The internalization of Externalities from Electrical Power Plants as a Tool for Progressing Towards Sustainability in Small Island Developing States: The Case of Bahrain

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De internalisering van externe effecten van energiecentrales als een instrument om duurzaamheid te bevorderen in kleine eilandstaten in ontwikkeling: De casus van Bahrein

Thesis

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Table of contents

Acronyms and abbreviations

ALBA: Aluminum Bahrain
BD: Bahraini Dinar
BAPCO: Bahrain Petroleum Company
Btu: British thermal unit
CH_4: Methane
CI: Confidence Interval
CO: Carbon Monoxide
CO_2: Carbon dioxide
CS: Consumption Surplus
CV: Contingent value
DALYs: Disability-Adjusted Life Years
DSM: Demand Side Management
ERF: Exposure Response Function
ES: Equivalent Surplus
GDP: Gross Domestic Product
GHG: Greenhouse Gas
GSO: Government Social Obligations
GWh: Gigawatt Hour
H_2O_2: Hydrogen Peroxide
IC: Illness Cost
IPCC: Intergovernmental Panel on Climate Change
IPWP: Independent Power and Water Producer
IRR: Increase Risk Ratio
IPA: Impact Pathway Approach
KISR: Kuwait Institute for Scientific Research
Kv : Kilo Volt
LE; Life Expectancy
MAC: Marginal Abatement Cost
MDC: Marginal Damage Cost
MEPA: Metrological and Environmental Protection Agency
MEW: Ministry of Electricity and Water
MWh: Megawatt Hour
N_2O: Nitrate Oxide
NCVTD: National Committee for Villages and Towns Development
NMVOC: Non-methane volatile organic compounds
NO_3: Trinitrate
NOx: Nitrogen oxides
O_2: Oxygen
O_3: Ozone
PC: Productivity Cost
PM: Particulate matter

PPB: Parts per Billion
PPM: Parts per Million
PWPA: Power and Water Purchase Agreement
RR: Relative Risk
R & D: Research and Development
SIDS: Small Island Developing State
SO_2: Sulphur dioxide
SO_4^{-2}: Sulphate Ion
SOx: Sulphur oxide
SPM: Suspended Particulate Matter
SUWM: Simple Uniform World Model
TJ: Tera Joules
TPC: Total Production Costs
U.S.A: United States of America
UNFCCC: United Nations Framework Convention on Climate Change
VOSL: Value of Statistical life
VPF: Value of Prevented Fatality
WHO: World Health Organization
WS: Wind Speed
WTA: Willingness to Accept
WTP: Willingness to Pay
YOLL: Years of Life Lost
EPS: Energy Performance Standard
EPC: Energy Performance Coefficient
MSC: Marginal Social Cost

List of figures

List of Tables

Chapter 1: Overview on the Bahraini Electricity Production Sector and its Externalities

Introduction:

Power is the engine of growth of any economy. Consumption of electrical energy is a universally accepted indicator of progress in the productive sectors, and of the well being of the people of any country. No major economic activity can be sustained without an adequate and reliable supply of power. It plays a critical role in employment generation, development and social welfare.

This chapter provides background information on this research. The first section provides general information about the electricity production sector in Bahrain and the scientific knowledge base about externalities. The second section examines theoretical discussions about externalities. It provides a theoretical base for building this thesis' research framework on how to use economic valuation of externalities in the policy making process in the electricity production sector? What is the appropriate methodology to calculate and internalize the externalized costs of electricity? This is one of the main questions that this thesis researcher sought to answer.

1.1 The Bahraini Electricity Production Sector

The electrical utility industry in the kingdom of Bahrain as a Small Island Developing State (SIDS) has come a long way from its beginnings more than seventy years ago when the government, in May 1931, commissioned the first electrical power station at Ras Romman with a capacity of 0.2 Megawatt. In 1932 another power plant was constructed on behalf of the Bahrain Refinery. Since then, electricity use has dramatically increased and is now contributing to the economic growth, and the well-being of Bahrain's inhabitants.

Electrical power generation has increased significantly over the years. Generated electricity increased by almost 6.5% between 2003 and 2004, (i.e., from 7,768 to 8,267 GWh). Very strong real estate development is now occurring and is expected to continue, and the Bahrain Gross Domestic Product (GDP) is projected to have annual increases of 5-6% in the medium term. Growing demand for power will require costly upgrades to the power infrastructure, including generation, transmission and distribution. The government of Bahrain is moving to address the requirements for additional power and water infrastructure. Following the August 2004 blackout, the ministry of Electricity & Water asked the government for 700 million BD (1.86 billion US$) to upgrade Bahrain's power facilities.

The installed electrical generating capacity in Bahrain in 2004 was 1849 MW that is provided by five publicly owned power stations (i.e., Manama, Muharraq, Riffa, Sitra, and Hidd) that are connected to the main power system through two 220 Kv and one 66 Kv links (Electricity Statistical Book, 2003)[1] The electrical utility industry consumes large volumes of fossil fuel; the publicly owned power stations consumed over three billion cubic meters per year of natural gas to generate about 83% of the total electricity generated, with the remainder (17%) obtained from the power station of the aluminum smelting plant (ALBA) which generates 1,527 MW. In the near future, with the new expansion, it will generate 3,613 MW.

Tariff rationalization is necessary if Bahrain is to improve the operational efficiency of power generation. Currently, the tariff structure for electricity in the Kingdom of Bahrain is not based on consumer-specific, long-term, marginal costs but is based upon a price structure that is used as an instrument to achieve political and socioeconomic objectives. Electrical Power tariffs in Bahrain are classified according to different customer classes as presented in Table 1.

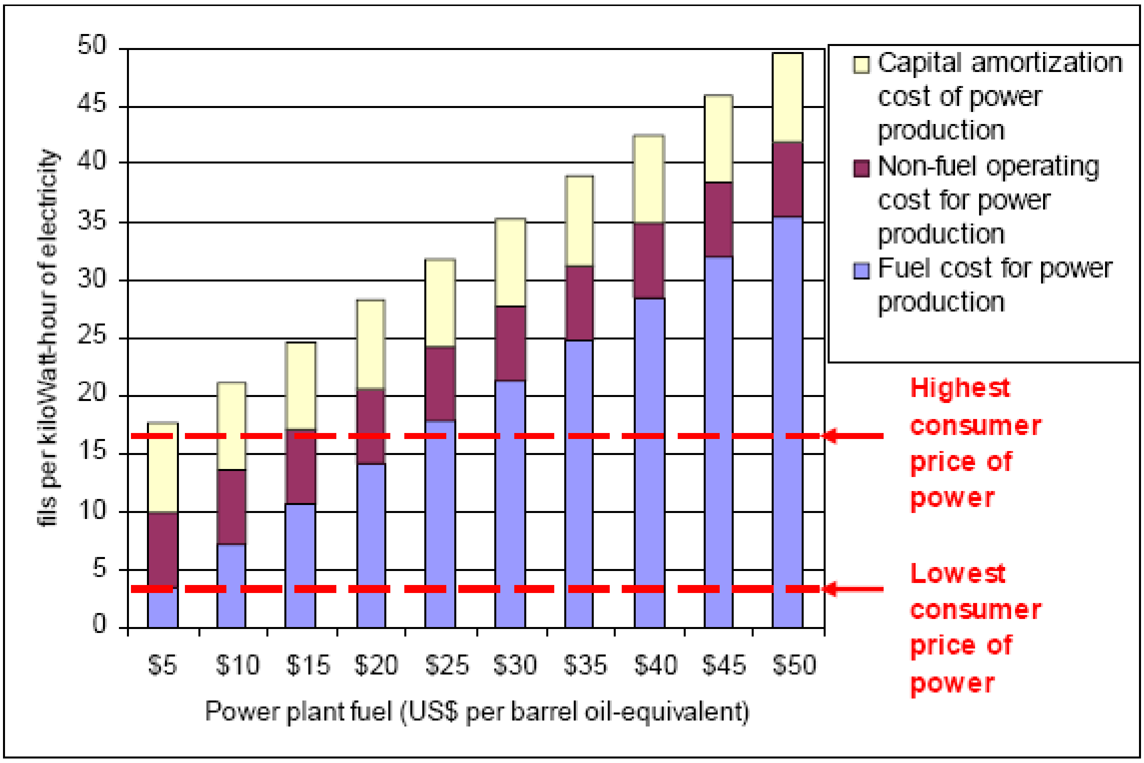
Table 1. Bahrain Electricity Tariffs, fils/kWh

Class	Cost per kWh(fils)*for monthly kWh		
	1-2000 kWh	2001-5000 kWh	5001 kWh - over
Domestic tariff for residents	3	6	16
Domestic tariff for non-residents	6	12	16
Commercial tariff	16	16	16
Industrial tariff	12	12	12

Source: Ministry of Electricity and Water, 2008
* The Dinar is the currency of Kingdom of Bahrain, the Bahraini Dinar (BD) is divided into 1000 fils, and the BD is equal US $ 2.65 and € 2.07 as per the exchange rates on 12 March, 2009.

Electricity prices in Bahrain are far below the total capital and operating costs of production and delivery. These costs are the ranges in prices between the lowest and highest tariffs charged to consumers, are illustrated in Figure 1.

Figure 1- Actual power Production Costs Compared to Rates Charged to Consumers



Source: Tabreed Bahrain, 2005

At a power generation fuel cost equivalent to US$20 per barrel oil, the actual electrical power production, operating costs are estimated to be 20.6 fils per kWh, of which 14.2 fils is for fuel and 6.4 fils is for non-fuel operation and maintenance costs. The operating cost increases to 34.8 fils/kWh with fuel at the equivalent of US$40 per barrel oil, which is a reasonable minimum assumption regarding long-term prices (Tabreed, 2005).[2]

In addition, the capital amortization cost of electrical power production should be accounted for when considering the need for incremental increases in new power production capacity. This capital amortization cost, according to the Ministry of Electricity and Water, is estimated to be 7.6 fils per kWh (the calculation is based on the assumption: 420 BD per kWh of power generation, transmission and distribution capacity; 75%/25% debt/equity mix; 5% debt interest cost; 18% return on equity; 30 years term; 0.57 capacity factor).

With current electrical power tariffs range from 3 to 16 fils per kWh, consumer power prices in Bahrain are below the actual costs of production and delivery, particularly when considering incremental capital costs for meeting new power production requirements. These costs, and comparisons to the rates charged to consumers are illustrated in the following paragraphs.

At $20 per barrel oil, the total power production subsidy is 18.8 fils per kWh, with consumers paying 34% of the total capital and operating cost. With oil at $40 per barrel, the total power production subsidy is estimated to be 26.5 fils per kWh, with consumers paying 22% of the total capital and operating costs. However, at the oil prices, which were approximately US $ 110 per barrel in 2008, the power production subsidy was estimated to be 83.8 to 97% of the total actual costs based on the minimum and maximum tariff (Table 1.2).

Table 2. The Gap between the Actual Electricity Production Costs and Tariff

Fuel Prices per barrel/ U$	Fuel Cost per KWh/ Fils	Operational Cost per KWh / Fils	Capital Cost per KWh / Fils	Actual Total Cost per KWh/Fils	% Subsidy per KWh Based on the Min. tariff (3 fils)	% Subsidy Based on the Max. tariff (16 fils)
55	0.041	0.006	0.008	0.055	94%	71%
60	0.045	0.006	0.008	0.059	95%	72%
65	0.049	0.006	0.008	0.063	95.2%	75%
70	0.053	0.006	0.008	0.067	95.5%	76%
75	0.057	0.006	0.008	0.071	95.8%	77.5%
80	0.061	0.006	0.008	0.075	96%	78.6%
85	0.065	0.006	0.008	0.079	96.2%	79.7%
90	0.069	0.006	0.008	0.083	96.4%	80.7%
95	0.073	0.006	0.008	0.087	96.5%	81.6%
100	0.077	0.006	0.008	0.091	96.7%	82.4%
105	0.081	0.006	0.008	0.095	96.8%	83.2%
110	0.085	0.006	0.008	0.099	97%	83.8%

Source: This table was developed by the author based on Tabreed Data.

At electricity production of 9.1 million MWh in 2005, the annual governmental subsidy to the power sector for operations were over 170 million BD assuming power generation fuel valued at $40/barrel oil. Chapter 2 of this thesis reviews the current Bahrain electricity policy and the factors that influence the policy and prices charged to customers.

Similarly, the tariff structure in the natural gas and petroleum products, used for power generation, does not reflect the true cost of exploration, production, transmission, and distribution. The gas prices are supposed to be linked to the international price of crude and fuel oil, but they are not now directly linked.

The reported electricity "Cost of Production" in 2002 was 72,091 Million Bahraini Dinar (191Millions US$), (Electricity Directorate data, 2002)[3]. With reported production of 7,278 million kWh in 2002, this indicates a cost of production of 9.9 fils per kWh that is based on an analysis in the region (Kuwait Institute for Scientific Research (KISR), April 2004[4]. The likely non-fuel production costs are 6.4 fils per kWh. This leaves 3.3 fils per kWh for fuel, which is equivalent to US$0.85 per million BTU (MBTU) of fuel or US $50.00/barrel of oil. This price level is less than 50% of the current market values (as of September 2011 the prices were around US$107).

Whatever price is charged to the electrical power utility for the fuel, the value of fuel far exceeds the level they are charged. The government will not be able to allocate its resources effectively unless and until it recognizes the actual value of the energy used for electrical power production and water processing. They need to eliminate the current price distortions, by adopting proper resource accounting methods that are designed to internalize all costs, including externalities and supply risks.

Resources accounting is the collection and aggregation of information for decision makers – including managers, investors, regulators, lenders, and the public. Accounting systems affect behavior and management and have affects across departments, organizations, and countries. Information contained within an accounting system has the power to influence actions. Accounting information systems are particularly strong behavioral drivers within the context of a corporation - where profits and the bottom line are daily concerns. In order for environmental concerns to be important criteria in everyday business management decisions, they need to be encapsulated within the accounting systems of the organization (Schempf, 2008)[5]

Bahrain has natural gas reserves of about 3.25 trillion cubic feet; much of it is associated gas from the Awali oil field. Bahrain produced 327 billion cubic feet of natural gas in 2002, all of which was consumed locally. The Bahrain Aluminum Smelter (ALBA) is the largest domestic gas consumer. Bahrain's growing demand for power is likely to cause it to become a net, natural gas importer by 2020 (U. S. Energy Information Administration, 2004)[6].

With gas demand growing world-wide, driven by rapidly growing energy requirements in China, India and other developing nations, and by declining domestic reserves in the United States, and in many other regions of the world, by the coming decade, the gas market will experience dramatic market driven, price increases.

The value of electrical power plant fuel should be based on a realistic assessment of long-term energy prices, in which Bahrain will either be paying more for imported fuel, or should factor in the opportunity costs of energy production that it could export at market prices. In this context, it would be prudent to assume that power plant fuel costs should be in a range consistent with US $ 100 per barrel oil.

The growth of the electrical power sector has been a mixed blessing while availability of low-priced electricity has proven itself to be the engine of industrialization and societal well-being; the byproducts of its generation, transmission, and distribution have significant negative effects. Most of the electricity in the Kingdom of Bahrain, as stated earlier, is produced by gas-fired power facilities; the major air emissions released from the combustion of gas include carbon dioxide (CO_2), particulates (PM_{10}), nitrogen oxides (NOx), and sulphur oxide (SOx). Other contaminants are also released but in much smaller or trace quantities, among them methane (CH_4) and non-methane volatile organic compounds (NMVOC). These contaminants are of concern because of the potential risks they pose to human and environmental health. In 2006, the World Health Organization (WHO)[7] released a report that estimated how much of global human disease could be prevented through a healthier environment. This work was built upon previous efforts that WHO coordinated to estimate the global burden of disease caused by 26 risk factors, published in the World Health Report 2002[8], in cooperation with numerous experts around the world, where five of these risk factors were environmental and six were occupational.

Of the 102 major diseases, disease groupings and injuries covered by the *World Health Report*, environmental risk factors contributed to the disease burden in 85 categories. The specific fraction of disease attributable to the environment varied widely across different disease conditions. Globally, an estimated 24% of the disease burden (healthy life years lost) and an estimated 23% of all deaths (premature mortality) were attributable to environmental factors. Among children 0–14 years of age, the proportion of deaths attributed to the environment was as high as 36%. There were large regional differences in the environmental contribution to various disease conditions, due to differences in environmental exposures and access to health care across the regions. For example, although 25% of all deaths in developing regions were attributable to environmental causes, only 17% of deaths were attributed to such causes in developed regions. Although this represents a significant contribution to the overall human disease burden, it is a conservative estimate because currently there is not adequate, scientifically sound, environmental-source causative linkages for many disease (WHO, 2006)[9].

Air pollutants, NOx and SO_2, collectively known as acid gas causing emissions, are largely responsible for the formation of the acid precipitation that damages aquatic and terrestrial ecosystems, structural materials such as limestone buildings and monuments and cause human health risks. These gases are also key components in the formation of ground-level ozone and smog. CO_2 is a greenhouse gas linked to climate change, and according to the available data, CO_2 emissions from power plants, is responsible for more than 90% of the energy sector emissions, and about 80% of the NOx (Bahrain Greenhouse Gas Inventory, 2005)[10].

The Kingdom of Bahrain is heavily dependent on natural gas as its main fuel for its electrical power plants; this dependence is likely to increase further due to additions in generating capacity that are envisioned in the governmental policy designed to cope with the increasing demands.

The indigenous natural gas has a sulphur content that exceeds 6% by volume (Bahrain Petroleum Company, Engineering division, 2007)[11] if one adds to this problem, the lack of the use of environmentally friendly technologies like electrostatic precipitators, desulphurization technologies and other technologies/equipment in most of the power plants, one can easily imagine the magnitude of the environmental and human health impact caused by the electrical power generation sector.

Currently, three of the seven power plants namely, ALBA, BAPCO, and RIFA are violating the environmental standard for NOx. In 1999, an independent assessment conducted by LAHMER Int., studied the contribution of power stations to pollutant emissions, they found that the highest NOx emission concentrations were in the flue gases of the large gas turbines without NOx reduction. They found NOx emission concentrations of (255-313 ppm) at RIFA, and (264-313 ppm) at ALBA. The NOx levels measured at these units exceeded the established emission standards of Bahrain, MEPA, the World Bank, and Germany, which are all in the range between 39 and 49 ppm (Lahmeyer International (1999)[12].

There is a growing recognition that such emissions adversely damage the environment nationally, regionally and globally. They also cause human health problems and infrastructure damages. Economists label these damages or impact as “externalities”. However, externalities are defined as costs generated as an unintended by-product of an economic activity that does not accrue to the parties involved in the activity and where no compensation takes place. Environmental and human health externalities are costs that manifest themselves through changes in the physical-biological environment. Pollution emitted by road vehicles, by fossil fuel fired power plants during power generation and other industrial activities are known to cause harm to humans, the environment, and to the built infrastructure.

In addition, upstream and downstream externalities, associated with securing fuel and waste disposal, are generally not included in power or fuel costs. To the extent that the ultimate consumer of these products does not pay these environmental costs, and does not compensate people for harm done to them and they do not pay the full cost of the services they purchase (i.e., implicitly their energy use is being subsidized) and thus, the nation's energy resources will not be allocated efficiently and equitably (Owen 2004)[13].

1.1.1 Cost of Electricity and the Environmental and Health Impacts:

The full cost for electricity includes internalizing all environmental costs in the price. This method is the simplest to describe but can be the hardest to do because including the full cost of environmental damage in prices can significantly raise the price of electricity. For this reason, planners and regulators recommend the use of "Externality Adders". This approach has the effect of passing less than the full environmental and human health costs to the customers (Carbonell 2005).[14]

In the context of electricity markets, an "externality adder" is simply the unit of externality cost added to the standard resource cost of electricity to reflect the social cost of its use. For power generation, the externality adder would generally be specified in terms of fils of-Bahraini Dinar per kWh, or ¢/ kWh. (Pearce 2002)[15] lists five uses for externality adders:

i. For public or quasi-public ownership of sources of electric power generation, the full social costs of alternative technologies could be used to plan future capacity with preference being given to that with the lowest social cost. Where electrical power generation is privately owned, then regulators could use the full social cost to influence new investments, perhaps through an effective environmental tax;

ii. Externality adders can be used to estimate the appropriate level of environmental taxes. Although estimates of environmental adders have been derived for a number of applications, examples of their actual implementation are few;

iii. Externality adders could be used to adjust the national account's data to reflect depreciation of natural resources and damage to the environment arising from economic activity, yielding so-called "green" national accounts;

iv. Externality adders could be used for "awareness raising"; i.e., to inform the public of the degree to which alternative energy sources have externalities that give rise to economically inefficient allocation of resources;

v. Externality adders might be used to assist in determining environmental policy priorities.

Environmental externalities of energy production/consumption (regardless of the fuel cycle used in generation) can be divided into two broad cost categories that distinguish emissions of pollutants with local and/or regional impactfrom those with global impact (Owen 2004)[16]:

a. Costs of the damage caused to human health and the environment by emissions of pollutants other than those associated with climate change; and

b. Costs resulting from the impact of climate change attributable to emissions of greenhouse gases.

The distinction is important, since the scale of damages arising from the former is highly dependent upon the geographic location of source and receptor points. The geographic source is irrelevant for damages arising from emissions of greenhouse gases. Costs borne by governments, including direct subsidies, tax concessions, indirect energy industry subsidies (e.g., the cost of fuel supply security), and support of research and development costs, are not externalities. They do, however, distort markets in a similar way to negative externalities, leading to increased consumption and hence increased environmental degradation (Owen 2004).

Among the major external impact attributed to electricity generation are those caused by atmospheric emissions of pollutants, such as particulates, sulphur dioxide (SO_2) and nitrogen oxides (NOx), and their impact on public health, materials and crops. The impact of these atmospheric pollutants on fisheries and ecosystems are also important but have not yet been quantified. Emissions of SO_2 and NOx have long-range, trans-boundary effects, which make calculation of damages an imprecise exercise. Such calculations require measurements to be based upon the unique link between fuel compositions, characteristics of the power units, and features of the receptor areas. Thus, estimated damage costs may vary widely across continents, and even within individual countries. Estimated damages per ton of pollutants for SO_2, NOx, and particulates vary greatly because of a number of factors. Briefly these are as suggested by (Owen 2004):

- Vintage of combustion technologies and presence of associated emission reducing devices such as flue gas desulphurization or low NOx burners;
- Population density in receptor areas for airborne pollutants;
- Fuel quality; and
- Mining and fuel transportation externalities.

However, damage estimates are dominated by costs arising from human health effects, which are largely determined by the population affected. Estimation of health impact is generally based upon exposure response epidemiological studies and methodologies for placing a valuation on human life, all of which remain controversial (Owen 2004).

As might be expected, countries that are sparsely populated, or populated in largely non-receptor areas, tend to have relatively low health damage costs. Chapters 3 and 4 of this thesis address the impact and damage cost assessments based upon the methodologies that are available as well as the approach adopted by the Kingdom of Bahrain to calculate the external costs of power plants.

The damage costs of carbon dioxide (CO_2) are considered to be the main external costs arising from greenhouse gas emissions from electricity generating facilities that lead to climate change with all its associated effects. This is a very contentious area, and the range of estimates for the possible economic ramifications of global climate change is vast. Costs associated with climate change, such as damage from flooding, changes in agricultural patterns and other effects, all need to be taken into account. However, there is much uncertainty about the magnitude of such costs, since the ultimate physical impact of climate change has yet to be determined with precision. Thus, deriving monetary values on the current basis of limited knowledge is an imprecise exercise.

The emissions of CO_2, CH_4 and N_2O for the energy sector of Bahrain and the upper and lower bounds of avoidance costs are addressed in Chapter 4. These costs are derived not only from the emissions of RIFFA, BAPCO and ALBA but also from the emissions of CO_2, CH_4 and N_2O in the whole energy sector.

1.2 Literature Review

Introduction

This introduction is developed in order to explore the context of power generation and the earlier research on externalities, as well as to allow the thesis author to position himself in that context.

Electric power generation plays important roles in modern societies, but also causes negative impact on the environment such as air, water, and soil pollution. A large number of regulations and economic incentives exist worldwide to promote the introduction of more environmentally benign power generation technologies. However, when implementing such policy efforts, two questions arise: (a) what technologies should be considered environmentally benign; and (b) how does one find a proper balance between the costs and benefits of electricity production and the costs and benefits of prevention or reduction of environmental degradation? During the last decades policy makers have shown an increased interest in the general recommendations found in the economics literature (Sundqvist and Soderholm 2002)[17].

According to this line of research, the answers to these questions lie in applying economic non-market valuation techniques to the specific environmental (and non-environmental) impact that can be labeled externalities. Formally, an externality, i.e., an external cost or benefit, is defined as an unpriced and uncompensated side effect of one agent's actions (in our case electrical power generation utilities) that directly affect the welfare of another agent (Baumol and Oates 1988)[18]. Since these affects are not reflected in market prices, there exists a need to assist market processes by assigning them monetary values and in this way to integrate them into private and public decision-making and subsequently, into the product or service unit cost, surcharge or tax structure (Sundqvist and Soderholm 2002).

The beginning of the 1980's are considered being the beginning of serious attempts to evaluate and assess the environmental impact of the electricity production sector, for example (Schumann and Cavanaugh 1982)[19] used the abatement cost approach to estimate the environmental impact of power generation in the U.S.A. During the 1990's there was a surge in the number of externality valuation analyses conducted, in large part due to increased attention from policy makers in Europe, with the ExternE-project (EC 1995; 1999)[20], and in the U.S. (e.g., Rowe et al. 1995[21]; ORNL and RFF 1994-1998[22]). The results and the methods of many of these studies have been utilized as inputs in important modeling work and have served as vehicles in developing additional methodological work in the environment and energy field (Krewitt 2002)[23]. For instance, past studies on how different environmental regulation schemes affect national energy systems have made use of external cost adders. Until now, the results from previous studies have only, to a limited extent, affected actual policy decisions. Some authors argue that this is because electricity production environmental impact studies may have raised more questions than they have answered, and that there are important limits to their usefulness in deriving policy-oriented recommendations (e.g., Stirling 1997)[24].

The main purpose of this Chapter is to provide a survey of previous external cost studies in the electrical power sector, and with this survey as a basis to discuss a number of conceptual and still unresolved issues in the economic valuation of electricity related environmental impacts.

Previous studies have also critically surveyed past research on electricity externalities. See, in particular, OTA[25] (1994), Kühn[26] (1996; 1998[27]), Lee[28] (1997), Ottinger[29] (1997), Stirling, the main conclusions for these studies can be summarized by the following; the cost estimates of environmental external effects of energy supply differ widely due to different methods and assumptions in different studies. For that reason, the resulting figures are difficult to combine or compare; they are variable and uncertain. All studies reviewed highlight that their results contain substantial uncertainties and cannot incorporate all relevant categories of externalities." Many of the differences can/should be addressed through further research and analysis. Some critical disagreements over methodology, however, mask deeper disputes over values, basic policy goals, and the intended role of environmental cost studies; it is unlikely that these disputes can be resolved by technical analysis or scientific research"(U.S. Congress/ OTA 1994)[30]. Thus, accepting and using the quantitative findings of a particular study implies accepting the goals and value judgments embedded in that study or using it in the context of the study's assumptions.

Stern[31] (2006) examined the evidence of the economic impact of climate changes and explored the economics of stabilizing greenhouse gases in the atmosphere. He also considered the complex policy challenges involved in managing the transition to a low-carbon economy and in ensuring that societies can adapt to the consequences of climate change that can no longer be avoided; The Stern report stated that the benefits of strong, early action on climate change outweigh the costs, and the scientific evidence points to increasing risks of serious, irreversible impact from climate change associated with business-as-usual (BAU) paths for emissions. However, the central estimates of the annual costs of achieving stabilization between 500 and 550ppm CO_2 emissions are around 1% of global GDP, if we start to take strong action now (Stern 2006) it is already very difficult and costly to aim to stabilize at the 450ppm CO_2 level, but if we delay, the opportunity to stabilize at the 500-550ppm CO_2 may also slip away.

The Stern report highlighted that while the transition to a low-carbon economy will bring challenges for competitiveness, it will also provide opportunities for growth in quality of life in other ways. Mitigation or prevention policies to support the development of multiple, low-carbon and high-efficiency technologies are urgently required. However, adaptation policies are also crucial for dealing with the unavoidable impacts of climate change, this is a concept that has been under-emphasized in many countries, therefore, establishing a carbon price through tax, trading or regulation, is an essential foundation for climate change policy. Creating a broadly similar carbon price signal around the world, and using carbon finance to accelerate action in developing countries are urgent priorities for international cooperation.

1.2.1 Externalities in Theory and in Practice

Externalities occur as a result of both consumption and production activities and they are the causes of market failures, something that in turn leads to a resource allocation that is non-optimal from society's point of view. Hence, theoretically an externality causes a type of situation in which the First Theorem of Welfare Economics [1] **(**Stavins, 2009**)[32]** fails to apply, and markets fail at accomplishing

1The "first theorem of welfare economics" states that private markets are perfectly efficient on their own, with no interference from government, so long as certain conditions are met. This theorem, easily proven, is exceptionally powerful, because it means that no one needs to tell producers of goods and services what to sell to which consumers. Instead, self-interested producers and self-interested consumers meet in the market place, engage in trade, and thereby achieve the greatest good for the greatest number, as if "guided by an invisible hand," as Adam Smith wrote in 1776 in The Wealth of Nations. This notion of maximum general welfare is what economists mean by the "efficiency" of competitive markets.

Pareto efficiency[2] (Sundqvist and Soderholm 2002)[33]. Specifically, in the case of a negative externality, there is a difference between the private and the social costs of an activity. The private costs facing a producer measure the best alternative uses of resources available as reflected by the market prices of the specific resources used by the producer.

The social costs of production, however, equal private costs plus external costs (Figure 2), and measure the best alternative use of resources available to society as a whole. Since there is a lack of a market for the external impacts, a profit-maximizing producer has no incentive to integrate these effects into the decision-making process. Thus, private costs are lower than the social costs. The difference between private and external costs is, however, not “fixed”. If the external costs can be “internalized” (i.e., made private), decision-makers will have an incentive to undertake actions that help mitigate, for instance, the negative environmental impact arising from electricity generation.

