable evaluation or appraisal of engaging in eco-innovation activities;
   b. "**Social factors**" refers to the societal and personal pressures. It is related to the beliefs held by "key individuals about the expectations of the social context within which their organizations operate" (Wehn de Montalvo, 2003: 97). It also relates to other social beliefs associated with their professional roles and their self-identification with the environmental causes. Finally, it regards managers' personal moral norms of performing pro-environmental behaviors.
   c. "**Control over innovation**" refers to beliefs related to the perceived ease or difficulty of engaging in GCE-based eco-innovation activities. It is assumed to be associated with to the presence or absence of resources and opportunities and to reflect past experience and anticipated impediments and obstacles.

This model was operationalized via a structured quantitative questionnaire that was applied to key managers and decision-makers in firms in the Brazilian petrochemical sector (cf. Chapter 6 and Appendix E). A system of hypotheses was generated from the model in order to test it against the collected empirical data.

The data produced by the application of the qualitative questionnaire allowed for the measurement and the explanation of companies´ willingness to engage in GCE-based eco-innovation processes and for the determination of its determinants. In parallel, these data were used to document the verification of the reliability of the qualitative questionnaire and to the validity of the model. These issues are covered in Chapter 6.

The full research´s structural descriptive model is depicted in Figure 5.8.

Figure 5.8- Research´s full structural descriptive behavioral operational model to predict and explain companies´ willingness to engage in eco-innovation activities that are based on Green Chemistry and Green Engineering



6. Companies´ Planned Behavior in Eco-Innovating in Green Chemistry and in Green Engineering

6.0 Introduction

This thesis research was designed to contribute to worldwide efforts to reverse the current trend of environmental overshooting. Reversing such trend requires huge amounts of change in the perceptions and beliefs, at the individual and societal levels, of the true requirements for a more sustainable world (economically, socially and environmentally). There is a mutual influence mechanism between individuals and society (cf. Chapter 1 and 4), which underscores the fact that decision-making processes are socially constructed processes.

This research was based upon the perspective that these changes are associated with individuals' behaviors and proposed that technological eco-innovation, that is based on Green Chemistry and Green Engineering (GCE), can provide important inputs on the path to be taken as society transforms itself and journeys toward more sustainable societal lifestyles.

This thesis research´s objective was to gain insights into these mutual individuals-society influences by identifying and measuring individuals´ perceptions and beliefs that can represent influence companies´ willingness for the adoption of pro-sustainability behaviors. In this study´s specific case, the behavior of interest was the engagement, in the next five years, of companies in the Brazilian petrochemical sector in eco-innovation processes that are based on the principles proposed by the GCE frameworks.

In order to accomplish this objective, a structured behavioral model was constructed (cf. Chapter 5) and a quantitive survey was implemented *via* the use of a self-administrated questionnaire (cf. Appendix E). The quantitative questionnaire was developed based on this researcher´s behavioral model. It generated empirical data that made it possible for the researcher to map the beliefs that gave positive contributions to willingness formation, which were investigated in-depth in Chapter 7 where the significant willingness determinants were clarified and quantified *via* statistical analyses.

In addition, the data generated by the quantitative survey were submitted to statistical analyses in order to calculate the companies´ planned behavior regarding their engagement in eco-innovation processes and to verify the reliability of the questionnaire and the validity of the behavioral model.

The quantitative survey encompassed the full spectrum of Brazilian petrochemical companies that produce basic and intermediate petrochemicals representing a total of twenty-one companies. According to the requisites of the survey, it was applied to companies´ managers and important decision-makers (cf. Chapter 4). The profile of the respondents is presented in Table 6.1 and in more details in Appendix G.

Table 6.1- *Profile of the hierarchical levels and of the main activities of the surveyed managers*

Hierarchical Level of the Respondents (%)				
Top Management			Mid Management	
25,7			74,3	
Respondents´ Main Activity (%)				
Environmental	Process	Commercial	Products and Processes	Other
16	31	5	32	16

Source: author

In terms of the number of responses, there were surprises. On the one hand, in terms of companies´ response rate, it was very acceptable. Ten out of the twenty-one surveyed companies responded the survey (47.6 percent response rate). On the other hand, if individuals were considered, the response rate was much lower than expected. Thirty-six managers and decision-makers engaged in responding to the survey. Issues on the influence of sample size on statistical multiple regression analyses and how statistical data interpretations were conducted were presented in Section 4.6.2.

Chapter 6 presented the results of this survey, and documented the degree of willingness of the respondents (managers) (Section 6.1). Sections 6.2, 6.3 and 6.4 plunged into the analysis of the surveyed managers´ attitudinal, normative and control beliefs perceptions (cf. Chapter 3) as a means to understand and explain the underlying motivational factors that can motivate companies to eco-innovate in GCE. Based on the scores obtained by this thesis research´s survey, Section 6.5 evaluated the findings of the planned behavior of the firms, in the sample, in respect to their willingness to engage in GCE-based eco-innovation activities. Section 6.6 provided a discussion about the reliability and validity of these measurements and assesses the appropriateness of the model to explain and predict the changes in companies´ willingness in the event of changes of the perception of their managers in respect to the willingness determinants.

6.1 To What Degree are Companies Willing to Engage in Green Chemistry and Green Engineering-Based Eco-Innovation Processes?

As noted in Section 3.2.1 of Chapter 3, according to Ajzen, (1991), Fishbein and Ajzen (1975) and Triandis (1977), the decision to engage in a behavior is mediated by the behavioral intention. That is, the individual's intention to perform a behavior is the immediate antecedent of the actual behavior performance. Intentions are assumed to capture the motivational factors that influence a behavior.

In this thesis research, intention was interpreted as the companies´, in the Brazilian petrochemical sector, willingness to engage in GCE-based eco-innovation activities. The degree of willingness, of the surveyed individuals in the sample, was assessed through the computation of the scores resulting from the response to the questions, in the thesis research´s quantitative questionnaire, on their willingness for such engagement.

The criteria used for measuring willingness, as well as all other variables in this Chapter, followed the measurement method that was used in the questionnaire construction (cf. Section 4.4.1 of Chapter 4). Osgood´s semantic differential technique was the standard technique that was used to measure the degree of influence that beliefs had on the intention to perform the eco-innovative behavior under study.

The semantic differential technique consisted of providing the respondent with one or more concepts and a set of bipolar adjectives based on which the respondent could make his or her judgment by rating each concept on each scale. In this thesis research, the concepts were judged according to opposing extreme adjectives (low-high, disagree-agree etc.) that were associated with scores that span from 1 to 7 (Figure 6.1).

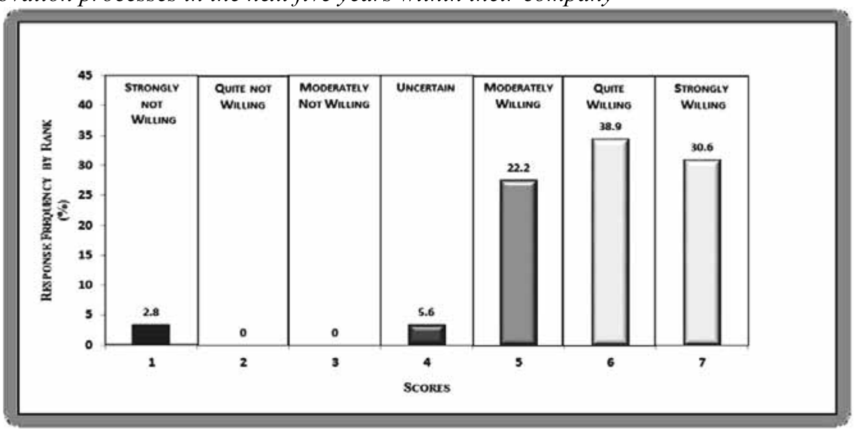
Figure 6.1- The terms, that describe the semantic differential scale scores in the questionnaire used in this research

Source: author

Following Montalvo Corral (2002), it was argued that the "low" and the "high" sides of the scale have a connotation associated with, respectively, the non-favorable and favorable preconditions that can induce the behavioral change.

In respect to managers´ and decision-makers´ willingness to engage in GCE eco-innovation processes, the survey results showed that 91.7 percent of the respondents (30.6 percent extremely, 38.9 quite and 22.2 percent moderately strong) demonstrated to be willing to engage in GCE-based eco-innovation processes. On the other hand, a much smaller percentage, 2.8 percent, presented a strong resistance towards such engagement. Finally, 5.6 percent were found to be uncertain. These figures are presented in Figure 6.2.

Figure 6.2- Willingness of questionnaire respondents to engage in GCE-based eco-innovation processes in the next five years within their company



Source: author

These results suggest that the GCE frameworks may have a favorable future in the Brazilian petrochemical sector as long as it is properly promoted and stimulated. This insight was underpinned not only by the factor that the majority of the respondents positioned themselves as strongly and quite willing to adopt the GCE principles and to engage in such innovation processes. It was also based on the potential engagement of the managers who are currently "only" moderately willing to incorporate GCE as one viable alternative towards a more sustainable chemical industry

The following sections present the preconditions that supported and catalyzed these results.

6.2 Mapping Behavioral Preconditions in the Attitude Domain

Section 6.2 presents an analysis on the attitudinal behavioral preconditions associated with the companies´ willingness to engage in GCE-based eco-innovation processes in the next five years.

6.2.1 Environmental Risk Perception

The environmental risk perception of the managers, in the Brazilian petrochemical sector, was assessed via the use of the scale developed by Slovic *et al*. (1984) presented in Section 5.2.2, in Chapter 5.

At this point, it is important to observe that the beliefs, originally presented in Chapter 5, were used in the development of the questions or statements, of this thesis research´s quantitative questionnaire, to assess managers´ perceptions. For practical reasons, they were presented again in Chapter 6 to promote a better and easier understanding of the survey results by making clear the association of the beliefs and survey respondents´ perceptions. The questions and the statements that compose the qualitative survey questionnaire are presented in their entirety in Appendix E.

The beliefs associated with environmental risk are presented in Table 6.2. Each of the items numbered *evr1* through *evr12* represents one question or a statement in the scale used to assess manager´s perceptions of the environmental risks (*evr*) at the behavioral domain´s scale level.

Table 6.2- Questions of the thesis research´s questionnaire used to assess managers´ perception of environmental risk

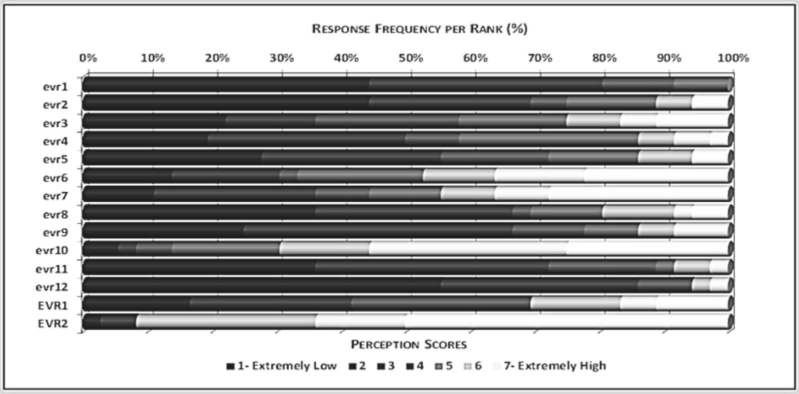
ENVIRONMENTAL RISK	Risk Perception		
•evr1	Controllable	1 2 3 4 5 6 7	Uncontrollable
evr2	Do not have global impacts	1 2 3 4 5 6 7	have global impacts
evr3	Consequences not fatal	1 2 3 4 5 6 7	Fatal consequences
evr4	Evenly distributed	1 2 3 4 5 6 7	Unevenly distributed
evr5	Low risk to future generations	1 2 3 4 5 6 7	High risk to future generations
evr6	Voluntary for those exposed	1 2 3 4 5 6 7	Involuntary for those exposed
evr7	Does not affect me	1 2 3 4 5 6 7	Affects me
evr8	Not observable	1 2 3 4 5 6 7	Observable
evr9	Known for those exposed	1 2 3 4 5 6 7	Unknown for those exposed
evr10	Delayed effects	1 2 3 4 5 6 7	Immediate effects
evr11	Old risks	1 2 3 4 5 6 7	New risks
evr12	Risks known to science	1 2 3 4 5 6 7	Risks unknown to science

Note: the notation *"evr"* refers to beliefs pertaining to the environmental risk realm upon which the questions or statements of this thesis research´s qualitative questionnaire were constructed
Source: Montalvo Corral (2002)

Figure 6.3 presents a condensed summary of the perceptions of the surveyed professionals in respect to the environmental risks currently associated to their companies´ operations.

The darker shades of the figure indicate the more unfavorable side of the scale in respect to the perception of environmental risks.

Figure 6.3- Results of this thesis research´s survey concerning the perception of managers´, in the Brazilian petrochemical sector, in respect to the environmental risks posed by their companies´ operations



Source: author

As shown in Figure 6.3, the perceptions of low environmental risks related to companies´ operations (products, processes and services) prevailed among the surveyed managers and influential decision-makers.

The results of detailed analyses of the contributions of each belief to such perception are presented in Table 6.3.

This table was developed to provide: (a) a macro (general) to a micro view (detailed) explanation of how managers reacted when confronted with issues associated with the environmental risks related to their companies´ operations, and (b) a direct and easy interpretation of the results.

In order to be in harmony with the theory and with the perceptions measurement method used in this research, the table was divided into two sub-tables. The first, presents a general and synthetic view of the overall results of the perceptions´ assessment. A detailed analysis of such general view is provided in the second sub-table. It presents the distribution of the strength of the each perception at the same time it points out how favorable or unfavorable their contributions are in respect to willingness formation. For a better visualization and interpretation of the results, the table highlights the relevant points by marking them in black.

Such favorable or unfavorable conditions were established based on the theory underpinning the Osgood´s semantic differential scales that were used to construct this thesis research´s questionnaire (cf. Chapter 4)[93]. As a rule, in this research, the scores obtained from the respondents´ answers showed that:

[93] Originally, the semantic differential method prescribes the use of scales composed by scores that vary from -3 to + 3. The scores ranging -3 to -1 represent the lower side of the scale. The scores ranging from 1 to 3

a) Scores from five to seven were considered to pertain to the positive side of the scale and, therefore, they were recognized as giving a positive contribution to willingness formation;
b) Scores from one to three were considered to pertain to the negative side of the scale and, therefore, they were recognized as giving a unfavorable contribution to willingness formation;
c) Scores with a value of four were considered to reflect managers´ uncertainty.

In the table, the most prevailing perceptions were marked in dark black. This allows the reader to easily understand how the managers perceived the environmental risks both at the beliefs (lower case letters - *evr*) and at the domain levels (capital letters – *EVR*). At the same time it permits the reader to directly interpret how each perception favored companies´ engagement in the behavior that is under study in this research (GCE-based eco-innovation).

In order to avoid unnecessarily repetitive explanations, it is important to note that the same method was used to present the results of responses, to this thesis research´s quantitative questionnaire, relative to the other behavioral domains and their respective beliefs.

Table 6.3– Detailed representation of the assessment of this thesis research´s survey in respect to the managers´ environmental risk perception

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Environmental Risks (%)			Detailed Assessment of the Perceptions of Environmental Risks (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
evr1- Controllable - Uncontrollable	91.7	8.3	0.0	44.4	36.1	11.1	8.3	0.0	0.0	0.0
evr2- Do not have global impacts - Have global impacts	75.0	13.9	11.1	44.4	25.0	5.6	13.9	5.6	0.0	5.6
evr3- Consequences not fatal - Fatal consequencesl	58.3	16.7	25.0	22.2	13.9	22.2	16.7	8.3	5.6	11.1
evr4- Evenly distributed - Unevenly distributed	58.3	27.8	13.9	19.4	30.6	8.3	27.8	5.6	5.6	2.8
evr5- Low risk to future generations - High risk to future generations	72.2	13.9	13.9	27.8	27.8	16.7	13.9	8.3	0.0	5.6
evr6- Voluntary for those exposed - Involuntary for those exposed	33.3	19.4	47.2	13.9	16.7	2.8	19.4	11.1	13.9	22.2
evr7- Does not affect me - Affects me	44.4	11.1	44.4	11.1	25.0	8.3	11.1	8.3	8.3	27.8
evr8- Not observable - Observable	69.4	11.1	19.4	36.1	30.6	2.8	11.1	11.1	2.8	5.6
evr9- Known for those exposed - Unknown for those exposed	77.8	8.3	13.9	25.0	41.7	11.1	8.3	5.6	8.3	0.0
evr10- Delayed effects - Immediate effects	13.9	16.7	69.4	5.6	2.8	5.6	16.7	13.9	30.6	25.0
evr11- Old risks - New risks	88.9	2.8	8.3	36.1	36.1	16.7	2.8	5.6	2.8	0.0
evr12- Risks known to science - Risks unknown to science	94.4	0.0	5.6	55.6	30.6	8.3	0.0	2.8	2.8	0.0
Overall response percentage per rank	64.8	12.5	22.7	28.5	26.4	10.0	12.5	7.2	6.7	8.8
EVR1- Direct measure of environmentl risk at the domain level	69.4	0.0	30.6	16.67	25.00	27.78	0.00	11.11	5.56	11.11
EVR2- Direct measure of environmentl risk at the domain level	8.3	0.0	91.7	2.78	5.56	0.00	0.00	27.78	13.89	50.00

Source: author

Data in Table 6.3 provided detailed information on how managers´ perceived each of the beliefs associated with the environmental risks produced by their companies´ operations.

represent the higher side of the scale. Scores with the zero values are considered uncertain. In order to adapt the method to this thesis research purposes, and to provide an easier way to operationalize the questionnaire and to interpret the results, modified seven point scales were used. In this case, the scores values were assumed to vary from 1 to 7 with a "uncertain" midpoint at 4.

The overall response percentage per rank of the results indicated that based on their beliefs, the managers perceived that the environmental risks associated with their companies' operations were predominantly extremely and quite low. According to what was proposed in Chapter 5, it was expected that such a low perception of environmental risks would not provide adequate contributions to the formation of managers´ willingness to deliberately engage in GCE-based eco-innovation processes. This was indicated by the detailed assessment of these levels of perception in which the majority of the answers were classified as extremely and quite unfavorable to the development of willingness.

It was expected that the stronger the managers perceptions that their companies' operations were risky, the stronger would be their willingness to engage in eco-innovation activities.

Complementarily, it is important to observe the relevant degree of uncertainty that managers presented in respect to such environmental risks.

In respect to the results produced by the direct question (*EVR1*) at the behavioral domain level, they showed that 69.4 percent of the managers perceived the environmental risk produced by their companies to be low (16.67 percent extremely low and 25 percent quite low and 27.78 moderately low). On the other hand, a total of 22.7 percent perceived these risks as being high.

One interesting finding from the results is that, although the respondents perceived that the environmental risks posed by their companies was low, 91.7 percent of them believed that GCE-based innovation processes are very important to solve or diminish the environmental challenges faced by their companies (*EVR2*).

6.2.2 Economic Risk Perception and Business Opportunities

As noted in Chapter 5, in order to define and operate the concept of economic risk and business opportunity, within the context of eco-innovative activities, four main areas for which possible gains and losses from which eco-innovative technologies may arise were proposed (economic opportunity, appropriability, technological risk, and financial risk). These areas provided a framework that enabled the identification of the sources of uncertainty and risk, in the organizational set, which may have influence in attitude formation,

Each subdomain encompassed a series of beliefs that may be held by managers, in the industrial organization, in relation to the economic risks and business opportunity associated with innovating in GCE. Each belief was assessed *via* its incorporation in this thesis research quantitative survey´s questionnaire in the form of a question or a statement. These four areas as well as their respective beliefs are shown inTable 6.4.

Table 6.4- Beliefs and that were used to assess the economic risks of innovating in GCE

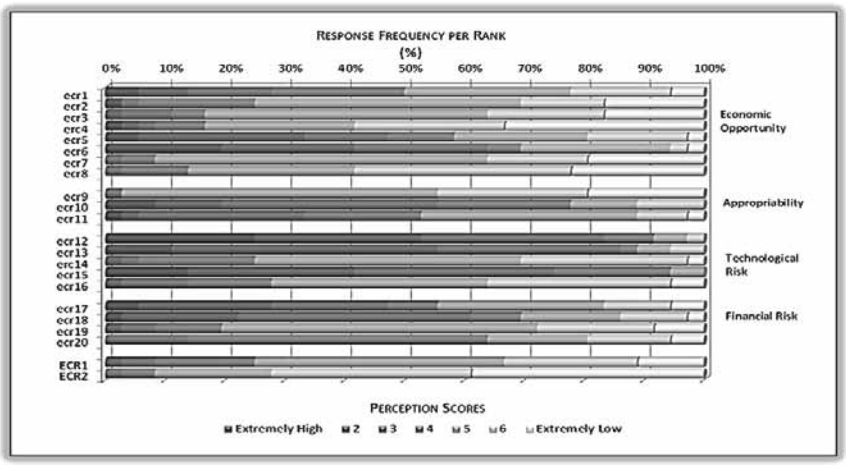
ECONOMIC RISKS AND BUSINESS OPPORTUNITIES

- **ECONOMIC OPPORTUNITY**
  - ecr1- Market niche opportunity loss
  - ecr2- Regulatory risk
  - ecr3- Distribution and novelty effects
  - ecr4- Entry timing
  - ecr5- Pioneer vs. Follower
  - ecr6- Customers expectancies (willingness to pay)
  - ecr7- Growth opportunities
  - ecr8- Market uncertainty
- **APPROPRIABILITY**
  - ecr9- Appropriability conditions
  - ecr10- Subcontracting risks
  - ecr11- Alliance risk (loss of technological control)
- **TECHNOLOGICAL RISK**
  - ecr12- R&D requirements
  - ecr13- R&D costs
  - ecr14- Economic resources availability
  - ecr15- Project life time
  - ecr16- Uncertainty of achievement and discovery
- **FINANCIAL RISK**
  - ecr17- Management uncertainty
  - ecr18- Resources uncertainty
  - ecr19- Capital risks
  - ecr20- Competitiveness uncertainty

Source: Montalvo Corral (2002)
Note: the notation *"ecr"* refers to beliefs pertaining to the economic risk and business opportunities realm upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: adapted from Montalvo Corral (2002)

Figure 6.4 presents a condensed summary of the perceptions of the surveyed professionals in respect to the economic risk and business opportunities currently associated to the engagement of their companies in GCE-based eco-innovation processes. The darker nuances indicate the more unfavorable side of the scale in respect to the perception of environmental risks.

Figure 6.4- Results of this thesis research´s survey concerning the perception of managers´, in the Brazilian petrochemical sector, in respect to the economic risk and business opportunities relative to eco-innovation processes



Source: author

In general terms, the predominance of the lighter shades of the bars in Figure 6.4, shows that the perceptions of the surveyed managers, regarding the beliefs that compose the economic risk and business opportunities scales, favored the development of willingness towards their companies´ engagement in GCE-based eco-innovation processes. It was expected that, the stronger managers´ perceptions that their companies' engagement in such processes did not generate economic risks and promoted business opportunities, the stronger would be their willingness to engage in eco-innovation activities.

Economic Opportunity

A detailed assessment of managers´ perceptions of the economic opportunities generated by eco-innovation is presented in Table 6.5.

Table 6.5- Detailed representation of the results of this thesis research´s survey in respect to the managers´ perceptions of economic risk and business opportunities in respect to GCE-based eco-innovation

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perception of Economic Opportunities (%)			Detailed Assessment of the Perception of Economic Opportunities (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
ecr1- Market niche opportunity loss	27.8	22.2	50.0	5.6	8.3	13.9	22.2	27.8	16.7	5.6
ecr2- Regulatory risk	5.6	19.4	75.0	2.8	0.0	2.8	19.4	44.4	13.9	16.7
ecr3- Distribution and novelty effects	11.1	5.6	83.3	0.0	2.8	8.3	5.6	47.2	19.4	16.7
ecr4- Entry timing	8.3	8.3	83.3	2.8	2.8	2.8	8.3	25.0	25.0	33.3
ecr5- Pioneer vs. Follower	47.2	11.1	41.7	5.6	27.8	13.9	11.1	22.2	16.7	2.8
ecr6- Customers expectancies (willingness to pay)	63.9	5.6	30.6	19.4	22.2	22.2	5.6	25.0	2.8	2.8
ecr7- Growth opportunities	2.8	5.6	91.7	0.0	0.0	2.8	5.6	55.6	16.7	19.4
ecr8- Market uncertainty	2.8	11.1	86.1	0.0	0.0	2.8	11.1	27.8	36.1	22.2
Overall response percentage per rank	21.2	11.1	67.7	4.5	8.0	8.7	11.1	34.4	18.4	14.9

Source: author

The results show that managers´ perceptions related to the beliefs associated with the economic opportunities that may be produced by their companies´ engagement in GCE-based eco-innovation processes were mostly positive and were classified as moderately to quite favorable to willingness formation[94].

An exception was made in regard to two beliefs. The first was related to the companies´ expectation in respect to customers' willingness to pay more for eco-innovative products and services (*ecr6*). According to their perceptions, such customers´ current willingness to pay more is not strong enough to push companies to innovate. (b) The second relates to the companies´ pioneer/follower character (*ecr5*). In this respect, companies were found be quite divided. In the one hand, 41.7 percent of the surveyed managers saw their companies as being pioneers. On the other hand, 47.2 percent perceived their companies as being followers.

Such follower character of companies could make the pace of introduction of GCE-based eco-innovations to be slower and therefore, some economic opportunities could be lost.

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[94] Following the TPB (Chapter 2), in this thesis research, willingness formation refers to the development of behavioral intention (willingness) as a function of its determinants. That is, its underlying beliefs.

Once again, in some instances, the answers indicated the number of managers who reported to be uncertain in respect to some beliefs.

Appropriability

Appropriability is understood as being the benefits of R&D and/or of investment in innovative new technologies, which can be secured by various mechanisms such as patents, licensing and transfer of technology. In this respect, the perceived economic risks associated with appropriability were considered to be mainly related to companies´ loss of control over their own knowledge and technology due to outsourcing processes via alliances or subcontracting.

Table 6.6 presents a detailed analysis of how managers perceived each of the beliefs that are associated with the appropriability of the benefits of GCE-based eco-innovation as well as the intensity that they contribute to willingness formation.

Table 6.6- Detailed representation of the results of this thesis research´s survey results in respect to the managers´ perceptions of appropriability of the benefits of CGE based eco-innovation

Questions of the Questionnaire/Beliefs	Overall Assessment of of the Perceptions of the Appropriability of Benefits of Eco-Innovation (%)			Detailed Assessment of of the Perceptions of the Appropriability of Benefits of Eco- Innovation (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
ecr9- Appropriability conditions	2.8	0.0	**97.2**	0.0	0.0	2.8	0.0	**52.8**	**25.0**	19.4
ecr10- Subcontracting risks	**55.6**	22.2	22.2	8.3	**11.1**	**36.1**	22.2	11.1	11.1	0.0
ecr11- Alliance risk (loss of technological control)	33.3	19.4	**47.2**	2.8	2.8	27.8	19.4	**36.1**	8.3	2.8
Overall response percentage per rank	**30.6**	**13.9**	**55.6**	**3.7**	**4.6**	**22.2**	**13.9**	**33.3**	**14.8**	**7.4**

Source: author

In respect to the appropriability of the benefits of innovation, the results showed that the surveyed managers´ perceptions regarding two out of the three beliefs that composed this scale contributed moderately to quite favorably to the development of willingness towards their companies´ engagement in GCE-based eco-innovation activities.

An exception was made to the perceptions regarding the risks of confidentiality breach due to the use, in processes of eco-innovation, of workforces that are external to the companies (*ecr10*). In this case, 55.6 percent of the managers perceived that such risks exist in moderate to quite high degree.

Again, the levels of uncertainty related to some beliefs were demonstrated to be relevant and should be taken into account during the design of eco-innovation related policies and strategies.

Technological Risks

In the context of this research, the Technological Risks were understood as the amount of R&D required, the costs involved, the time required to develop new technologies (both developed by the company itself or through alliances), the availability and the opportunity of economic resources and the compound uncertainties that are associated with new products and processes.

A detailed presentation of the perceptions of the managers concerning the beliefs associated with the GCE-based eco-innovation processes is presented in Table 6.7.

Table 6.7- Detailed representation of the results of this thesis research´s survey in respect to the managers´ perceptions of the technological risks associated with GCE-based eco-innovation

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Techlogical Risks (%)			Detailed Assessment of the Perceptions of Technological Risks (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
ecr12- R&D requirements	83.3	8.3	8.3	25.0	27.8	30.6	8.3	5.6	2.8	0.0
ecr13- R&D costs	86.1	2.8	11.1	11.1	44.4	30.6	2.8	5.6	5.6	0.0
ecr14- Economic resources availability	5.6	19.4	75.0	0.0	2.8	2.8	19.4	44.4	27.8	2.8
ecr15- Project life time	75.0	19.4	5.6	13.9	27.8	33.3	19.4	5.6	0.0	0.0
ecr16- Uncertainty of achievement and discovery	13.9	13.9	72.2	0.0	2.8	11.1	13.9	36.1	30.6	5.6
Overall response percentage per rank	52.8	12.8	34.4	10.0	21.1	21.7	12.8	19.4	13.3	1.7

Source: author

The overall assessment of the technological risks associated with GCE-based eco-innovation showed that the answers of 52.8 percent of the managers were unfavorable to the willingness formation. Only 34.4 percent of the responses demonstrated that they contribute positively to the development of willingness.

In opposition to this overall view, a detailed assessment indicated that the managers felt confident that their companies could bear the cost of eco-innovating (*ecr14*) at the same time that they were confident about the potential successfulness of their companies in finding the appropriate technological paths to fulfill their needs (e*cr16*).

Financial Risk

Financial risk connotes the possible losses of profits and capital. Four behavioral beliefs emerged in this domain. The first, concerned the timing of resource availability. This was followed by the possibility of the loss of capital investment on R&D and finally the reduction of competitiveness due to the increase in fixed costs.

Table 6.8- Detailed representation of the results of this thesis research´s survey in respect to the managers´ perceptions of the financial risks associated with GCE-based eco-innovation

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Financial Risks (%)			Detailed Assessment of the Perceptions of Financial Risks (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
ecr17- Management uncertainty	47.2	8.3	44.4	5.6	22.2	19.4	8.3	27.8	11.1	5.6
ecr18- Resources uncertainty	61.1	8.3	30.6	2.8	19.4	38.9	8.3	16.7	11.1	2.8
ecr19- Capital risks	8.3	11.1	80.6	0.0	2.8	5.6	11.1	52.8	19.4	8.3
ecr20- Competitiveness uncertainty	13.9	50.0	36.1	0.0	0.0	13.9	50.0	16.7	13.9	5.6
Overall response percentage per rank	32.6	19.4	47.9	2.1	11.1	19.4	19.4	28.5	13.9	5.6
ECR1- Direct measure of economic risk and business opportunities at the domain level	8.3	16.7	75.0	0.0	2.8	5.6	16.7	41.7	22.2	11.1
ECR2- Direct measure of economic risk and business opportunities at the domain level	2.8	5.6	91.7	0.0	0.0	2.8	5.6	19.4	33.3	38.9

Source: author

Table 6.8 indicates that, in general, although the results showed a prevalence of answers that were supportive to willingness development as compared to those that were unfavorable, the total number of answers that were unfavorable plus those that indicated that managers were uncertain surpassed the favorable ones.

A look into the detailed assessment of the managers' perceptions indicated the existence of barriers to willingness formation that arose from:

a) The perceptions related to resources uncertainty (*ecr18*), which were classified as quite (19.2 percent) to moderately (38.9 percent) unfavorable. Resources uncertainty regards to The likelihood of the company loses, due to turnover, of trained human resources who hold the required knowledge for the development of more sustainable and cleaner technological solutions for its environmental and economic challenges, and
b) Managers' perceptions of the likelihood that the GCE-based eco-innovation investments could affect their companies´ fixed costs, and therefore, could influence their company's global competitiveness (*ecr17*). They were almost equally divided in their answers with forty-seven percent of them who answered that this is likely to occur as opposed to forty four percent who had the contrary perceptions.

A great relevance can be attributed to the degree of uncertainty (50 percent) demonstrated by managers in respect to the likelihood of their companies to lose their investment in case of unsuccessful GCE-based eco-innovation outcomes (*ecr20*).

In respect to the direct measures of economic risks and business opportunities, conducted at the domain level, the results showed that, in general, the managers in the Brazilian petrochemical sector revealed perceptions that GCE-based eco-innovation can promote business opportunities at the same time that it represents economic risks at acceptable levels.