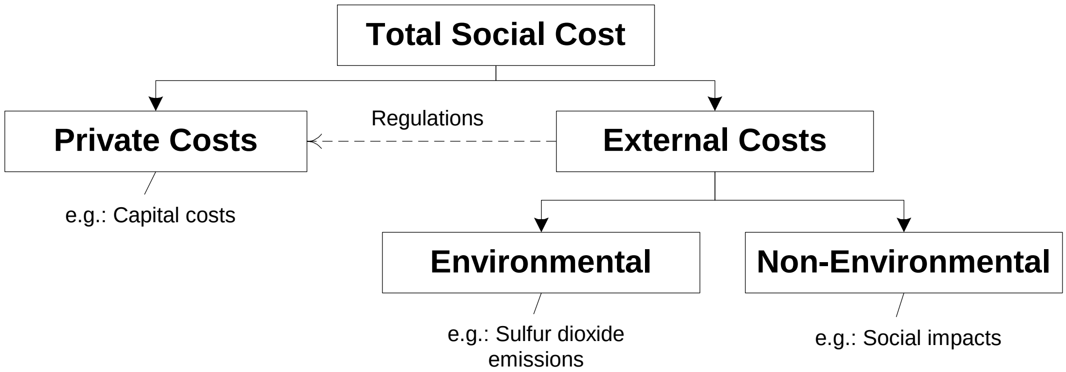


Figure 2: Total Costs to Society of a Productive Activity

Source: IEA (1995)[34] cited from (Sundqvist and Soderholm, 2002).

Coase (1960)[35] demonstrated that bargaining between the polluter and affected agents can, under certain circumstances (such as low transaction costs and full information), internalize externalities and achieve an efficient outcome. However, in most cases, due to the large number of parties involved, some kind of governmental intervention is necessary. One way of correcting the inefficiency of an external cost is the use of so-called ‘Pigouvian’ taxes as originally suggested by Pigou (1924). This implies setting a tax equal to the value of the marginal external cost (at the optimum level of the activity in question) so that the private decision maker is provided with an incentive to economize not only on the traditional input factors but also on unpriced goods and services such as those provided by the natural environment. However, this

2An economic system that is Pareto inefficient implies that a certain change in allocation of goods (for example) may result in some individuals being made "better off" with no individual being made worse off, and therefore can be made more Pareto efficient through a Pareto improvement. Here 'better off' is often interpreted as "put in a more preferred position." It is commonly accepted that outcomes that are not Pareto efficient are to be avoided, and therefore Pareto efficiency is an important criterion for evaluating economic systems and public policies.

solution to the externality problem requires that the tax authority is able to identify the external cost functions. How do we go about assessing the size of this function, and hence the value of the damage caused by a negative externality (or the benefits derived from a positive one)? The theoretical bases of such valuation exercises and the practical approaches used to empirically determine these values are discussed in subsequent sections. However, there is also the issue of the '*will*' to enforce the charges and to do so fairly and consistently. These dimensions of the equation also have to be addressed somewhere in the transformation of the society from one which does not internalize their presently externalized impact to one which does internalize them.

1.2.2 Externalities from the Theoretical Economic Perspective

The theoretical basis of the economic valuation of externalities is outlined in the welfare economics literature. This strand of research recognizes that the economic value of a resource or service is ultimately a function of individual preferences, and the tool for analyzing welfare changes is therefore, utility theory. Our focus is on the economic valuation of an environmental good, but the general concepts are applicable to the valuation of all non-market goods. Perman et al. (1999)[36], considered an individual that derives utility (*U*) from two goods, *Q* and *Y*. *Q* represents an environmental "good" that the individual consumes and *Y* all other consumption possibilities available to the individual. Changes in the level of *Q* can refer to quantity changes or quality changes depending upon the type of environmental good or service involved. Assume that *Q* is a public good that is non-exclusive and non-divisible, so that the individual cannot adjust his or her consumption level. Now consider a project (e.g., a policy change) that causes the environmental quality to increase (or improve) from *Q'* to *Q"* (see Figure 3).

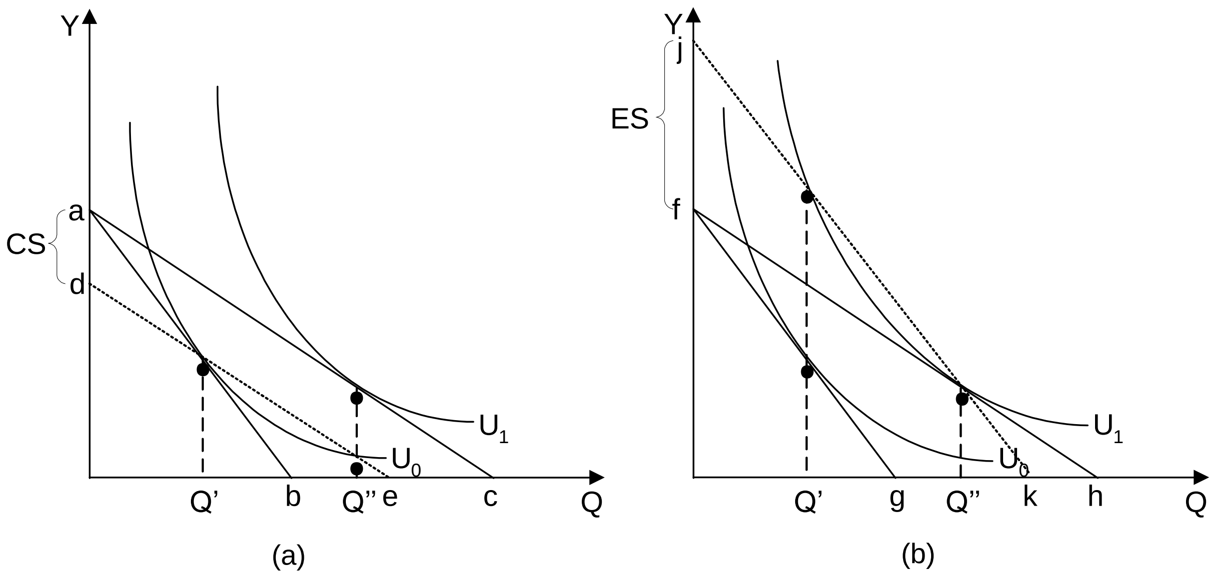


Figure 3. Compensating Surplus (CS) and Equivalent Surplus (ES)

Source: Sundqvist and Soderholm, (2002).

The project causes a positive change in the utility (or welfare) for the individual (represented by the move from indifference curve U_0 to indifference curve U_1). Given the presence of the project the individual is thus, made to be better off. However, since utility is not directly observable and since environmental "goods" are not part of market transactions we need to find alternative ways of assessing the value of this welfare change. Theoretically two standard monetary measures of quality based welfare changes are the compensating surplus (CS) and the equivalent surplus (ES).

To find the first CS of these measures, we start by noting that an increase in *Q*, everything else held constant, is equivalent to a reduction in the price of *Q*. And since the slope of the budget line is given by the relative price, the budget line (representing the individual's consumption possibilities) will change from a–b to a–c. In order to identify *CS* in Figure 2a we, hypothetically, constrain the individual at the pre-change environmental quality level (*Q'*) and utility level (U_0) by taking away just enough of the individual's income so that he or she can just afford to consume at the pre-change level (represented by the "dotted" budget line d–e). *CS* is then a–d or the amount of money, that if foregone by the individual with the policy change, would result in him or her experiencing the pre-change level of utility or, in other words, the maximum willingness to pay (*WTP*) for the environmental improvement (Sundqvist and Soderholm 2002).

The derivation of the ES measure is presented in Figure 3b. *ES* is given by j–f; it is the amount that, at the original prices, would, if paid to the individual, result in him or her experiencing the same level of utility as the environmental improvement would have done, given that the environmental improvement, hypothetically, does not take place. Here ES equals the minimum willingness to accept (*WTA*) compensation for the environmental improvement not occurring. The interpretations of the *CS* and *ES* measures are reversed in the case of environmental quality deteriorations; *CS* is then equal to the minimum *WTA* and *ES* would be the maximum *WTP*.

In empirical studies, it is generally the case that *WTA* measures tend to be substantially higher than *WTP* measures for the same change (e.g., Kahneman *et al.* 1990)[37]. Thus, the choice of *WTP* or *WTA* as a measure of economic value may significantly affect the size of the resulting valuation estimate. Even though there are theoretical reasons for this difference (e.g., Hanemann 1991)[38], *WTP* is generally being advocated as the most appropriate measure of changes in welfare, primarily since *WTA* is not constrained by income and therefore, creates an incentive problem (e.g., Arrow et al. 1993)[39].

In sum, the economic valuation of many environmental (and non-environmental) impacts, builds on the assumption that people seek to satisfy their preferences, which are exogenously determined, complete, continuous, and ethically unchallengeable. The environment is essentially treated as any other private commodity, and people are willing to consider tradeoffs in relation to the quantity or quality of environmental “goods”. According to the welfare economics literature the appropriate role of policy in the field of energy externalities would be to aggregate the monetary estimates of individual preferences and to weigh them against other (more tangible) economic benefits and costs. Thus, the economics of non-market valuation builds on: (a) clear but also relatively restrictive behavioral assumptions (i.e., utility maximization); (b) a sense of society as the sum of the preferences of its individual members; and (c) a view of the task of public policy involving the internalization of external impact and with utilitarianism as the ethical principle guiding social choice (Sundqvist and Soderholm 2002).

1.2.3 Externalities in Practice

In practice, there are two basic methodological approaches used for the valuation of externality impact in the energy sector: the abatement cost approach and the damage cost approach.

The *abatement cost approach* uses the costs of controlling or mitigating damage or the costs of meeting legislated regulations as an implicit value of the damage avoided. The rationale behind this approach is that legislatures are assumed to have considered the willingness of the public to pay for alleviation of the damage in setting the standard, thus providing a revealed preference damage estimate no less reliable than the more direct valuation methods (see below). Pearce et al. (1992)[40] stressed that one of the serious caveats with the approach is that it relies on the rather strong assumption that these same decision-makers make optimal decisions, i.e., they know the true abatement and damage costs. Figure 5 illustrates this problem. It displays the marginal abatement cost curve (*MAC*) and the marginal damage cost curve (*MDC*) resulting from some emissions (*E*). Thus, increased abatement is equivalent to lowered emissions (i.e., damage). Given that the curve *MDC* shows the true disutility of the damage done by the emissions, and if decision makers set a maximum standard of emissions at E_3, the abatement cost will underestimate the true damage cost, while if only emissions up to E_1 are permitted the abatement cost will provide an overestimation. Only at E_2can marginal abatement costs correctly measure marginal damage costs. A necessary condition for social optimality, as Joskow (1992)[41] noted, is that the abatement costs used are derived from the pollution control strategy that provides the least cost of control. If not, the estimates cannot adequately reflect damage costs.

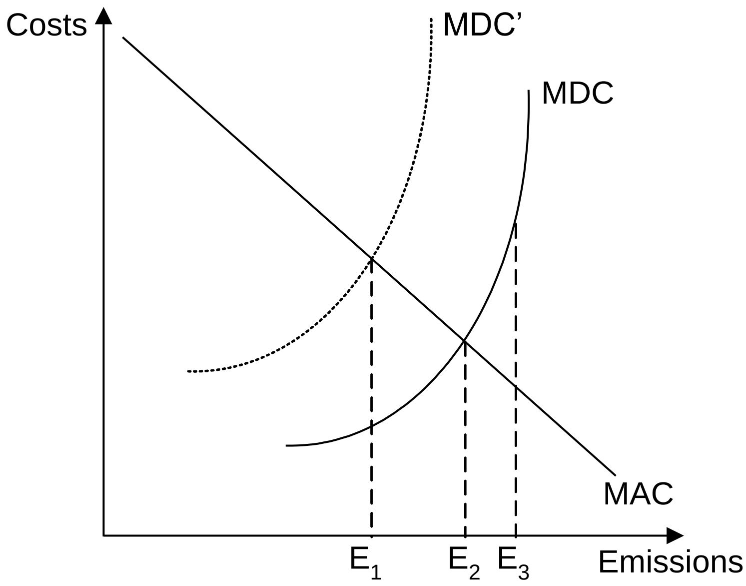


Figure 4. Marginal Abatement and Damage Costs

Source: Sundqvist and Soderholm (2002).

Another limitation of the abatement cost approach, as noted by Bernow and Marron (1990)[42], is that society's preferences change over time as information, analysis, values and policies change. Hence, past revealed preferences might bear little relation to actual impact today and their current value to society. For instance, the implicit value of CO_2 emissions indicated by a revealed preference analysis would, in many cases, be very low since there are still relatively few regulations targeted towards this problem. This built-in "tautology" of the approach means that estimates need to be constantly revised as regulations and policies change. More importantly perhaps, since policy is (per definition) optimal, the abatement cost analysis provides no room for relevant policy implications, and one must therefore, question why the analysis is needed in the first place (Bernow and Marron 1990).

The second approach the *damage cost approach* is aimed at measuring the net economic damage arising from negative externalities by focusing more or less directly on explicitly expressed preferences. This approach can be subdivided into two main categories: top-down and bottom-up. Top-down approaches make use of highly aggregated data to estimate the environmental costs of, say, a particular pollutant. Top-down studies are typically done at the national or the regional level, using estimates of total quantities of pollutants and estimates of total damage caused by the pollutants. Specifically some estimate of national damage is divided by total pollutant depositions to obtain a measure of physical damage per unit of pollutant (Figure 5). These physical damages are then attributed to electrical power plants and are converted to damage costs using available monetary estimates of the damages arising from the pollutants under study. The main critique against the top-down approach is that it "generically" cannot take into account the site specificity of many types of impacts, nor the different stages of the fuel cycle. Another argument that has been raised against the approach is that it is derivative since it depends mostly on previous estimates and approximations (Clarke 1996).[43]

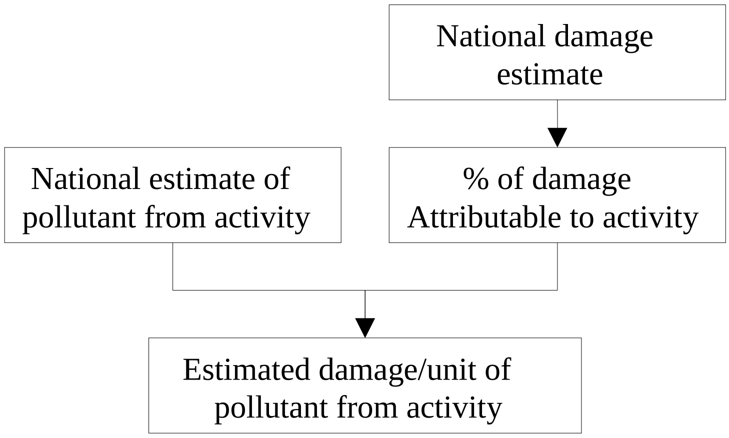


Figure 5. The Top-Down Approach in Estimating the Cost of Environmental Damage.

Source: EC (1995) cited from (Sundqvist and Soderholm 2002).

In the *bottom-up approach*, environmental damages from a single source are typically traced, quantified and monetized through damage functions/impact pathways (see Figure 6). This method makes use of technology-specific data, combined with dispersion models, information on receptors, and dose-response functions to calculate the impact of specific externalities. The bottom-up approach has been criticized since applications of the method have unveiled a tendency for only a subset of impact to be included in assessments, focusing on areas where data are readily available and where, thus, impact pathways can be easily established. Consequently, bottom-up studies tend, it is argued, to leave out potentially important impact where data are not readily available (Clarke 1996). Also, Bernow et al. (1993)[44] caution that the bottom-up approach relies on models that may not adequately account for complexities in “the real world”, especially noting that there may be synergy effects between pollutants and environmental stresses, and that there may be problems in establishing the timing of effects (i.e., between exposure and impact). The argument is that bottom-up approaches may not be sufficiently transparent. Still, this is the approach that, due to its focus on explicit estimates of economic welfare (rather than implicit ones such as are used in the abatement cost approach), appears to be most in line with economic theory. As is evident from the methodological choices of recent externality studies, it is also the preferred approach to the empirical assessment of externalities in the electricity production sector (See Chapter4).

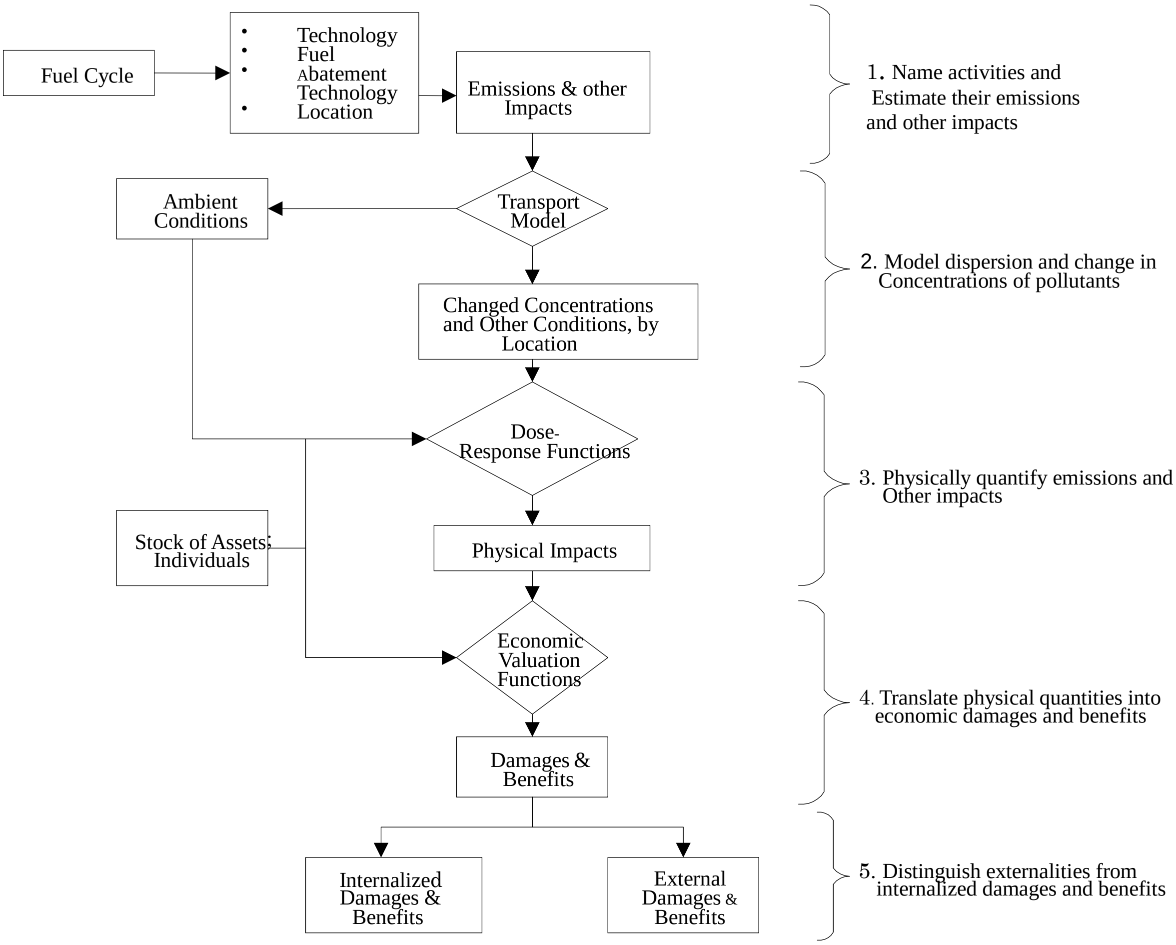


Figure 6. The Impact Pathway (Bottom-Up Approach) in Estimating the Cost of Environmental Damage.

Source: ORNL and RFF (1994)[45].

There are several ways of addressing the problem of placing a monetary value on externalities in general and environmental impact in particular. The first two approaches discussed above (abatement cost and top-down damage cost) directly give a monetary estimate of the damage associated with the impact from an environmental impact. The third approach, bottom-up damage cost, however, needs to translate the identified and physically quantified impactinto monetary terms. Generally, it can be said that whenever market prices can be used as a basis for valuation, they should be used. However, since externalities, by definition, are external to markets, most impact from externalities are not reflected in existing prices. Consequently, any attempt to monetize an environmental impact using bottom-up damage costing must rely on impact valuation methods. These methods can be sub-divided into *direct* and *indirect* methods. Figure 7 illustrates the various methods available for monetizing environmental impacts.

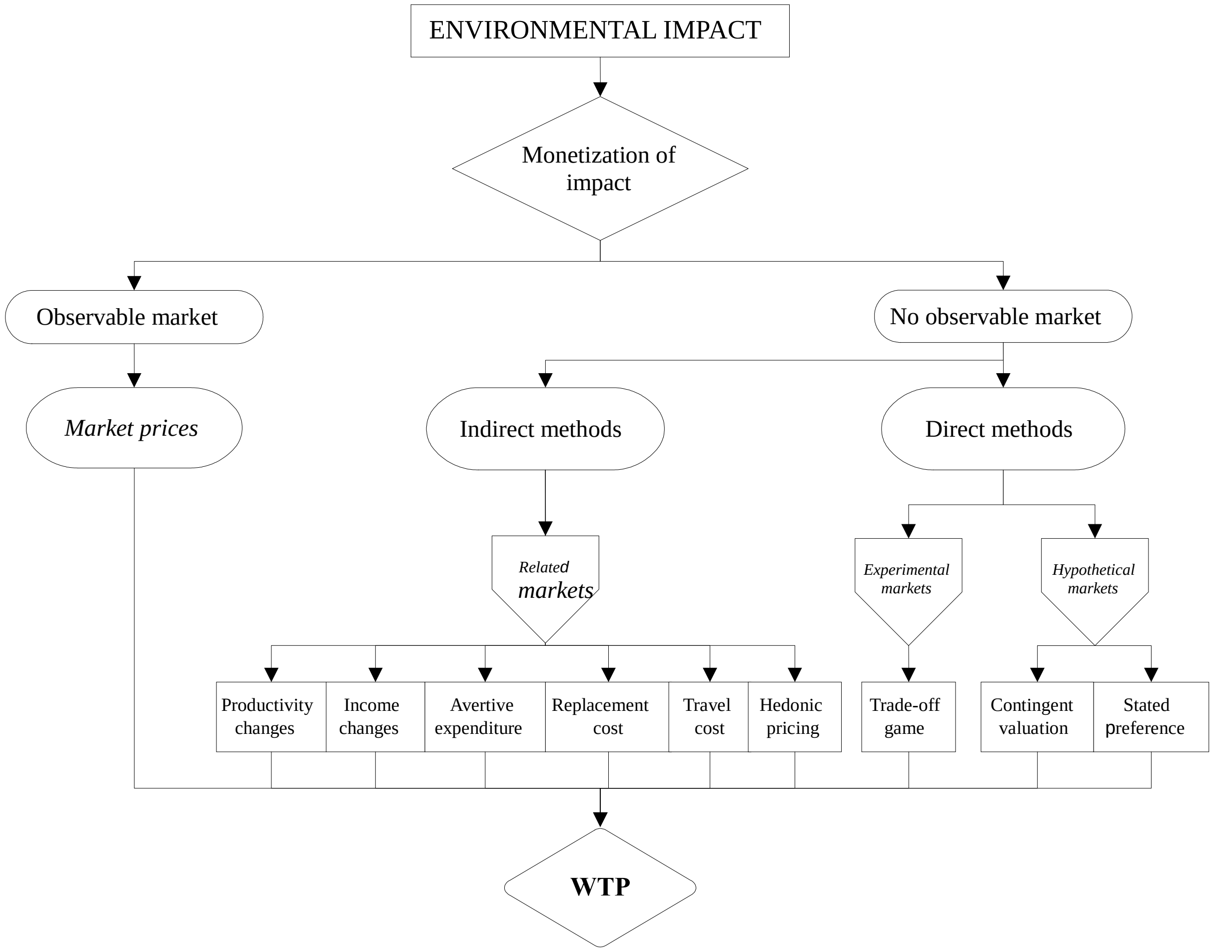


Figure 7. Overview of Impact Valuation Methods

Source: Sundqvist and Soderholm (2002).

Even if no information is available from existing markets, it may be possible to derive values using *direct methods* that simulate a market. These methods are direct in the sense that they are based on direct questions about – or are designed to directly elicit – *WTP*. An important advantage of the direct methods is that they can assess total economic values, i.e., use as well as non-use values (such as existence values). Well-known direct valuation methods include contingent valuation and stated preferences (Pearce 2007)[46]

None of the *indirect methods* can assess non-use values of the environment; they are based on the actual (rather than the hypothetical) behavior of individuals. Either the environmental values show up as changes in costs or revenues on observable markets or in markets closely related to the resource that is affected by the environmental impact. The damage is thus, valued indirectly using a relationship between the environmental impact and some good that is traded in a market. Examples of indirect valuation methods are hedonic pricing, travel costs, and replacement costs (Pearce 2007).

There are also methods that do not easily fit into the categories discussed above but that may nevertheless prove useful. The first of these, the so-called benefit transfers, does not involve any valuation in itself. Benefit transfers instead make use of the results of previous studies that have derived monetary estimates for the environmental impact in question. That is, a study may utilize the results from another valuation study and adjust them for use in the present context; this method, beside the bottom-up approach, has been utilized in our calculations for the external costs of power generation in the kingdom of Bahrain (see Chapter 4). Economic values may also be evaluated through opportunity costs, i.e., the net benefit of an environmental service. For example, a hydro- electrical power development on a river affects the recreational possibilities in the river. The opportunity costs of the development are then the forgone net benefits of the affected recreational activities in the river (Pearce 2007).

From this literature, it is clear that there is an abundance of methods and techniques to approach the problem of monetizing external costs. These methods may, however, as illustrated in Table 1, only be useful under specific circumstances and for specific impacts. As a result, a single method may not permit all of the impact to be addressed, and this necessitates the use of several methods in the assessment. What complicates things further is that the types of externalities that arise from various forms of electricity production also differ. Thus, since the types of externalities differ among fuels, different methods may have to be utilized in the monetization of impact for the variety of fuels. This is especially a problem if different methods tend to yield different results, thus producing environmental impact estimates that are incomparable with those of other methods. If this is the case, it may be hard to draw reliable conclusions about the ranking of different fuel sources in terms of external costs.

Table 3. Relevance of Methods to Value Specific Effect

Assessment Method	Resource Degradation	Pollution	Recreation	Natural Amenity	Work Environment	Non-Use Benefits
Indirect Methods						
Productivity Changes	!!	!		!	!!	
Income Changes		!!			!!	
Avertive Expenditure	!	!!	!!	!		
Replacement Cost	!			!		!
Travel Cost			!!	!!		
Hedonic Pricing	!!	!!	!	!	!	
Direct Methods						
Trade-off Game	!		!	!		!
Contingent Valuation	!		!	!		!!
Stated Preference	?	?	?	?	?	?

!! = Highly relevant ! = Relevant ? = Possibly relevant

Source: Binning *et al*, (1996)[47] quoted from ((Sundqvist and Soderholm 2002).

1.3. Overview on Previous Electricity Externalities Studies

Many externality studies were performed during the 1980s and 1990s. The focus in this survey is on studies, with the objective to assess the total external costs (and in some cases benefits) per kWh of different electrical power technologies. Some studies were therefore, deemed to be irrelevant for the present purpose since they only covered one specific impact, e.g., Fankhauser (1993)[48] only assessed global warming impacts, and some studies were identified but could simply not be obtained (e.g., BPA 1986). Table 1-3, provides an overview of about 40 externality studies covered in the analysis. An assessment of the different externality assessments listed in Table 2, revealed several conceptual issues of importance, out of which five are highlighted here.