In this respect, the direct measure of the economic risk (*EVR1*) showed that 75 percent of the respondents thought that eco-innovating in GCE can produce a high degree of economic benefits for their company as opposed to 8.3 percent who perceived that this will lead to economic losses.

On the other hand, 91.7 percent agreed that the existence currently and in the future, of business opportunities for companies that are more environmentally sustainable, justify the engagement of their companies in GCE-based eco-innovation activities (*ECR2*).

Summary

In general, the professionals who participated in the survey perceived that the environmental risks that were faced or produced by their companies were low. Despite this, perception of low risk, they very much acknowledged that eco-innovating in GCE is an important approach for their companies to achieve higher states of sustainability and lower environmental risks.

In respect to economic risks, the evidence provided by the managers´ general perceptions indicated that the economic risks associated with engaging in GCE-based eco-innovation processes are low. They believed that their companies can take advantages of market opportunities by eco-innovating in GCE and profit from the moderately low appropriability risks that are associated with it. Complementarily, the majority of the respondents believed that, although they are confident in their companies´ capability to innovate in GCE, they perceived that there may be technological risks. On the other hand, despite high uncertainty in how GCE-based investments could affect the fixed costs of the companies and their competiveness, in general terms, it was commonly perceived that the financial risks range from quite to moderately low.

In light of these arguments, it was suggested that the conjunction of high market opportunities, moderately low risk of appropriability and low financial risk represent positive pre-dispositional factors, or attitudes, towards companies' potential engagement in implementing GCE-based eco-innovation processes.

6.3 Mapping Behavioral Preconditions Generated by the Perceived Social and Personal Pressures

Section 6.3 presented the assessment of the behavioral preconditions, based on the social and personal realms that can influence companies´ willingness to engage in GCE-based eco-innovation processes.

6.3.1 Perceived Social Norm (Social Pressure)

As noted in Section 5.2.2 of Chapter 5, according to Montalvo Corral (2002), the sources of social influence span a variety of agents and institutions, such as competitors, customers, legal requirements, employees, shareholders, general public, NGOs, to cite a few. In the context of GCE-based eco-innovation in the industrial sector, it was proposed that the possible sources of social pressure can be classified into three groups: (a) the market, (b) the communities directly related to the firm and (c) the regulatory regime.

Market Pressure

Perception of market pressures were identified to originate from three main sources: (a) the competitive context in which the company operates, (b) the need for companies to be followers and/or pioneers, and (c) the customers' demands (cf. Chapter 5).

Table 6.9- Possible sources of social pressure that might arise from the market in respect to the adoption, by companies, of cleaner and more sustainable technologies for their products, processes and services

SOCIAL NORM **Social Pressure - Market Pressure**

- COMPETITIVE CONTEXT
  - mp1- Pace of technical change
  - mp2- Competitors' behavior
  - mp3- Competition drive
  - mp4- Market competition
  - mp5- Sector dynamism
  - mp6- Market heterogeinity
- PIONEER-FOLLOWER
  - mp7- Pioneer in product technology
  - mp8- Pioneer in process technology
  - mp9- Follower in innovation
- CONSUMERS
  - mp10- Consumer expectations
  - mp11- Future consumers pressure
  - mp12- Motivation to comply with consumers

Note: the notation *"mp"* refers to beliefs pertaining to the market pressure realm upon which the questions or statements of this thesis research´s questionnaire were constructed.

Source: adapted from Montalvo Corral (2002)

Table 6.10 presents a detailed analysis of how managers perceived each of the beliefs that are associated with the market pressures towards companies´ adoption of cleaner and more sustainable technologies for their products, processes and services as well as how they contribute to willingness formation.

Table 6.10- Detailed representation of the results of this thesis research´s survey in respect to the managers´ perceptions of the market pressures associated with companies´ adoption of cleaner and more sustainable technologies for products, processes and services

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Market Pressures (%)			Detailed Assessment of the Perceptions of Market Pressures (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
Competitive Context										
mp1- Pace of technical change	8.3	0.0	91.7	0.0	2.8	5.6	0.0	38.9	27.8	25.0
mp2- Competitors' behavior	8.3	13.9	77.8	0.0	8.3	0.0	13.9	47.2	16.7	13.9
mp3- Competition drive	8.3	11.1	80.6	0.0	5.6	2.8	11.1	38.9	19.4	22.2
mp4- Market competition	8.3	11.1	80.6	2.8	2.8	2.8	11.1	25.0	30.6	25.0
mp5- Sector dynamism	11.1	5.6	83.3	0.0	5.6	5.6	5.6	36.1	27.8	19.4
mp6- Market heterogeinity	13.9	8.3	77.8	0.0	8.3	5.6	8.3	36.1	16.7	25.0
Overall response percentage per rank	9.7	8.3	81.9	0.5	5.6	3.7	8.3	37.0	23.1	21.8
Pioneer-Follower										
mp7- Pioneer in product technology	16.7	13.9	69.4	0.0	0.0	16.7	13.9	19.4	38.9	11.1
mp8- Pioneer in process technology	22.2	8.3	69.4	0.0	2.8	19.4	8.3	22.2	30.6	16.7
mp9- Follower in innovation	13.9	11.1	75.0	0.0	2.8	11.1	11.1	25.0	38.9	11.1
Overall response percentage per rank	17.6	11.1	71.3	0.0	1.9	15.7	11.1	22.2	36.1	13.0
Consumer Pressure										
mp10- Consumer expectations	19.4	25.0	55.6	2.8	5.6	11.1	25.0	27.8	22.2	5.6
mp11- Future consumers pressure	11.1	8.3	80.6	0.0	2.8	8.3	8.3	25.0	25.0	30.6
mp12- Motivation to comply with consumers	0.0	11.1	88.9	0.0	0.0	0.0	11.1	30.6	38.9	19.4
Overall response percentage per rank	10.2	14.8	75.0	0.9	2.8	6.5	14.8	27.8	28.7	18.5

Source: author

The results of this thesis research´s survey, presented in Table 6.10, showed that the managers´ perceptions related to their beliefs associated with the pressures that may arise from the market mostly favored the development of willingness to engage in GCE-based eco-innovation processes.

This can be observed based upon the overall response rate, percentage for the three scales that are associated with the perceived market pressures:

a) In respect to the competitive context scale, the responses that moderately contributed to willingness formation (37.0 percent) were superimposed by the sum of the ones that contributed at the quite and extremely strong levels (23.1 and 21.8 percent respectively);
b) Regarding the pioneer-follower character of the companies, 36.1 percent of the answers supported the development of willingness quite strongly. This was followed by 22.2 percent, which influenced willingness moderately. Thirteen percent favored willingness in an extremely strong way, and
c) The results to questions or statements related to the beliefs associated with consumers´ pressures revealed that the answers were almost equally supportive to willingness formation at the moderately and quite strong levels (27.8 and 28.7

percent respectively). On the other hand 18.5 percent supported willingness formation in an extremely strong way.

It is important to observe the overall levels of uncertainty that were revealed by the survey in regard to the beliefs associated with the pioneer-follower and consumers pressure scales, which presented values above 10 percent. Special attention was given to the degree of managers´ uncertainty in respect to consumers´ expectations about the adoption, by the companies, of cleaner and more sustainable technologies for their products, processes and services (*mp10*) such as those that are developed based on the principles of GCE.

Although the pioneer-follower scale showed that most answers were predominantly supportive of willingness formation, it was detected that some companies were in a slow pace in respect to the development of product (*mp7* - 16.7 percent) and process (*mp8* - 19.4 percent) technology as well as in respect to innovation processes (*mp9* – 11.1 percent).

Community Pressure

The idea of community pressure, concerning environmental protection in the industrial set, may be conceived and synthesized by the concept of "social license to operate" under which companies should perform their activities. That is, companies are constrained to meet the expectations of societies and to avoid activities that they (or influential elements within them) deem unacceptable (cf. Chapter 5).

Table 6.11 listed the beliefs, which may be held by managers, in the industrial organization, in relation to the perceived community pressures towards companies´ adoption of GCE-based cleaner products and production processes

Table 6.11- Possible sources of social pressure that might arise from the community in respect to the adoption, by companies, of cleaner and more sustainable technologies for their products, processes and services

SOCIAL NORM — **Social Pressure – Community Pressure**

- MANAGERS´ PERSONAL IMPORTANT REFERENTS
  - cp1- Manager's conciousness
  - cp2- Managers close personal relationships
- FIRMS´ IMPORTANT EXTERNAL REFERENTS
  - cp3- Outsiders social norms
  - cp4- Outsiders pressure capabilities
  - cp5- Environmental experts norm agreement
  - cp6- Perceived pressure from experts
  - cp7- Motivation to comply with experts
- PERCEIVED COMMUNITY PRESSURE
  - cp8- Community expectations
  - cp9- Compliance with community demands
  - cp10- Community current lobbying capability
  - cp11- Community future lobbying capability
  - cp12- NGO's pressure
- FIRMS´ IMPORTANT INTERNAL REFERENTS
  - cp13- Important staff
  - cp14- Staff capabability pressure
  - cp15- Motivation to comply with staff pressure

Note: the notation *"cp"* refers to beliefs pertaining to the community pressure realm upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: adapted from Montalvo Corral (2002)

Table 6.12 presents the results of a detailed analysis of how managers perceived each of the beliefs that are associated with the community pressures towards companies´ adoption of cleaner and more sustainable technologies for their products, processes and services as well as how they contribute to willingness formation.

Table 6.12- Detailed representation of the results of this thesis research´s survey in respect to the managers´ perceptions of the community pressures associated with companies´ adoption of cleaner and more sustainable technologies for products, processes and services

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Community Pressures (%)			Detailed Assessment of the Perceptions of Community Pressures(%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
Managers´ Personal Important Referents										
cp1- Manager's counciousness	5.6	0.0	94.4	0.0	0.0	5.6	0.0	38.9	38.9	16.7
cp2- Managers close personal relationships	13.9	16.7	69.4	5.6	2.8	5.6	16.7	25.0	25.0	19.4
Overall response percentage per rank	**9.7**	**8.3**	**81.9**	**2.8**	**1.4**	**5.6**	**8.3**	**31.9**	**31.9**	**18.1**
Firms´ Important External Referents										
cp3- Outsiders social norms	16.7	16.7	66.7	5.6	0.0	11.1	16.7	27.8	27.8	11.1
cp4- Outsiders pressure capabilities	13.9	16.7	69.4	2.8	0.0	11.1	16.7	16.7	44.4	8.3
cp5- Environmental experts norm agreement	13.9	8.3	77.8	2.8	8.3	2.8	8.3	19.4	22.2	36.1
cp6- Perceived pressure from experts	16.7	11.1	72.2	5.6	5.6	5.6	11.1	22.2	27.8	22.2
cp7- Motivation to comply with experts	27.8	13.9	58.3	2.8	8.3	16.7	13.9	19.4	27.8	11.1
Overall response percentage per rank	**17.8**	**13.3**	**68.9**	**3.9**	**4.4**	**9.4**	**13.3**	**21.1**	**30.0**	**17.8**
Perceived Community Pressure										
cp8- Community expectations	27.8	22.2	50.0	5.6	2.8	19.4	22.2	13.9	22.2	13.9
cp9- Compliance with community demands	16.7	11.1	72.2	0.0	2.8	13.9	11.1	22.2	33.3	16.7
cp10- Community current lobbying capability	41.7	27.8	30.6	2.8	5.6	33.3	27.8	8.3	19.4	2.8
cp11- Community future lobbying capability	19.4	19.4	61.1	2.8	2.8	13.9	19.4	22.2	27.8	11.1
cp12- NGO's pressure	25.0	8.3	66.7	8.3	2.8	13.9	8.3	33.3	19.4	13.9
Overall response percentage per rank	**26.1**	**17.8**	**56.1**	**3.9**	**3.3**	**18.9**	**17.8**	**20.0**	**24.4**	**11.7**
Firms´ Important Internal Referents										
cp13- Important staff	13.9	16.7	69.4	2.8	2.8	8.3	16.7	19.4	36.1	13.9
cp14- Staff capability pressure	16.7	8.3	75.0	2.8	2.8	11.1	8.3	33.3	33.3	8.3
cp15- Motivation to comply with staff pressure	13.9	2.8	83.3	0.0	0.0	13.9	2.8	13.9	44.4	25.0
Overall response percentage per rank	**14.8**	**9.3**	**75.9**	**1.9**	**1.9**	**11.1**	**9.3**	**22.2**	**38.0**	**15.7**

Source: author

The results presented in Table 2.16 showed that the answers provided by the surveyed managers in respect to their beliefs related to all four scales that constitute the social pressure realm, were mostly quite and moderately strongly supportive to willingness formation.

An exception was made to the community's current lobbying capability (*cp10*), which was reported as moderately low towards pushing companies to adopt GCE-based cleaner production processes.

Once again, uncertainty was found to be significantly high especially with regard to the beliefs pertaining to the firm´s important external referents and the perceived community pressure scales.

Regulatory Pressure

In the industrial set, regulatory pressures in the environmental domain refers to how managers perceive that regulations affect their companies´ business and the degree to

which their important referents, in the regulatory and in the business domains, influence them to perform innovative eco-environmental behaviors.
Table 6.13 listed the beliefs that managers may hold that in the industrial organization, in relation to the perceived regulatory pressures towards companies´ adoption of cleaner products and production processes.

Table 6.13- Possible sources of social pressure that might arise from the regulators, from the companies´ representative organizations and agreements in respect to the adoption, by companies, of cleaner and more sustainable technologies for their products, processes and services

SOCIAL NORM **Social Pressure - Regulatory Pressure**

- **REGULATORS**
    - **rp1- Environmental agencies**
    - **rp2- Risk of future regulations**
    - **rp3- Regulators´ enforcement capability**
    - **rp4- Motivation to comply with regulators**
- **NATIONAL AND INTERNATIONAL STANDARDS, TRADE ORGANIZATIONS AND AGREEMENTS**
    - **rp5- Influence exerted by ISO, ICCA and ABIQUIM**
    - **rp6- Motivation to comply with ISO, ICCA and ABIQUIM**
    - **rp7- National and international agreements**

Notes:
The notation *"rp"* refers to beliefs pertaining to the regulatory pressure realm upon which the questions or statements of this thesis research´s questionnaire were constructed.
ABIQUIM: Brazilian Chemical Industry Association
ICCA: The International Council of Chemical Associations
ISO: International Organization for Standardization
Source: adapted from Montalvo Corral (2002)

Table 6.14 presented a detailed analysis of how managers perceived each of the beliefs that are associated with the regulatory pressures towards companies´ adoption of cleaner and more sustainable technologies for their products, processes and services as well as how they contribute to their willingness formation.