Table 4. The Previous Electricity Externalities Studies

Study	Country	Fuel	Externality Estimate (US cents/kWh)	Method
Schuman & Cavanaugh (1982)	US	Coal Nuclear Solar Wind	0.06-0.44 0.11-0.64 0-0.25 0-0.25	Abatement cost
Hohmeyer (1988)[49]	Germany	Fossil fuels Nuclear Wind Solar	0.02-0.065 0.07-0.15 0.18-0.36 0.68-1.03	Damage cost (top-down)
Chernick & Caverhill (1989)[50]	US	Coal Oil Gas	0.04-0.08 0.05-0.08 0.075-2.62	Abatement cost
Bernow & Marron (1990)[51]; Bernow et al. (1991)[52]	US	Coal Oil Gas	0.057-0.12 0.044-0.13 0.02-0.08	Abatement cost
Hall (1990)[53]	US	Nuclear	0.024-0.034	Abatement cost
Friedrich & Kallenbach (1991)[54]; Friedrich & Voss (1993)[55]	Germany	Coal Nuclear Wind Solar	0.36-0.86 0.03-0.56 0.02-0.33 0.05-1.11	Damage cost (bottom-up)
Ottinger et al. (1991)[56]	US	Coal Oil Gas	3.62-8.86 3.87-10.36 1.00-1.62	Damage cost (bottom-

		Nuclear Hydro Wind Solar Biomass Waste	3.81 1.43-1.62 0-0.12 0-0.50 0-0.87 5.00	up)
Putta (1991)[57]	US	Coal	1.75	Abatement cost
Hohmeyer (1992)[58]	Germany	Fossil fuels Nuclear Wind Solar	11.12 7.01-48.86 0.12-0.24 0.54-0.76	Damage cost (top-down)
Pearce et al. (1992)	UK	Coal Oil Gas Nuclear Hydro Wind Solar	2.67-14.43 13.14 1.05 0.81 0.09 0.09 0.15	Damage cost (top-down)
Carlsen et al. (1993)[59]	Norway	Hydro	2.68-26.26	Abatement cost
Cifuentes & Lave (1993)[60]; Parfomak (1997)[61]	US	Coal Gas	2.17-20.67 0.03-0.04	Abatement cost
ORNL & RFF (1994-1998)	US	Coal Oil Gas Nuclear Hydro	0.11-0.48 0.04-0.32 0.01-0.03 0.02-0.12 0.02	Damage cost (bottom-up)
RER (1994)[62]	US	Oil Gas	0.03-5.81 0.003-0.48	Damage cost (bottom-up)
EC (1995)	Germany	Coal Oil Lignite	2.39 3.00 1.37	Damage cost (bottom-up)
--	France	Nuclear	0.0003-0.01	Damage cost (bottom-up)
--	Norway	Hydro	0.32	Damage

				cost (bottom-up)
--	UK	Coal Gas Wind	0.98 0.10 0.11-0.32	Damage cost (bottom-up)
Pearce (1995)[63]	UK	Coal Gas Nuclear	3.02 0.49 0.07-0.55	Damage cost (top-down)
Rowe et al. (1995)	US	Coal Oil Gas Nuclear Wind	0.31 0.73 0.22 0.01 0.001	Damage cost (bottom-up)
van Horen (1996)[64]	South Africa	Coal Nuclear	0.90-5.01 1.34-4.54	Damage cost (bottom-up)
Bhattacharyya (1997)[65]	India	Coal	1.36	Damage cost (bottom-up)
Ott (1997)[66]	Switzerland	Oil Gas Nuclear Hydro	12.97-20.57 8.85-13.22 0.62-1.50 0.25-1.50	Damage cost (top-down)
Faaij et al. (1998)[67]	Netherlands	Coal	3.98	Damage cost (top-down)
--	Netherlands	Coal Biomass	3.84 8.10	Damage cost (bottom-up)
EC (1999)[68]	Austria	Gas Hydro Biomass	0.88 0.02 1.54-7.56	Damage cost (bottom-up)
--	Belgium	Coal Gas Nuclear	3.22-67.72 0.67-9.73 0.02-0.79	Damage cost (bottom-up)
--	Denmark	Gas Wind Biomass	0.99-11.19 0.08-0.51 2.34-12.55	Damage cost (bottom-

				up)
--	Finland	Coal Biomass Peat	1.07-18.15 0.83-2.00 0.69-1.69	Damage cost (bottom-up)
--	France	Coal Oil Gas Biomass Waste	9.61-29.45 11.79-39.93 2.70-7.68 0.82-2.51 22.17-68.73	Damage cost (bottom-up)
--	Greece	Oil Gas Hydro Wind Biomass Lignite	2.07-19.89 0.57-4.97 0.71 0.31-0.80 0.14-3.43 3.67-36.54	Damage cost (bottom-up)
--	Germany	Coal Oil Gas Nuclear Wind Solar Biomass Lignite	2.38-23.67 5.30-35.16 0.83-9.55 0.08-1.45 0.05-0.31 0.08-1.69 3.78-13.19 2.83-56.57	Damage cost (bottom-up)
--	Ireland	Coal Peat	6.16-31.90 4.62-5.32	Damage cost (bottom-up)
--	Italy	Oil Gas Hydro Waste	3.24-24.52 1.21-11.78 0.47 --	Damage cost (bottom-up)
--	Netherlands	Coal Gas Nuclear Biomass	1.68-24.48 0.43-9.65 1.03 0.49-2.86	Damage cost (bottom-up)
--	Norway	Gas Hydro Wind Biomass	0.26-8.04 0.32 0.07-0.35 0.33	Damage cost (bottom-up)
--	Portugal	Coal Gas Hydro Biomass	3.69-30.22 0.28-8.74 0.03-0.07 1.53-8.52	Damage cost (bottom-up)
--	Spain	Coal	4.64-32.60	Damage

		Gas Wind Biomass Waste	7.13-9.53 0.24-0.34 2.41-22.09 3.58-26.19	cost (bottom-up)
--	Sweden	Coal Hydro Biomass	0.84-16.93 7.83-18.54 0.35-0.60	Damage cost (bottom-up)
--	UK	Coal Oil Gas Wind Biomass Orimulsion	4.06-33.01 3.22-22.10 0.73-10.21 0.17-0.34 0.72-3.22 2.94-24.20	Damage cost (bottom-up)
Hirschberg & Jakob (1999)[69]	Switzerland	Coal Oil Gas Nuclear Hydro Wind Solar Biomass	4.54-23.16 5.13-26.09 1.17-8.06 0.29-1.90 0-1.76 0.15-0.88 0.15-2.20 3.67-8.50	Damage cost (bottom-up)
Maddison (1999)[70]	UK/Germany	Coal Oil Gas Lignite	0.31/0.71 0.78 0.13 0.73	Damage cost (bottom-up)

Source: Binning *et al* (1996) cited from (Sundqvist and Soderholm, 2002).

From these studies, the author concluded the following: *first*, most of the fuel sources available for power generation have been addressed in previous valuation efforts, including coal, oil, natural gas, nuclear, hydro, wind, solar, biomass, and in a few cases lignite, waste incineration, and geothermal. However, most studies focus on the traditional fuels, such as coal and nuclear. There is therefore, a tendency that many studies focus on existing technologies rather than on the technologies generally accepted to play a significant role in the future (i.e., wind, biomass etc.). In many cases this is understandable given that empirical data clearly are more available for existing (rather than for emerging) technologies. Nevertheless, an important goal of externality valuation in the electrical power sector has been to "level the playing field" in the selection between traditional and new generating technologies, and this would probably require a stronger focus on promising but not yet commercialized technologies (Sundqvist and Soderholm 2002).

Second, a majority of the studies have been done for the developed world (mostly for Western Europe and the US). Therefore, only in rare cases, has the focus been on developing countries where the need for additional electrical power capacity is by far the greatest (IEA 1998)[71]. There are also reasons to believe that valuation estimates should differ substantially between developing and developed countries. In the developing countries incomes are lower, and the environmental effects of electrical power production may be fundamentally different. Important examples of the latter are the environmental externalities stemming from hydro electrical power development. For instance, hydro electrical power development in a temperate climate may give rise to global warming impact due to decomposition of vegetation left in the reservoir, while hydro electrical power development in colder climates will not or will do so at a slower rate (Moreira and Poole 1993)[72]. This raises serious concerns about transferring environmental values from studies conducted in Europe and U.S.A for use in a developing country context. Therefore, appropriate scaling factors should be used for transferring the damage calculations.

Third, examining the methodologies utilized over time reveals that the bottom-up damage cost approach seems to have become the dominant approach, while the abatement cost and top-down approaches were predominantly used in the 1980s and early 1990s (Figure 8). An important reason for this development is that the national implementation phase of the ExternE project (EC 1999), relies solely on damage cost bottom-up models, and these studies together represent a large share of the total number of projects conducted during the latter part of the 1990s. This also indicates, however, that the bottom-up model has been accepted as the most appropriate method with which to assess the electrical power generation externalities.

The ExternE project has largely served as a vehicle in the methodological development of externality valuation. The principles of transparency, consistency, and comprehensiveness, which are practiced by the ExternE work as well as the methodologies used have been well accepted at the international level, and many followers rely heavily on the numbers and the methods presented (Krewitt 2002). However, this development raises the question of whether the choice of methodological approach (between abatement costs and damage costs) matters for the results (Sundqvist and Soderholm, 2002). In section 4, the author refers to this question in more detail and suggests that this choice is important, this in turn, raises important concerns about the reliability of external cost valuation exercises in the electrical power-generating sector (Sundqvist 2000).

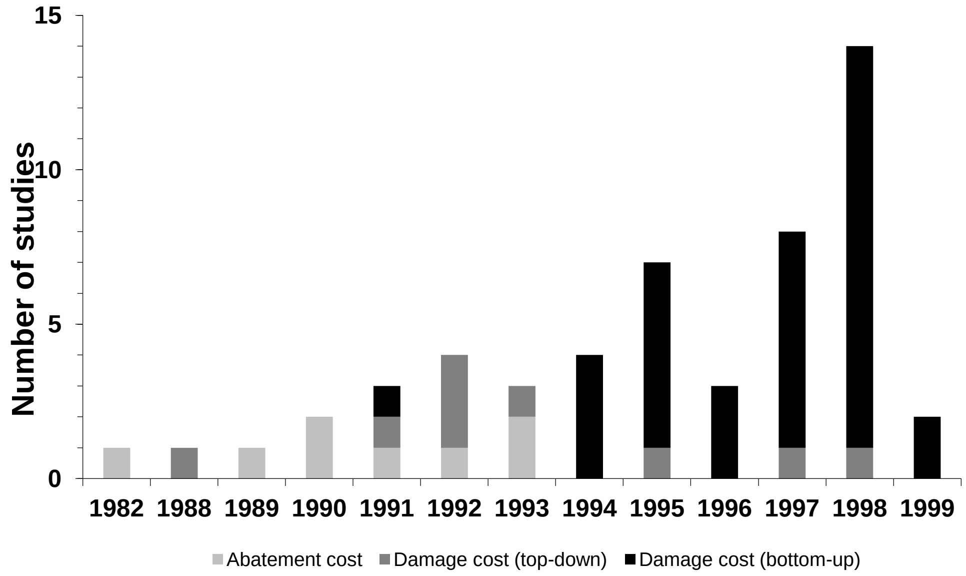


Figure 8. Methodological Choice over Time

Source: Sundqvist (2000)[73]

Fourth, as can be seen in Table 2 the disparity of external cost estimates is considerable when compared across different studies. The ranges also overlap making the ranking of various fuels with respect to externality impact a difficult task. Still, some tentative conclusions can be drawn. For instance, the results suggest that fossil fuel fired electrical power production, in particular coal and oil, give rise to the highest external costs, while some of the renewable energy sources, solar, wind and also hydropower, tend to have lower impacts.

It is also of interest to note that biomass-based electrical power production appears to incur substantially higher external costs than the other renewable energy alternatives. These findings raise questions about some of the recent policy initiatives especially in the developed countries that are designed to encourage the use of renewable energy *per se*, i.e., without distinguishing between the different renewable sources, through green certificates and competitive bidding systems (Sundqvist and Soderholm 2002).

For a specific fuel source, the differences between low and high values is substantial and this is also true if one looks at single studies; the ranges reported can often vary from a tiny fraction of electricity market prices and the private costs of producing power to a number that is way above private cost levels. Looking at, for example, coal and oil, the range of results produced by recent studies is from 0.004 to roughly 68 US cents per kWh for coal and from 0.03 to almost 40 US cents per kWh for oil (Table 3).

In comparison, the projected lifetime generation costs for the cheapest new power plants (coal and natural gas) normally range between 2.5 and 7 US cents per kWh depending on the country and site (IEA/NEA 1998)[74]. The reported discrepancies in results for similar fuels raise some concerns about the validity and reliability of the conducted valuation studies. Still, it must be made clear that, there is no reason to question the general notion that, to some extent, the numbers *should* differ due to, for instance: (a) the use of different technologies (e.g., implying separate emission factors); (b) the characteristics of the specific sites under consideration (e.g., population density, income, transport distances etc.); and (c) differences in scope (e.g., a fraction of all externalities may be included, and/or the entire fuel cycle rather than only the generation stage has been evaluated etc.).

Table 5. Descriptive Statistics of Previous Externality Studies

(US Cents/kWh)	**Coal**	**Oil**	**Gas**	**Nuclear**	**Hydro**	**Wind**	**Solar**	**Biomass**
Min	0.004	0.03	0.003	0.0003	0	0	0	0
Max	67.72	39.93	13.22	64.45	26.26	0.88	2.20	22.09
Difference	16930 %	1331%	441%	214833 %	--	--	--	--

Finally, Table 2 and does not display the different types of externalities covered, but a closer examination of these data reveals important disparities among the studies. For example, Table 4 lists eight studies that have assessed the impact of hydropower. It is apparent that the types and the classifications of impact differ among the studies (Sundqvist 2000), e.g., some of the hydropower studies have left out the "typical" recreational impacts.

Table 6. Impact Monetized in Eight Hydropower Studies.

Study	**Impacts**	**Study**	**Impacts**	**Study**
Ottinger et al. (1991)	Forest Wildlife Recreation Fur trapping	Martins et al. in EC (1999)	Health Agriculture Crops	Ottinger et al. (1991)
Pearce et al. (1992)	Health Global warming	Nilsson & Gullberg in EC (1999)	Ecological Social	Pearce et al. (1992)
Carlsen et al. (1993)	Regional economic Nature conservation Forest Recreation Fish Reindeer herding	Diakoulaki et al. in EC (1999)	Health Forest Agriculture Noise Water Biodiversity	Carlsen et al. (1993)

			Employme nt	
EC (1995)	Health Forest Agriculture Water supply Recreation Cultural sites Ecosystems Employment Ferry traffic Local income	ORNL & RfF (1994)	Recreation Employme nt	EC (1995)

Source: Sundqvist (2002)

There are also important differences among the different studies with respect to the number of stages of the entire fuel cycle assessed. For instance, all the hydropower studies only assess the construction and generation stages. For coal, on the other hand, a large part focuses on several stages of the fuel cycle (Table 5). This also raises the question of the relevant scope and the appropriate externality classifications to use in these types of studies. Krewitt (2002) concludes in his evaluation of the ExternE project that it has provided some partial answers to this question but many important issues remain unsolved. The lack of uniformity of both the life cycle assessment and resultant synthesis approaches (combination of two or more approaches) to evaluating power production systems is one of the shortcomings in the process of estimating the external costs associated with power generation.

Table 7. Fuel Cycle Stages Monetized in Eight Coal Studies

Study	Stages
Schuman & Cavanaugh (1982)	Generation
Chernick & Caverhill (1989)	Generation
Ottinger et al. (1991)	Generation
Pearce et al. (1992)	Generation
ORNL & RfF (1994)	Extraction Transport Generation
EC (1995)	Construction Mining Fuel processing Transport Generation Decommissioning
Krewitt et al. in EC (1999)	Extraction Transport

	Generation
Linares et al. in EC (1999)	Construction Extraction Transport Cleaning Generation Waste disposal

Source: Sundqvist (2002)

To conclude, this section has provided an overview of previous research to put value upon the external costs of electrical power production.

1.4 Research Questions and Research Methodology:

The Bahraini Legislative Decree No. 21 of 1996 in respect with the Environment has sought to improve and protect the environmental media’s (air, water, and soil) in Kingdom of Bahrain, even though this step has made significant progress in meeting the goals of air quality standards, there are still significant sources of air pollution in Kingdom of Bahrain. Part of the pollution comes from motor vehicles, but the main sources of emissions are industrial activities.

Industrial pollution causes a wide range of damage to human health in the form of asthma attacks in adults and children, colds and bronchitis in children, heart ailments in elderly, limited or restricted activity days in adults, respiratory related hospital admissions in the general population and even death in vulnerable individuals who belong to high risk groups such as the old and the very sick, the industrial pollution also causes damage to ecosystems (flora and fauna) and materials (The Built Environment), and reduces amenities from visual intrusion of plant or noise annoyance, since these costs are not reflected in the price of goods and services. Thus, the damage caused by this sector should be known and transformed into monetary values. Then is must work to reduce these impact through the use of different tools and policies including the internalization of the externalized costs of industry in the prices of goods and services such as energy and electricity prices.

Environmental pollution associated with industry in general and electricity generation, in particular has been subject to public attention in the kingdom of Bahrain; the immense impact on daily lives has increased the importance of conducting research that will enable decision–makers, environmentalists and economists to assess and quantify the cost of environmental damage. An assessment will improve the ability of the community to quantitatively grasp the impact of environmental pollution and the effectiveness of existing environmental and energy policies, quantitative assessment of the impact of pollution will also provide data to enhance the government’s decision-making process.

Obtaining reliable estimates of the environmental impact due to airborne pollution is a multi disciplinary effort, involving expertise in the fields of engineering design (R&D), pollutant fate analysis (dispersal of pollutants within and between different transport media), terrestrial science (ecological behavior), epidemiology (physical impact of pollutants on public health) sociology (risk perception and management) and economics (monetary valuation of impact assessment). Often, data are unavailable, unreliable, and/or difficult to interpret due to the current lack of standard methods & procedures. Subjectivity judgments are unavoidable, as a result the uncertainties associated with impact assessment are hard to quantify and are typically large (Rabl and Spadaro 1999).

1.5- Objectives:

The main objectives of this thesis are:

- Develop an effective and appropriate structure for costing, pricing, and taxing of electricity.
- Design a sustainable energy policy model suited to Bahrain as a Small Island Developing State (SIDS).

1.6- Research Questions:

The thesis author sought to answer the following questions:

The main Question:

- To what extent is it possible to use economic valuation of externalities in the policy making process in the electricity sector?

To answer this question, the following sub-questions were developed and answered:

- What is the structure of the Bahrain electricity production sector and what are the environmental and health impact for electricity generation and usage?
- “What is the current electricity policy, and what are the key factors that influence it?”
- What are the external costs in the current situation?
- What policies and structural changes can result in more sustainable generation and usage of electricity?

With regard to the first sub-question, results of an in-depth analysis of the current governmental policy towards the energy sector, and the key factors influencing this policy, are incorporated in the beginning of this thesis. The analysis was performed by reviewing the laws and regulations of the Ministry of Electricity and statistics and periodic reports in addition to interviews with officials.

With regard to the second and third sub-questions, the environmental and health impact associated with the current energy policy are presented in Chapter 4 through the use of the RiskPoll program which calculates the physical impact and the associated damage costs for the following type of pollutants: particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), and secondary species such as nitrate and sulfate aerosols.

The RiskPoll program was used to assess the consequences to human health, agricultural crops and man-made environments (building materials) from exposure to atmospheric emissions from routine or steady state processes. For materials, pollutants cause building soiling, structural damages and loss of detail due to acidic erosion due to some air pollutants. Monetization of the physical impact gives rise to the damage costs or social burdens.

Chapter 5and 6 answer the fourth sub-question by identifying the policy-makers and stakeholder's choices for suitable policies and the related instruments to internalize the externalities of electricity generation and usage; finally, Chapter 7 presents a detailed list of policy options that could be used as parts of an integrated approach to internalize the currently externalized impact of electrical power production and usage within the Kingdom of Bahrain.

Summary of Chapter 1

Chapter 1 provided the required information to answer the research sub-question regarding the structure of Electricity production sector in Bahrain, and a literature review on externalities of power generation. In the first section, the thesis author reviewed the capacity, tariff regime, subsidy and the environmental status of the electricity sector. In addition to that, the author highlighted ways for internalizing the environmental and health impact(externalities) in the price of electricity.

The analysis for the structure of the Electricity production sector in Kingdom of Bahrain revealed that electrical power generation has increased significantly over the years. Generated electricity increased by almost 6.5% between 2003 and 2004, (i.e., from 7,768 to 8,267 GWh). The installed electrical generating capacity in Bahrain in 2004 was 1849 MW and consists of five publicly owned power stations. The electrical utility industry consumes large volumes of fossil fuel; the publicly owned power stations consumed over 3 billion cubic meters per year of natural gas to generate about 83% of the total electricity generated, with the remainder (17%) obtained from the power station of the aluminum smelting plant (ALBA) which generates 1,527 MW.

The tariff structure for electricity in the kingdom of Bahrain is not based on consumer-specific, long-term, marginal costs but it is based upon a price structure that is used as an instrument to achieve political and socioeconomic objectives. Electrical prices in Bahrain are far below the total capital and operating costs of production and delivery. The government subsidy to the electricity prices range between 70-80% based on power generation fuel priced at U$ 70-100/barrel oil.

Similarly, the tariff structure in the natural gas and petroleum products, used for power generation, does not reflect the true cost of exploration, production, transmission, and distribution. The Kingdom of Bahrain is heavily dependent on natural gas as its main fuel for its electrical power plants. The indigenous natural gas has a sulphur content that exceeds 6% by volume, currently; three of the seven power plants namely, ALBA, BAPCO, and RIFA are violating the environmental standard for NOx.

The author also reviewed the theoretical discussion on externalities of power generation; by presenting the results of his literature review on externalities of electricity production and usage. Literature was reviewed that explored the basic methodological approaches used for the valuation of externality impact in the energy sector. The investigation into the literature was designed to build the foundation for answering of the research sub-questions of this thesis, namely, “What are the external costs related to the current situation of power generation and usage in Kingdom of Bahrain?” Furthermore, this Chapter also begins to build the theoretical framework for the subsequent empirical research.

Chapter 2 presents an overview of the current policy of the Electricity production sector in the Kingdom of Bahrain. The author presents the structure and the regulations of power generation in Bahrain and compares the ongoing restructuring process for the Electricity production sector with the global trend to liberalize public services. The review of the current electricity policy enables the author to present the social obligations of this policy and the characteristics of the electricity sector.

Chapter 2: Bahrain Electricity Policy

Introduction

The electricity systems in the Kingdom of Bahrain are facing considerable challenges in terms of low operational efficiency, cost recovery, and responsibility towards the community, especially the environmental and health impact for power plants. Large investments are required to rehabilitate, modernize and expand the electricity system to meet the growing demand and to optimize the development opportunities; without such investments, the supply of electricity and its impact on the people of Bahrain, will be significant.

Sustained economic growth and employment in Bahrain are dependent upon efficient and environmentally sound electricity supplies. Meeting the investment requirements solely from the governmental budget would require diverting resources away from other important priorities such as health, education and other services. Therefore, it is very important to embark on governmental policy reform: a. to create an efficient market structure based on the market economy within clear regulatory frameworks; b. to encourage more efficient utilization of energy and other natural resources; c. to improve environmental performance, competitiveness; d. to ensure protection of humans from negative consequences of air pollutants; e. to integrate the concept of sustainability to ensure economically sound development of the electricity system and of the society of Bahrain. By adopting such policy options, the electricity production sector can meet the electricity needs of Bahrain as efficiently as possible.

This chapter provides the background information to review and assess Bahrain's current electricity policy, and to highlight the major issues identified, to date. The review is based upon the available information, and the inputs received from the Ministry of Electricity and Water (MEW) in the Kingdom of Bahrain during the policy review. It provides the theoretical basis to answer one of the sub-questions of this thesis "What is the current electricity policy, and what are the key factors that influence it?"

2.1 The Electricity Production Sector in Bahrain:

The power and water services are available for all Bahrain's inhabitants; their electricity service is technically comparable with that of any other country in the world. These services are considered to be the public services, which are still provided by the government through MEW. The installed electrical generating capacity in Bahrain in 2004 was 1849 MW. It is produced at five, publicly, owned power stations (i.e., Manama, Muharraq, Riffa, Sitrah, and Hidd) generating about 83% of the total electricity used. These sources serve more than 200,622 customers (Bahrain Statistical Abstract, 2004). In addition, two major industrial companies, namely Bahrain Aluminum (ALBA), and Bahrain Petroleum Company, generate 1,527 MW, and 161 MW respectively, most of their electricity is used for their industrial needs. However, ALBA provides the national grid with about 17% of the governmental capacity.

The most recent electrical energy consumption forecast shows projected growth over the next 10 years, in the order of 8% annually (Figure 9). This consumption growth will require increasing the output capacity by at least 150 MW per year.

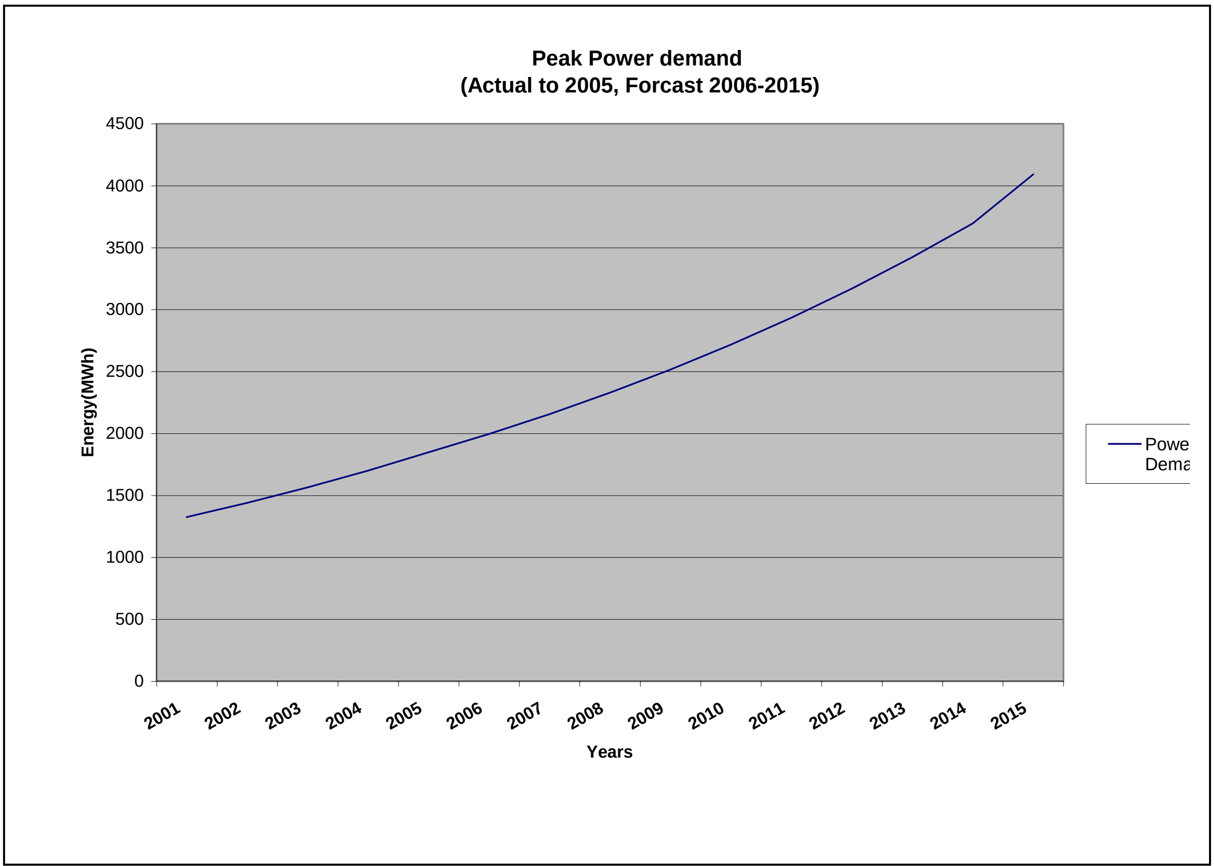


Figure 9. Projected Peak Power Demand in Bahrain during the Period from 2002-2015

Source: developed by this thesis author

The current electricity system is to be augmented by about 400 MW from the Al-Hidd power station. Additionally, a new generation facility (1000MW) was built at Al-Ezzel power station in 2008. This is the first power plant to be operated by an international consortium of companies based on a Power and Water Purchase Agreement (PWPA) developed with the Bahraini government to sell electricity and water to the grid as an Independent Power and Water Producer (IPWP). With the resultant increase in electrical energy supply, it is projected to meet Bahrain’s requirements until 2012, the year in which the first phase of Al-Dur power & water station will be operational with a designed capacity of approximately 3000 MW. It will be built in three stages with production capacity of 1000 MW for each stage. When all three stages are complete Bahrain’s total installed generation capacity will be 6249 MW.

2.1.1 Independent Power and Water Producer (IPWP) Contractual Structure:

The IPWP will be structured around a 20-year electrical power and water purchase agreement (PWPA) with MEW after the scheduled commercial start-up operational date.

The initial buyer under the PWPA will be MEW, although MEW has the right, at its discretion, to assign its rights and obligations under the PWPA to a newly formed governmental entity. The purchaser under the PWPA will pay a two-part tariff consisting of fixed "capacity charges" for the plant's capacity to generate electricity and to produce desalinated water and an "energy charge" for the electricity and water that the plant actually produces. The capacity charges will cover the company's fixed costs (i.e. equity return, debt service, insurance and fixed operation and maintenance expenses) while the energy and water charges will cover variable costs, principally fuel. The tariff structure will include a summer and winter weighting that will take into consideration the difference in demand, depending on the season. The payment of obligations of the buyers under PWPA will be guaranteed by the Kingdom of Bahrain, through the Ministry of Finance.

Regarding the gas supply, the Bahrain Petroleum Company (BAPCO) and the project company will sign a Gas Sales Agreement. BAPCO will have the right, in the future, to assign this agreement to another government-controlled entity. The potential risks of a gas supply failure are to be assumed by the buyer under the PWPA. The gas will not be provided on a take-or-pay basis but simply on receipt of dispatch instructions from the buyer under the PWPA; consequently the price of gas will be at arm's length and will be passed through to the electricity buyer. This policy was designed to remove electrical energy subsidies and to charge the electricity consumers, the actual price of gas, which is expected to be imported in the near future.

As for Al-Ezzel, the land use agreement for the site will have a term of thirty years (30 years) from the start of commercial operation.

The project company will be required to provide a performance bond to support its obligations under the PWPA during the construction period.

The project company could be entirely owned by the sponsors even though it may offer to sell a portion of its shares on the local stock exchange at a later stage (although the sponsors will not be required to do so).

2.1.2 Electricity Regulations:

The electricity production industry in Bahrain; is regulated by the Ministry of Electricity and Water (MEW). However, there are no legislative instruments, which define how the MEW determines electricity rates. The tariff policy for services in Bahrain is very complicated; the tariff structure for electricity in the Kingdom of Bahrain, for instance, is not based on consumer-specific long-run marginal costs but is used as an instrument to achieve political and socioeconomic objectives. The MEW uses tariff rates, which depend upon the customer categories, which are divided into residential, commercial or industrial.

Until now, the MEW is accountable only to the government for its capital budget and major decisions such as construction of new power plants, and examining the operational costs. These arrangements allow the government to guide major decisions of the MEW in the overall public interest.

In response to perceived institutional rigidities associated with many publicly owned sectors, in 2002 the government announced its intent to restructure the electricity production sector. The privatization act No. (41) of 2002 vested the government with the right to establish the administrative and technical arrangements to privatize many publicly owned sectors, among these sectors Electricity and Water utilities. The act states:

Article No. (4):

> The privatization program shall involve the services and productive sectors, especially tourism, communications, transportation, electricity and water, air and seaports services, oil and gas services, posts, and any other productive and services sectors.

Article No. (5):

> Privatization shall be gradually accomplished, and cope with the socio-economic factors, in order to achieve economic stability and social security.

Article No. (6):

> The economic reform shall be consistent with national interest, and shall comply with the international standards.

The Cabinet of Ministers, through ministerial Order No. (14) Of 2003, formulated a national governmental committee functioning as an independent regulator to follow up the privatization of electricity production from the publicly owned power plants.

However, according to information obtained from the senior planner (Head of research and planning in MEW) assure that, new legislation for electricity, reflects the political direction of the Kingdom was sent to the cabinet of ministers, and is expected to be passed through the parliament during the new legislative term which will start on October 2011, It argues that changes in the international marketplace, demands of customers, and the problems with the existing structure are driving the government to undertake liberalization of the electricity market. If this legislation is adopted, it will give the private sector an opportunity to be a partner with the government by operating the existed power plants and to construct new ones. In spite of this policy reform, the government will continue to have the upper hand and will control the rates for transmission, and electricity distribution.

The new policy objectives for the sector were outlined in the government's proposal as follows:

- To provide the necessary conditions for the public electricity system to efficiently meet electricity demands.

- To protect consumer interests, in terms of prices, services and quality of supply.

- To ensure that the electricity producers have the necessary conditions to fulfill their contract and the respective licensing obligations.

- To promote competition in situations in which there exists the potential to improve the efficiency of the electricity sector's activities.

- To ensure that the regulatory rules have objectives so that the commercial relations among the operators are transparent and non-discriminatory.

- To contribute to the improvement of the technical, economic and environmental operation conditions of the means to be used from production to consumption of electricity.

The liberalization of the electricity production sector and establishment of effective competition will depend on many actions among them, the removal of any formal barriers to generation entry, action to mitigate informal difficulties, and to be non-discriminatory. Therefore, any continued public ownership in the sector, particularly in generation and supply, must be on the basis of competitive neutrality with private sector entrants. Publicly owned utilities should have equivalent policies, and generally should be subject to an equivalent regulatory framework as private companies.

2.2 Overview in Restructuring the Bahrain Electricity Production Sector and its Possible Components:

The restructuring of the electricity production sector is part of a global trend to liberalize public services like the postal service, telecommunication and transportation that have often been provided by monopolies (Lopes *et al.*1999)[75] ; In this case, the electricity production sector restructuring process is comprised of five major components:

- **Commercialization:** through the introduction of commercial objectives in the management of the sector. This implies full cost recovery, which frequently includes keeping separate accounts for different functions (generation, transmission and distribution). It may lead to a new tariff structure. However, the restructuring process in Bahrain is different; the government doesn't have, at least, in the short term, the desire to achieve the full cost recovery for the supply of electricity. This is obvious from the reaction of the government regarding the criticism of the privatization scheme. In many occasions, through the media, politicians assured the people that, there will be no change in the electricity tariff, and the social obligations provided to the community will not be affected. According to the new IPP/PPA agreements for Al-Ezzel and Al-Hidd power stations, the government will pay the independent electricity producers 84 fils (U$0.211) per KWh on the basis of "take it or leave it." The government will then re-sell it to groups of consumers (residential, commercial and industrial) in the range of 3-16 fils (U$0.0075-0.04); this means, that full cost recovery is not a target in the government's short term planning, due to political and socio-economic considerations. Furthermore, buying electricity at this rate seems more feasible for the government, because the current production costs are more than the purchase price.

- **Privatization:** total or partial recovery, of one or more of the typical functions (generation, transmission, distribution and supply). However, the restructuring in Bahrain, at this stage, is only liberalized electrical power generation; all other services are still in the hands of the government.

- **Unbundling:** in which the functions of the electricity system are split. The restructuring process in Bahrain was started with the separation of electricity generation from distribution and sales.

- **Competition:** in the generation and retail market. In Bahrain the restructuring is limited to electrical power generation. The new law will remove current, formal barriers to entry of generation capacity, and will also remove the requirement, on the part of central procedures, to receive ministerial approval before starting new power plants.

Internationalization: A larger international participation of electricity companies is occurring, even in countries with international monopolistic national companies. In Bahrain, an international consortium was awarded the concessions to transfer the construction and the operation of power and water facilities of the Al-Ezzel and Al-Hidd power stations under a 'Build-Own-and Operate,' scheme, the overall objectives being the following:

i- Reducing the costs;

ii- Improving the efficiency through better risk management;

iii- Making the sector more competitive;

iv- Meeting the increasing demand.

Bahrain can be considered to be a country that is becoming a changing market in comparison to the above mentioned components, commercialization, unbundling, and privatization of the state owned utilities can be found, to some extent, in the restructuring process. However, as a consequence of this reform, the legislative and regulatory frameworks of the electricity production sector must be completely reorganized; including special attention must be given to the optimal use of resources and to the protection of human health and the environment.

2.3 The Electricity Policy and Government Social Obligations:

The government Social Obligations (GSO) encompasses several non-commercial services provided by the MEW under regulations or governmental direction. The information relating to the nature of these services and the annual estimated costs are set out in Table-1-2. The major GSOs applying to electricity and water authority include:

- Uniform tariffs within customer classes;
- Subsidized tariffs to certain customer classes;
- Obligation to supply;
- National development and employment programs.

As is illustrated in Table-1, additional service obligations are provided by the ministry of electricity and water.

2.3.1 Uniform Tariffs within Customer Classes:

The requirement to apply uniform tariffs to particular classes of customer (residents, non-residents, commercial and industrial) is considered to be a governmental social obligation because the price of electricity or water does not reflect the cost of providing the service. Uniform tariffs give rise to cross-subsidies between users within the same class because some (non-residents) pay higher tariffs in order to partially finance supply costs to others (residents).

The uniform, tariff arrangements are funded by the electricity authority. However, the existing monopoly in the electricity market in Bahrain Island enables the authority to engage in cross-subsidizations between users whereby shortfalls, by some groups of customers are offset through overpayments by others.

2.3.2 Subsidized Tariffs to Certain Customer Classes:

In addition to cross-subsidies to support uniform tariffs, the MEW also subsidizes consumers in certain tariff classes such as residential and industrial customers. The estimated annual governmental subsidies to the electricity production sector for operations based on production of 9.1 million MWh in 2005 are over 170 million BD (1 BD equal U$ 2.65) assuming the power generation's fuel is valued at $40/barrel oil. However, according to oil prices in the international market, the subsidies exceeded BD 500 million, based on $110/barrel oil as of the third quarter of 2008.

2.3.3 Obligation to Supply:

Another governmental, social obligation provided by MEW arises from their obligation to supply customers (electricity and water) wherever they are located on the Island, on request, the MEW recovers less than the full cost of connections to the national network.

The cost recovery for new connections varies between customers; the recovery ranges from zero to above 70%. For instance, a customer granted a residential plot from the government is exempted from paying the connection fee. Also, there is a scheme funded by the MEW, which subsidies some connections such as the connections for industrial, agricultural or commercial purposes.

2.3.4 National Development and Employment Programs:

The electricity production authority, represented by the MEW, is expected to assist the government in its development and employment policies, in compliance with governmental policy in the area of national development and employment. This has resulted in some authorities, particularly the MEW, to support the agricultural sector for social considerations, as well as some of the non-competitive industries. This uneconomical use of valuable and scarce resources will be continued as a means of sustaining local sectors and employment.

Other national development programs undertaken by the MEW include:

- Limiting tariff increases to an amount less than the real cost;
- Providing subsidized electricity at uniform prices within customer groups to relatively undeveloped sectors;
- Subsidizing the cost of grid connections for selected customers, for example, MEW has a subsidy scheme for government housing projects in towns and villages.

According to the National Committee for the Villages and Towns Development (NCVTD) the provisions of grid connection subsidies for the housing sector was designed to overcome the chronic problems facing government housing projects. The Ministry of Housing and Works (MHW) statistics shows that, there are more than 50,000 applicants waiting to get subsidized houses.

2.3.5 Other Governmental Social Obligations:

The government, represented by the MEW is expected to undertake a number of other social obligations including:

- Providing electricity advisory services: As a part of discharging its obligations, the MEW provides the public with information and advice about electricity use and how to use electricity more efficiently.

- Installing high voltage lines in urban areas underground, because of safety and health risks associated with over-head power lines. MEW has an ongoing program to place existing overhead transmission lines underground in certain residential areas. Such actions are considered a governmental, social obligation. Such operations are usually funded by the MEW, implying a subsidy from the government to those who benefit from diminished safety and health risks, and the increased aesthetic value of their surroundings.

- Funding the cost of street lighting, traffic route lighting, and relocating hazardous power line poles.

- Licensing and Safety requirements: The provision of safe and reliable electricity is usually a requirement under the regulations of electricity authority, in addition, the authority is required to establish safety standards for electrical products and licensing provisions for electrical contractors, the MEW currently provides these services as one of the social obligations toward the community.

- Complying with environmental regulations: The environmental regulations include requirements to limit pollution, to determine construction standards for energy efficiency for buildings and to develop alternative energy resources. The MEW must comply with national environmental protection legislation, because any development undertaken by the MEW is subject to Amiri decree no. (21) for 1996 with respect to environment and to Ministerial Order no. (8) for 1998 with respect to environmental assessment of projects. These are pieces of environmental legislation, which, among other things, contain provisions on use of environmentally friendly technologies, use of resources, waste treatment and disposal, and emissions to the environmental media's (air, land, and water).

- Providing emergency services: Electricity and water emergency situations, either natural or human caused are managed by the MEW through emergency units distributed geographically across the island, the purpose of these units is to respond effectively on any emergency incidents such as power failure or water leakage, usually the MEW considers these services as part of their social obligations that are funded from the governmental budget.

Table 8. Obligations of the Ministry of Electricity & Water Service

Directorate	Nature of service	Estimated Annual Cost/Million BD
Electricity Supply	- Electricity connection and metering.	4.5
	- Uniform tariffs.	?
	- Subsidy to customers.	170
	- Street lighting.	1.8
	- Emergency service.	0.9
	- Under grounding of cables.	4.0
	- Remote area supply.	10.0
	- Poor and low-income rebates.	?
	- Account Payment assistance.	?
Water Supply	- Water connection and metering.	3.7
	- Uniform tariffs.	?
	- Subsidy to customers.	?
	- Emergency service.	1.2
	- Underground, relocation, and replacement of distribution lines.	5.0 7.0
	- Remote area supply.	?
	- Poor and low-income rebates.	?
	- Account Payment assistance.	

Source: Ministry of Electricity and Water, Kingdom of Bahrain

2.4 The Characteristics of the Electricity production sector in Bahrain:

As stated earlier, the government owned and operated the electric utilities in Bahrain, during the last decades and until the beginning of 90's; during that time, economic efficiency was not a priority, since the government was seeking to catalyze economic development and to extend modern infrastructure and services to a much larger share of the population. As a result, the electricity revenues were insufficient to cover the costs; consequently this continues to constrain the government to do the needed upgrading and expansion. The electricity system suffers from supply shortages in peak hours, especially in the summer, due to huge demand and due to losses in transmission and distribution, and to high pollution. Some of the power stations do not have appropriate equipment such as desulphurization and electrostatic precipitator units. The following are key features for the electricity production sector in Bahrain (Table 9).

Table 9. Characteristics of the Electricity Production Sector in Bahrain

Issues	Sector Characteristics	Range of Conditions
Sector Structure	- State owned - Highly bundled - Vertically integrated	- Government owned generation, transmission and distribution facilities.
Government priorities for sector	- National industrialization - Universal Access for Electricity. - Overcome unemployment - Improve Standard of living - National Prestige - Technology indigenization	- Electricity central to government's development policy. - Power sector often used to subsidize the rest of economy. - Environmental and economic efficiency of sector often low priority.
Policy and regulation	- National Electricity ministry	- Ministerial autonomy. - Regulation authority tied with others.
Revenue and tariffs	- Tariffs set by ministry. - Direct subsidies from state budget. - Cross-subsidies from industry.	- Cross-subsidies for residential, commercial, and public agencies.
Finance and investments conditions	- Sector financing tied to national budget. - Self-financing limited by revenue generation, and tariff arrangements.	- Negative rate of return. - Operating losses, requiring subsidies from national budget. - Public debt (Arab

		developing funds) financing of capital projects.
Physical organization	- Extent of grid integration determined by geography of load and generation.	- Integrated national grids in industrial and densely populated areas.
Operational performance	- Operational performance tied to sector financial conditions. - National economic conditions. Management practice. - National technical capacity.	- System losses are below 10%. - Consumers per employee above 177. - Service quality is high. - Negative reserve margin in summer. - System facing obstacles in terms of capacity factors.
Consumption and access	- Very high per capita consumption and access.	- More than 9000Kwh per capita. - Access more than 95%.
Fuel type and sources	- Fuel type is function to domestic resources. - Critical energy security and financing.	- Natural gas dominant, extracted locally. - Very low gas reserve. - Sector will depend in Gas import in the near future.
Environment	- Access to clean technology limited by finance. - Subsidy for domestic fuels. - Environmental protection commission has limited authority and capability. - Environmental concerns not a priority.	- Serious local pollution from the Electricity production sector (documented by several reports). - Climate concerns due to the nature of the island. - Ecological and population problems associated with the operations of power plants (Riffa, ALBA, and BAPCO).

Source of data: Ministry of Electricity and Water.

2.5 The Issues Related to the Current Electricity Policy:

Due to the absence of a written electricity policy for the MEW, several personal interviews, with senior staff were conducted by this thesis author, in order to clarify the significant issues, which have implications for the electricity policy and upon Bahrain's future options.

2.5.1 Efficiency and Costs:

Important indicators of performance, which apply to private organizations, are not applicable to public electricity utilities. Governmental enterprises are not subject to the disciplines of the share market. Takeovers and bankruptcy are non- existent. Indeed, with government support, inefficient enterprises can continue to exist indefinitely. Where there are no competitors, there are no meaningful market share data with which to analyze performance (Energy Generation and Distribution, 1991).[76]

Assessment of the operating efficiency of publicly owned utilities in Bahrain is complicated by: the divergent and, in some cases, unorthodox accounting practices adopted; requirements imposed on utilities by governments to discharge certain social service obligations; absence of clear policy, transparency and accountability; and by the presence of other factors affecting financial performance (e.g. subsidies and other exemptions for certain groups which do not apply to private sector enterprises).

Due to these facts, it is very difficult to make a comprehensive assessment of the economic performance of the electricity production sector in Bahrain. Nevertheless, there is some information, which provides insight into the performance of the electricity production sector from the Ministry of Electricity and Water (MEW). The following are some of the performance and efficiency problems related to the electricity policy. These problems cover two major dimensions of economic efficiency: "Productivity Efficiency and A locative Efficiency".

2.5.2 Productivity Efficiency

One of the key business objectives of electric power suppliers, in any country, is to control the costs involved in supplying electrical services. In order to achieve this objective, increased productivity is an absolute prerequisite. It would be useful therefore, to formulate and to publish a productivity measurement tool that would make it possible to conduct comparisons of productivity among different companies in the industry[77].

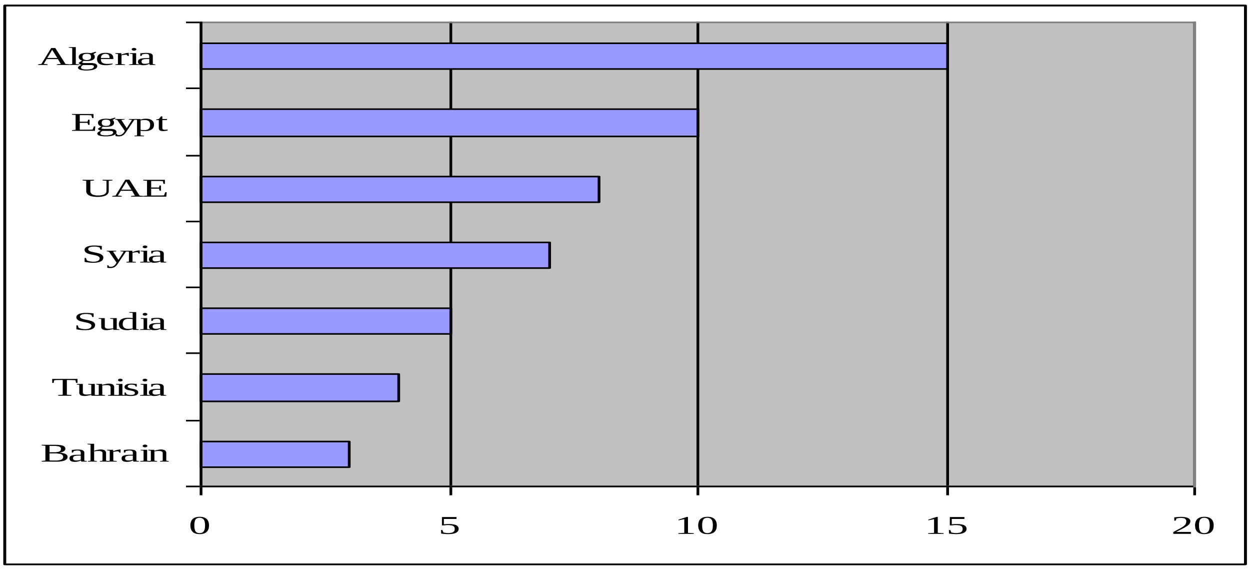
Several technical indices are used to measure operating efficiencies in the electricity production industry; these indices include electricity prices, total production cost and revenue, which are important indices for gauging operating performance in the industry.

The regional and international electricity prices are frequently cited as good indicators of productivity efficiency. The available data, rank Bahrain's electricity prices as the cheapest compared with those in other developing and developed countries (see figs. 10-11). This is attributed to many reasons; the most important among them is that there are substantial subsidies for all users of electricity, consequently the consumer prices are well below the actual costs, as well as below the prevailing regional and international prices. Additionally, the real subsidy rates in the presence of other distortions such as the hidden environmental and health impact of power generation are even more substantial.

The subsidy for different electricity consumer groups is approximately 78%. This calculation is based on $40 per barrel of oil, which causes significant competitive disadvantage to the national industries; this in turn, leads to the threat of retaliation with antidumping and other countervailing measures against the Bahraini export (European Union imposed a tax on the Bahraini and GCC chemical products due to the subsidy for Energy). Furthermore, energy policy reform, in general and for electricity, in particular, should not remain an obstacle in the ongoing trade negotiation within WTO, and within bilateral agreements.

The data analyzed with regard to the price of electricity show that pricing policies pursued by the MEW are not consistent with efficient pricing principles, mainly because they have not accurately reflected supply costs. Uniform pricing and cross-subsidies between different users are major factors that contribute to this outcome.

Figure 10. Comparison of Electricity Prices in Selected Arab Countries/Price in fils/KWh

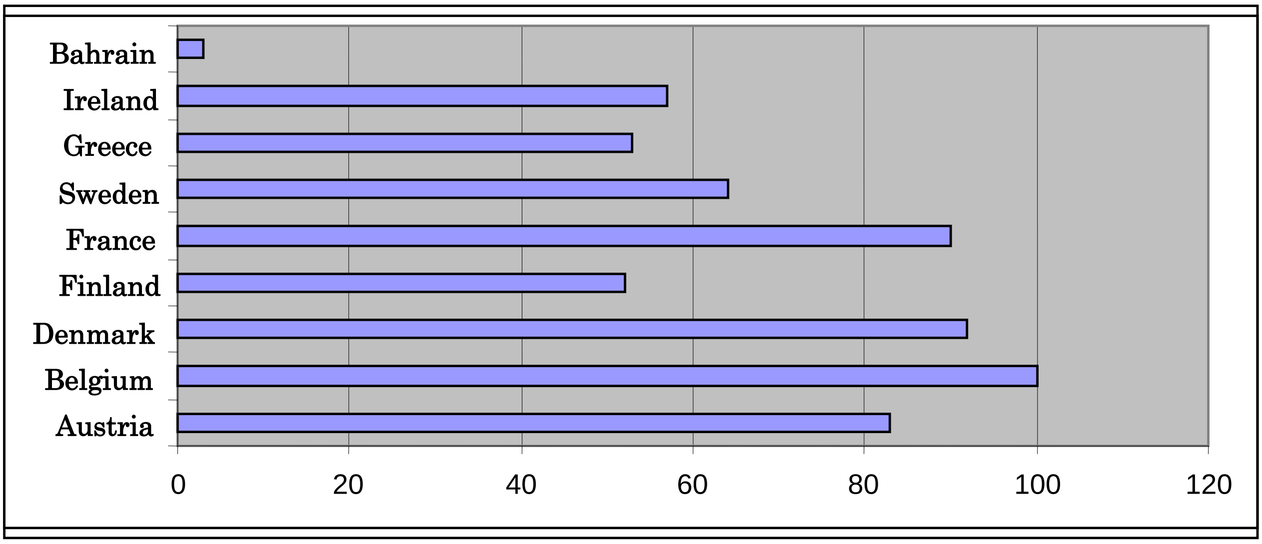


Note:

- Prices quoted in Bahraini currency in 2006.
- Data are exclusively for residential tariffs.

Source: OAPEC (http://www.oapecorg.org/images/DATA/)

Figure 11. Comparison of Electricity Prices in Selected Developed Countries/Price in fils/KWh



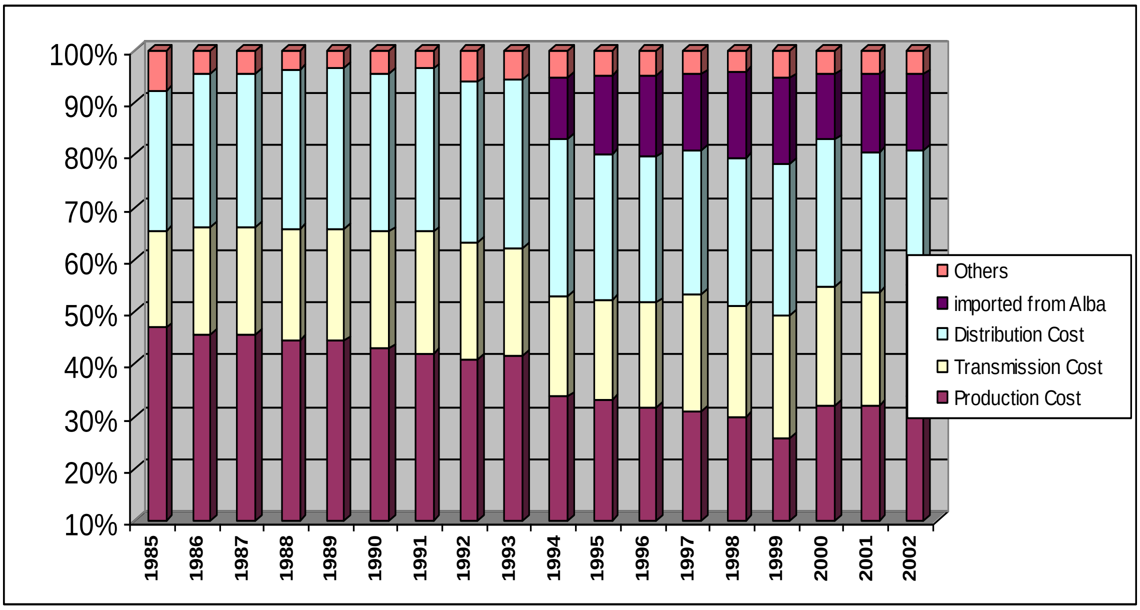
Note:

- Prices quoted in Bahrain currency in 2006.
- Data are exclusive for Domestic tariff.

Source: Public Services International Research unit (http://www.psiru.org/edu/Resources/Res13.htm)

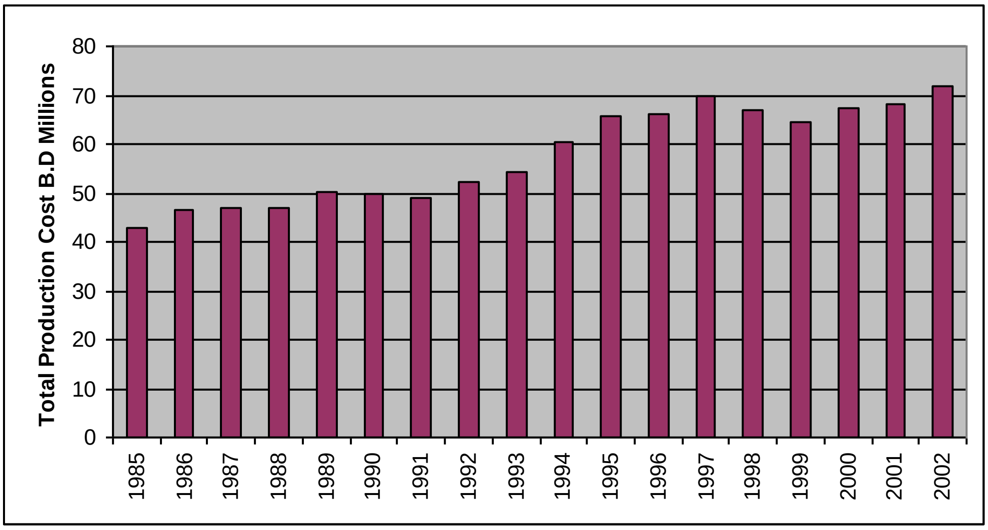
Total production costs (TPC) and revenues are indices used to measure the efficiency of the electricity production sector, as well as to reflect the percentage of the TPC attributed to the production, transmission, distribution, and other costs such as the cost of buying electricity from ALBA (Figure 12). The estimated average costs for production, transmission, and distribution are 40, 15, and 30% respectively. More than 15 years of time series for costs and revenues were analyzed (Figure 13 & 14) the data analyzed show that a revenue deficit of 20-40% occurred during the period 1985 to 2002. This gap in recovering the full cost of the electricity was attributed to the inconsistent governmental pricing mechanism with the electricity policy objectives in using the national resources in a sustainable and rational way especially the non-renewable resources. For instance, the government calculated electricity prices based on US$1.00 per million Btu (MBtu) of fuel or about US$6.00 per barrel of oil, which is far below the international prices for oil, which exceeded US$100.00 per barrel of oil in the second half of 2008.

Figure 12- Breakdown of Total Production Costs from 1985-2002



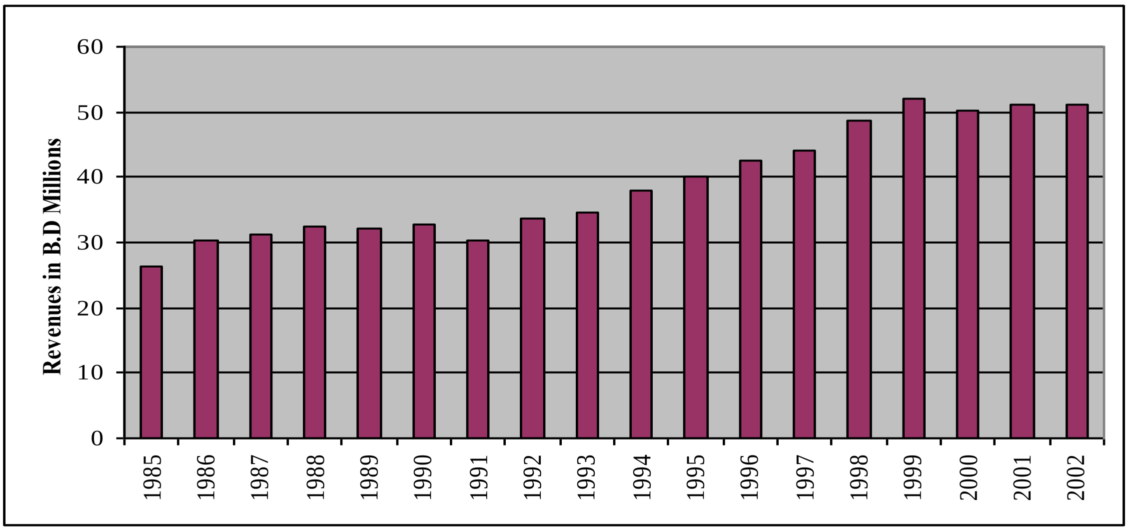
MEW Statistical Book, 2003.

Figure 13- Total Production Costs for Electricity from 1985-2002 (BD Millions)



Source: MEW Statistical Book, 2003.

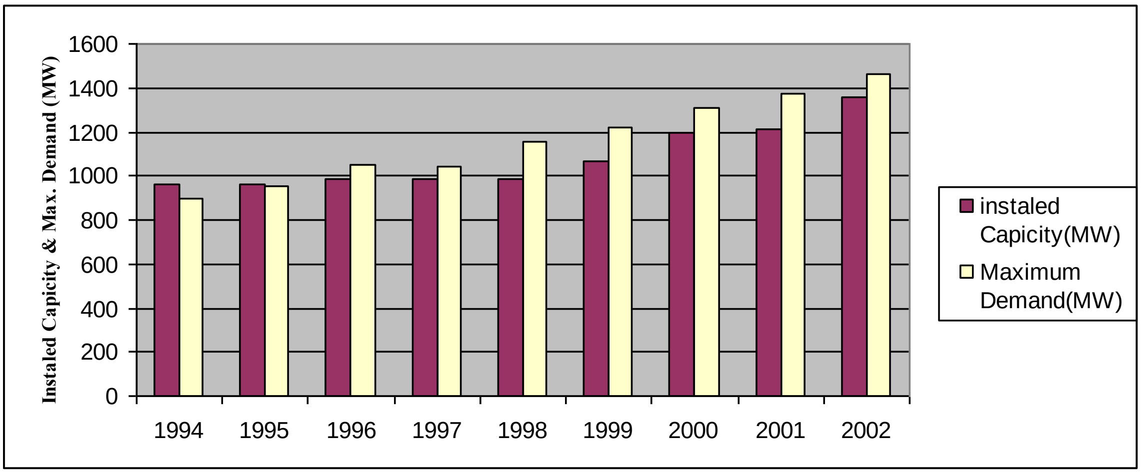
Figure 14- Electricity Revenues from 1985-2002 (BD Millions)



Source: MEW Statistical Book, 2003

Ensuring sufficient capacity to cover demand for power, at all times, is a cornerstone in Bahrain's Electrical policy objectives. The government always focuses its efforts and financial resources to achieve their policy objectives by building more power stations to cope with the growing power demands. This approach has been criticized by many experts in the field, including NGO's such as 'The Bahrain Society of Economists'. However, the available information shows that, the power system is suffering from capacity shortages during peak-demand periods, often during hot summer days (Figure-15); during such times, electrical power outages are rotated in order to manage the power demands.