Table 6.14- Detailed representation of the results of this thesis research´s survey in respect to the managers´ perceptions of the market pressures associated with companies´ adoption of cleaner and more sustainable technologies for products, processes and services

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Regulatory Pressure (%)			Detailed Assessment of the Perceptions of Regulatory Pressure (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
Regulators										
rp1- Environmental agencies	16.7	22.2	61.1	0.0	2.8	13.9	22.2	30.6	25.0	5.6
rp2- Risk of future regulations	8.3	5.6	86.1	0.0	2.8	5.6	5.6	19.4	25.0	41.7
rp3- Regulators' enforcement capability	13.9	13.9	72.2	2.8	0.0	11.1	13.9	30.6	25.0	16.7
rp4- Motivation to comply with regulators	5.6	5.6	88.9	2.8	0.0	2.8	5.6	13.9	36.1	38.9
Overall response percentage per rank	11.1	11.8	77.1	1.4	1.4	8.3	11.8	23.6	27.8	25.7
National and International Standards, Trade Organizations and Agreements										
rp5- Influence exerted by ISSO, ICCA and ABIQUIM	16.7	5.6	77.8	0.0	5.6	11.1	5.6	25.0	33.3	19.4
rp6- Motivation to comply with ISSO, ICCA and ABIQUIM	2.8	0.0	97.2	2.8	0.0	0.0	0.0	33.3	25.0	38.9
rp7- National and international agreements	11.1	16.7	72.2	2.8	2.8	5.6	16.7	36.1	19.4	16.7
Overall response percentage per rank	10.2	7.4	82.4	1.9	2.8	5.6	7.4	31.5	25.9	25.0
SP- Direct measure of social pressure at the domain level	19.4	8.3	72.2	2.8	2.8	13.9	8.3	30.6	25.0	16.7

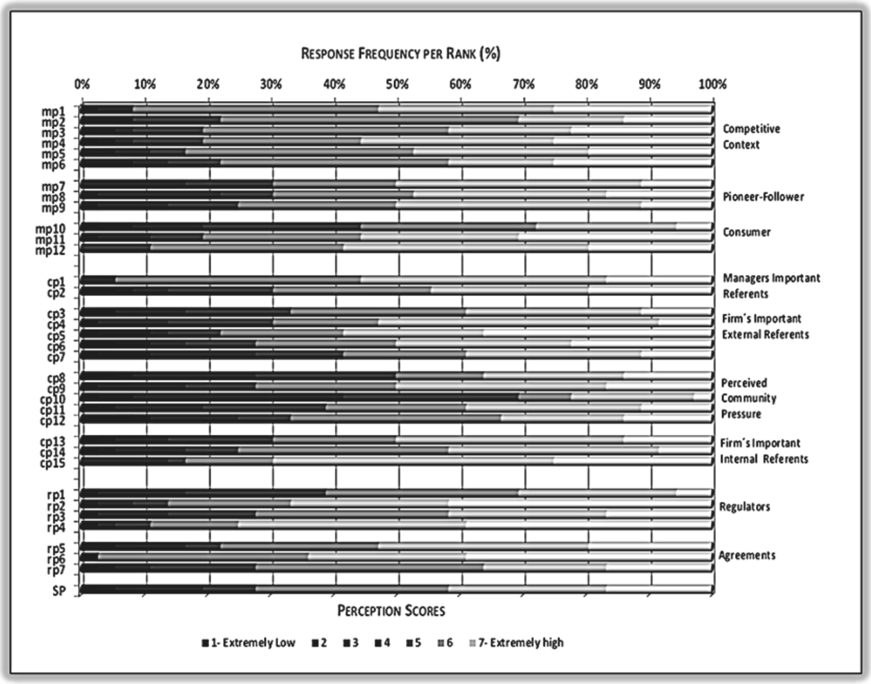
Source: author

In the case of the beliefs pertaining to the regulatory pressures that may influence companies' willingness to engage in GCE-based eco-innovation processes, the overall response percentage for these results showed that managers' perceptions were widely favorable. In the same level of analysis, the detailed assessment of managers´ perceptions, in Table 6.14, showed that the strength of such favorableness was much equally distributed among the three classes (moderately, quite and extremely strong) that compose the measurement scale.

In addition, a significant percentage of the managers were uncertain in respect to beliefs such as the degree to which: (a) regulators think that their companies should develop/adopt cleaner and more sustainable products and processes (*rp1*), (b) the environmental authorities have the necessary legal means and the capability to force the companies to adopt products and production processes that are cleaner and more sustainable (*rp3*), and the likelihood that new agreements and programs, developed at national and international levels, with focus on the environmental and economic sustainability of the petrochemical industry will, in the next five years, exert pressures that can push your company to engage in GCE-based eco-innovation processes (*rp7*).

Figure 6.5 presented a summary of the perceptions of the surveyed professionals in respect to the social pressures associated to the engagement of their companies in GCE-based eco-innovation processes. The darker shades of the graph indicate the more unfavorable side of the scale in respect to the perception of environmental risks

Figure 6.5- Results of this thesis research´s survey concerning the perception of managers´, in the Brazilian petrochemical sector, in respect to the social pressures related to companies´ adoption of cleaner and more sustainable products, processes and services



Source: author

Summary

Overall results from this thesis research´s survey regarding the pressures arising from the market, the community and from the regulatory organizations indicated that these pressures can contribute to the development of manager´s willingness to develop/adopt cleaner and more sustainable GCE-based products and processes technologies.

In parallel, it was found that, in the managers´ perspectives, companies were predisposed to comply with the environmental demands arising from the market, from society and from the regulatory and agreements demands, which, in the end, are likely to push their firms to engage in GCE-based eco-innovation processes.

In general, these responses at the scales level were confirmed by the direct measures at the domains level (*SP*). In this respect 72 percent of the managers (16.7 percent extremely, 25 percent quite and 30.6 moderately strong) perceived that these social pressures were likely to push their companies, in the next five years, to engage in eco-innovation activities such as those that are based on GCE

6.3.2 Perceived Social Norm (Roles Beliefs)

In this thesis research, the roles beliefs are those professional roles associated with managers' engagement in eco-innovative activities (eco-behavior). Roles beliefs are associated with managers' perception of correctness of the performance of such behavior by someone occupying his or her position, or function, in the company

Table 6.15 lists the beliefs that may be held by managers, in the industrial organization, in relation to their perceived professional roles towards companies´ adoption of cleaner products and production processes such as those that are based on the principles that are established by the GCE framework.

Table 6.15- Possible sources of pressures that might arise from manager's professional roles in respect to their engagement in Green Chemistry and Green Engineering-based eco-innovation processes

SOCIAL NORM Role Beliefs

- ACCEPTANCE OF CLEANER PRODUCTION
  - rlp1- Regulation
  - rlp2- Green market expansion
  - rlp3- Quality and technical efficiency considerations
  - rlp4- The culture and values within organizations

Note: the notation *"rlp"* refers to beliefs pertaining to the professional roles realm upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: author

Table 6.16 presents a detailed analysis of how managers perceived each of the beliefs that are associated with their professional roles.

Table 6.16 - Detailed representation of the results of this thesis research´s survey in respect to the managers´ perceptions of their professional roles associated their

engagement in Green Chemistry and Green Engineering based eco-innovation processes in the search for technologically more advanced and sustainable states

Questions of the Questionnaire/Beliefs	Overall Assessment of Managers´ Professional Roles (%)			Detailed Assessment of Managers´ Professional Roles (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
rlp1- Regulation	2.8	2.8	94.4	0.0	2.8	0.0	2.8	11.1	13.9	69.4
rlp2- Green market expansion	0.0	0.0	100.0	0.0	0.0	0.0	0.0	13.9	16.7	69.4
rlp3- Quality and technical efficiency consideration	0.0	0.0	100.0	0.0	0.0	0.0	0.0	16.7	27.8	55.6
rlp4- The culture and values within organizations	0	2.8	97.2	0.0	0.0	0.0	2.8	13.9	19.4	63.9
Overall response percentage per rank	0.7	1.4	97.9	0.0	0.7	0.0	1.4	13.9	19.4	64.6
RLP- Direct measure of managers´ personal roles at the domain level	2.8	0.0	97.2	0.0	0.0	2.8	0.0	8.3	25.0	63.9

Source: author

In respect to their professional roles, managers in the survey reported that they were highly conscious in respect to the correctness of their engagement in GCE-based eco-innovation processes as part of their professional obligations. This is reflected by the high percentage of answers that indicated that managers support this view in an extremely (63.9 percent), quite (19.4 percent) and moderate (13.9 percent) strongly way.

These perceptions were also identified *via* the direct measures at the domain levels. In response to the direct measures of their professional roles associated with the environment and eco-innovation (*RLP*), 97.2 percent of the managers (63.9 percent extremely, 25.0 percent quite, and 8.3 moderately strong) reported a clear, direct link between their position/function in the companies and environmental responsibility.

Summary

Regarding their professional roles relative to the corporate sustainability and the dissemination and the use of GCE-based innovative solutions at the company level, 97.7 percent of the managers perceived that these aspects are an inherent part of the responsibilities of someone who occupies their position/function in the firm. As presented in Table 6.16, such perceptions are very supportive for the development of willingness in the context of this thesis research.

6.3.3- Perceived Personal Norm (Moral Obligation)

For the purposes of this thesis research, the influence of personal normative beliefs on managers' intention to promote companies´ engagement in eco-innovative activities were focused on their perceived personal moral obligation in respect to key activities within the organization that can promote pro-environmental changes by:

- Providing support and defend pro-environmental technological changes at the upper management level decision-making processes;
- Influencing people and disseminating pro-environmental culture, and

- Taking active and objective actions to identify new (short and long-term) alternatives and innovative solutions for the company's environmental and economic sustainability challenges (cf. Chapter 5).

Table 6.17 lists the beliefs, which were held by managers, in the industrial organization, in relation to their perceived personal norm (moral) towards companies´ adoption of GCE-based cleaner products and production processes

Table 6.17- Possible sources of perceived personal norm (moral) relative to the promotion of companies' engagement in GCE-based eco-innovative activities

PERSONAL NORM	Personal (moral) norms influence on managers´ environmental activities

- pn1- Decision-making processes
- pn2- Influencing people and disseminating pro-environmental culture
- pn3- Active and objective actions to identify new alternative and innovative environmental solutions

Note: the notation *"pn"* refers to beliefs pertaining to the personal norm realm upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: author

Table 6.18 presents a detailed analysis of how managers perceived each of the beliefs that are associated with the personal norm (moral obligation) in respect to their pro-environmental and pro-active postures as a means to promote their companies´ technological transition towards more advanced environmentally and economically sustainable states.

Table 6.18- Detailed representation of the results of this thesis research´s survey in respect to the influence of the personal norm (moral obligation) on managers´ pro-environmental and pro-active postures towards advanced states of sustainability

Questions of the Questionnaire/Beliefs	Overall Assessment of the Influence of the Personal Norms (%)			Detailed Assessment of the influence of the Personal Norms (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
pn1- Decision-making processes	0.0	0.0	100.0	0.0	0.0	0.0	0.0	16.7	22.2	61.1
pn2- Influencing people and disseminating pro-environmental culture	2.8	0.0	97.2	0.0	0.0	2.8	0.0	8.3	27.8	61.1
pn3- Active and objective actions to identify new alternative and innovative environmental solutions	0.0	8.3	91.7	0.0	0.0	0.0	8.3	22.2	27.8	41.7
Overall response percentage per rank	0.9	2.8	96.3	0.0	0.0	0.9	2.8	15.7	25.9	54.6
PN- Direct measure of the personal norm at the domain level	0.0	0.0	100.0	0.0	0.0	0.0	0.0	11.1	36.1	52.8

Source: author

The survey results regarding the personal norm (moral obligation) influence on managers in respect to the reduction and the prevention of the negative environmental impact resulting from activities performed by their companies indicated that they are very morally motivated towards environmental issues. This resulted in personal perceptions that were highly favorable to the development of willingness to engage in GCE-based eco-innovation processes.

Nearly one hundred percent of all respondents (96.3 percent) indicated that they felt morally correct and stimulated to support decisions that favored pro-environmental actions and behaviors and to support the development/adoption of innovative technologies such as those based on GCE. This included:

a) Supporting decisions that favor pro-environmental actions and behaviors and promote the development/adoption of innovative technologies such as those that are based on GCE;
b) Using their influence to advocate pro environmental initiatives, and
c) Engaging in the identification of new and innovative, more sustainable alternatives such as those that are based on GGE.

These perceptions were also identified by the direct measures at the domains level. In response to the direct measures of their moral personal norm (*PN*) associated with the environment, 100 percent of the managers (52.8 percent extremely, 36.1 quite and 11.1 percent moderately strong) reported clear feelings of moral obligation in respect to the prevention of the environmental impacts produced by their companies.

Summary

Regarding the perceived personal moral norms, almost all of the surveyed managers in the Brazilian petrochemical sector, believed that it is their moral obligation to act, decide and influence people, throughout their companies, towards corporate sustainability and the engagement in eco-innovation efforts such as those that are based in GCE.

6.3.4 Perceived Self-Identity

For the purposes of this thesis research, managers´ self-identities, which may contribute to eco-innovation behaviors, were assessed regarding their social role identities associated with their identification with environmental sustainability issues, innovation and self-perception of responsibility and competence.

Table 6.19 lists the beliefs that were held by managers, in the industrial organization, in relation to their self-identity towards environmental issues, innovation and professional competence.

Table 6.19- Possible sources of managers´ perceived self-identity in respect to environmental issues, innovation and professional competence

SELF-IDENTITY

- **si1- Self-identification with environmental sustainability issues**
- **si2- Self-identification with innovativeness and competency**

Note: the notation *"si"* refers to beliefs pertaining to the self-identity realm upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: author

Table 6.20 presents a detailed analysis of how managers perceived each of the beliefs that were associated with their social roles identity.

Table 6.20- Detailed representation of the results of this thesis research´s survey in respect to managers´ social identity related to their identification with environmental sustainability issues and self-perception of responsibility and competence

Questions of the Questionnaire/Beliefs	Overall Assessment of Managers´ Self-Identity (%)			Detailed Assessment of the Influence of Managers´ Self-Identity (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
si1- Self-identification with environmental sustainability issues	2.8	0.0	97.2	0.0	0.0	2.8	0.0	0.0	19.4	77.8
si2- Self-identification with innovativeness and competency	0.0	0.0	100.0	0.0	0.0	0.0	0.0	19.4	41.7	38.9
Overall response percentage per rank	1.4	0.0	98.6	0.0	0.0	1.4	0.0	9.7	30.6	58.3
SI- Direct measure of managers´ self-identity at the domain level	0.0	0.0	100.0	0.0	0.0	0.0	0.0	11.1	41.7	47.2

Source: author

In respect to managers' perceptions of their social role identities in respect to environmental causes and professional competence, Table 6.20 indicates that nearly one hundred percent of the managers (98.7 percent) considered themselves to be highly identified with such beliefs. This was illustrated by the fact that 58.3 percent of the managers reported extremely strong self-identity perceptions. In addition, 30.6 percent reinforced this perception reporting quite strong perceptions.

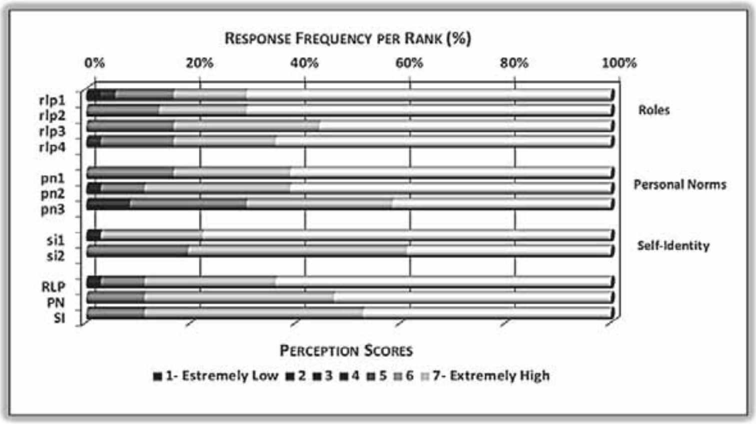
Responses to the direct measure of self-identity (*SI*) also revealed that 100 percent of the managers have the same pattern of self-identification with these issues.

Summary

Responses to this thesis research´ survey indicated a high degree of self-identification (self-concept) with both the environmental causes and a sense of being competent and innovative professionals. This self-identification may produce pro-environmental influences in the performance of their professional activities and can stimulate their engagement in GCE-based innovation activities.

Results for the perceived pressures originated in the professional roles, in the personal moral norms and in the self-identity domains are synthetized in Figure 6.6. As showed in the previous section, the darker nuances represent non-favorable conditions for eco-innovation in GCE.

Figure 6.6- Results of this thesis research´s survey concerning the perception of managers, in the Brazilian petrochemical sector, in respect to their professional roles, to the personal norm (moral obligation) and to their self-identity regarding to their environmental conduct and their engagement in Green Chemistry and Green Engineering based eco-innovation processes



Source: author

6.4 Mapping Perceived Behavior Control Determinants of Willingness Formation

As noted in Chapters 4 and 5, the concept of behavioral control (control beliefs) relates to an individual´s perception of the extent to which he or she has have control over the opportunities and resources that are required for the performance of a given behavior.

In this thesis research, the identification of the behavioral domains that may contribute to willingness formation in respect to the voluntary engagement of companies, in the Brazilian petrochemical sector in GCE-based eco-innovation processes, was conducted and structured *via* the use of the Sectoral System of Innovation framework (SSI). As stated in Section 3.5.2 of Chapter 3 and Section 5.2.2 of Chapter 5, three dimensions (the SSI building blocks) comprised the SSI framework: (a) knowledge and technological domain, (b) actors and networks, and (c) institutions.

The following sections present the results of this thesis research's qualitative survey in which managers´ clarified their perceived control over the opportunities and resources required for their engagement in GCE eco-innovation processes.

6.4.1 Knowledge and Technologies

For this behavior domain, four groups of beliefs, related to the key dimensions of knowledge, were identified: (a) accessibility to knowledge, (b) technological opportunities, (c) appropriability and (d) cumulativeness (cf. Section 5.2.2 of Chapter 5).

Accessibility to Knowledge

Table 6.21 lists the beliefs that may be held by managers, in the industrial organization, in relation to their perceived behavior control, relative to the accessibility to knowledge and technologies that may promote the engagement of their companies in GCE-based eco-innovation processes.

Table 6.21- Possible sources of perceived behavior control over companies´ accessibility to knowledge

KNOWLEDGE AND TECHNOLOGIES **Accessibility to Knowledge**

- ak1- Internal to the sector
- ak2- External to the sector
- ak3- Public research organizations
- ak4- Brazilian and foreign universities
- ak5- Professional and technical organizations
- ak6- Independent inventors
- ak7- Technologies Providers´ Organizations

Note: the notation *"ak"* refers to beliefs pertaining to the accessibility to knowledge realm upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: author

Table 6.22 presented a detailed analysis of how managers perceived each of the beliefs that are associated with their companies' accessibility to knowledge that may be required to eco-innovate in GCE.

Table 6.22- Detailed representation of the results of this thesis research´s survey in respect to managers´ perceptions in respect to their companies´ accessibility to knowledge that may be required to eco-innovate in Green Chemistry and Green Engineering

Questions of the Questionnaire/Beliefs	Overall Assessment of the Peceptions of Accessibiity to Knowledge (%)			Detailed Assessment of the of the Peceptions of Accessibility to Knowledge (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
ak1- Internal to the sector	5.6	13.9	80.6	0.0	5.6	0.0	13.9	22.2	25.0	33.3
ak2- External to the sector	13.9	8.3	77.8	0.0	2.8	11.1	8.3	36.1	27.8	13.9
ak3- Public research organizations	8.3	11.1	80.6	2.8	2.8	2.8	11.1	22.2	33.3	25.0
ak4- Brazilian and foreign universities	2.8	5.6	91.7	2.8	0.0	0.0	5.6	22.2	30.6	38.9
ak5- Professional and technical organizations	11.1	8.3	80.6	5.6	0.0	5.6	8.3	25.0	33.3	22.2
ak6- Independent inventors	25.0	16.7	58.3	5.6	0.0	19.4	16.7	33.3	16.7	8.3
ak7- Technologies Providers´ Organizations	5.6	2.8	91.7	2.8	2.8	0.0	2.8	30.6	44.4	16.7
Overall response percentage per rank	10.3	9.5	80.2	2.8	2.0	5.6	9.5	27.4	30.2	22.6

Source: author

In respect to the accessibility to knowledge, according to 80.2 percent of the surveyed managers, knowledge, can be easily accessed by their companies in the various public and private knowledge-producing organizations and individuals. The strength of such perceptions varied across the three positive levels of assessment (22.6 percent extremely, 30.2 percent quite, and 27.4 percent moderately easy) and produced a very favorable inclination to willingness formation at the companies and at the sectoral level.

Technological Opportunities

Table 6.23 lists the beliefs that that may be held by managers, in the industrial organization, in relation to their perceived behavior control over the technological opportunities associated with the engagement of their companies in GCE-based eco-innovation processes

Table 6.23- Possible sources of perceived behavior control over the technological opportunities that are required to eco-innovate in Green Chemistry and Green Engineering

KNOWLEDGE AND TECHNOLOGIES **Technological Opportunities**

- **to1- Advances in scientific understanding and technique**
- **to2- Technological advances from other industries and other private and governmental organizations**
- **to3- Feedbacks from the industry's own technological advances**

Note: the notation *"to"* refers to beliefs pertaining to the technological opportunities realm upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: author

Table 6.24 presented a detailed analysis of how managers perceived each of the beliefs that are associated with the technological opportunities that can facilitate their companies to eco-innovate in GCE.

Table 6.24- Detailed representation of the results of this thesis research´s survey in respect to managers´ perceptions regarding the technological opportunities that can facilitate their companies to eco-innovate in GCE

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Technological Opportunities (%)			Detailed Assessment of the Perceptions of Technological Opportunities (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
to1- Advances in scientific understanding and technique	5.6	16.7	77.8	0.0	2.8	2.8	16.7	22.2	36.1	19.4
to2- Technological advances from other industries and other private and governmental organizations	13.9	8.3	77.8	2.8	2.8	8.3	8.3	27.8	36.1	13.9
to3- Feedbacks from the industry's own technological advances	11.1	11.1	77.8	5.6	0.0	5.6	11.1	30.6	30.6	16.7
Overall response percentage per rank	10.2	12.0	77.8	2.8	1.9	5.6	12.0	26.9	34.3	16.7

Source: author

Eco-innovation in GCE may require technological opportunities based on new technological paradigms and technological trajectories (cf. Chapters 3 and 5). In this respect, the results obtained by this thesis research´s quantitative survey indicated that 77.8 percent of the managers perceived that the proposed beliefs can represent sources of technological opportunities that can facilitate the deliberate engagement of companies in GCE-based eco-innovation processes

The strengths of these perceptions were predominantly positive (16.7 percent extremely, 34.3 percent quite and 26.9 percent moderately strong), which contributed favorably to companies´ willingness formation relative to their engagement in GCE-based eco-innovation processes.

Appropriability

In the innovation domain, appropriability represented the possibility of protecting innovation from imitation and consequently absorbing the benefits and returns of innovation activities

Table 6.25 listed the beliefs that that were held by managers, in the industrial organization, in relation to their perceived behavior control over the appropriability conditions of the innovation outcomes.

Table 6.25- Possible sources of perceived behavior control over the appropriability of the results of innovation processes

KNOWLEDGE AND TECHNOLOGIES **Appropriability**

- app1- Invest in low cost technologies with low appropriability
- app2- Invest in high costs technologies with high appropriability
- app3- Invest in both oprions
- app4- Existence of appropriability means outside the company domains at national and international levels
- app5- Existence of appropriability means within the company domain

Note: the notation *"app"* refers to beliefs pertaining to the appropriability realm upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: author

Table 6.26 presented a detailed analysis of how managers perceived each of the beliefs that were associated with the appropriability conditions that can facilitate their companies to eco-innovate in GCE.

Table 6.26- Detailed representation of the results of this thesis research´s survey in respect to managers´ perceptions in respect to the appropriability of the results of eco-innovation processes

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Appropriability (%)			Detailed Assessment of the Perceptions of Appropriability (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
app1- Invest in low cost technologies with low appropriability	2.8	19.4	77.8	0.0	0.0	2.8	19.4	30.6	33.3	13.9
app2- Invest in high costs technologies with high appropriability	8.3	19.4	72.2	2.8	0.0	5.6	19.4	25.0	33.3	13.9
app3- Invest in both oprions	5.6	19.4	75.0	0.0	0.0	5.6	19.4	25.0	30.6	19.4
app4- Existence of appropriability means outside the company domains at national and international levels	11.1	27.8	61.1	0.0	2.8	8.3	27.8	38.9	16.7	5.6
app5- Existence of appropriability means within the company domain	11.1	19.4	69.4	2.8	0.0	8.3	19.4	41.7	19.4	8.3
Overall response percentage per rank	7.8	21.1	71.1	1.1	0.6	6.1	21.1	32.2	26.7	12.2

Source: author

In respect to the appropriation of the benefits generated by eco-innovation, 71.1 percent of the surveyed managers´ responses (21.1 percent moderately, 32.2 percent quite and 12.2 percent strongly) favored companies´ willingness development to engage in GCE-based eco-innovation processes.

In general, the results suggested that appropriability is not a barrier in respect to the adoption of GCE-based technologies. Additionally, they indicated that managers perceived the existence of appropriability means within as well as outside the companies' realm at both the national and at the international levels. It is also important to call attention to the degree of uncertainty presented by a relevant number of managers in respect to the beliefs associated with these appropriability issues.

Cumulativeness

Cumulativeness conditions in innovation reflect the characteristic of innovation processes in which new innovation can be developed upon current knowledge and are underpinned by evolutionary processes that have self-reinforcing effects, which allow for companies to innovate in specific technological trajectories (cf. Chapter 5).

Table 6.27 listed the beliefs that may be held by managers, in the industrial organization, in relation to their perceived behavior control, relative to knowledge cumulativeness, which can facilitate and make viable companies' engagement in GCE-based eco-innovation processes.

Table 6.27- Possible sources of perceived behavior control over knowledge cumulativeness processes that may be necessary for companies' engagement in eco-innovation processes

KNOWLEDGE AND TECHNOLOGIES **Cumulativeness**

- **LEARNING PROCESSES**
  - cmt1- External knowledge-acquisition processes
  - cmt2- Internal knowledge-acquisition processes
  - cmt3- Knowledge-socialization processes
  - cmt4- Knowledge-codification processes
  - cmt5- Integration of learning processes
- **INTERMEDIATE TECHNOLOGICAL INNOVATION CAPABILITIES (SEARCH BASED)**
  - cmt6- Search for technology source
  - cmt7- Equipment procurement, detailed engineering, equipment procurement, detailed engineering, training and recruitment of skilled personnel
  - cmt8- Equipment stretching, process adaptation and cost saving, licensing new technology
  - cmt9- Product quality improvement, licensing and assimilating new imported product technology
  - cmt10- Monitoring productivity, improved coordination
  - cmt11- Technology transfer of local suppliers, coordinated design, S&T links
- **ADVANCED TECHNOLOGICAL INNOVATION CAPABILITIES (RESEARCH BASED)**
  - cmt12- Development of new production systems
  - cmt13- Basic process design and related R&D
  - cmt14- In-house process innovation and basic research
  - cmt15- In-house product innovation and basic research
  - cmt16- Collaboration with suppliers and partners for technological development
  - cmt17- Turnkey capability, cooperative R&D, licensing own technology to others
- **KNOWLEDGE INTEGRATION**
  - cmt18- Rules and directives
  - cmt19- Organizational routines
  - cmt20- Self-management teams
- **CAPABILITIES/KNOWLEDGE AND ORGANIZATIONAL STRUCTURE CORRESPONDENCE**
  - cmt21- Correspondence of the capabilities hierarchies and the authority-based hierarchies

Note: the notation *"cmt"* refers to beliefs pertaining to knowledge cumulativeness realm upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: author

Table 6.28 presented a detailed analysis of how managers perceived each of the beliefs that are associated with the knowledge cumulativeness that can facilitate their companies to eco-innovate in GCE.

Table 6.28- Detailed representation of the results of this thesis research´s survey in respect to managers´ perceptions regarding the control over the knowledge cumulativeness that is required for them to eco-innovate

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Knowledge Cumulativeness (%)			Detailed Assessment of the Perceptions of Knowledge Cumulativeness (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
Learning Processes										
cmt1- External knowledge-acquisition processes	11,1	2,8	86,1	2,8	2,8	5,6	2,8	30,6	33,3	22,2
cmt2- Internal knowledge-acquisition processes	16,7	11,1	72,2	0,0	2,8	13,9	11,1	30,6	27,8	13,9
cmt3- Knowledge-socialization processes	30,6	0,0	69,4	0,0	5,6	25,0	0,0	38,9	22,2	8,3
cmt4- Knowledge-codification processes	30,6	19,4	50,0	2,8	13,9	13,9	19,4	30,6	16,7	2,8
cmt5- Integration of learning processes	22,2	5,6	72,2	2,8	2,8	16,7	5,6	27,8	36,1	8,3
Overall response percentage per rank	22,2	7,8	70,0	1,7	5,6	15,0	7,8	31,7	27,2	11,1
Intermediate Technological Innovation Capabilities (search based)										
cmt6- Search for technology source	11,1	13,9	75,0	0,0	2,8	8,3	13,9	36,1	33,3	5,6
cmt7- Equipment procurement, detailed engineering, equipment procurement, detailed engineering, training and recruitment of skilled personnel	11,1	8,3	80,6	0,0	0,0	11,1	8,3	30,6	33,3	16,7
cmt8- Equipment stretching, process adaptation and cost saving, licensing new technology	8,3	13,9	77,8	0,0	2,8	5,6	13,9	27,8	41,7	8,3
cmt9- Product quality improvement, licensing and assimilating new imported product	8,3	16,7	75,0	0,0	0,0	8,3	16,7	30,6	36,1	8,3
cmt10- Monitoring productivity, improved coordination	8,3	2,8	88,9	0,0	0,0	8,3	2,8	25,0	55,6	8,3
cmt11- Technology transfer of local suppliers, coordinated design, S&T links	8,3	2,8	88,9	0,0	0,0	8,3	2,8	38,9	41,7	8,3
Overall response percentage per rank	9,3	9,7	81,0	0,0	0,9	8,3	9,7	31,5	40,3	9,3
Advanced Technological Innovation Capabilities (research based)										
cmt12- Development of new production systems	30,6	2,8	66,7	2,8	2,8	25,0	2,8	38,9	22,2	5,6
cmt13- Basic process design and related R&D	22,2	11,1	66,7	0,0	5,6	16,7	11,1	36,1	25,0	5,6
cmt14- In-house process innovation and basic research	27,8	13,9	58,3	2,8	8,3	16,7	13,9	27,8	19,4	11,1
cmt15- In-house product innovation and basic research	25,0	5,6	69,4	2,8	11,1	11,1	5,6	36,1	22,2	11,1
cmt16- Collaboration with suppliers and partners for technological development	22,2	11,1	66,7	2,8	2,8	16,7	11,1	36,1	25,0	5,6
cmt17- Turnkey capability, cooperative R&D, licensing own technology to others	16,7	11,1	72,2	0,0	5,6	11,1	11,1	30,6	30,6	11,1
Overall response percentage per rank	24,1	9,3	66,7	1,9	6,0	16,2	9,3	34,3	24,1	8,3
Knowledge Integration										
cmt18- Rules and directives	25,0	16,7	58,3	0,0	5,6	19,4	16,7	22,2	22,2	13,9
cmt19- Organizational routines	11,1	8,3	80,6	0,0	0,0	11,1	8,3	25,0	30,6	25,0
cmt20- Self-management teams	25,0	11,1	63,9	2,8	2,8	19,4	11,1	36,1	16,7	11,1
Overall response percentage per rank	20,4	12,0	67,6	0,9	2,8	16,7	12,0	27,8	23,1	16,7
Capabilities/knowledge and organizational structure correspondence										
cmt21- Correspondence of the capabilities hierarchies and the authority-based hierarchies	8,3	13,9	77,8	0,0	2,8	5,6	13,9	22,2	47,2	8,3
KTC- Direct measure of the perceptions related to knowledge and technologies at the domain level	13,9	11,1	75,0	0,0	2,8	11,1	11,1	16,7	44,4	13,9

Source: author

Learning Processes

In respect to learning processes, the results of the survey indicated that, although 70.0 percent of the managers' answers favored the development of willingness towards companies´ engagement in GCE-based eco-innovation processes, there were some points in which such support to willingness was weak. This was indicated by managers´

perception of a weak control over the knowledge-socialization processes (*cmt3* - 30.6 percent), and over the knowledge-codification processes (*cmt4* – 30.6 percent).

Intermediate Technological Innovation Capabilities (Search-Based)

Because this thesis research was focused on eco-innovation, the study of technological capabilities that may lead companies to engage in innovation activities and help to promote pro-environmental technological change, are the sole element of interest.

In this section, intermediate technological innovation capabilities (search-based) are related to the technological capabilities that may be required to promote technological changes *via* the acquisition of innovative GCE-based new technologies.

The innovation search based capabilities presented in Table 5.26 and Table 5.27 were assessed in light of the perceptions of the surveyed managers in respect to how easy or difficult it would be for them to be acquired by their companies:

In this respect, the results showed that 81.0 percent of the managers perceived that it would be easy (31.5 moderately, 40.5 percent quite and 9.3 percent extremely) for their companies to acquire the proposed basic innovation capabilities that are required for search-based innovation. This can facilitate and encourage companies to engage in eco-innovation activities such as those that are based on GCE.

Advanced Technological Innovation Capabilities (Research-Based)

In this section, advanced technological innovation capabilities (research-based) are related to the technological capabilities that may be required to promote technological changes *via* development of innovative GCE-based new technologies.

The innovation research based capabilities presented in Table 6.27 and Table 6.28 were assessed, in light of the perceptions of the surveyed managers, in respect to how easy or difficult it would be for them to be acquired by their companies

The results presented in Table 6.28 showed that the majority of the managers (34.3 percent moderately, 24.1 quite and 8.3 percent extremely) reported that it would be easy for their companies to acquire such advanced technological innovation capabilities. It is important to highlight the perceptions of 24.1 percent of other managers who perceived that it would be difficult for their companies to acquire such research-based capabilities. Such perceptions represented unfavorable conditions, and therefore, barriers, for willingness to eco-innovate in GCE.