Figure 15- The Installed Capacity and Maximum Demand



Source: MEW Statistical Book, 2003

The absence of demand side management programs (DSM) and the lack of an efficient price policy are undermining the performance of the electricity production sector. The real social costs of producing and using electricity at a subsidized price that is lower than it's opportunity costs is that it promotes the development of energy-intensive economic activities, producing distortions in industrial and the service sector's outputs. It also promotes inefficient practices and sends signals that are unfavorable to sustainable development. To bridge the gaps, the government should finance programs that promote energy conservation and promote production of electrical power via solar powered renewable energy sources.

If the government wants to alleviate the impact on lower income households, it can use appropriate income redistribution mechanisms that are already in place, combined with incentive programs to protect them from price increases.

The efficient use of electricity is more and more often prescribed by the regulator, in order to achieve this, the methods of electricity production and pricing as well as environmental planning must improve, in particular by taking into account the management of the load curves in order to optimize the use of the existing generation capacities and to support the development and the use of an efficient transportation network.

According to the proposed new legislation, the regulators should be concerned with economic and technical efficiency, and should encourage the regulated electricity companies to behave in accordance with public interests, like the promotion of improvements in energy efficiency, generation of electricity via renewable energy sources, protection of human health and improved environmental protection.

2.5.3 Environmental Performance:

The Electricity production sector in Bahrain is regulated under ministerial order (10) for 1999 with respect to environmental standards of air and water, and hence each operating power plant has to operate under the specified constrains within the environmental commission authorization. It is not possible in today's commercially driven electricity market to succeed without due regard for improved environmental performance. (Adrian and Housley 1998) "Environmental performance of the liberalized U.K power Industry" Environmental science and Technology No.11, London) However, the electricity production sector in Bahrain, in contrast to these fundamentals due to the absence of a documented and clear electricity policy, does not now comply with environmental requirements. They must increasingly be committed to improve the environmental performance of power plants, and to share information with external stakeholders.

Summary of Chapter 2

This chapter provided the answer for the research sub-question: *What is the current electricity policy, and what are the key factors that influence it?* The discussion focused on the current and on the proposed future policy structure, and on the regulations controlling the electricity production sector. This thesis' author conducted an analysis of the governmental policies, social obligations, and characteristics of the existing policies.

The discussion revealed that the electricity services in Kingdom of Bahrain are technically comparable with that of any other country in the world. These services are considered to be the public services, the electricity industry in Bahrain, is regulated by the Ministry of Electricity and Water (MEW), in 2002 the government announced its intent to restructure the electricity production sector. The privatization act No. (41) of 2002 vested the government with the right to establish the administrative and technical arrangements to privatize many publicly owned sectors, among these sectors Electricity and Water utilities. Al-Ezzel power station is the first power station that operated in 2008 by an international consortium of companies based on a Power and Water Purchase Agreement (PWPA).

The government Social Obligations (GSO) encompasses several non-commercial services provided by the MEW under regulations or governmental direction. The major GSOs applying to electricity and water authority include:

- Uniform tariffs within customer classes;
- Subsidized tariffs to certain customer classes;
- Obligation to supply;
- National development and employment programs.

In Chapter 3, the author presented the environmental and health impact that resulted from the existing power generation policies.

Chapter 3- The Environmental and Health Impact of Power Generation in Bahrain:

Introduction:

Electrical power generation is a significant source of pollutants that can impair human health and the environment including Sulphur Dioxide (SO_2), Nitrogen Oxide (NOx), and other pollutants. Implementation of Ministerial Order No. (10) for 1998 with respect environmental standards, has contributed positively in reducing these emissions, but electrical power generation still contributes approximately 65% of the NOx.

The electricity generation industry releases huge quantities of gases each year into the atmosphere. These include lead (Pb), carbon monoxide (CO), carbon dioxide (CO2; not a pollutant), methane (CH4), nitrogen oxides (NOx), nitrous oxide (N2O), chlorofluorocarbons (CFCs), perfluorocarbons (PFCs), silicon tetraflouride (SF6), benzene and volatile components (BTX), heavy metals (zinc, chrome, copper and cadmium) and particulate matter (ash, dust). There is an ongoing debate to what extent some of these emissions may be linked to climate change and the role of anthropogenic factors in climate changes. Some of these gases, particularly nitrous oxide, also participate in depleting the stratospheric ozone (O3) layer, which naturally screens the earth's surface from ultraviolet radiation.

Power plants are the source of pollution in the form of diverse gases and particulate matter emissions that affect air quality, which causes human health effects. Those toxic air pollutants are associated with some types of cancer, as well as with cardiovascular, respiratory and neurological diseases. Carbon monoxide (CO), when inhaled reduces the availability of oxygen from the red blood cells and can be extremely harmful to public health. Emissions of nitrogen dioxide (NO2) from power plants reduce lung function, affect the respiratory immune defense system and increase the risk of respiratory problems. The emissions of sulphur dioxide (SO2) and nitrogen oxides (NOx) in the atmosphere form various acidic compounds that when mixed in cloud water creates acid rain. Acid precipitation has detrimental effects on the built environment, reduces agricultural crop yields and causes forest decline. The reduction of natural visibility by smog has a number of adverse impacts on the quality of life and the attractiveness of tourist sites. Particulate emissions in the form of dust emanating from power plants have an impact on air quality. The physical and chemical properties of particulates are associated with health risks such as respiratory problems, skin irritations, eyes inflammations, blood clotting and various types of allergies (Rodrigue *et al.* 2009)[78].

As a result of this situation, there exists a concern regarding the implications of environmental impact from electrical power plants. Therefore, an assessment of the relation between power generation and the environmental parameters has been performed. Additional evidence was obtained through a review of air quality (ambient) in Bahrain based upon the results of two important studies that were conducted previously i.e. "Assessment and Possible Reduction of Pollutant Emissions from Power Stations in Bahrain". Study was prepared by Lahmeyer International in 1999. A study of the "Greenhouse Gas Inventory for Bahrain" was done with this thesis author’s involvement. The report of the results was published in 2005[79].

An epidemiological assessment of the situation has not been made in Kingdom of Bahrain. This chapter highlights the environmental health hazards caused by SO_2 and NO_X in Bahrain by addressing the link between air pollution and its impact upon human health.

This chapter begins with a literature review of research on energy and environment, and on other studies related to environment and health. The second part presents air quality data. Finally, the author seeks to establish a link between emissions of NO_X and SO2 with human health impacts. This chapter is concluded with a brief summary of the implications of the results.

3.1 Literature Review:

A number of studies concentrate on energy and environment; for example a publication by Lin and Chang (1996)[80] used an index to evaluate emission changes of sulphur dioxide, nitric oxide, and carbon dioxide from major economic sectors in Taiwan during 1980 to 1992. The study highlighted the interrelationships between energy use and environmental quality and provides insight for policy makers. The emissions were divided into five components: pollution coefficient, fuel mix, energy intensity, economic growth and industrial structure. Of all components analyzed, economic growth had the largest positive effect on emission changes for Taiwan's major economic sectors. Emissions of sulphur dioxide in industry and other sectors showed a decreasing trend due to fuel quality improvements and pollution control. However, nitric oxide and carbon dioxide emissions increased sharply in all sectors. Comparisons were made with Germany, Japan & U.S.A. This study found that improvements in energy efficiency helped to reduce sulphur dioxide, NOx, CO2 emissions.

Another study by Wier (1998)[81] explored the anatomy of Danish energy consumption and emissions of carbon dioxide, sulphur dioxide, nitrogen oxide. Changes in emissions between 1966 and 1988 were investigated using Input-Output analysis. The work showed that production-based emissions have undergone substantially greater changes than private consumption emissions, and the increased level of final demand explains most of this development. Although the levels of CO2 emissions have risen proportionally to energy consumption, the NOx emissions have increased relatively more and the SO2 emissions level has declined considerably. The main reason for these results is due to changes in the fuel mix in the energy- supply sector. Finally, the study showed that although energy conservation has been carried out in most sectors, NOx emissions have increased markedly.

Emission of SO2, NOx and CO2were estimated by Viguier (1999)[82] using cross-country data, derived by the divisia index[3] method. He studied emission data from three Eastern European countries (Hungary, Poland and Russia) and from three OECD countries (France, UK and US) for 1971-94. The energy balance method was used to evaluate the emissions from the major economic sectors. His emphasis was on explaining the reasons for the high per capita levels of emissions in the three transition economies in the study. The analysis of the environment and economic growth relationships showed that these economies have high emission intensities compared to OECD countries. The main contribution to high emission intensities in transition economies is from the persistence of inefficient technologies with high-energy intensities.

The research efforts on the human health effects due to acute exposure to air pollution are quite large; Ellison & Waller (1978)[83] illustrated that, toxic effects attributable to acute exposure to air pollutants vary widely and have been reported since the beginning of the industrial revolution where episodes of high levels of pollutants were associated with increases in diverse respiratory and heart diseases and death. These episodes occurred on more than a single occasion in different parts of the world, especially in highly industrialized and/or in densely populated areas.

Dockery *et al.* (1993)[84] observed statistically significant and robust associations between air pollution and mortality. The adjusted mortality-rate ratio for the most polluted of the cities as compared with the least polluted was 1.26 (95 percent confidence interval, 1.08 to 1.47). Air pollution was positively associated with death from lung cancer and cardiopulmonary disease but not with death from other causes considered together. Mortality was most strongly associated with air pollution with fine particulates, including sulfates.

The most studied toxic effect due to acute exposure to environmental pollutants is mortality. Many reports describe an increase in total mortality (not including accidental death) associated mainly with exposure to particulate matter (PM), ozone and sulphates (Schwartz 1994)[85].

A great number of studies report increases in mortality due to respiratory complications, and in this case, the mechanism can be related to exposure to air pollution. Many reports also claim an increase in death due to cardiovascular ailments, which would implicate a mechanism with an indirect effect from air pollution. Both causes of death are associated with exposure mainly to PM, ozone and sulphates. Mortality attributable to exposure to air pollution occurs

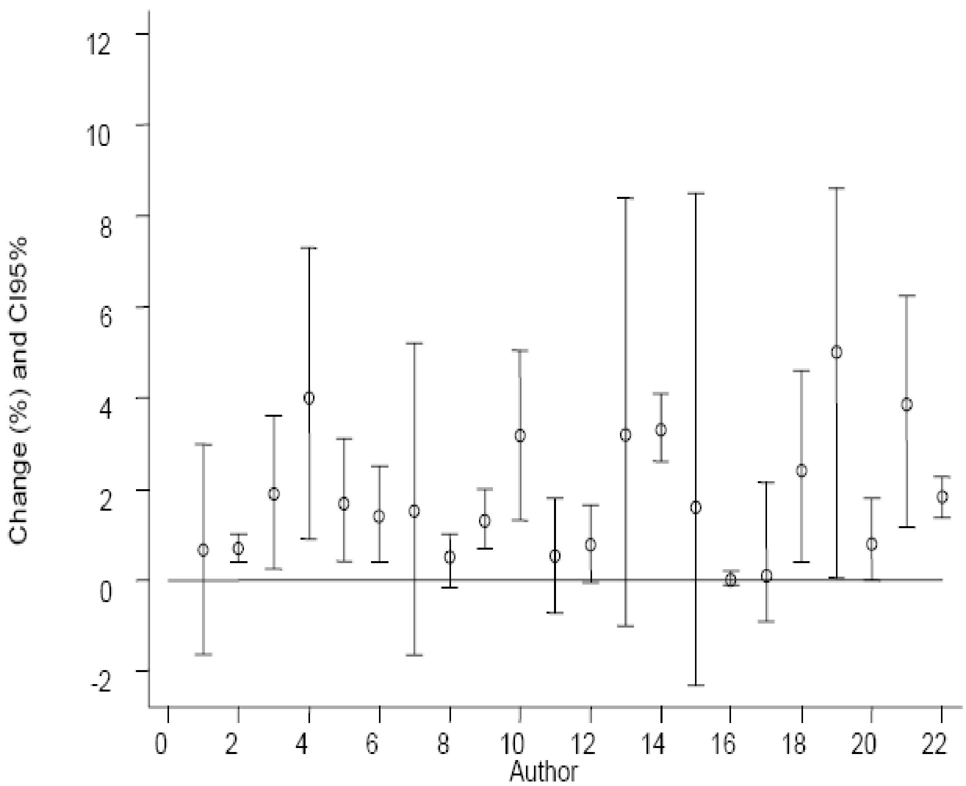
[3]The original continuous time Divisia index was derived by Francois Divisia in his classic paper published in French in 1925 in the *Revue d'Economie Politique*. The discrete time Divisia weights are defined as the expenditure shares averaged over the two periods of the change.

mainly in individuals who suffer from cardiac and/or respiratory diseases. Increased mortality in these groups occurs within 1 to 5 days following the hazardous exposure (Wilson *et al.* 1996)[86], and (Cropper 1999)[87].

Figure 17 shows data from studies where increases in deaths due to respiratory causes were evaluated with high levels of PM10 pollution. The increases are greater than those describing total death, with a range of percent increase from 0.4 to 5.0%. Only the two studies by (Simpson *et al.* 1997) (0.01%) and (Sunyer *et al.* 1996) (0.09%) reported low increases. For these studies the pooled estimate is greater than that reported for total, non-accidental death, 1.82 (CI 95% 1.37-2.22).

From these reports it is clear that there is conclusive scientific evidence on the relationship of air pollution and mortality from lung disease, cardiovascular, and certain types of cancers such as lung cancer etc., and therefore, the calculation of the externalized cost of pollution that is associated with these premature deaths and morbidity could help decision-makers to address this problem through the use of policies that would limit the sources of these problems.

Figure 16. Percent Change in Mortality due to Respiratory Causes for Each 10 μg/m^{3}Increase in pm$_{10}$



Source: Borja, Castillo, Meza, Corey, and Fernandez 1997[88]

Note: The numbers of the authors on the x-axis of Fig 16, pertain to the following studies: 1. Anderson[89] 1996 (London), 2. Ballester[90] 1996, (Valencia)

,3. Borja-Aburto 1997 (México), 4. Brenner[91] 1999 (London), 5. Dab[92] 1996 (Paris), 6. Ito[93] 1996 (Chicago), 7. Neas[94]1999 (Philadelphia), 8. Ostro[95] 1995b (California), 9. Ostro[96] 1996[97] (Santiago), 10. Pope III[98] 1999 (Ogdem), 11. Pope III[99] 1999 (Provo), 12. Pope III[100] 1999 (Utah), 13. Schwartz [101]1994c (Cincinnati), 14. Schwartz[102] 1992b (Philadelphia), 15. Schwartz[103] 1993a (Birmingham), 16. Simpson[104] 1997 (Brisbane), 17. Sunyer[105] 1996 (Barcelona), 18. Vigotti1[106]996 (Milán), 19. Wordley [107]1997 (Birmingham), 20. Zmirou[108] 1996 (Lyon), 21. Castillejos[109] 2000 (México), 22. Pooled estimated.

Figure 17 shows the results of studies where an increase in death due to respiratory causes was evaluated based upon correlations with high levels of PM10 pollution. The increases are greater than those describing total deaths, with a range of percent increase from 0.4 to 5.0%. Only the two studies by Simpson *et al.* in 1997 (0.01%) and Sunyer *et al.* in 1996 (0.09%) reported low increases. From these studies, the pooled estimated increase is greater than that reported for total, non-accidental death, 1.82 (CI 95% 1.37-2.22).

Besides mortality, a great number of chronic health problems have been reported to be associated with exposure to air pollutants. Among these are diseases of the respiratory tract, both upper and lower, bronchitis, pneumonia, chronic obstructive pulmonary disease and cough with phlegm.

In exposed animals (SO_4^{-2} and NO_3), a decrease in the affinity of macrophages for the Fc section of antibodies has been observed. Intuitively, in a human organism with diminished immune response, the capability to mount an adequate defense in a populated, urban environment, where exposure to multiple pathogens is high, would be unfavorable (Ehrlich 1980)[110], and (Schlesinger 1995)[111].

Many laboratory animal studies have evaluated the effects of pollutants on macrophages, one of the major cellular defense responses present in the respiratory apparatus. Two types of effects have been observed. Exposure to certain pollutants (SO_4^{-2} and NO_3, for example) causes a decrease in affinity for the Fc section of the immunoglobulin and limits the antibody-mediated response. In addition, exposure to transition metals results in increased secretion of reactive intermediates of oxygen (O_2, OH. and H_2O_2) and nitrogen (NO. and Peroxynitrite ONOO-), producing a state of tissue inflammation. It is possible that other cytokines, such as some of the interleukins, are affected, as well (Wilson *et al.* 1996, Martin *et al.* 1997[112], Ghio *et al.* 1999[113]).

Health effects due to chronic exposure to air pollutants are also well documented; for example, there are several reports of increased mortality, however, most cases involve mainly elderly individuals where respiratory and cardiovascular problems are already the principle cause of death (Anderson 1996[114], Borja 1997[115], Pope 1996[116]).

Increased respiratory diseases (such as bronchitis) have also been reported associated with chronic exposure to air pollutants. The mechanisms causing these diseases are similar to those occurring for acute exposure.

The best documented chronic effect of exposure to air pollution is cancer. Approximately 70 to 80% of all cancer types have been reported as being due to exposure to environmental pollutants. The mutagenic properties of different substances (e.g. diesel) have been demonstrated, and, as is well known, mutation is an essential step in the transformation of a normal cell into a cancerous cell. The mutagenic ability of a substance is not the only property that can stimulate cell transformation, however. Over-activation or inhibition of regulatory enzymes can also lead to cellular transformation. However, over-activation or inhibition of regulatory enzymes can also lead to cellular transformation.

3.2- Air Quality and Electrical Power Generation:

Poor air quality has become an acute problem in the Kingdom of Bahrain. The air pollution that occurs in urban areas is due to transportation, and industrial activities mainly electrical power generation. Some environmental laws and rules to reduce air pollution have been issued and are being enforced, to some extent, in Bahrain. Such laws include Ministerial Order No. 10 of 2006 with respect to the emissions of air pollutants from sources; online monitoring is now being used.

The ambient air quality status derived from a network of four monitoring stations (See Figure 17) covering Bahrain Island, in recent years, indicates that while non-methane hydrocarbons (NMHC), PM10, and ozone are consistently at critical levels in many areas, the concentration of NOx, and SOx, are also increasing and are already transitioning from Moderate to High Levels.

The industrial units in the Kingdom of Bahrain have largely been concentrated in the south and southeast. The highest concentrations of SOx and NOx are, therefore, usually found in those areas. Now, new industrial areas in Al-Hidd are also manifesting a disturbing upward trend in air pollution. The documented concentrations are compared against the Bahrain national standard and the World Health Organization (WHO) air quality guidelines (See Table -10).

Furthermore, the pollution rose diagram for certain parameters have been developed in order to identify the potential pollution sources. The wind direction data are used to identify the prevailing wind direction at violating times; these data are used to develop the pollution rose, which can be easily interpreted and effectively analyzed.

Fig 17. Locations of Air Quality Monitoring Stations.

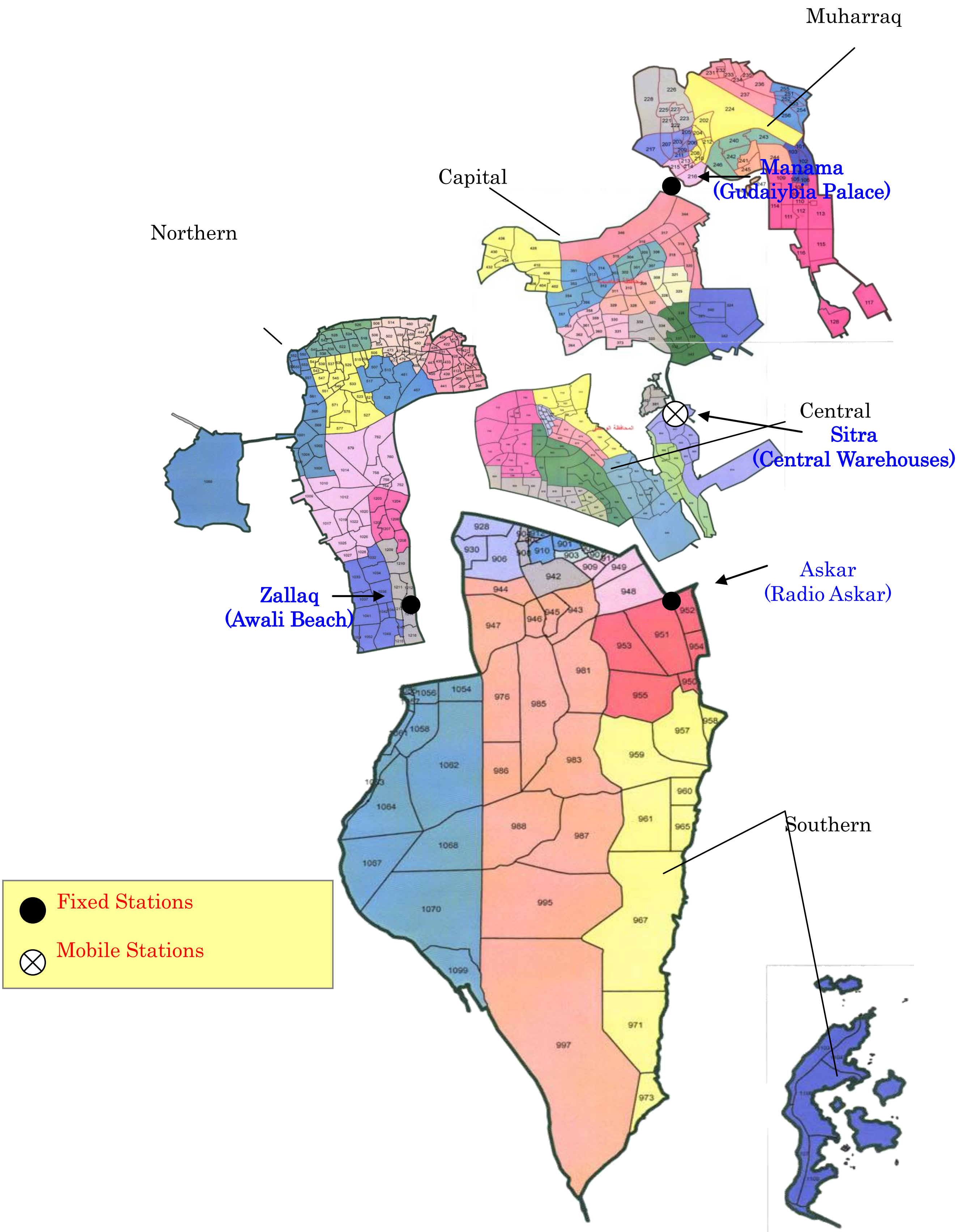


Table 10. Bahrain National Standard and the World Health Organization (WHO) air quality guidelines

Pollutants	Average Period	Bahrain (μg/m³)	WHO (μg/m³)
Sulphur Dioxide (SO_2)	10 minutes	-	500
	Hourly	350	-
	Daily	125	125
	Annually	50	50
Nitrogen Dioxide (NO_2)	Hourly	200	200
	Daily	150	-
	Annually	40	40
Particulate Matter (PM_{10})	Daily	340	-
	Annually	80	-
Carbon Monoxide (CO)			
Ozone (O_3)	8-hourly	-	120

3.2.1- Ambient Air Quality Analysis

3-2.1.1 Carbon Monoxide – CO (ppm)

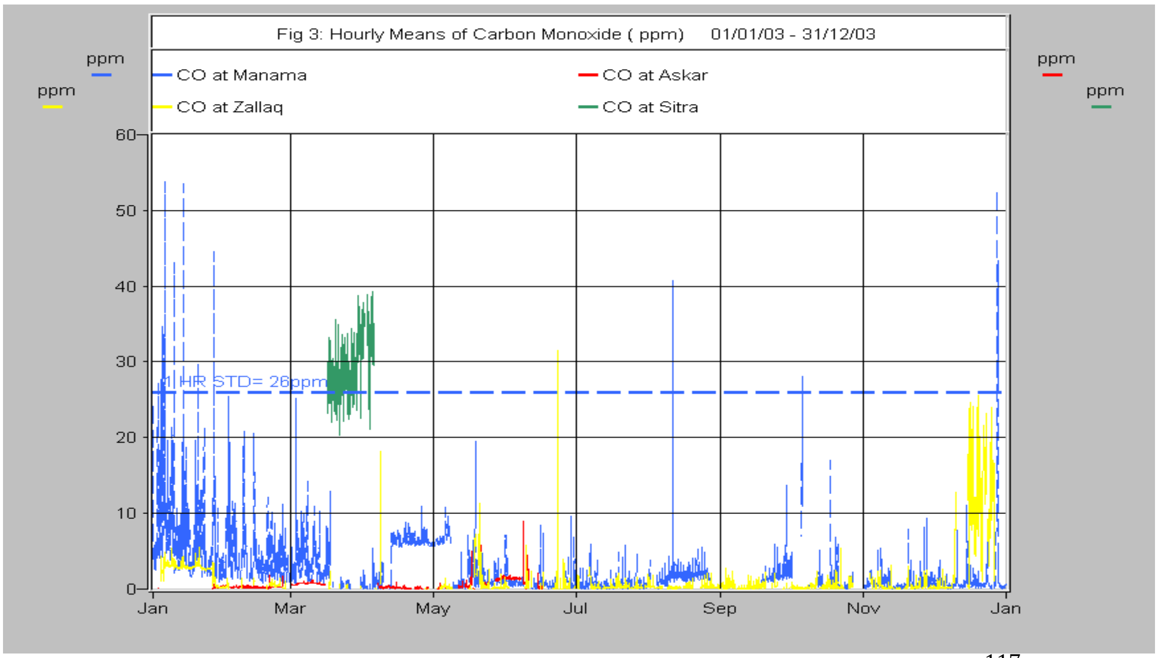
The measured maximum hourly concentrations at monitoring sites during 2003 were in the range of 8.9 ppm to 53.85 ppm and the monthly means were in the range of 0.16 ppm to 33.66 ppm.

At Manama, Askar, Zallaq and Sitra, the maximum levels were as follows: 53.85, 8.94, 31.63 and 39.24 ppm, respectively. Whereas the averages were 2.78 ppm at Manama, 0.50 ppm at Askar, 0.71 ppm at Zallaq and 29.3 ppm at Sitra.

The hourly ambient air quality standard (26 ppm) was exceeded at Manama (53.9 ppm) with total number of Excedances of 29, at Zallaq (31.6 ppm) with one exceedance and finally at Sitra (39 ppm) with 351 excedances (Figure 18).

The measured high levels at Manama site were attributed to transportation activities whereas at the Sitra site, the pollution is due to surrounding industries. At Zallaq and Askar, the measured levels are within the ambient air quality standards and can be considered as being in an acceptable range.

Figure 18- Hourly Means of Carbon Monoxide (ppm) Jan-Dec. 2003



Source: Air Quality Unit, Bahrain Environmental Authority 2003[117]

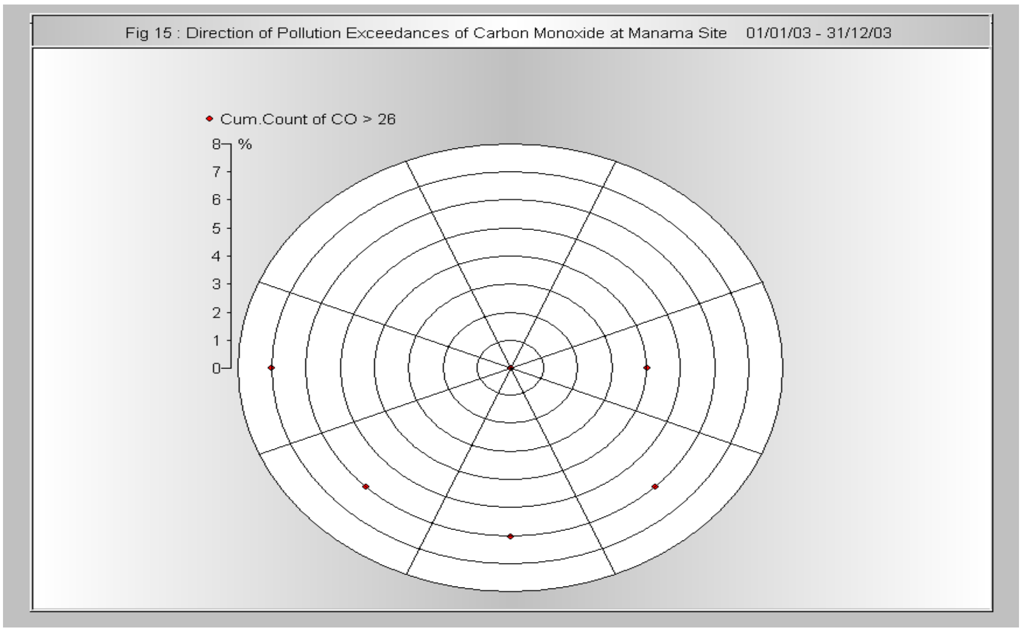
3.2.1.2 The Pollution Rose Analyses for Carbon Monoxide – CO (ppm):

The variation of the pollution wind rose[4] is used to pinpoint the pollution sources. The wind direction data are used to identify the prevailing wind direction at air quality standard violation times.

The pollution rose diagram of the times and locations during which Carbon Monoxide (CO) levels were exceeded at the Manama site showed that the violations occurred when the wind was from the east, south and west directions. (See Figure 19) Traffic activity at this site is known to be the principal source of pollution.