Knowledge Integration

As noted in, Section 5.2.2, in Chapter 5, the “integration of specialist knowledge to perform a discrete productive task is the essence of organizational capability defined as a firm's ability to perform repeatedly a productive task which relates either directly or indirectly to a firm's capacity for creating value through effecting the transformation of inputs into outputs” (Grant, 1996a: 377).

The knowledge integration mechanisms proposed in Table 6.27 and Table 6.28 (rules and directives, organizational routines and self-management teams) were assessed in light of the perceptions of the surveyed managers in respect to their existence, their efficiency, and their effectiveness to promote learning.

In this regard, 67.6 percent of the managers perceived (27.8 moderately, 23.1 quite and 16.7 percent extremely strongly) that these learning mechanisms exist and are considered to be efficient in integrating knowledge in their companies´ realms. It is important to note the fact that elements of resistance to eco-innovate were also detected. This was represented by the 20.4 percent of the managers who perceived that these mechanisms are inefficient (16.7 percent moderately, 2.8 percent quite and 0.9 percent extremely) in their organizations.

Capabilities/Knowledge and Organizational Structure Correspondence

In addition to the mechanisms mentioned in the previous section and as part of organizational capabilities for the promotion of the integration of knowledge for technological development, the correspondence of the firm´s capabilities hierarchy to its hierarchic (authority-based) structures plays an important role in the management such integration.

In this respect, 77.8 percent of the managers (8.3 percent extremely, 47.2 percent quite, and 22.2 percent moderately high) perceived as high the degree of correspondence of their companies' functional and hierarchical structures for the integration and application of knowledge. This represents a positive influence to the development of companies´ willingness to engage in GCE-based eco-innovation processes.

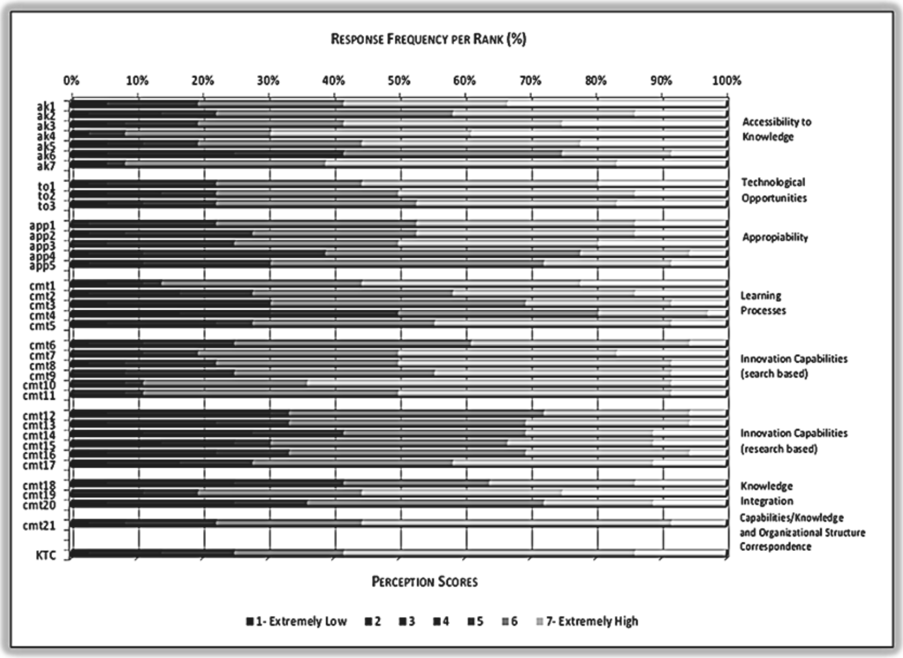
Summary

The overall results of this thesis research´s quantitative survey, regarding the perceived behavioral control over the resources and opportunities associated with the knowledge and technologies domain, indicated that the perception of the majority of the surveyed managers is that these opportunities exist to a favorable degree. Based on the TPB, it can be argued that this represents a favorable contribution to predispose the companies to engage in such eco-innovation processes.

These arguments were supported by the responses obtained for the direct questions, at the behavioral domains level, about the managers' perception regarding their companies' perceived behavioral control over knowledge and technologies (*KTC*). In this respect, 75 percent of the managers reported that companies´ control over knowledge and technologies was high (13.9 percent extremely, 44.4 percent quite and 16.7 percent moderately). Fourteen percent believed that this influence was low (2.8 quite and 11.1 percent moderately).

Results for the perceived behavioral control relative to knowledge and technologies were summarized in Figure 6.7. As showed in the previous section, the darker nuances represent non-favorable conditions for eco-innovating in GCE.

Figure 6.7- Scales used to assess the perceived behavioral control relative to knowledge and technologies



Source: author

6.4.2 Actors and Networks

For the purposes of this thesis research, actors and networks refer to the extent to which individuals and organizations have control over the opportunities and resources that are required to form strategic alliances and networks of collaboration that can help and stimulate companies to deliberately engage in GCE-based eco-innovation processes (cf. Chapter 5).

This thesis author proposed that it can be verified by measuring the extent to which managers perceived that they hold enough control (control beliefs) over: (a) the availability of key actors holding the required capabilities (internal and external to the firm), (b) the capability of forming strategic alliances with external actors and (c) the capability of forming networks of collaboration.

Availability of Key Internal Actors Holding the Required Capabilities

The availability of key internal actors holding the required capabilities refers to actors that are part of the company staff who can influence the establishment and development of innovation processes by contributing with knowledge, initiative power, leadership and supporting capacity.
Table 6.29 listed the beliefs that that were held by managers, in the industrial organization, in relation to their perceived behavior control over the availability of internal actors holding key skills to innovate.

Table 6.29- Possible sources of perceived behavior control over the availability of key internal actors holding key required capabilities to innovate

Actors and Networks | **Availability of Internal Actors Holding Key Capabilities**

- avc1, avc2 and avc3- Polifunctionality and technological knowledge
- avc4- Influence Power and responsibility
- avc5- Culture building, motivation and participation

Note: the notation *"avc"* refers to beliefs pertaining to realm of availability of internal actors holding key capabilities to innovate in GCE upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: author

Table 6.30 presented a detailed analysis of how managers perceived each of the beliefs that are associated with the availability of actors, internally to the organizations, who hold key capabilities, which can help companies to eco-innovate in GCE.

Table 6.30- Detailed representation of the results of this thesis research´s survey in respect to managers´ perceptions in respect to the availability of actors who hold key innovation capabilities

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Availability of Internal Actors Holding Key Capabilities (%)			Detailed Assessment of the Perceptions of Availability of Internal Actors Holding Key Capabilities (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
avc1- Polifunctionality and technological knowledge	2.8	5.6	91.7	0.0	2.8	0.0	5.6	30.6	22.2	38.9
avc2- Polifunctionality and technological knowledge	2.8	2.8	94.4	0.0	2.8	0.0	2.8	22.2	30.6	41.7
avc3- Polifunctionality and technological knowledge	2.8	0.0	97.2	0.0	0.0	2.8	0.0	19.4	44.4	33.3
avc4- Influence Power and responsibility	0.0	0.0	100.0	0.0	0.0	0.0	0.0	30.6	47.2	22.2
avc5- Culture building, motivation and participation	2.8	2.8	94.4	0.0	0.0	2.8	2.8	25.0	38.9	30.6
Overall response percentage per rank	2.2	2.2	95.6	0.0	1.1	1.1	2.2	25.6	36.7	33.3

Source: Author

The overall results presented in Table 6.30 show that the 95.6 percent of the surveyed managers (33.3 percent extremely, 36.7 quite and 25.6 moderately) agreed that their companies´ human resources hold key capabilities that are required for eco-innovating. Such perceptions provided a positive incentive to the formation of willingness regarding companies´ engagement in GCE-based eco-innovation processes.

These individuals are polifunctional in the sense that they that can speak two or more professional languages and see the world from two or more different professional perspectives. They hold critical knowledge that can help their companies to engage in GCE-based eco-innovation processes (Montalvo Corral, 2002). In addition, they hold the appropriate skills for the collection of information on cleaner and more sustainable products and process technologies in order to introduce them into the *nuclei* of decision-making in the corporation.

These individuals have influence in the decision-making processes and are committed with the corporations´ environmental and sustainability policies as well as with the dissemination of the culture of cleaner production, sustainability and eco-innovation such as GCE-based eco-innovation

Strategic Alliances with External Actors

In this thesis research, it was proposed four aspects that are necessary to support firms´ strategic alliances building: (a) access to strategic synergies, (b) availability of support and commitment from the top commitment, (c) the possibility to achieve influence via cooperation and (c) outsourcing opportunities.

Table 6.31 listed the beliefs that that were held by managers, in the industrial organization, in relation to their perceived behavior control over the strategic alliances with external actors.

Table 6.31- Possible sources of perceived behavior control relative to the strategic alliances with external actors aimed at the development of eco-innovation processes

ACTORS AND NETWORKS — **Strategic Alliances with External Actors**

- STRATEGIC SYNERGY
  - sac1- Strategic fit
  - sac2- Chemistry fit
  - sac3- Operational fit
  - sac4- Financial fit
- SUPPORT AND COMMITMENT
  - sac5- Win/win negotiations
  - sac6- Values pro-environment
  - sac7- Support from CEO and sharehorders
  - sac8- Previous alliances experiences
- COOPERATION - INFLUENCE
  - sac9- With suppliers (inputs)
  - sac10- With suppliers (process technologies)
  - sac11- With customers
- OUTSOURCING OPPORTUNITIES
  - sac12- Life-cycle analysis expertise
  - sac13- Cleaner product technologies
  - sac14- Cleaner process technologies

Note: the notation *"sac"* refers to beliefs pertaining to realm of the strategic alliances with external actors upon which the questions or statements of this thesis research´s questionnaires was constructed.
Source: Montalvo Corral (2002)

Table 6.32 presented a detailed analysis of how managers perceived each of the beliefs that are associated with the strategic alliances realm aimed at the development of GCE-based eco-innovative solutions for companies´ products processes and services.

Table 6.32- Detailed representation of the results of this thesis research´s survey regarding managers´ perceptions associated with the strategic alliances with external actors

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Strategic Alliances with External Actors (%)			Detailed Assessment of the Perceptions of Strategic Alliances with External Actors (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
Strategic Synergy										
sac1- Strategic fit	16.7	13.9	69.4	0.0	2.8	13.9	13.9	44.4	16.7	8.3
sac2- Chemistry fit	11.1	19.4	69.4	0.0	0.0	11.1	19.4	33.3	33.3	2.8
sac3- Operational fit	25.0	22.2	52.8	0.0	5.6	19.4	22.2	33.3	13.9	5.6
sac4- Financial fit	38.9	30.6	30.6	2.8	0.0	36.1	30.6	13.9	16.7	0.0
Overall response percentage per rank	22.9	21.5	55.6	0.7	2.1	20.1	21.5	31.3	20.1	4.2
Support and Commitment										
sac5- Win/win negotiations	27.8	27.8	44.4	2.8	8.3	16.7	27.8	33.3	11.1	0.0
sac6- Values pro-environment	5.6	27.8	66.7	0.0	0.0	5.6	27.8	27.8	36.1	2.8
sac7- Support from CEO and sharehorders	22.2	13.9	63.9	8.3	2.8	11.1	13.9	30.6	25.0	8.3
sac8- Previous alliances experiences	16.7	19.4	63.9	2.8	2.8	11.1	19.4	25.0	27.8	11.1
Overall response percentage per rank	18.1	22.2	59.7	3.5	3.5	11.1	22.2	29.2	25.0	5.6
Cooperation - Influence										
sac9- With suppliers (inputs)	22.2	11.1	66.7	2.8	8.3	11.1	11.1	33.3	27.8	5.6
sac10- With suppliers (process technologie	22.2	13.9	63.9	5.6	5.6	11.1	13.9	22.2	25.0	16.7
sac11- With customers	30.6	25.0	44.4	2.8	2.8	25.0	25.0	13.9	30.6	0.0
Overall response percentage per rank	25.0	16.7	58.3	3.7	5.6	15.7	16.7	23.1	27.8	7.4
Outsourcing Opportunities										
sac12- Life-cycle analysis expertise	13.9	8.3	77.8	0.0	0.0	13.9	8.3	30.6	27.8	19.4
sac13- Cleaner product technologies	25.0	16.7	58.3	5.6	5.6	13.9	16.7	27.8	27.8	2.8
sac14- Cleaner process technologies	16.7	13.9	69.4	2.8	2.8	11.1	13.9	33.3	33.3	2.8
Overall response percentage per rank	18.5	13.0	68.5	2.8	2.8	13.0	13.0	30.6	29.6	8.3

Source: author

Strategic Synergy

In this thesis research, strategic fit involves four dimensions, which were considered basic elements for strategic alliances formation (cf. Chapter 5):

a) Strategic fit: concerned the strengths and complementarities in innovative technical know-how;
b) Chemistry fit: related to truth, honesty, common success commitment, good reputation, predictability under pressure and creativity in the face of adversity that prospective partnering may need to have;
c) Operational fit: related to the reference framework upon which prospective partners operate their respective business (business strategies, communication methods, management styles, labor relations, technologies and business government relations, and
d) Financial fit: related to partners who can provide investment capital in favorable and fair conditions and who can provide support to companies´ investments in GCE-based eco-innovation.

In respect to these elements, the surveyed managers' perceptions were quite divided. Although the majority of the managers (55.6 percent) perceived that it is easy (31.3 percent moderately, 20.1 percent quite and 4.2 extremely) to find partners with these characteristics, there were significant numbers of managers (22.9 percent) who found it difficult and 21.5 percent who were uncertain.

Support and Commitment

Support and commitment relates to the support and commitment from key elements within the organization in respect to the establishment of strategic alliances aimed at innovation activities.

In general, although there has been a high indication of uncertainty (22.2 percent), most of the surveyed managers (59.7 percent) reported positive previous experiences and that they perceived it was easy (29.2 percent, moderately, 25.0 percent quite and 5.6 percent extremely easy) finding:

a) Support from CEOs and shareholders;
b) Partners who shared the same pro-environmental values, and
c) Partners with whom win-win negotiations could be conducted.

Cooperation-Influence

Cooperation and influence related to the capability to influence supply agents and customers to cooperate for the development of critical cleaner substitute inputs for and for new process technologies.

In this regard, the majority of the surveyed managers (58.3 percent) had the opinion that the power of their companies to exert such influence for cooperation is high. This represents a favorable point to willingness creation.

On the other hand, it was also identified sources of resistance to willingness formation. Such resistance was represented by the relevant percentage of managers who perceived that their companies´ power to exert such influence low (25.0 percent) and those who reported to be uncertain (16.7 percent) about these issues.

Outsourcing Opportunities

With regard to the outsourcing opportunities, Montalvo Corral (2002) illustrated this issue with the view of diverse authors. According to him, cooperation between firms can provide leverage for off-the-shelf technological and know-how resources and opportunities specifically in the fields of life-cycle analysis expertise and knowhow, cleaner products and cleaner processes technologies (cf. Chapter 5).

In this realm, most of the surveyed managers (68.5 percent) reported that, for their companies, outsourcing the development of these activities is easy (30.6 percent moderately, 29.6 quite and 8.3 extremely easy). This represented a favorable point for willingness development. The remaining 31.5 percent represented sources of resistance for willingness development. They were composed by 18.5 percent of the managers who reported that outsourcing was difficult and those 13.0 percent who were uncertain about the easiness of outsourcing.

Networks of Collaboration

For the purposes of the thesis research, the following organizations were identified as central for companies to building collaboration networks aimed at the development of GCE-based technological solutions for their sustainability challenges: (a) public R&D laboratories, (b) providers of raw-materials and other inputs, (c) consultancies, (d) sectoral inter-firms collaboration and (e) specialized engineering firms – SEF.

Table 6.33 listed the beliefs that that may be held by managers, in the industrial organization, in relation to their perceived behavior control over the strategic alliances with external actors.

Table 6.33- Possible sources of perceived behavior control over the constitution of networks of collaboration aimed at the development of Green Chemistry and Green Engineering based cleaner products, processes and services

Actors and Networks — **Networks of Collaboration**

- **nwc1- Public R&D laboratories**
- **nwc2- Providers of raw-materials and other inputs**
- **nwc3- Consultancies**
- **nwc4- Colaboration with companies within the sector**
- **nwc5- Specialized engineering firms (SEF)**

Note: the notation *"nwc"* refered to beliefs pertaining to the realm of networks of collaboration with external actors upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: author

Table 6.34 presented results of a detailed analysis of how managers perceived each of the beliefs that are associated with the networks of collaboration with external actors that can help and facilitate companies to eco-innovate in GCE.