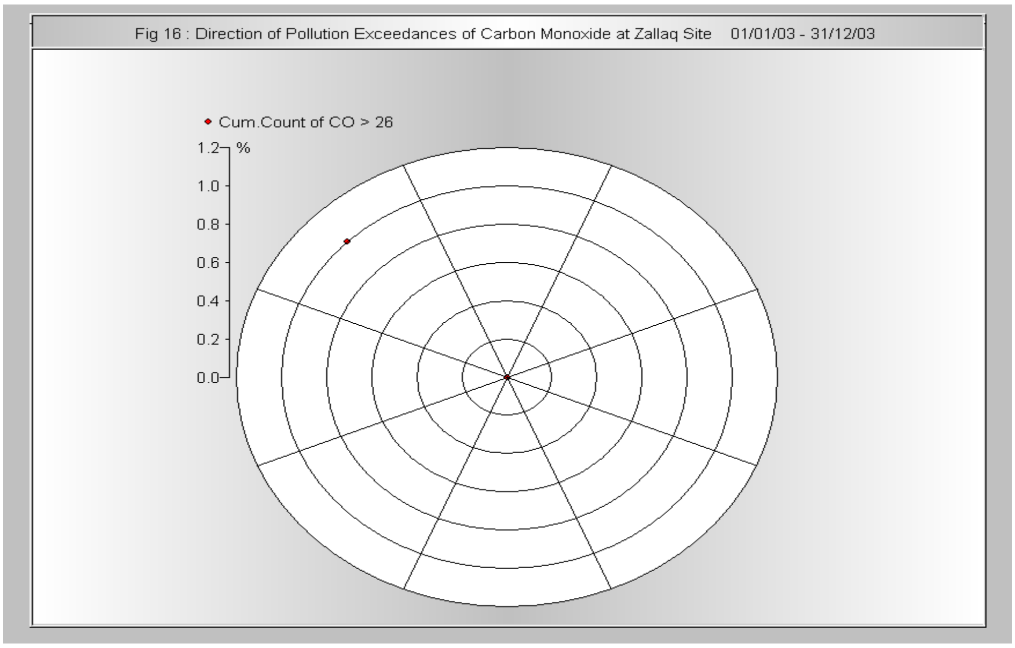
[4] A **wind rose** is a graphic tool used by meteorologists to give a succinct view of how wind speed and direction are typically distributed at a particular location. Presented in a circular format, the wind rose shows the frequency of winds blowing *from* particular directions. The length of each "spoke" around the circle is related to the frequency that the wind blows from a particular direction per unit time. Each concentric circle represents a different frequency, emanating from zero at the center to increasing frequencies at the outer circles. A wind rose plot may contain additional information, in that each spoke is broken down into color-coded bands that show wind speed ranges. Wind roses typically use 16 cardinal directions, such as north (N), NNE, NE, etc., although they may be subdivided into as many as 32 directions (Wikipedia)

Figure 19. Direction of Pollution Exceedances of Carbon Monoxide at the Manama Site Jan-Dec. 2003



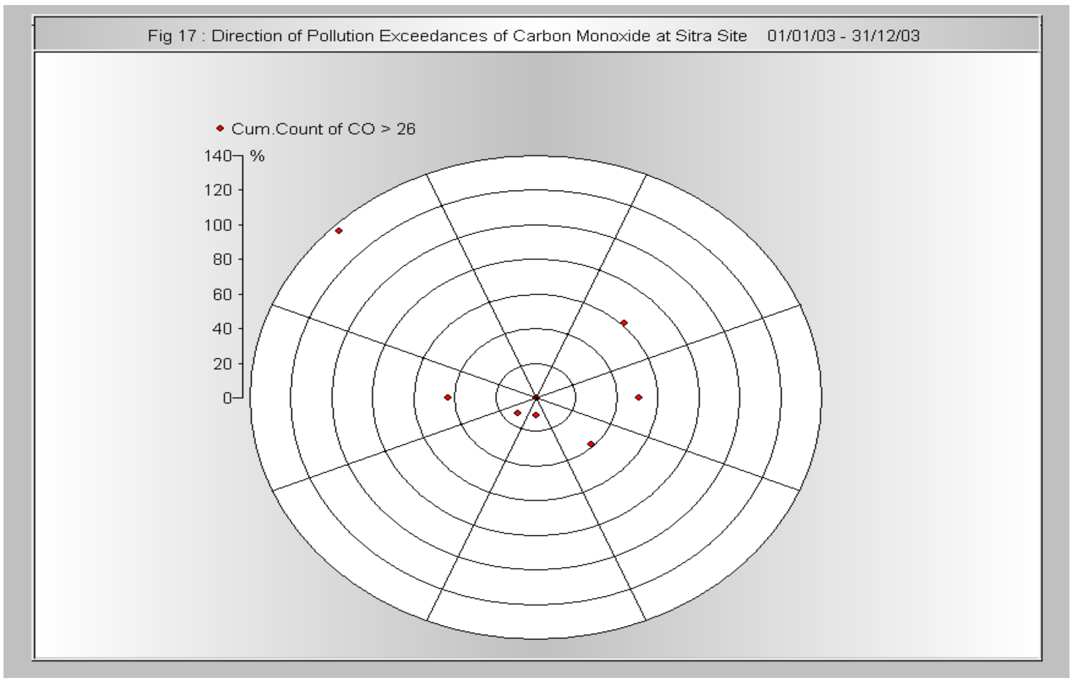
At the Zallaq site, the only documented record in which the concentrations exceeded the air quality standard was observed from the west direction (Figure 20). The King Fahad Causeway that is 15 km in the west direction of the Zallaq site is the suspected pollution source.

Figure 20. Direction of Pollution Exceedances of Carbon Monoxide at the Zallaq Site Jan-Dec. 2003



At Sitra Site, the number of exceedances reported was 351, these levels were observed from east, south, west and northwest direction (Figure 21) where major industries such as Gulf Petrochemical Industries Co. (GPIC) and Bahrain Petroleum Co. (Bapco) are located.

Figure 21. Direction of Pollution Excedances of Carbon Monoxide at the Sitra Site Jan-Dec. 2003



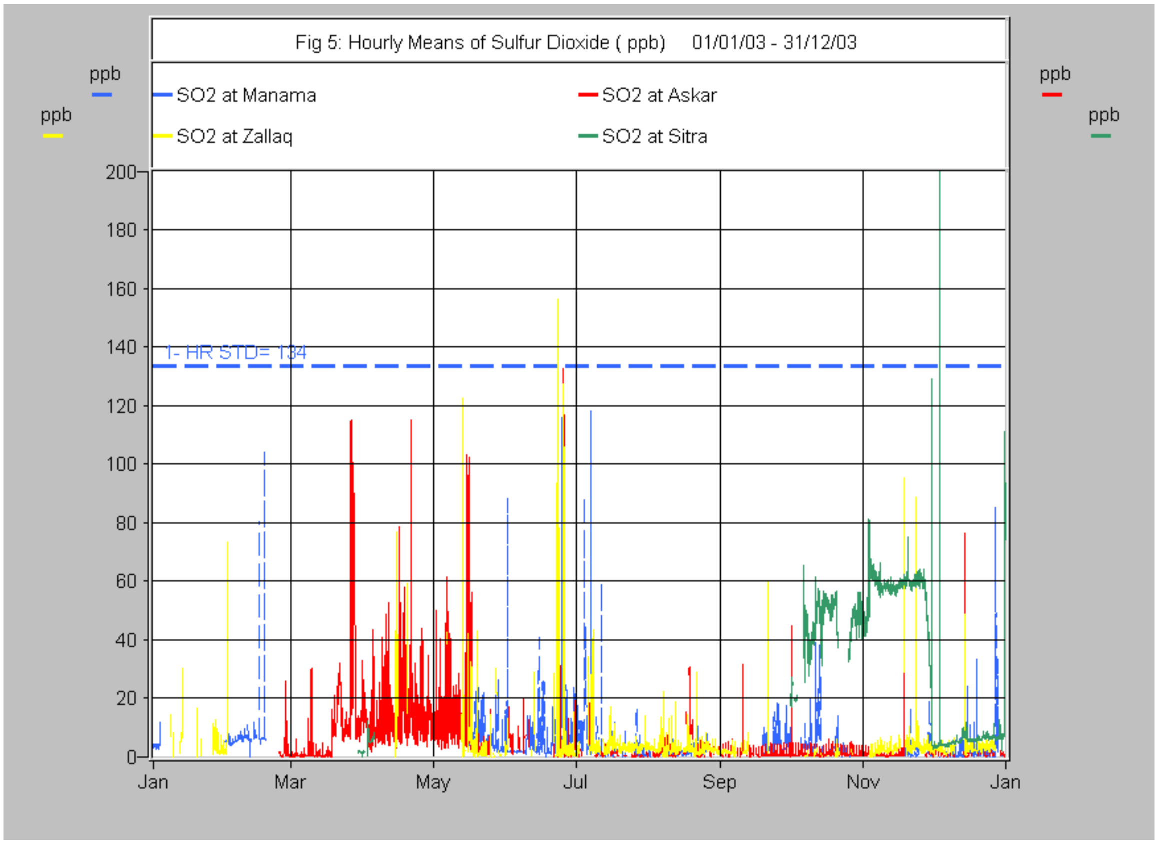
3.2.1.3 Sulfur Dioxide – SO_2 (ppb):

The range of the measured maximum levels at monitoring sites was as follows: 12.19 ppb to 118.09 ppb at Manama, 18.26 ppb to 132.70 ppb at Askar, 6.19 ppb to 156.54 ppb at Zallaq and 2.23 ppb to 129.84 ppb at Sitra.

Whereas, the monthly averages were in the range of 1.95 ppb to 8.05 ppb, 1.0 ppb to 14.0 ppb, 1.0 ppb to 42.6 ppb and 1.66 ppb to 56.0 ppb at Manama, Askar, Zallaq and Sitra, respectively.

The measured levels of Sulfur dioxide are within the ambient air quality standard (134 ppb) at most of the monitoring sites and can be considered to be normal (Figure 22).

Figure 22. Hourly Means of Sulfur Dioxide Jan-Dec. 2003

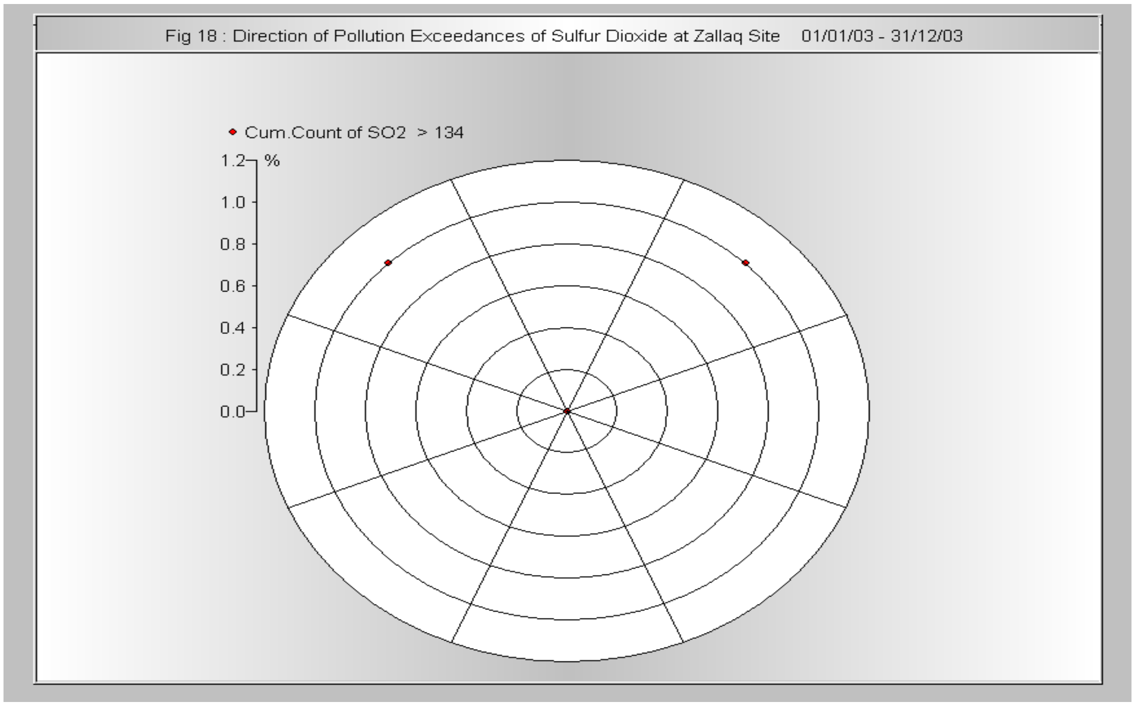


Source: Air Quality Unit, Bahrain Environmental Authority, 2003

3.2.1.4 Pollution Rose Analysis for Sulfur Dioxide (ppb):

The pollution rose analysis of the reported exceedances of Sulfur Dioxide at Zallaq site are presented in (figure 23). The exceedances were recorded from the northeasterly and northwesterly directions. In addition to the vehicle emissions as was emphasized earlier in this chapter, the emission from King Fahad Causeway, power plants and Oil field production are located in the same direction of the reported exceedances.

Figure 23. Direction of Pollution Excedances of Sulfur Dioxide at the Zallaq Site Jan-Dec. 2003



Source: Air Quality Unit, Bahrain Environmental Authority, 2003

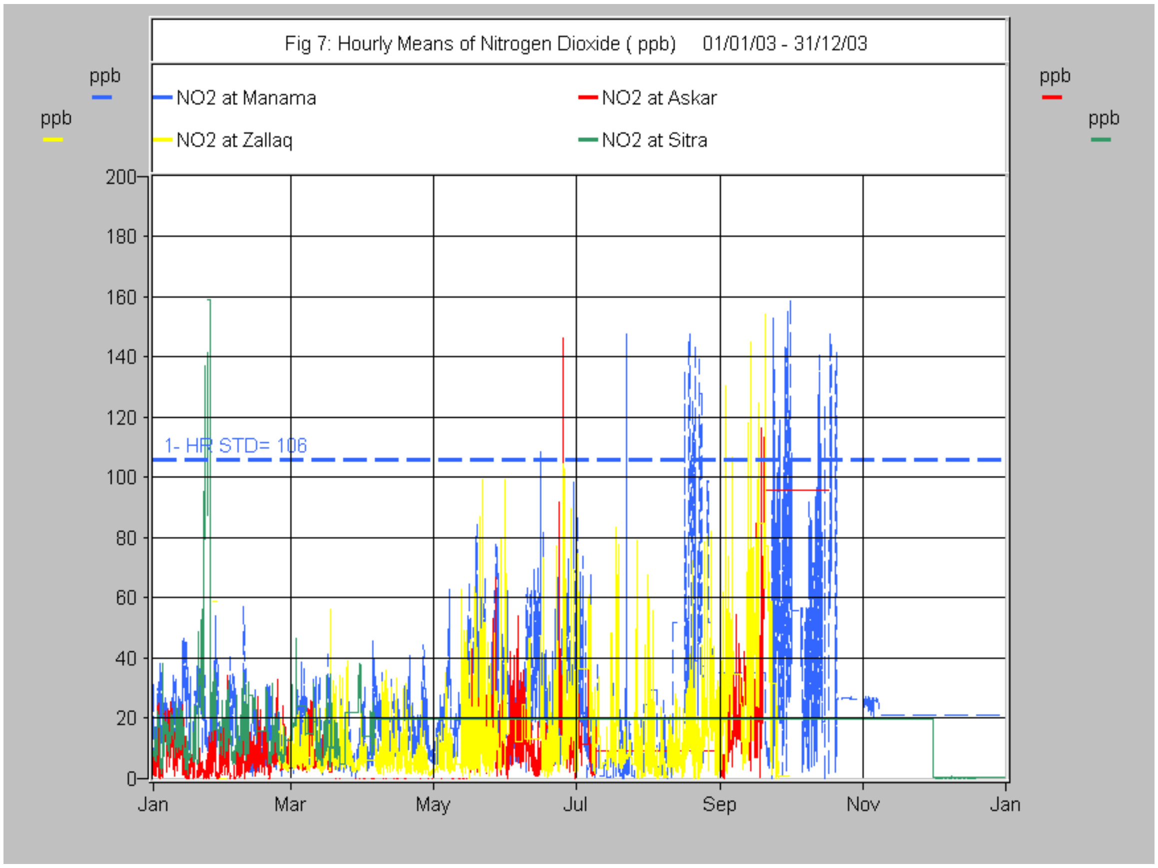
3.2.1.5 Nitrogen Dioxide – NO_2 (ppb):

Measurements of Nitrogen dioxide at the monitoring sites revealed levels of 45.9 ppb to 88.8 ppb at Manama, 9.4 ppb to 146.3 ppb at Askar, 19.8 ppb to 154 ppb at Zallaq and 25.6 ppb to 56 ppb at Sitra (Figure 24).

Average values were in the range of 9 ppb to 28.2 ppb, 5.9 ppb to 52.5 ppb and 6.1 ppb to 15 ppb, 13.3 ppb to 18 ppb at Manama, Askar, Zallaq and Sitra, respectively.

The measured levels exceeded the ambient air quality standards (106 ppb) at Zallaq and Askar.

Figure 24. Hourly Mean of Nitrogen Dioxide, Jan-Dec. 2003



Source: Air Quality Unit, Bahrain Environmental Authority, 2003

3.2.1.6 Pollution Rose analysis for Nitrogen Dioxide (ppb):

The pollution rose analysis of the reported excedances of Nitrogen Dioxide at Askar and Zallaq as shown in (figure-25 and 26) below: the excedances were recorded mostly from south and east directions at Askar site, whereas at Zallaq, the reported excedances were recorded from North and east directions. Riffa, Alba and Bapco power stations and others industries are located in the direction line of the sources at Askar site.

Figure 25. Direction of Pollution Exceedances of Nitrogen Dioxide at the Askar Site Jan-Dec. 2003

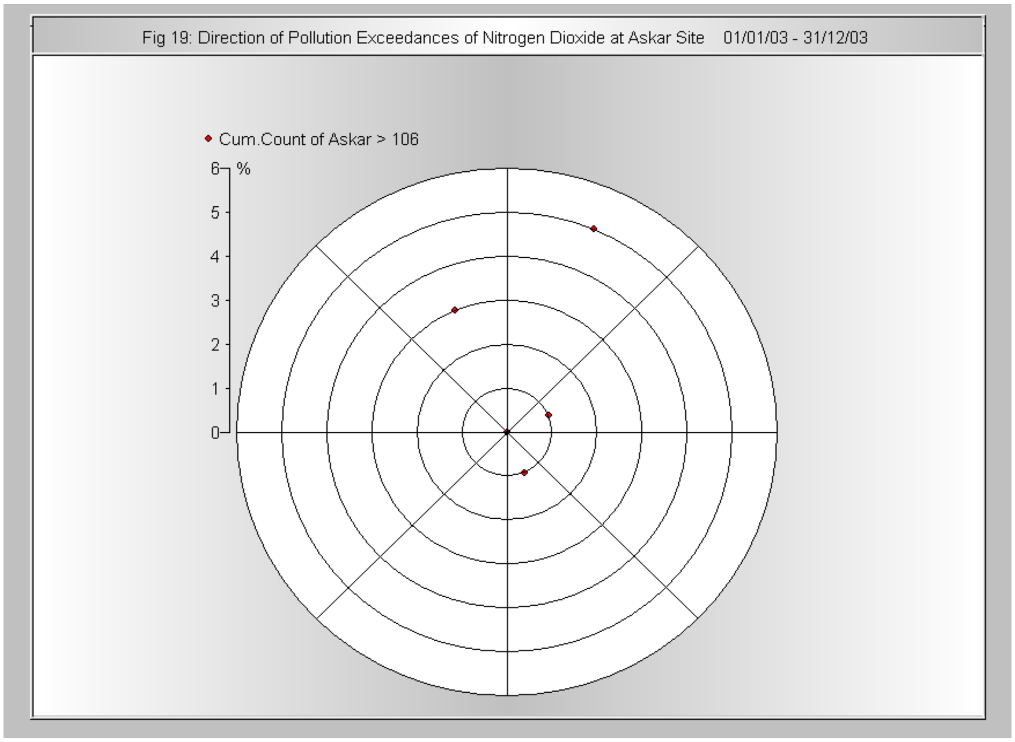
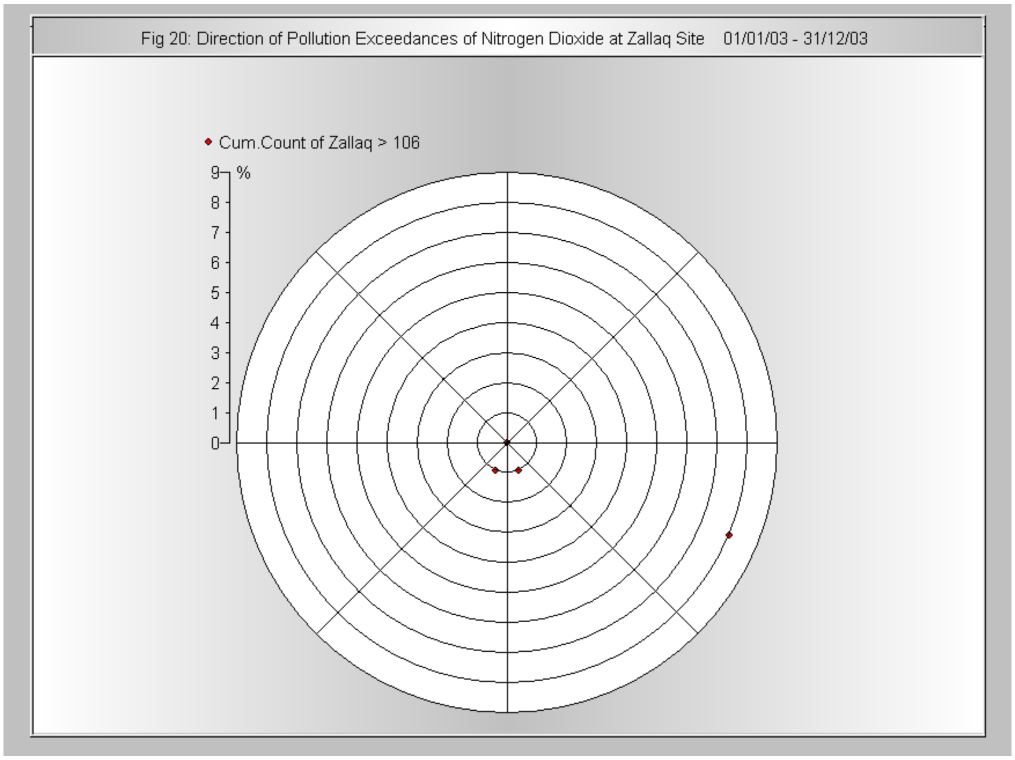


Figure 26. Direction of Pollution Exceedances of Sulfur Dioxide at the Zallaq Site Jan-Dec. 2003



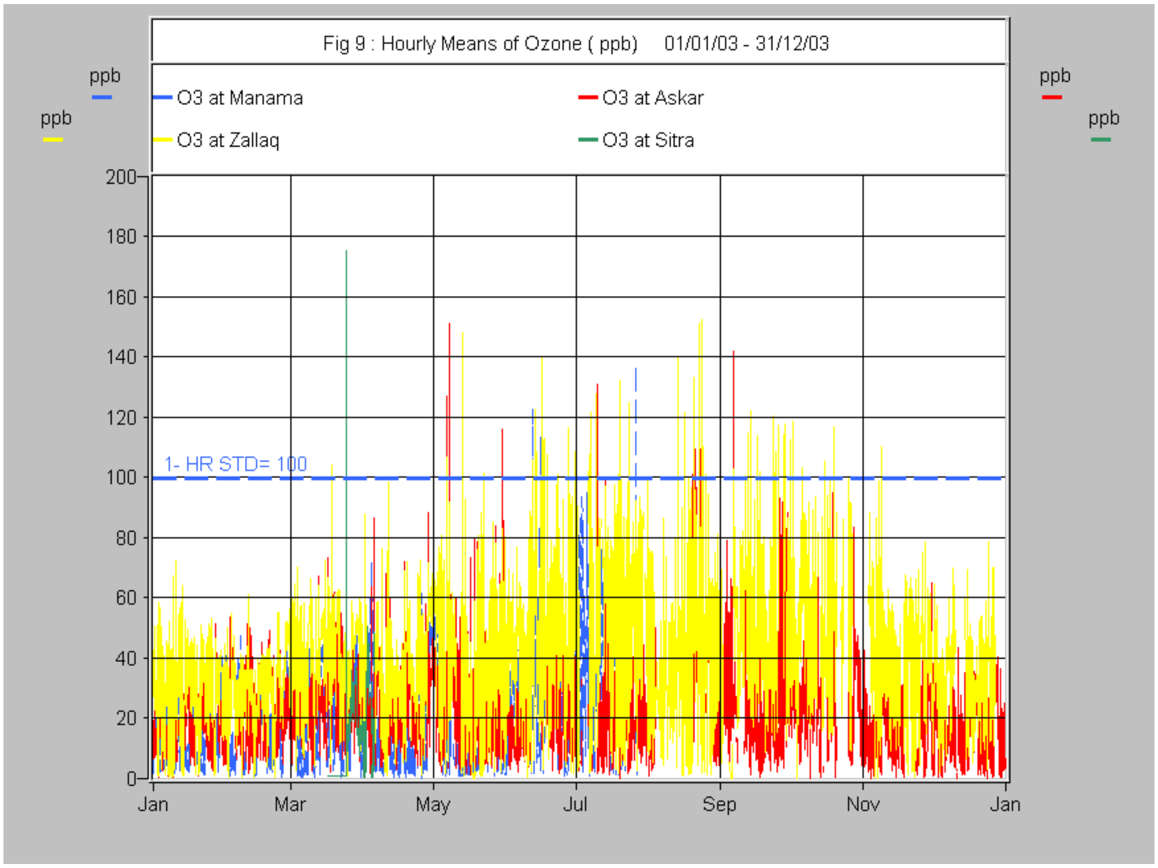
3.2.1.7 Ozone – O_3 (ppb):

Measurements of Ozone concentrations in ambient air of selected monitoring locations at Manama, Askar, Zallaq and Sitra have reached maximum levels in the range of 46.69 ppb to 136.39 ppb, 51.37 ppb to 151.0 ppb, 61.0 ppb to 152.58 ppb and 50.35 ppb to 175.37 ppb, respectively.

The mean values were in the range of 13.92 ppb to 38.71 ppb at Manama, 13.3 ppb to 33.12 ppb at Askar, 30.82 ppb to 55.83 ppb at Zallaq and 10.8 ppb to 16.62 ppb at Sitra.

The hourly ambient air quality standard (100 ppb) was exceeded at all sites as follows: the measured maximum levels were 136 ppb, 151 ppb, 153 ppb and 175.5 ppb with a total number of excedances of 11, 21, 90 and 1 at Manama, Askar, Zallaq and Sitra, respectively (Figure 27).

Figure 27. Hourly Mean of Ozone (ppb), Jan-Dec. 2003

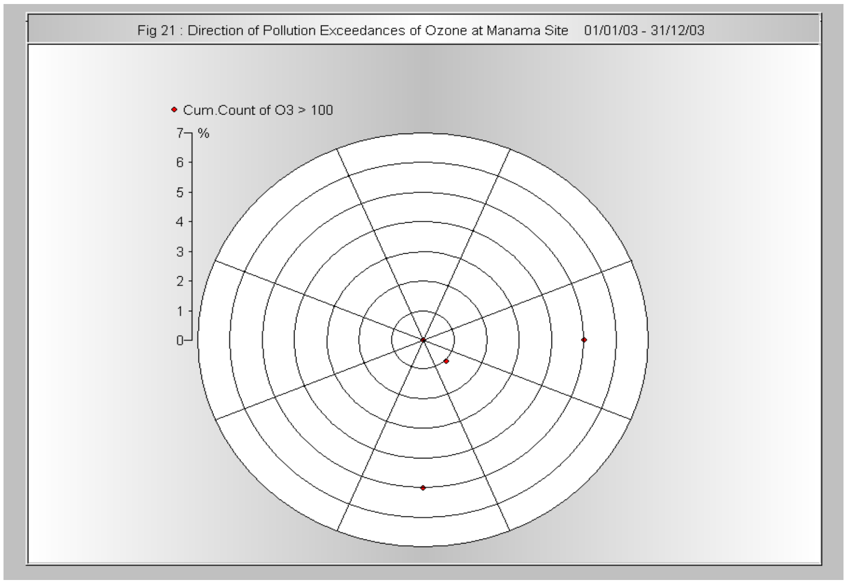


Source: Air Quality Unit, Bahrain Environmental Authority, 2003

3.2.1.8 The Pollution Rose Diagram for Ozone – O_3 (ppb):

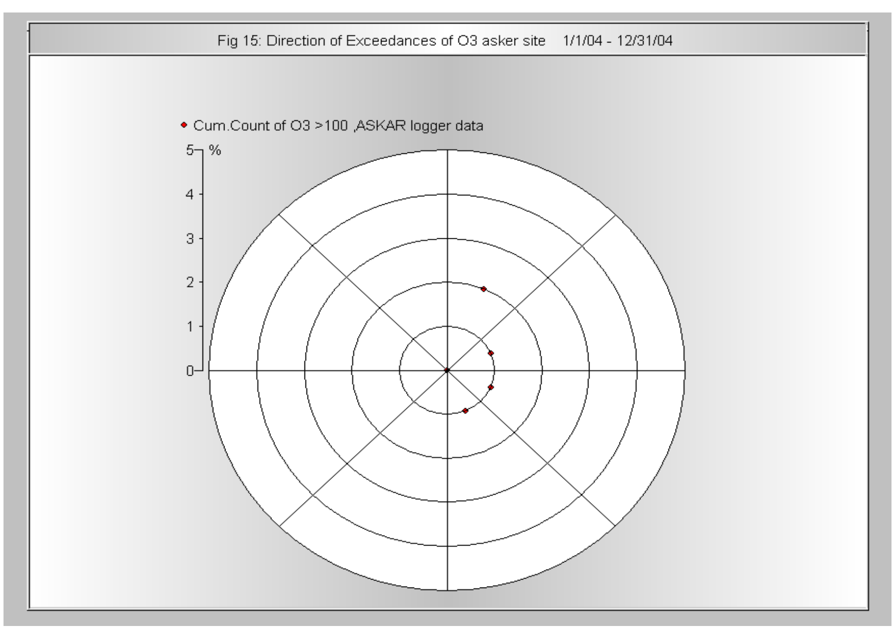
At Manama site the ozone concentration has exceeded the hourly air quality standard (100 ppb) and showed 11 exceeded cases as presented in (Figure 28). The reported exceedances were observed from the south and east. The traffic in this area is considered to be the main source of pollution at this site.

Figure 28. Direction of Pollution Exceedances of Ozone at Manama site from Jan-Dec. 2003



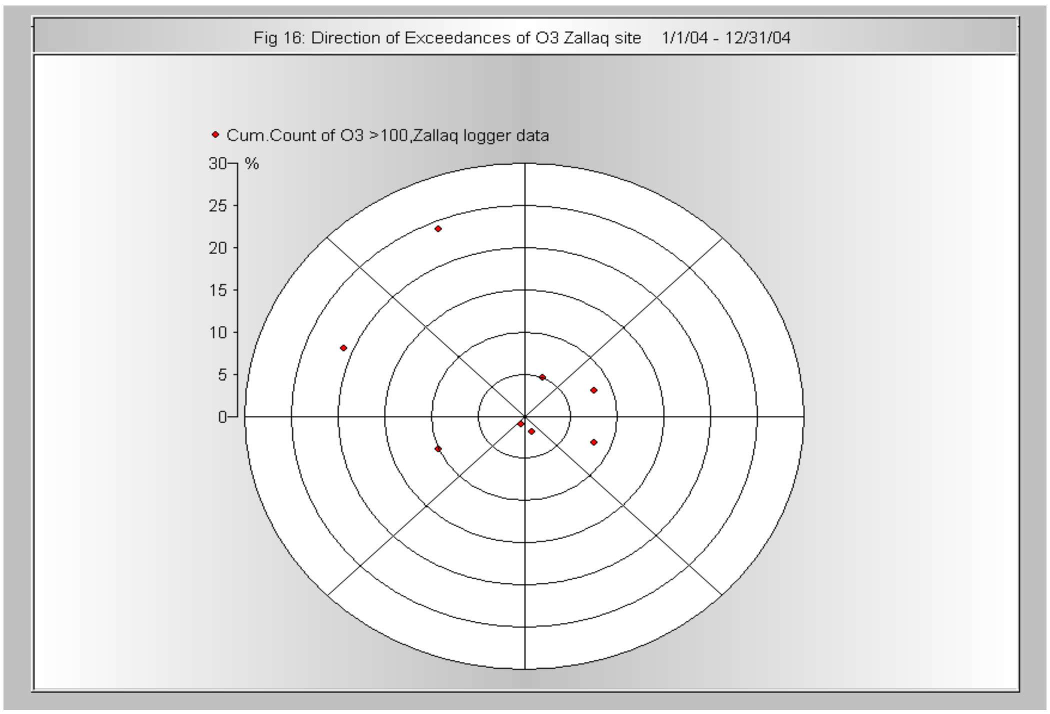
At Askar Site, 22 records have exceeded the hourly air quality standard as shown in (figure 29). The exceeded levels were observed from south and east directions.

Figure 29. Direction of Pollution Exceedances of Ozone at the Askar site from Jan-Dec. 2003



The total number of exceedances at Zallaq was 79 and approximately more than 50% of these exceedances were mainly reported from the northern western direction (Figure 30). The reported exceedances during the last year were observed from the same directions. The directions of reported exceedances give evidence that the King Fahad Causeway is the source.

Figure 30. Direction of Pollution Exceedances of Ozone at Zallaq site from Jan-Dec. 2003



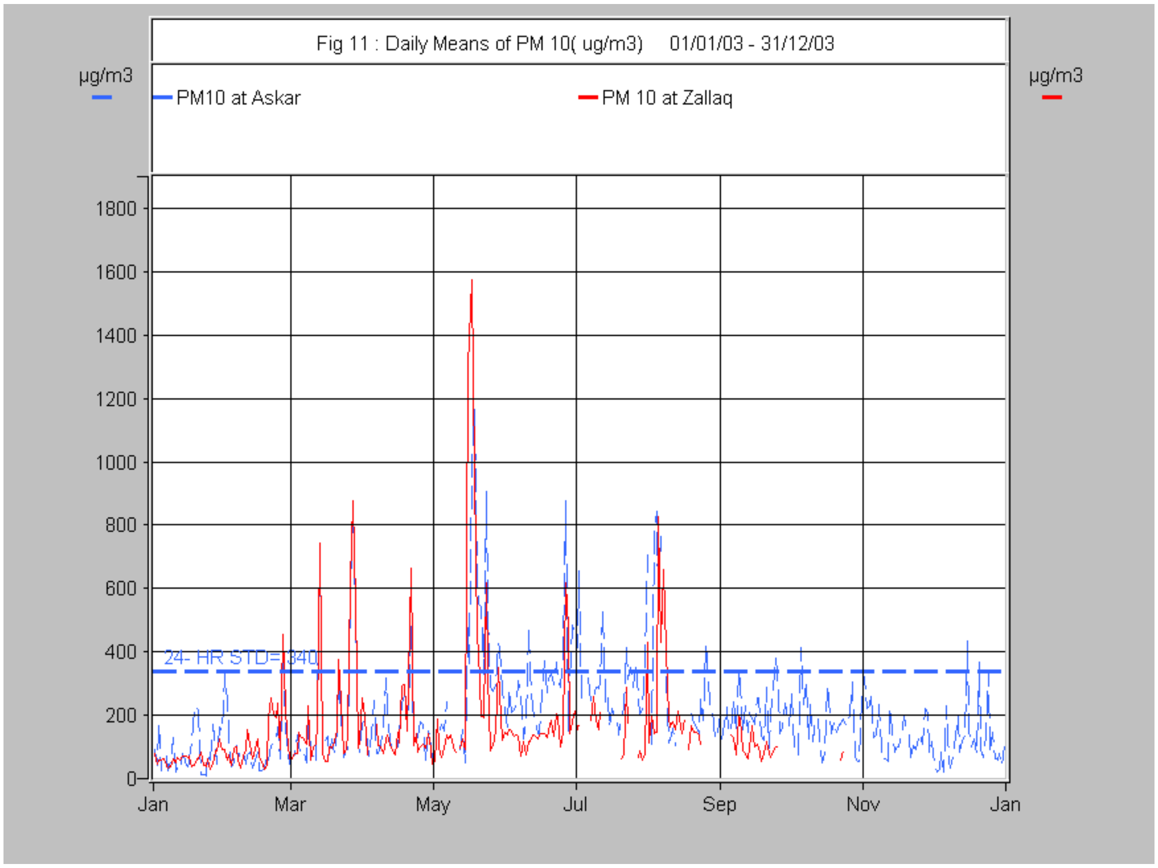
3.2.1.9 Inhalable Particulate Matter – PM_{10} ($\mu g/m^3$):

Daily maximum concentrations measured at monitoring sites; Zallaq and Askar were in the range of 125 - 1575 $\mu g/m^3$ and 321-1163.7 $\mu g/m^3$ (Figure 31).

The monthly mean values were in the range of 61.7 – 334.3 $\mu g/m^3$ at Zallaq and 93.9-306.2 $\mu g/m^3$ at Askar.

The daily ambient air quality standard of (340 $\mu g/m^3$) was exceeded at all monitoring sites. The maximum daily average was 1575 $\mu g/m^3$ at Zallaq with a total number of 22 exceedances. Whereas, at Askar the maximum daily average was1163.7μg/m^3 with 43 exceedances.

Figure 31. Hourly Mean of PM_{10} (μg/m^3), Jan-Dec. 2003



3.2.1.10 Pollution Rose analysis for Inhalable Particulate Matter – PM_{10} (μg/m^3):

The pollution rose (figures 32 & 33) analysis shows that the PM10 concentrations exceeded the daily air quality standard (340μg/m^3) at Askar and Zallaq site during this year with a total of exceedances of 43 and 22, respectively.

The reported exceedances at Askar were observed mostly from the north and west. In contrast, at Zallaq station the reported exceedances were observed from all directions. In addition to the trans-boundary sources of particulates matters, most of these levels were received from the western and northern western directions where Quarries at Hafira are located north of the Askar site.

Figure 32. Direction of Pollution Excedances of PM_{10} at the Askar site from Jan-Dec. 2003

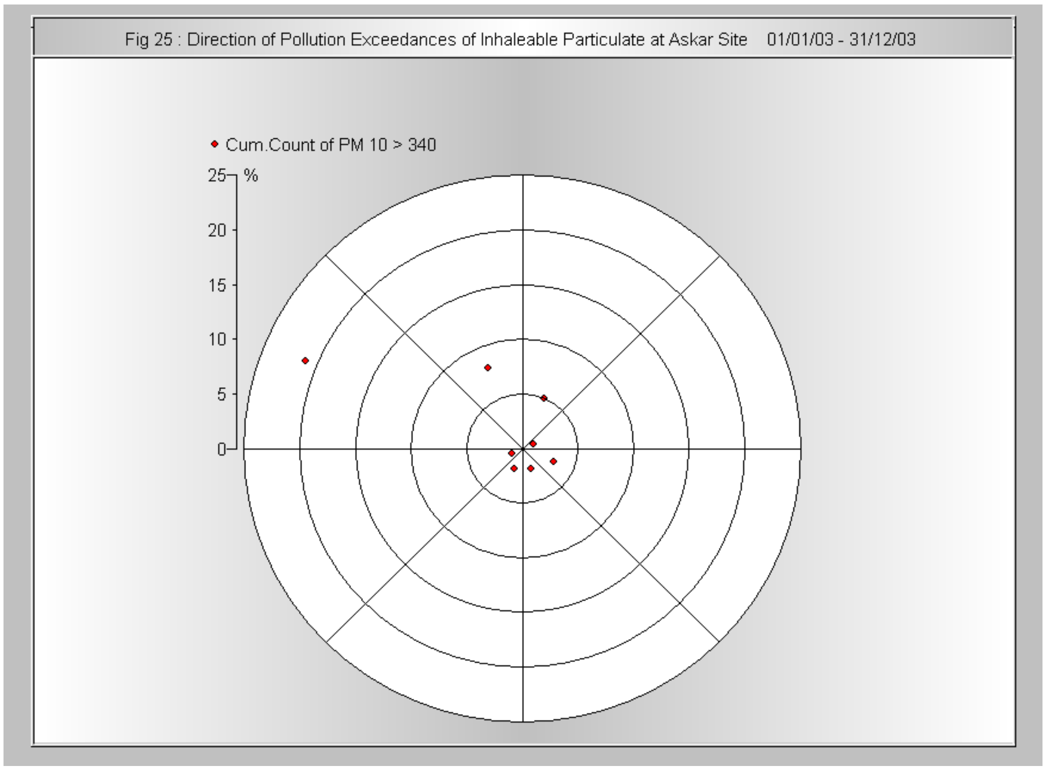
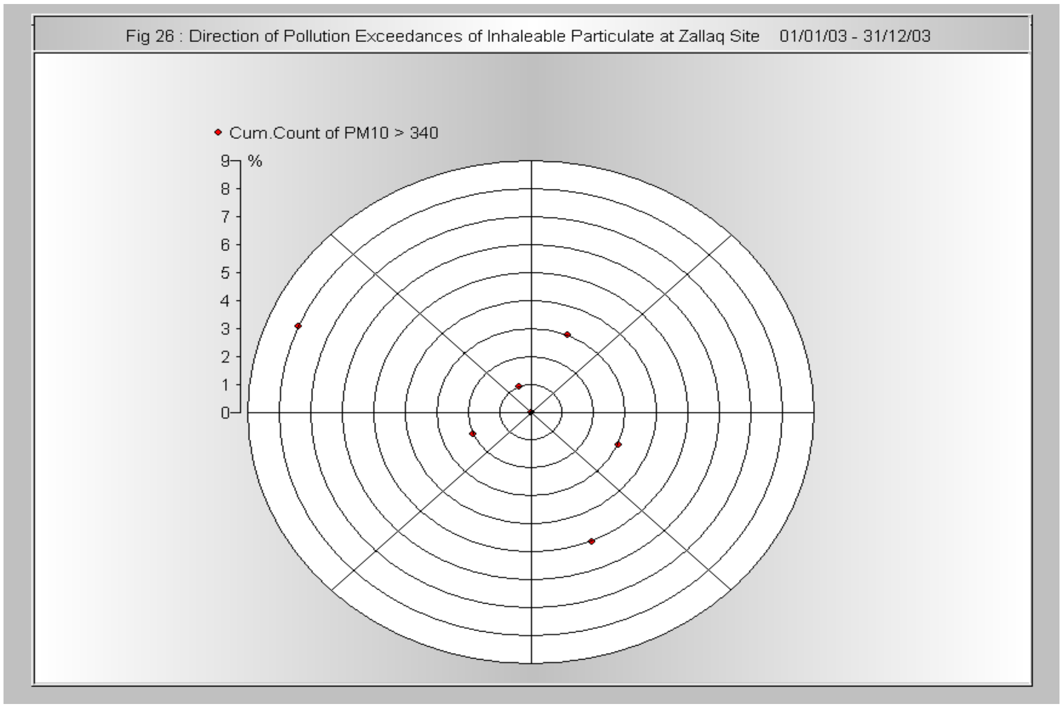


Figure 33. Direction of Pollution Exceedances of PM_{10} at the Zallaq site from Jan.-Dec. 2003



3.2.1.11 Non Methane Hydrocarbons – NMHC (ppm): Ambient air quality standard of USEPA (0.24 ppm)

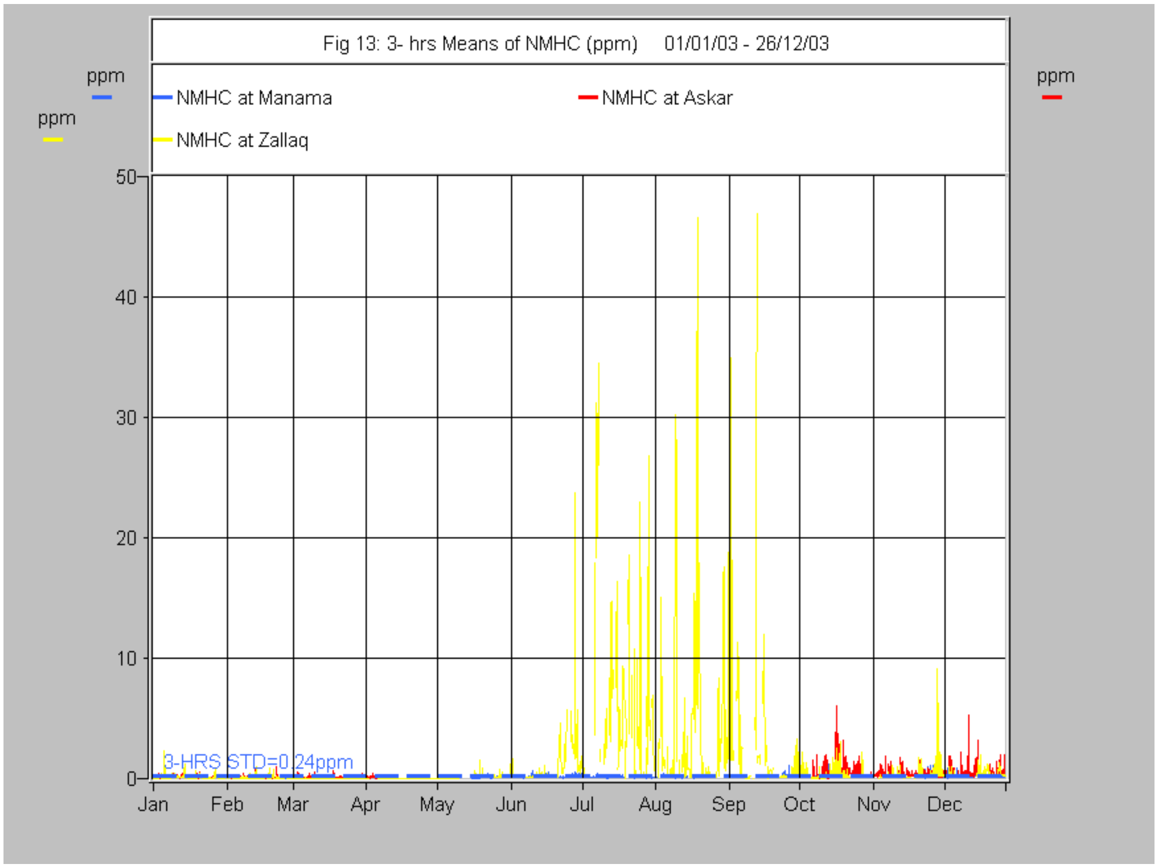
Three hour average maximum levels of Non Methane Hydrocarbons measured at monitoring sites were as follows: 0.02 ppm to 5.01 ppm at Manama site, 0.03 ppm to 6.01 ppm at Askar site and 0.07 ppm to 47.06 ppm at Zallaq site (Figure 34).

The monthly averages were in the range of 0.01 ppm to 4.35 ppm, 0.03 ppm to 0.53 ppm and 0.03 ppm to 6.55 ppm at Manama, Askar and Zallaq sites, respectively.

The three hours average maximum levels of NMHC exceeded the three-hour ambient air quality standard of USEPA (0.24 ppm). Total numbers of excedances were as follows: 200 readings at Manama site, 471 readings at Askar site and 808 readings at Zallaq site.

Based on USEPA ambient air quality standard (0.24 ppm), the none methane hydrocarbon levels can be considered high at all monitoring sites, many reasons contributed in these exceedances , among them the rapid growth in motorization, industrial activities, and the harsh climate condition in the very small island.

Figure 34. Three Hour Means of NMHC (PPM) from Jan. – Dec. 2003



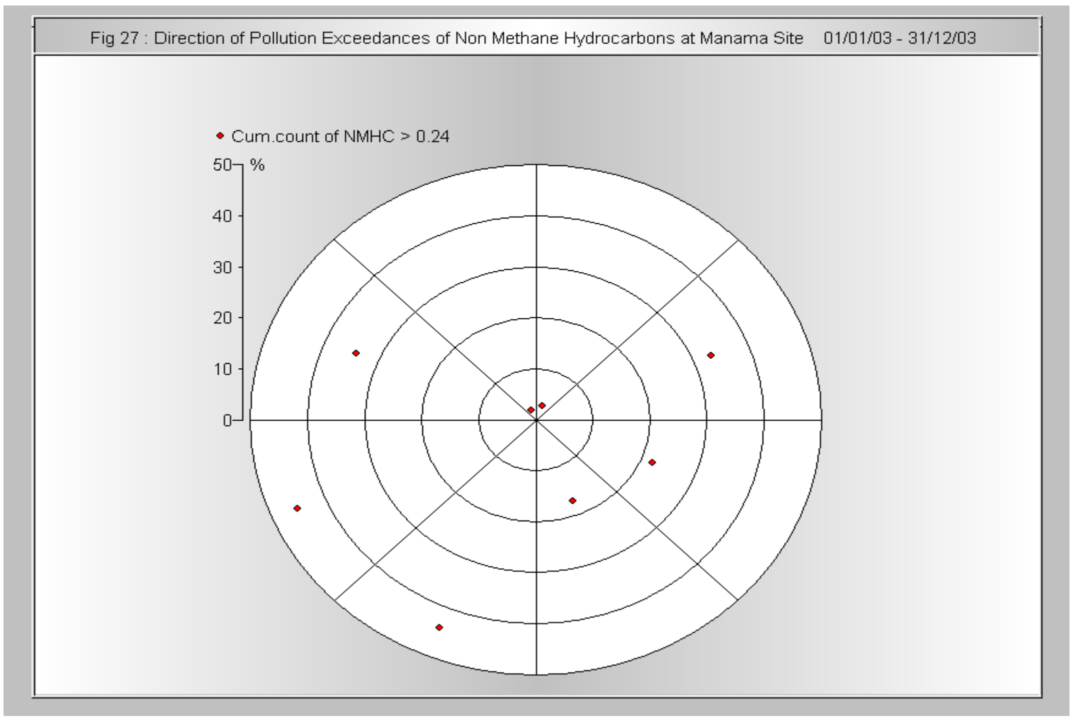
Source: Air Quality Unit, Bahrain Environmental Authority, 2003

3.2.1.12 Pollution Rose Analysis for Non Methane Hydrocarbons – NMHC (ppm):

From the previous data of NMHC it was noticed that this parameter was reported to exceed the three-hour ambient air quality standard (0.24 ppm) permanently at all monitoring sites during the years 1993-2003.

At Manama site, the excedances were observed from the east, west and south directions as illustrated in (figure 35). The principal source of pollution at this site is traffic.

Figure 35. Direction of Pollution Excedances of NMHC at Manama from Jan.-Dec. 2003



Source: Air Quality Unit, Bahrain Environmental Authority, 2003

At the Askar site, most exceedances in 2003 were reported from west and south directions and were in same manner of the previous year 2002. The gas production and oil fields located at these directions could be the responsible sources for the exceedances at this site. Industrial activities south of Alba and heavy vehicle traffic surrounding the projects sites under construction south of the Kingdom could contribute to these levels (Figure 36).

At the Zallaq site, the exceedances were observed from all directions. The pollution rose analysis of the exceeding levels showed that a total 475 exceedances out of 808 exceedances were observed from the east and southeast directions; the oil field and gas production facilities are 16 km in the easterly direction of the Zallaq site (Figure 37).

Figure 36. Direction of Pollution Excedances of NMHC at the Askar Site from Jan.-Dec. 2003

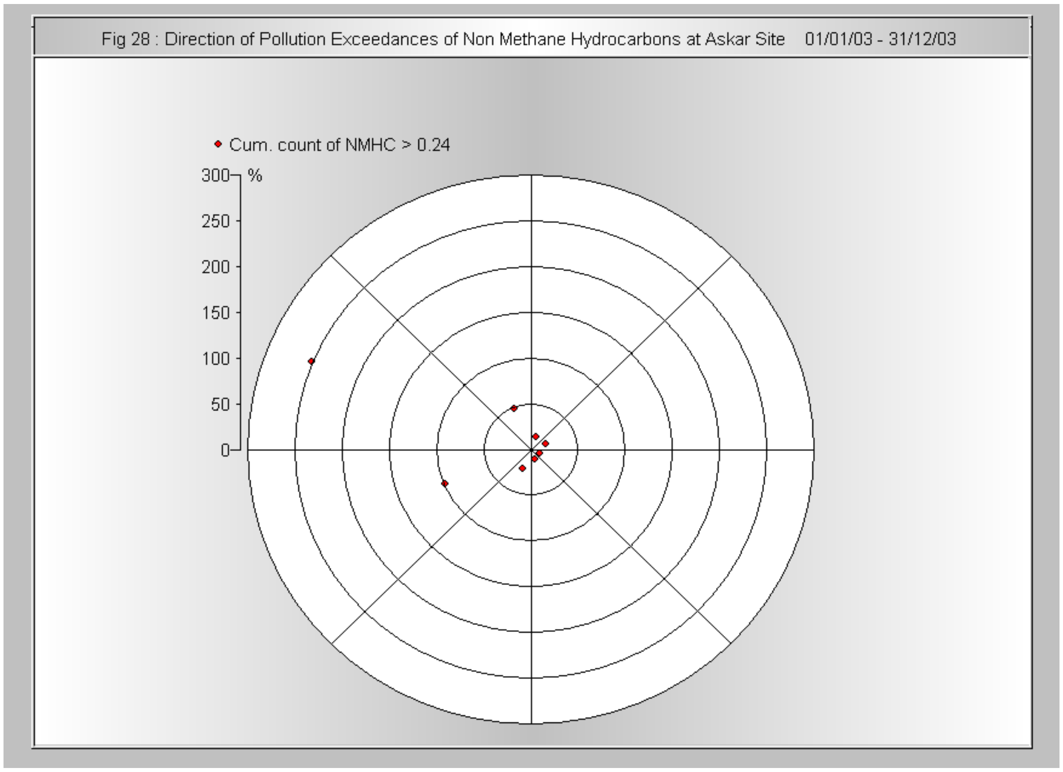
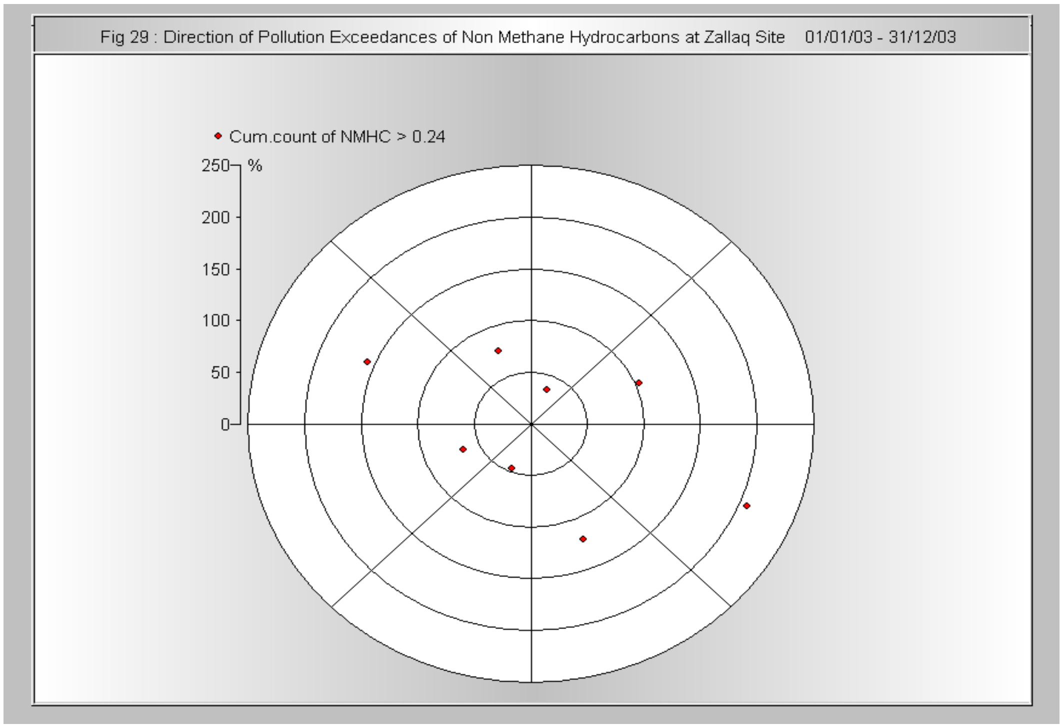


Figure 37. Direction of Pollution Excedances of NMHC at Zallaq from Jan.–Dec.2003



3.3 - Assessment of Emissions from Electrical Power Stations in Bahrain:

The Kingdom of Bahrain is presently expanding its electrical power generation capacities by using environmentally friendly technologies such as low NOx burners in order to reduce the impact on air quality to the feasible minimum. However, there are still older power plant units being operated in Bahrain, which are known to contribute to the elevated NOx emissions.

The electrical power plants which contribute to the major portion of NOx emissions in the eastern central area of Bahrain are the gas turbine units installed at the Riffa power station, the Bahrain Petroleum Company (BAPCO) refinery, and the Bahrain Aluminum smelter (ALBA).

In 1999[118] emission measurements were carried out by an independent and the certified German Consultant called Lahmeyer International, the measurement results showed that the highest NOx emission concentrations were found in the flue gas of the large gas turbines without NOx reduction equipment at Riffa (255-344 ppm) and ALBA (264-313 ppm). The NOx levels measured at these units exceed, by far, the established emission standards of Bahrain, Metrological and Environmental Protection Agency in Saudi Arabia (MEPA), World Bank, and Germany, which are in the range of 39 - 49 ppm. The corresponding total NOx emission rates at full base load are of similar magnitude at Riffa (4425 kg/h) and ALBA (3775 kg/h), whereas, the contributions from BAPCO (101 kg/h) and AL-Hidd (502 kg/h after full extension of all 3 phases expected 2007) are negligible in comparison.

On the basis of the measurements of NOx emission rates, dispersion calculations were performed to show the present ambient air impactcaused by the electrical power plants studied, as well as their individual contribution to the overall situation. Assuming all the plants at base load operation (Maximum Capacity Rate), the highest values of ground level NO_2 were calculated for locations near ALBA (short term peak 1544 $\mu g/m^3$, annual average 58$\mu g/m^3$).

The study revealed that, the individual contribution of ALBA to the ambient air NOx impact is higher than the contribution of Riffa, mainly due to the fact that some units at ALBA are operated in combined cycle mode. In the combined cycle mode, the waste heat recovery cools down the exhaust gases, which are then released at a much lower temperature than would be the case with open cycle operation. Consequently, the efficiency of atmospheric dilution of NOx is significantly reduced due to the lower temperature.

3.3.1 Assessment of Calculation Results:

Eight NOx emission scenarios were considered in this study including the present separate contributions from ALBA, Riffa, BAPCO, as well as the total NOx impact in Bahrain from the installed power stations, including the gas turbines at Hidd power plant. For the purpose of assessing the contributions of these four plants, three plots were made (See Figures 38, 39, and 40) which show graphical results of the dispersion calculations for the present scenarios in the form of concentration iso-lines. These plots representing the ambient air impact due to power plant emissions are expressed as:

- Annual Average NO_2 concentration increments;
- 98th percentile value of all NO_2 concentration increments calculated for a period of 1 year;

  (*the 98th percentile value is a measure for high level short-term impact and can be interpreted as follows: 98th Percent of all values measured (or calculated) within a given time period (usually one year) remain under the 98th percentile value. Two percent of all measured values are exceeding the 98th percentile value. The 98th percentile value will be exceeded for a total of 7.3 days through one year, equivalent to 175 one hour mean values).*
- The absolute maximum NO_2 concentration increments within a period of 1 year (peak concentration occurring only once in a year, is equivalent to the 100 percent value).

The maximum annual average NOx concentration increment was calculated to be 58µg/m^3 for a location approximately 1 km southeast of ALBA. This value exceeds the Bahrain standard of 40 µg/m^3, but is well below the other standard values of 100 µg/m^3 (MEPA), 150 (WHO), and 80 (Germany).