Table 6.34- Detailed representation of the results of this thesis research´s survey regarding managers´ perceptions relative to the networks of collaboration with external actors aimed at the development of eco-innovation processes

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Networks of Collaboration (%)			Detailed Assessment of the Perceptions of Networks of Collaboration (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
nwc1- Public R&D laboratories	22.2	19.4	58.3	2.8	8.3	11.1	19.4	30.6	22.2	5.6
nwc2- Providers of raw-materials and other inputs	27.8	19.4	52.8	2.8	5.6	19.4	19.4	36.1	11.1	5.6
nwc3- Consultancies	8.3	8.3	83.3	2.8	0.0	5.6	8.3	41.7	25.0	16.7
nwc4- Colaboration with companies within the sector	19.4	22.2	58.3	2.8	5.6	11.1	22.2	36.1	16.7	5.6
nwc5- Specialized engineering firms (SEF)	11.1	11.1	77.8	2.8	0.0	8.3	11.1	44.4	27.8	5.6
Overall response percentage per rank	17.8	16.1	66.1	2.8	3.9	11.1	16.1	37.8	20.6	7.8
AN- Direct measure of the perceptions related to actors and networks at the domain level	2.8	11.1	86.1	0.0	2.8	0.0	11.1	36.1	25.0	25.0

Source: author

In respect to the constitution of networks of collaboration with organizations within and outside the petrochemical sector, according to the survey results, most of the managers (66.1 percent) saw that participating in such networks was easy (37.8 moderately, 20.6 percent quite and 7.8 extremely). Such perception was not shared by 17.8 percent of the managers who perceived that the participation of their companies in such networks was difficult. Sixteen percent reported to be uncertain.

Summary

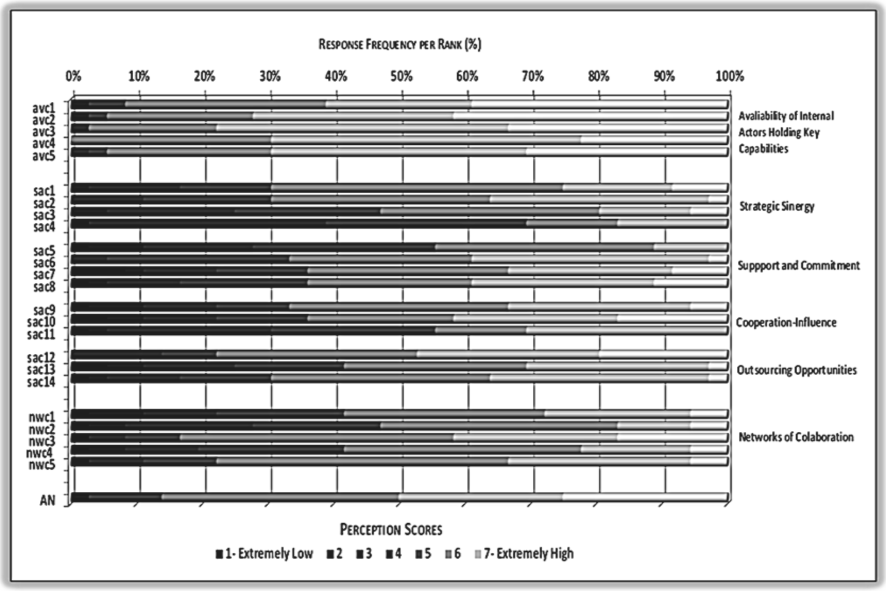
The overall results of the qualitative survey regarding the perceived behavioral control over the actors and over the participation in networks of cooperation that may be required for the engagement of companies in GCE-based eco-innovation processes indicated that, in the perception of the majority of surveyed managers, the opportunities and resources exist and are accessible to a favorable degree. Based on the TPB, it can be argued that this provided a positive contribution for the predisposition (willingness) of companies to engage in GCE-based eco-innovation processes.

These arguments were backed by the responses obtained for the direct questions, at the domain level (*AN*), relative to the managers' perception about their companies' perceived behavioral control over the actors and networks that are required for the establishment of innovation processes.

In this regard, 86.1 percent of the managers reported that in light of: (a) the availability of human resources holding key innovation capabilities, (b) the easiness of establishing strategic alliances, and (c) participating in techno-scientific networks of collaboration, the likelihood for the engagement of their companies in GCE-based eco-innovation processes is high. This expectation became more evident in the more detailed analysis of the results. The results revealed that 50.0 percent of these managers perceived such likelihood as extremely to quite high.

Results for the perceived behavioral control relative to actors and networks are synthetized in Figure 6.8. As noted in the previous section, the darker nuances represent non favorable conditions for eco-innovation in GCE.

Figure 6.8- Scales used to assess the perceived behavioral control relative to actors and networks



Source: author

6.4.3 Institutions

In this thesis research, institutions represent those that pertain to the organizational, legal, social and ethical, and political and public domains. It was expected that the managers who perceive that the current institutional set provides their companies with enough protection against imitation, facilitate and guarantee the appropriability of knowledge and innovation benefits and regulate companies´ relationships with other actors (formal and informal and market and non-market) are likely to be more prone to engage in eco-innovation activities (cf. Chapter 5).

Table 6.35 listed the beliefs that that may be held by managers, in the industrial organization, in relation to their perceived behavior control over the institutional set in which their companies operate.

Table 6.35- Possible sources of perceived behavior control relative to the current innovation related institutional set in which companies operate

INSTITUTIONS **Institutional Domains**

- **inst1- Organizational**
- **inst2- Legal**
- **inst3- Social and ethical**
- **inst4- Political and public**

Note: the notation *"inst"* refered to beliefs pertaining to realm of current innovation related innovation set upon which the questions or statements of this thesis research´s questionnaire were constructed.
Source: author

Table 6.36 presented results of a detailed analysis of how managers perceived each of the beliefs that are associated with the institutional set that influence eco- innovation processes.

Table 6.36- Detailed representation of the results of this thesis research´s survey regarding managers´ perceptions in respect to current innovation related institutional set

Questions of the Questionnaire/Beliefs	Overall Assessment of the Perceptions of Networks of Collaboration (%)			Detailed Assessment of the Perceptions of Networks of Collaboration (%)						
	Willingness Unfavorable Zone	Uncertain	Willingness Favorable Zone	Willingness Unfavorable Zone			Uncertain	Willingness Favorable Zone		
	Overall Results		Overall Results	Extremely	Quite	Moderately		Moderately	Quite	Extremely
inst1- Organizational	16.7	19.4	63.9	2.8	8.3	5.6	19.4	33.3	22.2	8.3
inst2- Legal	25.0	22.2	52.8	2.8	8.3	13.9	22.2	19.4	30.6	2.8
inst3- Social and ethical	16.7	36.1	47.2	2.8	2.8	11.1	36.1	22.2	22.2	2.8
inst4- Political and public	47.2	11.1	41.7	5.6	13.9	27.8	11.1	19.4	13.9	8.3
Overall response percentage per rank	26.4	22.2	51.4	3.5	8.3	14.6	22.2	23.6	22.2	5.6
INST- Direct measure of the perceptions related to institutions at the domain level	27.8	16.7	55.6	0.0	8.3	19.4	16.7	33.3	16.7	5.6

Source: author

From the qualitative survey results, it is clear that the current innovation-related institutional set was not seen, by the surveyed managers, as providing ample support to the development of companies´ willingness to eco-innovate in GCE. This was supported by the percentage of managers´ responses (51.4 percent) that were favorable to willingness development.

At a more specific level, the percentage of managers who believed that current social and ethical (*inst3*) and political and public institutions (*inst4*) could provide the required protection and incentives for the their companies´ engagement in GCE-based eco-innovation processes indicated that they were a minority. They were outnumbered by the sum of those who had the opposite perception and those who were uncertain about the efficiency and effectiveness of these institutions.

In respect to legal institutions (*inst2*), this relation only marginally favored the perception of the effectiveness and efficiency of these institutions towards innovation.

The most positive point in respect to institutions, as reported by the surveyed managers, regarded the majority of the managers´ trust in the institutions at the organizational level (*inst1*) as truly supportive, flexible and protective regarding GCE-based eco-innovation processes.

Summary

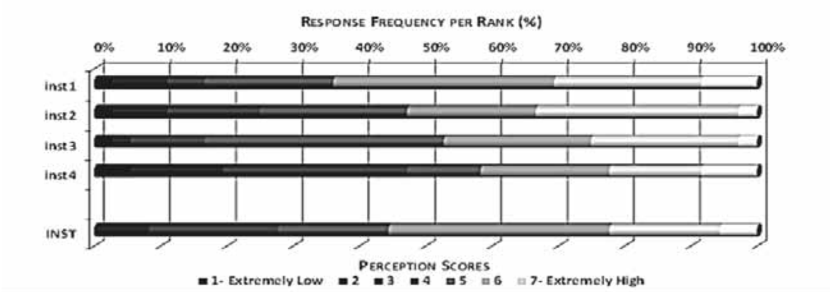
In terms of the strength of the institutional set in promoting confidence, support and incentives for companies to invest and to engage in GCE-based eco-innovation processes, managers reported to be comfortable in respect to their organizations´ internal institutions and in respect to the legal framework at the national and international levels.

Their comfort decreased when social and ethical institutions were involved. Lower evaluations were perceived in relation to the political and public institutional set. The majority of the managers perceived that there is a lack of institutional support from these domains or that they exist at such a low strength that they are not sufficient to motivate their companies to deliberately engage in GCE-based eco-innovation processes.

Such perceptions were verified by the direct questions, at the domain level regarding managers´ perceptions of current innovation related institutional set (*INST*). Fifty-five percent of the managers responded positively to the question about the capability of current institutions to protect companies and their investments and to encourage firms to engage in GCE-based eco-innovation processes. Almost twenty-eight percent of the managers had the opposite perception.

Results for the perceived behavioral control relative to current innovation related institutional set were synthesized in Figure 6.9. As noted in the previous section, the darker nuances represent non-favorable conditions for eco-innovation in GCE.

Figure 6.9- Scales used to assess the perceived behavioral control over innovation related institutions.



Source: author

6.5 Companies Willingness to Eco-Innovate in Green Chemistry and Engineering: Firms´ Suggested Planned Behavior

As noted in Chapter 3, the TPB postulates that the intention to perform a behavior constitutes the immediate preceding step to its actual performance.

In this thesis research, intention to perform a behavior was interpreted as the companies´, in the Brazilian petrochemical sector, willingness to engage in GCE-based eco-innovation processes (cf. Chapter 3 and 5).

Additionally, it was postulated that behavioral intentions are a direct function of the accumulated connotative load of the (salient) beliefs an individual has about the behavior in question. According to the TPB, behavioral intention (willingness) represents individuals´ and organizations´ planned behavior.

The direction taken by the strategic planning of a company can be revealed by its planned behavior because planning is generally agreed to be based on the rational expectations of the CEO´s, top management and important and influential referents in the company (Montalvo Corral, 2002).

In light of the TPB theory and based upon the responses to this thesis research´s quantitative survey, it was possible to draw the planned behavior of the companies in respect to such engagement in the next five years.

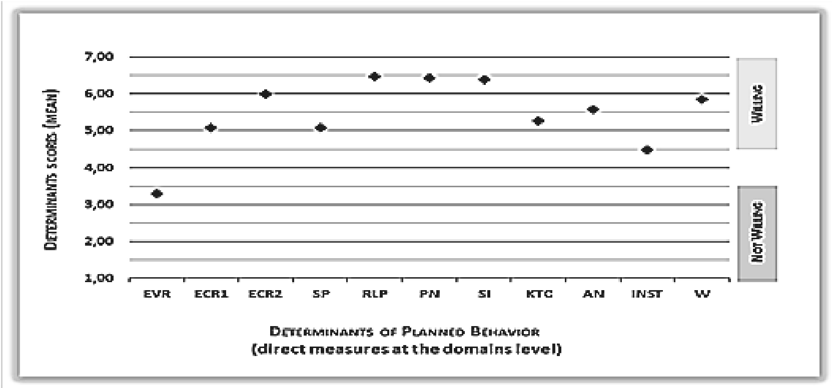
By following the relationships that were established by the behavioral model and by the system of hypotheses proposed in Chapter 5, the scope of the planned behavior of firms´ was drawn *via* the use of the mean of the scores obtained in the direct measures of willingness and of the behavioral domains.

The use of the direct measures of the behavioral domains for the calculation of the companies´ planned behavior were based on: (a) the fact that the behavioral domains captured the accumulated connotative load of their respective beliefs, and (b) their capability to predict and explain willingness as it was postulated by the linear causal relationships, between them and willingness. Such linear relationships were proposed by the system of hypothesis in Chapter 5, which were empirically validated *via* statistical multivariate methods (cf. Section 6.6 and Appendices A, B and C).

The planned behavior of companies, in the Brazilian petrochemical sector, is presented in Figure 6.10. In this Figure, the acronyms used for representing willingness and its determinants were the same that were used in this thesis research´s questionnaire to identify the questions or statements regarding the direct measures of: (a) willingness, and (b) managers' perceptions at the behavioral domain´s level. They were written in capital letters and had the following meanings.

EVR	• Environmental Risks
ECR	• Economic Risks
SP	• Social Pressures
RLP	• Professional Roles Pressures
PN	• Personal Norms (Moral Norms)
SI	• Self-Identity
KTC	• Knowledge and Technologies
AN	• Actors and Networks
INST	• Institutions
W	• Willingness

Figure 6.10 – Planned behavior of the companies in the Brazilian petrochemical sector regarding their engagement in eco-innovation processes based in the Green Chemistry and Green engineering



Source: author

Results presented in
Figure 6.10 corroborate those presented in the preceding sections. Although no optimal score (7) was achieved, managers´ perceptions demonstrated a high degree of willingness (*W*) to engage in GCE-based eco-innovation processes in the next five years.

The scores reflected that managers, at the personal and social levels, were very aware of the significance of the environmental issues in their professional activities and responsibilities and had a high perception of the importance of their personal moral and social commitment in reducing the environmental negative impacts produced by their companies (*RLP, PN, SI*). They also perceived as moderately high, the social pressure (*SP*) arising from the market, local community and regulators, which can push their companies, in the next five years, to adopt/develop cleaner and more sustainable product and process technologies.

In respect to the scores in the attitudinal domains, they were perceived, by managers, as being very low in respect to the environmental risks generated by their firms (*EVR*). The perceived economic risks associated with the engagement in GCE-based eco-innovation processes were reported be low at the same time that managers believed that such GCE-based technologies can generate moderately high benefits (*ECR1*) and very high business opportunities (*ECR2*).

The scores for the control over the requisite resources and opportunities for innovating were found to be moderately high in respect to the access to knowledge and technologies, to the possession of technological and organizational capabilities, to the availability of learning mechanisms and knowledge accumulation, and to the appropriability of the innovation outcomes (*KTC*). In respect to the control over the requisites to establishing and engaging in strategic alliances and networks of technological cooperation, scores were moderately high (*AN*).

Scores were only slightly favorable with regard to the support, incentives and protection to GCE-based investments that can be provided by current institutions (*INST*).

Although the principles and justifications underpinning the measurements of these beliefs and their use to predict and explain companies´ willingness, to deliberately engage in GCE-based eco-innovation processes, have been extensively discussed in this thesis research, one basic and important point has not yet been clarified. It is related to the extent to which the scores that were produced by the survey were reliable and that the inferences on the companies planned behavior are valid. A discussion on the reliability of the measures and on the validity of this thesis research´s behavioral model is presented in Section 6.6.

6.6 Reliability of the Measurements and the Behavioral Model Validation

Based on the empirical data obtained in this thesis research´ qualitative survey, Section 6.4 presented the measures of the perceptions of managers, in the Brazilian Petrochemical sector, in respect to the determinants of their companies´ willingness to engage deliberately in GCE-based processes in the next five years. In parallel, Section 6.5 introduced the companies' planned behavior regarding such behavior. On the other hand, Section 6.5 called attention to the fact that the scores generated by this thesis research´s survey as well as the inferences that were made from its results are of no use if these measures are not reliable and if the behavioral model is not valid.

As the conceptual and theoretical aspects and the results of the reliability and validity statistics were extensively presented in Chapter 4, and in Appendices A, B and C, Section 6.6 provided an in-depth discussion of the results of the reliability and validity tests. It also demonstrated the adequacy of this thesis research´s questionnaire and behavioral model for explaining and predicting the willingness of companies to engage deliberately in GCE-based eco-innovation processes in the next five years.

6.6.1 Reliability of the Measurements

With respect to the reliability of the measurements, the results presented Table 9.1, of Appendix A, show that all scales used to measure the different behavioral domains, in this thesis research´s questionnaire, produced values of the Cronbach´s alpha coefficient that surpassed the 0.7 criterion (cf. Section 4.6.1 of Chapter 4). Most of the alpha values approached or surpassed the 0.8 level, which is considered good in psychometric research (Montalvo Corral, 2002). Two scales produced lower values of alpha. The sub-scale assessing appropriability in the perceived control over the knowledge and technologies showed an alpha value of 0.704. In parallel, the same value was obtained for the scale for assessing the perceived environmental risks. In this case, three items were excluded from further analysis (the only three in the entire questionnaire).

These results indicated that the measures employed by this thesis research´s quantitative questionnaire to assess the determinants of the planned behavior of the companies in the Brazilian petrochemical sector, in respect to their engagement in GCE-based eco-innovation processes, are satisfactorily one-dimensional, internally consistent and, therefore, they are reliable.

This result coincides with those obtained by Montalvo Corral (2002) and by When de Montalvo (2003) in which "the research procedure of eliciting beliefs and grouping them into domains and into sub-areas within some of the domains is appropriate for producing consistent scales" (When de Montalvo, 2003: 224).

6.6.2 Behavioral Model Content Validity

The results of the principal components analysis, presented in Appendix B, showed similar results for the data set related to the scores obtained for the domains scales and for the data set associated with scores of the direct measures of the behavioral domains. The confirmatory factor analysis was used to confirm the extent to which the empirical data adhered to this thesis research´ proposed structured behavioral model whose structure dictates that the number of factors to be extracted should be set to three.

Behavioral Domain Scales

With respect to the principal component analysis, for the data set related to the behavioral domain scales, the results of the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (0.63) and Bartlett test of sphericity indicated that the dataset had significant correlations between variables (cf. Table 10.1, in Appendix B) and it was therefore, adequate for the factor analysis.

The analysis, after the performance of a Varimax factor rotation, produced three factors with *eigenvalues* of 3.74, 2.35 and 1.29 explaining 70.77 percent of the variance in the sample variables (cf. Table 10.2 in Appendix B).

The first factor, explaining 30.37 percent of the variance, represented: a) the perceived control over the opportunities and requisite resources for engaging in GCE-based eco-innovation processes and corresponded to scales pertaining to the knowledge and technologies, actors and networks and institutions behavioral domains *(∑ktc, ∑an, ∑inst*), and b) scales belonging to the perceived social pressure (∑*sp*). The second factor was related to the perceived social factor's pressures behavioral domain scales. It explained 25.94 percent of the variance in the sample and represented the perceived social pressure towards eco-innovating arising from the market, from the communities and from the regulation (∑*sp*) and by the managers´ social and personal norm (∑*rlp,* ∑*pn,* ∑*si*). The third and last factor explained 14.41 percent of the variance. It represented the attitude towards eco-innovating in GCE and the perceptions of environmental and economic risks (∑*evr,* ∑*ecr*).

Direct measures of the domains

The principal component analysis, conducted for the data set associated with the direct measures of the behavioral domains, produced similar results as those obtained for the measures related to the behavioral domains scales. The results of the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (0.64) and the Bartlett test of sphericity showed that the dataset had significant correlations between variables (cf. Table 10.4 in Appendix B) and it was, therefore, adequate for the factor analysis.

After the performance of a Varimax factor rotation, the three factors that were extracted had eigenvalues of 3.02, 2.28 and 1.18 and explained 72.11 percent of the total variance in the sample. These results are presented in Table 10.5 of Appendix B.

The first factor, the perceived behavior control factor, explained 33.58 percent of the variance. It was composed by the variables representing the companies´ capabilities to engage in GCE-based eco-innovation processes and the innovation related institutional set (*KTC, AN, INST*). The second factor, explained 25.42 percent of the variance. It encompassed the perceived social and personal pressures (*SP, RLP, PN, SI*). The third factor, representing the attitudinal determinants of willingness, explained 13.12 percent of the variance and corresponded to the indexes of environmental (*EVR*) and economic (*ECR*) risks.

Expected Outcomes from the Validity Analysis

A more thorough interpretation of these results can be conducted based on the three outcomes that were expected from this analysis, which according to Montalvo Corral (2002) were:

a) The first outcome is related to content validity that refers to the confirmation of the proportionality between the domain scales scores and the scores of the direct measures. This is one of the implicit propositions of the Theory of Planned Behavior. Montalvo Corral (*ibid*: 206) emphasized that "to confirm such proportionality, the results of the principal component analyses in both datasets should produce similar structural clustering and should show a set of similar loadings within each factor for both domain scales and direct measures.
b) The second outcome referred to the confirmation that the proposed scales measure what they are intended to measure. In order to verify that the structure of the data fits or corresponds to the proposed theoretical structure "the clustering of the scales resulting from their inter-correlation should be consistent with the nature of the factors in the construct definition" (*ibid*: 206 *apud* Ghiselli *et al*., 1981);
c) The third outcome, was concerned to "how well the entire set of scales represented all aspects that the model was expected to capture" (*ibid*: 207). It is related to the amount of variance on the sample that can be explained by the behavioral domain. The degree of comprehensiveness of the model was directly related to the amount of variance that it is capable to capture (*ibid*).

In respect to first expected outcome, the results presented in Table 10.3 and Table 10.6, in Appendix B, showed that the domain scales and the direct measures loaded the three factors in a very similar manner and presented similar loading values. This represented a clear indication of the proportionality of both datasets.

In terms of the verification of the correspondence of the data to the proposed model´s structure, the second expected outcome, it can be argued that the empirical components extracted in the principal component analysis, corresponded closely to the structure and contents of the behavioral model that were proposed in Chapter 5. Some deviations were observed in respect to:

a) The social pressure (*SP*), which besides loading on the perceived social factors pressure (*PSFP*) factor (expected loading) it also loaded on the perceived behavioral control *(PBC*) factor in both levels of analysis (domain scales and direct measures of the behavioral domains) (cf. Table 10.3 and Table 10.6 in Appendix B);
b) The perceived professional roles (*rlp*), which besides loading on the perceived social factors pressure (*PSFP*) factor (expected loading) of the domain scales, it also loaded on the perceived behavioral control (*PBC*) factor in the direct measures of the domains level of analysis (cf. Table 10.3 and Table 10.6 in Appendix B);

This suggested that there are relevant relationships between the social pressure and professional roles domains with the perceived behavioral control. The strength of such relationships is presented by the bivariate correlations in Appendix D, between:

- The direct measures of the social pressure (*SP)* and the professional roles (*RLP)* with the direct measures of the three behavioral domains that form the perceived behavior construct (*KTC*, *AN* and *INST*) (cf. Table 12.1 of Appendix D), and
- The domain scales for the social pressure ∑*sp* and the domains scales that are associated with the three behavioral domains that form the perceived behavior control domains construct (∑*ktc,* ∑*an* and ∑*inst*) (cf. Table 12.2 of Appendix D).

These evidences indicated the existence of positive relationships between the social pressures and professional roles with the perceived behavioral control over the requisite opportunities and resources for companies´ engagement in GCE-based eco-innovation processes. They suggested that the need for the control over the requisite opportunities and resources for eco-innovating in GCE, in terms of knowledge and technologies (*KTC*), actors and networks (*AN*) and innovation supporting institutions (*INST*) may increase as social pressures (social norm and professional roles) towards a cleaner and more sustainable petrochemical industry increases. An in-depth analysis of these relations and their influence on willingness was conducted and is presented in Chapter 7.

Another significant finding from the factor analysis is the negative loading of the economic risk perception in the attitude component (cf. Table 10.3 and Table 10.6 in Appendix B). This inverse relation was also indicated by the bivariate inverse correlations, at the behavioral domains and the domain scales, between the environmental and the economic risk perceptions (cf. Table 12.1and Table 12.2 of Appendix D).

Based on these findings, it can be argued that, in the realm of this thesis research, the perceived environmental risk is related with the economic risks, associated with eco-innovating in GCE, in an inverse direction. This suggested that perceptions of low environmental risks, of companies´ products, processes and services, may induce companies to fail in identifying important and basic environmental challenges. As a consequence, it increased the risk of establishing the wrong GCE-based eco-innovation priorities, which may result in higher economic risks and may fail to take advantages of the market opportunities that may arise from an increasingly demanding market for more sustainable products manufactured by more environmentally sustainable manufacturing processes.

These findings and their related arguments indicated that the empirical data structure corresponded closely to the behavioral model´s structure and contents proposed in Chapter 5.

In respect to the third expected outcome, the factor analyses revealed that both datasets, at the direct measures of the behavioral domains and their respective scales, explained a large proportion of the variance in the sample and, therefore, they were capable of capturing most aspects that the model was designed to capture.

Finally, based on the results of the factor analyses and on the attainment of these analyses´ expected outcomes, it can be argued that the structure of the empirical data that were obtained by the thesis research´s survey corresponded to the behavioral model´s contents and the hypothesized structure. Therefore, the behavioral model can be considered valid in respect to its content.

6.6.3 Behavioral Model Construct Validity

In respect to the behavioral model´s construct validation, as its conceptual, theoretical and computational aspects were covered in detail in Chapter 4 and Appendix C, only the results of the validation process were presented in this section.

Basically, the construct validation of the behavioral model refers to confirmation or falsification of the linear relationships of dependence between the model´s proposed dependent and independent variables in the form that they were proposed by a system of hypotheses in Chapter 5. These tests were performed *via* a series of multiple regression analyses. The acceptance or rejection criteria of the proposed hypotheses and the results of the analyses were presented in Section 4.6.2 of Chapter 4 and Appendix C. The results of the analysis of variance are presented in a summarized form in Table 6.37.

Table 6.37– Summary of the analysis of variance for the research´s behavioral model´s three levels of explanation according to the model´s construct validation criteria: the coefficient of determination, the dimension of the standard error of the estimate and the statistical significance of the model

HYPOTHESES		ANOVA			
		R^2	SE	F	Sig
Explanatory level one					
H_1:	W = W(A, PSFP, PBC)	0.65	0.73	17.78	0.000
Explanatory level two					
H_2:	W = W(EVR, ECR, PSP, RLP, PN, SI, KTC, AN, INST)	0.72	0.73	7.58	0.000
Explanatory level three					
H_3:	$EVR = EVR(\sum_{b=1}^{12} evr_b)$	0.57	1.42	14.2	0.000
H_4:	$ECR = ECR(\sum_{b=1}^{20} ecr_b)$	0.49	0.86	15.98	0.000
H_5:	$PSP = PSP(\sum_{b=1}^{12} mp_b + \sum_{b=1}^{15} cp_b + \sum_{b=1}^{9} rp_b)$	0.81	0.72	33.30	0.000
H_6:	$RLP = RLP(\sum_{b=1}^{4} rlp_b)$	0.16	0.78	6.42	0.022
H_7:	$PN = PN(\sum_{b=1}^{3} pn_b)$	0.54	0.45	19.05	0.000
H_8:	$SI = SI(\sum_{b=1}^{2} si_b)$	0.32	0.51	17.95	0.001
H_9:	$KTC = KTC(\sum_{b=1}^{2} ak_b + \sum_{b=1}^{5} to_b + \sum_{b=1}^{4} app_b + \sum_{b=1}^{13} cmt_b)$	0.93	0.35	50.79	0.000
H_{10}:	$AN = AN(\sum_{b=1}^{12} avo_b + \sum_{b=1}^{15} sac_b + \sum_{b=1}^{5} nwc_b)$	0.80	0.49	25.10	0.000
H_{11}:	$INST = INST(\sum_{b=1}^{5} inst_b)$	0.62	0.83	26.85	0.000

Source: author

The analysis of these results in confrontation with the criteria for the acceptance or rejection of the hypothesis, presented in Appendix C, showed that:

a) **Verification of the coefficient of determination (R^2)[95]:** the variance of the dependent variables, in all hypothesized relationships, were explained by the combinations of the independent variables (combined effect of the prediction statistical variable) as shown by the coefficients of determination. In its first hierarchical level of explanation (the first level-hypothesis H_1), the model explained 65 percent of the variance of the sample. The second level of explanation (hypothesis H_2), based on which all inferences in respect to willingness formation were made (cf. Chapter 7), explained 72 percent of the variance in willingness.

[95] Coefficient of determination (R^2) measures the proportion of the variance of the dependent variable, around its mean, that is explained by the independent (predictor) variables. If the regression model is properly applied and estimated, the researcher can assume that the higher the R^2 value, the higher the explanation power of the regression equation and, therefore, better predictions of the dependent variable are obtained (Hair *et al.*, 2005).

b) **The dimension of the standard error of the estimate (SE):** the standard errors of the estimates, in all hypothesized relationships were below or very close to 1.0. This indicated that there is a satisfactory level of prediction (cf. Section 4.6.2 of Chapter 4);
c) **Significance test of the general regression model:** the results showed that the regression model fit the population from which the data were sampled and the F-tests were significant at the 0.05 level. This demonstrated that at least one of the coefficients was not zero;
d) **Significance test for the regression coefficients:** the stepwise regression method selected the significant regressions coefficients (cf. Appendix C). Due to small sample size that was obtained by this thesis research's quantitative survey, some regression coefficients, although having low collinearity, they failed to be proved significant;
e) **Assessment of the impact of the multicollinearity in the regression model:** all variables presenting significant coefficients, selected by the stepwise regression method, showed low collinearity (tolerances values superior to 5 and VIF below 5) (cf. Appendix C);
f) **Assessment of the normality of the distribution of the residuals:** the visual inspection of the normal probability plots of the residues showed distributions that approximate the normal distribution ("fat pencil" test[96]).

The results presented in Table 6.37, indicated that: (a) for every hypothesis, there is a linear relationship of dependence between the dependent and independent (predictors) variables, (b) the system of hypotheses was not rejected and, as a consequence, the links of causality that were proposed can be accepted. **This verified that the behavioral model is valid and can be used to explain and predict willingness in the context to which it was designed.**

These results verified what was posited in Section 4.6.2, in Chapter 4, in respect to the importance and necessity of the construct validation of this thesis research´s behavioral model. Based on the findings, it can be argued that the model measures the concept it was intended to measure and that the measures relate to other measures consistent with the theoretically derived hypotheses that were proposed in Chapter 5.

Summary

As a concluding remark, in light of the analytical tests´ results, it can be argued that the results presented in Section 6.6, attested to the reliability and validity of the measurements involved in this thesis research. In parallel, it answered the question posed at the conclusion of Section 6.5 about the extent to which the scores presented, in the analyses, conducted in the previous sections of this chapter, were reliable and the behavioral model is valid.

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[96] If the hypothesized normal distribution adequately describes the data, the plotted points fall approximately along a straight line. If the plotted points deviate significantly from the straight line, especially at the ends, then the hypothesized distribution is not appropriate. In assessing the "closeness" of the points to a straight line, the "fat pencil" test is often used. If the points, are all covered by the imaginary pencil, then the hypothesized distribution is likely to be appropriate. (http://www.statit.com/support/quality_practice_tips/normal_probability_plot_interpre.shtml), accessed in May, 2012.

It can be concluded that the model appropriately measured and explained the planned behavior of the Brazilian petrochemical companies in the sample (cf. Section 6.5), for the next five years (time criterion adopted in this thesis research)[97], in respect to their willingness to engage in GCE-based eco-innovation activities. It was found to appropriately predict changes that can occur to companies´ willingness as a consequence of changes in the perceptions of their managers in relation to its determinants. These predictions can be used to support the development of policies focused on the promotion of companies' engagement in GCE-based eco-innovation activities. This issue is explored in Chapter 7.

At the conclusion of Chapter 6, it is important to call the readers´ attention that it provided the base upon which Chapter 7 was developed, where a deeper study on the significant determinants of willingness was conducted and the best conditions for willingness, in the context of this research, were identified. In parallel it also provided the basic elements for this thesis research´s qualitative survey to be developed.

[97] "Intentions can change overtime, the longer the time interval, the greater the likelihood that events will occur or new information will produce changes in intentions" (Montalvo Corral, 2002: 40)