However, the annual average values are only that low because there are two main seasonal wind directions in Bahrain, southeast and northwest. This means that at locations along these axes (e.g. Isa Town and Askar) the seasonal average values are considerably lower than the calculated annual average in the first season and approximately double the calculated annual average in the second season.

The area of exceeded annual average referring to the Bahrain standard is located around the site of ALBA. The calculated absolute maximum concentration increment of 1544 µg/m^3 for one hour exposure clearly exceeds the Bahraini standard and the MEPA (200 µg/m^3 and 660 µg/m^3) standard as well as the standard of the WHO (400 $^{\mu}$g/m^3). However, the first two standards allow two, 1-hour average values to be exceeded during one month. The location of the calculated maximum is approximately 500 m west of ALBA.

The geographical area of exceeded maximum NOx values above the Bahrain standard is extended, including Riffa Town, Awali, Isa Town, Sitra, as well as parts of Hamad Town and Manama, these areas are distinguished by a

high population density (Table 11). The WHO short-term standard for NOx is exceeded around ALBA from Askar to the east of Riffa Town.
The German standard for short-term NOx exposure is defined as the 98^{th} percentile of 1-hour average values. The maximum of the 98^{th} percentile values were calculated at the monitoring point next to ALBA in the eastern direction; that value was found to be 473 $\mu g/m^3$. This value exceeds the German standard value of $200 \mu g/m^3$ by a factor of two.

The area which exceeded the 98^{th} percentile for NOx values, according to the German standard is located around ALBA from Askar to the east of Riffa Town. The peak levels calculated for NOx at the plant sites of ALBA and Riffa also exceeded the German maximum allowable workplace concentration of $200 \mu g/m^3$.

Due to the high ambient NOx concentrations around ALBA, Riffa, and BAPCO power plants, researchers who are did the study anticipated that the applicable short-term standards for ozone would also be exceeded frequently in west Bahrain. Indeed the measurements of ozone concentrations in the ambient air of selected monitoring locations at Manama, Askar, Zallaq and Sitra found that, the hourly ambient air quality standard (100 ppb) was exceeded at all sites as follows: the measured maximum levels were 136 ppb, 151 ppb, 153 ppb and 175.5 ppb with a total number of Excedances of 11, 21, 90 and 1 at Manama, Askar, Zallaq (located in the west of Bahrain) and Sitra, respectively (Figure 27).

Table 11. Population Densities by Area for 2005

Name of Area	Population	% of total Population	Total Area/km^2	Population density/ km^2
Central	47,216	6.8	35.34	1336
Hamad Town	39,578	5.7	13.12	3017
Hidd	11,804	1.7	10.8	1093
Isa Town	47,216	6.8	12.43	3799
Jidhafs	61,102	8.8	24.3	2514
Manama	187,419	27.1	26.68	7025
Muharraq	102,069	14.8	20.84	4898
Northern	46,521	6.7	37.29	1248
Riffa	68,045	9.8	292.35	233
Sitra	49,993	7.2	29.2	1712
Western	29,857	4.3	156.79	190
Total	**690,819**	**100**	**659.14**	**1048**

Source: Health Information Centre, 2004, Salmaniya Medical Complex,

Figure 38. Annual Average Value of Ambient Air NOx Concentration Increments in µg/m3

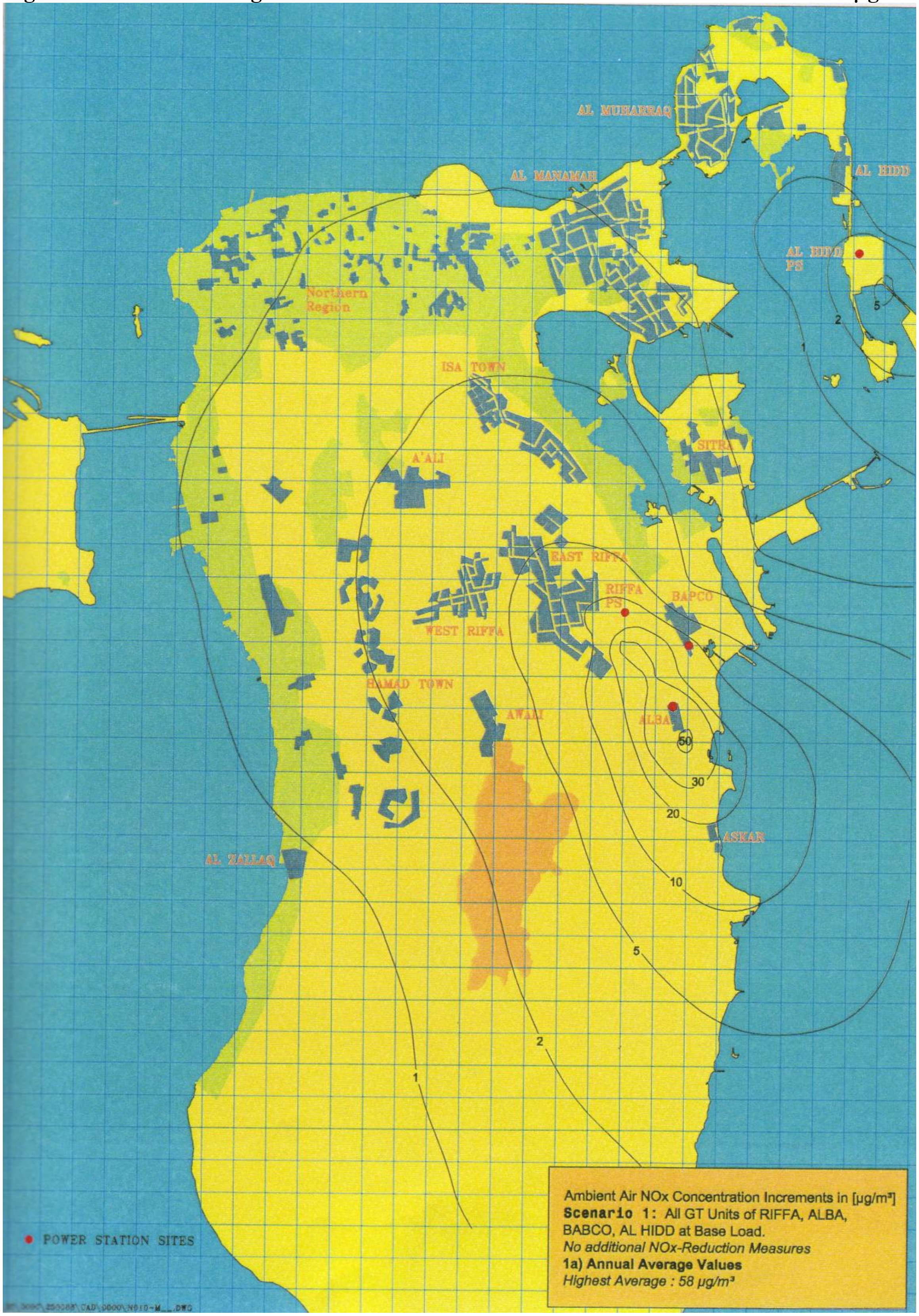


Figure 39. The 98th Percentile Concentration Values of NOx in the Ambient in µg/m3

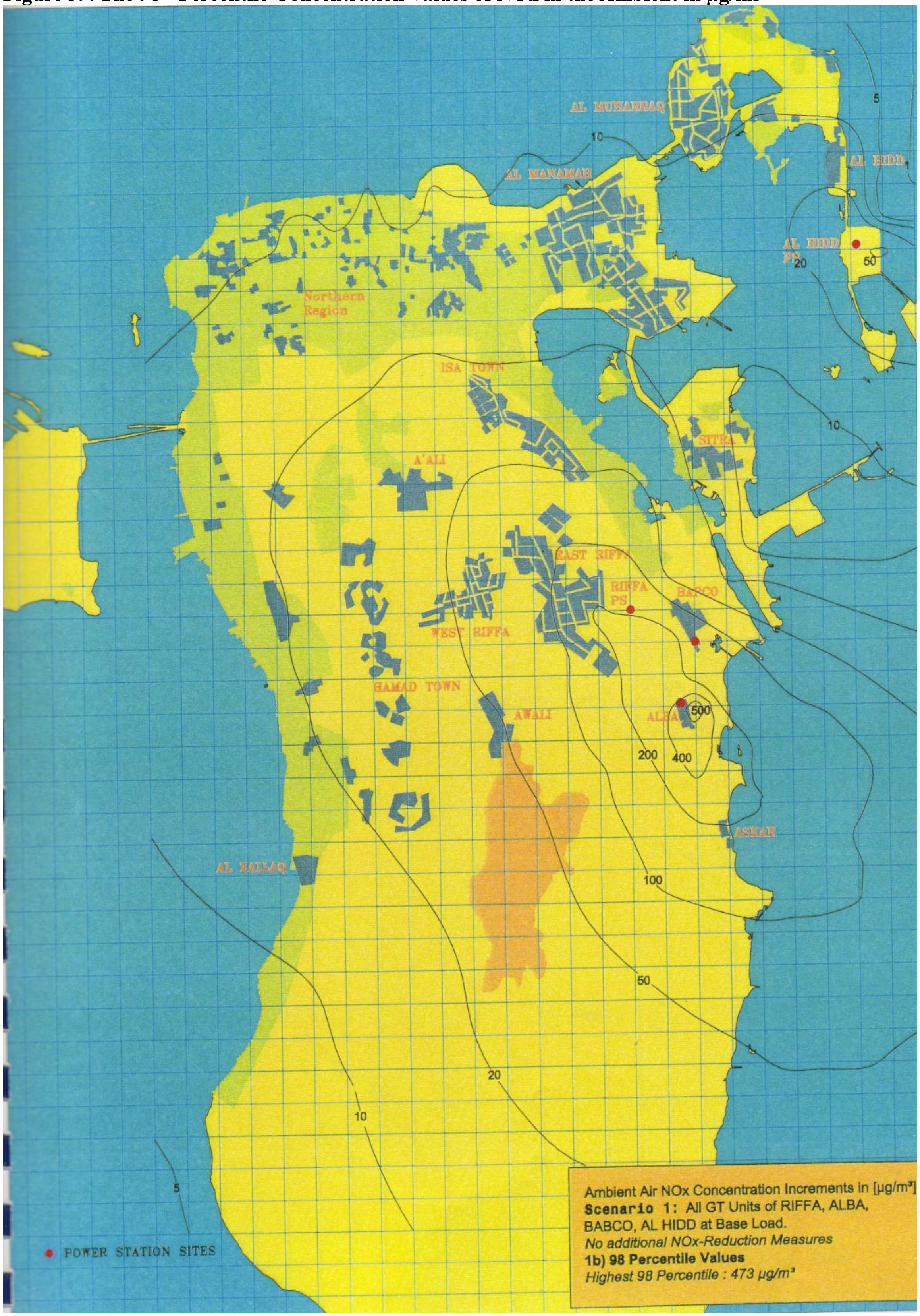
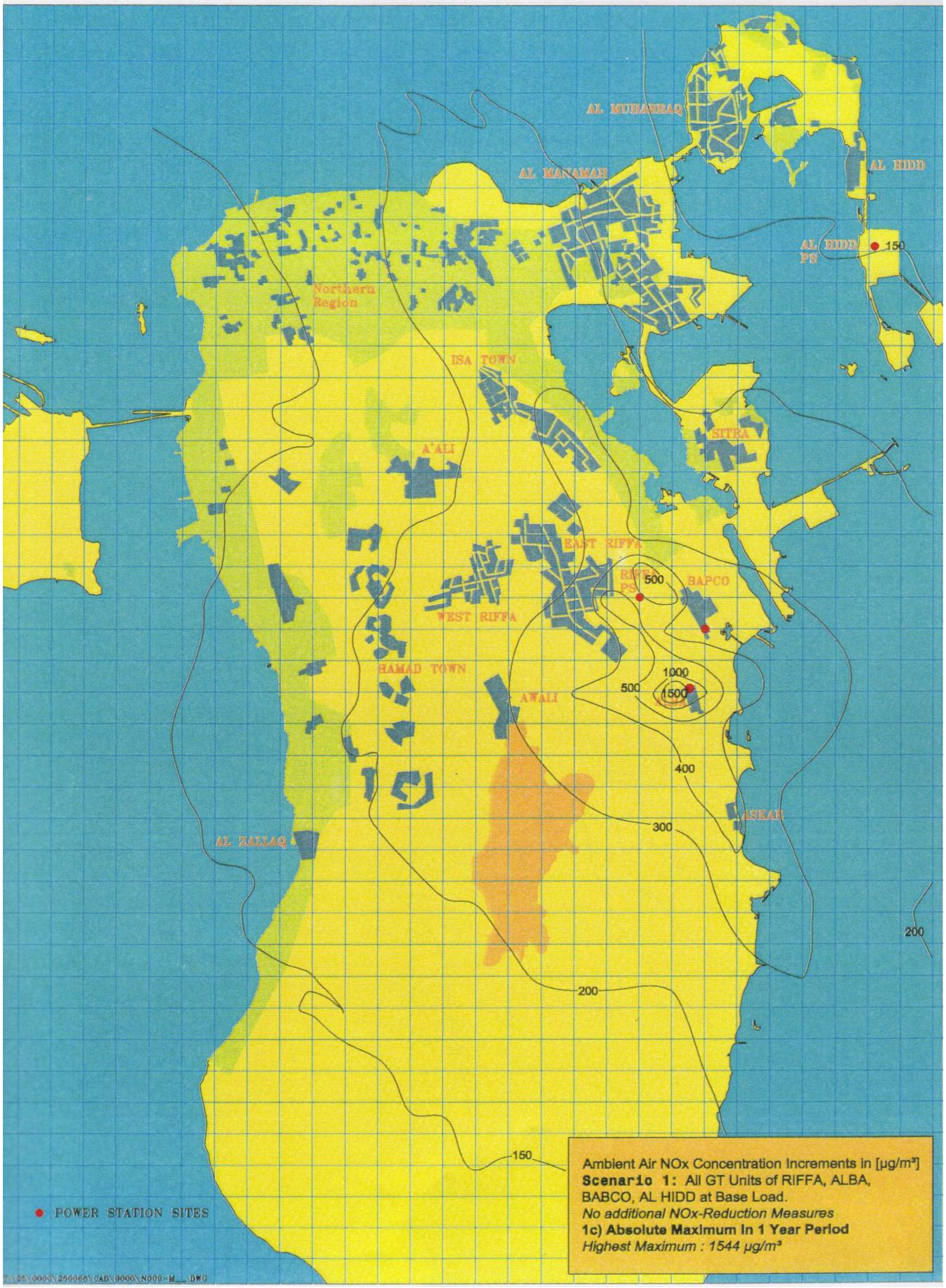


Figure 40. The Highest Maximum 1 year Values of Ambient Air NOx Concentration in µg/m^3



3.4 Potential Health Impact Related to Electrical Power Generation:

There is evidence from the literature that the air pollutants emitted by power plants causes many and serious health, and environmental effects. The old power plants in Bahrain emit high levels of NOx. However, it has to be taken into account that NOx is a precursor of ozone in the atmospheric chemistry. Due to considerable emissions of volatile organic compounds (VOC's) at BAPCO refinery (Table 12 shows the estimated annual emissions from the refinery and wharves) it can reasonably be assumed that enough VOC's are contained in the ground level atmosphere around power plants mainly Riff, BABCO, and ALBA, to efficiently catalyze the formation of ground level ozone. This means, there may be synergistic effects of both NOx and ozone that should be considered, since both compounds lead to similar health effects due to their oxidative potential.

Table 12. Total Annual VOC's Emissions to the Air from BAPCO Refinery and Sitra Wharves

Emission Source	Total VOC Emission Quantity	
	Tons/day	Tons/year
Evaporation losses from storage tanks for Naphtha, Gasoline, Kerosene and Crude Oil at BAPCO Refinery and Sitra Wharves (78 Tanks).	6.8	2488
Emissions from product loading at the SITRA Wharves	1.8	637
Pump Seal Losses	1.2	447
Fugitive Emissions from other devices	40.5	14778
Emissions from Naphtha Lead Sulphide Treating	6.9	2527
Emissions related to vacuum distillation unit vents	13.7	5006
Total VOC's Emissions	**70.9**	**25,883**

Source: Lahmeyer (1999)

As indicated by air quality data for Bahrain, the maximum ozone concentration short-term levels are usually higher than the NOx concentrations at all monitoring stations especially those sites close to the

Askar, and Sitra electrical power plants. However, as indicated in the Lahmeyer report, the highest concentrations of both pollutants do not occur at the same time since the buildup of ozone concentrations due to atmospheric radical chain reactions takes 1-2 hours.

As the Lahmeyer report revealed and it was supported by other air quality data, the highest peak concentration increments were detected within and near the site of ALBA were NO_2 concentrations in the range of the calculated maximum of 1544 µg/m^3which might not lead to significant adverse health effects in healthy adult people. However, people suffering from bronchitis and asthma may complain about an increase of respiratory resistance after short-term exposures as well as have irritation of the respiratory organs leading to coughing and to increased formation of mucous phlegm when exposed to such concentrations of NO_2.

The report results also show the 98th percentile values of 200-500 µg/m^3 of NOx in the region between Askar and Riffa Town that represent a concentration range, which is frequently present for a few hours during some days. Such concentrations lead to an impairment of eye adaptation to darkness. Children exposed to NOx concentrations higher than 500µg/m^3 may suffer a higher frequency of acute respiratory diseases, which are often the cause of a higher susceptibility to respiratory infection lasting well into adolescence.

Much stronger adverse effects of a similar kind are associated with ozone levels in this range, which are very likely to be present together with NO_2. Such effects include complaints about wheezing, coughing, and chest irritation, especially of children and people suffering from asthma and bronchitis, dry cough, decrease of the ability to concentrate, as well as an increased respiratory resistance and a decrease of the partial pressure of oxygen in the blood, can result in reduced athletic performance.

The adverse health effects described above are increased after light or medium exercise. In the U.S.A for instance, if the ozone ground level around or above 200 µg/m^3 it is recommended that active children and adults, and people with respiratory disease such as asthma should avoid all outdoor exertion at times when the ground ozone level is that high. Everyone else should limit outdoor exertion in the presence of such ozone concentrations (NIEHS homepage, U.S.A)[119].

Populated areas in Bahrain where people may likely suffer from adverse health impact due to the impact of NO_2 and ozone include east Riffa, Askar, and the plant sites of ALBA, Riffa, and BAPCO, especially the short-term pollutants concentrations at ALBA are expected to reach critical levels very frequently.

In Bahrain, the measurement of health parameters pose a challenge for the evaluation of health impact of environmental pollution, for instance, absence of epidemiological studies, the cause of death and illness data are not routinely collected and therefore, are not reliable. Also varying quality of services, poor diagnosis and poor record keeping complicates studies of health impacts.

According to Salmaniya medical centre, they treated about 0.6% of the population for respiratory illness in 2005; the number of respiratory patients peaked at 3645 patient/year for the last year, the bulk of the patients (59.5%) were children (below 19 years of age).

Salmaniya hospital represents only one health facility. If the Medical data for the regional health centers and private clinics were included, that would push the percentage of the population afflicted by respiratory diseases closer to 2%.

Medical care is free or subsidized for Bahraini's. However, to calculate the cost of medical care, we refer to the information provided by the health information centre of the Ministry of Health; according to their information 3645 patients admitted to Salmaniya hospital during 2005 suffering from respiratory disease related to air pollution (Table 13), the total patients spent about 17,339 health care days, with an average of 4.76 days per patient (Table 14).

Table 13. Numbers of Patients Admitted to Salmaniya Hospital due to Disease Related to Air Pollution 2000-2005

Disease Name	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Malignant Neoplasm of respiratory	85	72	77	154	123	125
Ischemic heart disease	531	544	592	659	583	508
Acute Respiratory Infections	666	684	651	773	739	733
Other Disease of Upper respiratory Tract	1181	1116	1255	1376	1250	1460
Chronic Obstructive Pulmonary Disease (COPD)	573	575	566	696	563	507
Asthma	325	352	369	440	375	312
TOTAL of Patients	**3325**	**3343**	**3510**	**4098**	**3633**	**3645**

Source: Health Information Centre, Bahrain (2005)

Table 14. Numbers of Health Care Days in Salmaniya Hospital due to Disease Related to Air Pollution 2000-2005

Disease Name	2000	2001	2002	2003	2004	2005
Malignant Neoplasm of respiratory	1022	1537	1565	2512	2146	1985
Ischemic heart disease	3647	3695	3820	4030	3575	2908
Acute Respiratory Infections	2045	2120	2277	2656	2468	2489
Other Disease of Upper respiratory Tract	4120	3862	4494	4949	4377	4862
Chronic Obstructive Pulmonary Disease (COPD)	3596	3377	3577	4801	3953	3462
Asthma	1519	1537	1751	2081	1904	1633
Total/day	**15949**	**16128**	**17484**	**21030**	**18423**	**17339**
No. of Patients	**3325**	**3343**	**3510**	**4098**	**3633**	**3645**
Avg. Health care day per patient	**4.80**	**4.82**	**5.00**	**5.13**	**5.07**	**4.76**

Source: Health Information centre, Bahrain (2005)

The information presents the cost per day for the inpatient, and the cost per visit for respiratory outpatients. The daily cost for inpatients is about BD 109.3 (equal U$ 288.00), and the cost per visit estimated to be BD 27.3 (equal U$ 71.00) (Table 15).

Table 15. Health Care Cost for In and Out- Patients in Bahraini Dinar

Description	2000	2001	2001	2002	2003	2004	2005
Average Recurrent Health Expenditure/per Capita (BD)	79.3	82.0	82.0	90.0	87.4	86.1	85.8
Cost per Inpatient Day (BD)	79.5	83.8	83.8	92.0	95.6	100.5	109.3
Cost per Outpatient Day (BD)	-	21.0	21.0	23.0	23.9	25.1	27.3

Source: Health Information centre, Bahrain (2005)

In light of the above medical information, we can make a rough estimation of the medical cost provided to respiratory patients. In 2005 there were 3645 patients admitted to Salmaniya hospital for treatment, they spend about 17339 BD/ day with an average of 4.76 health care days per patient. Since we know the cost per day is around BD 109.3, this means that the government bears about BD 2 million (equal US $ 5.3 million), costs due to inpatients. Additionally, there were 2717 out-patients suffering from respiratory illness who visited the specialized clinics in the same hospital (Table 16) These patient visits cost about BD 0.08 million (equal U$ 0.2 million) based on BD 27.3 for visit. Of course this may underestimate the actual cost if more expensive procedures, tests, and medications were involved.

Table 16. Respiratory Diseases Outpatient Visited Salmaniya Hospital during the Period 2004-2005

Year	New patients	Follow-up Patients	Total
2004	537	1796	2333
2005	650	2067	2717

Source: Health Information centre, Bahrain (2005)

The human health damage from air pollution reach far beyond morbidity related to pollution a significant number of deaths due to respiratory illness are the result, not only to adults but also to children. In 2005 there were 3645 patients, with over 10% of these for patients below the age of nineteen.

How much is a life worth? It is very difficult to assign an economic cost to a fatality, the loss of a breadwinner or children represent real emotional losses beyond the future earning potentials for people. The cost of mortality related to pollution is a very complicated issue, especially, in developing countries due to many factors. As such it is difficult to calculate their cost other than through proxy calculations.

The literature on the Value of Statistical life (VOSL) or Willingness-To-Pay (WTP) to avoid a statistical premature death is a relatively well-developed approach. Lovesky (1998)[120] reviewed some of the empirical estimates mainly from the US. He refers in his work to a survey that a range of VOSL of U$ 3.6 million (IEI 1992)[121] to U$ 4.8 million (US EPA 1997)[122] in 1990 dollars was considered.

With addition to these two approaches, there is a substantial literature on the valuation of life that relies in the Human Capital Approach (HCA); human capital is the present value of future labor income. Therefore, the WTP and the human capital approaches are entirely connected to each other because high-income earners have a greater WYP to avoid the premature death. However, the application of the two approaches to Bahrain, as a developing country, is inappropriate due to distorted wages. Given the dependence of the Kingdom of Bahrain on cheap foreign labor, and the decline in per capita income, where about 60% of the total labor force does not exceed income of $ 1000/month according to the official figures of the Kingdom.

Therefore, to stay on the conservative side within a range of reasonable estimates, the author used the lower value of U$ 3.6 million for the US WTP to avoid statistical premature death; however this value should only be used as a basis for initiating the benefit transfer process, which involves essential adjustments.

There are many problems, which complicate the transfer of available WTP estimates into the context of premature deaths caused by air pollution in developing countries. The, first of these problems stem from the fact that the existing results refer primarily to lives lost as a result of accidents at work rather than due to air pollution (Lovesky 1998). It is argued that the remaining life-years of those who die in occupational accidents are much greater than those who die as a result of poor air quality. Also, it is argued that those who are most at risk are already suffering from some underlying condition that may affect the value to be attached to their lives. Further, it is argued that the contextual effects are important, and also there is the issue of latency or the delay between the exposure(s) and the expression of the diseases. Finally, the income level is very important because the incomes differ greatly between the surveyed populations and the target populations of the developing countries that require a significant adjustment in comparison with those of the US-based VOSL. Since the assumed VOSL determines the damage cost estimates which emerge from air pollution studies, these issues should be carefully interpreted in the approaches adopted for placing a monetary value on the health outcomes of human exposure to air pollution.

The concept of disability-adjusted life years (DALYs) provides a standard measure of the burden of disease (Murray and Lopez 1996). DALYs combine life years lost due to premature death and fractions of years of healthy life lost as a result of illness or disability. A weighting function that incorporates discounting is used for years of life lost at each age to reflect the different social weights that are usually given to illness and premature mortality at different ages. Thus, it is possible to link the VOSL obtained from labor market studies with the corresponding number of DALYs lost and thereby, to, estimate the implicit value per DALY, as well as adjust the respective VOSL according to an average number of DALYs lost in a specific study (World Bank 1998)[123].

For instance, according to the age group distribution of DALYs the VOSL from the US labor market studies that represent people of around 40 years old corresponds to 22 DALYs lost while an average death of one who was 65 years old (assumed to be a mean age of those fatally affected by pollution) corresponds to approximately to 10 DALYs lost. This implies that a value per DALY in the US is$164,000 and the WTP to avoid a premature death due to air pollution should be scaled down to 45 percent (=10/22) of the mean VOSL, or a value of U$ 1.6 million (Lovesky 1998).

Using the obtained VOSL and DALYs from the US labor market as a proxy for Bahrain, enabled the author to develop an estimated value for the mortality cost related to air pollution. However, this required adjustment to bring this value in-line with the current market prices in Bahrain.
To get the appropriate economic value for the VOSL, we have to make an equilibrium equation between the exchange rate between the US$ and

Bahraini Dinar (BD) by applying the theory of Purchasing Power Parity. The basis of PPP is the "law of one price" in the absence of transportation and other transaction costs, competitive markets will equalize the price of an identical good or service in two countries when the prices are expressed in the same currency:

$PPP = (PPP\ GNP\_y / PPP\_x)^{E}$

Where *PPP GNP* is the purchasing power parity to Gross National Product for country *y*, and *y* in this case is Bahrain and *x* is the USA; *E* denotes the elasticity factor. Furthermore, if we know that, the PPP GNP for Bahrain according to World Bank statistics in 2004 is about US$ 19,670, and for USA it is US$ 29,240. Hence, by applying an elasticity factor equal to 1, we can obtain the PPP for Bahrain:

PPP GNP for Bahrain = 19,670 / 29,240^1= 0.67

Value per DALY in the US is US$ 164,000

Value per DALY in Bahrain = US$ 164,000 * 0.67= $ 0.11 Million

VOSL in Bahrain = US$ 1.6 million * 0.67= $ 1.07 Million

To conclude this chapter all the data in this chapter either for the air quality in Kingdom of Bahrain or the illness costs for Respiratory and Cardiovascular hospital admission, average numbers of health care days per patient, and the Value of Statistical life were used as in-put data to run the RiskPoll model presented in Chapter 4.

Summary of Chapter 3

Chapter 3 presented the answer to the question posed within the research framework: "What are the environmental and health impact associated with electricity generation in Kingdom of Bahrain?"

The author assessed the environmental and health impact of power generation in Kingdom of Bahrain. He first analyzed the air quality data and the link of air pollution to electrical power generation. Then, based on previous studies, he evaluated the data on air pollutant emissions from three electrical power stations in Bahrain and sought to ascertain the resultant Potential Health Impact from those air pollutants.

The ambient air quality standards were exceeded at all sites with the reported excedances recorded from North and East directions. Riffa, Alba and Bapco power stations are located in direct line. Dispersion calculations were performed to show the present ambient air impact caused by the three electrical power plants studied, as well as their individual contributions to the overall air pollution situation. Assuming that all the plants are operating at base load (Maximum Capacity Rate), the highest values of ground level NO_2 were calculated for locations near ALBA (short term peak 1544 $\mu g/m^3$, annual average 58$\mu g/m^3$).

Chapter 4 presents the results of this thesis author's empirical research. It presents the Estimation of Environmental Impact in Bahrain from Exposure to Atmospheric Emissions using the RiskPoll model. The author then assessed the consequences to human health, agricultural crops and man-made environments (building materials) from exposure to atmospheric emissions from routine or steady state processes within Bahrain.

Chapter 4- Estimation of Environmental Impact in Bahrain from Exposure to Atmospheric Emissions Using the RiskPoll Model

Introduction:

The environmental and human health impact due to industrial activities, which involve fossil fuels, are a matter of intense interest and deep concern throughout the world. The use of fossil fuels creates many undesirable effects. At this time, however fossil fuels are still the most competitive energy sources on the market, especially for developing countries. However, in some regions, hydro- power is more economical and has fewer negative environmental and human health impacts.

However, it is necessary to find a balance between the costs of achieving a lower level of environmental and health injures and the benefits of providing services at a reasonable cost. A promising way of achieving this is to internalize the costs derived from environmental and human health damages into the market prices, thereby making fossil fuel-based energy less competitive. In order to do so, one must quantify the currently externalized costs.

This approach has weaknesses, such as the difficulties in assigning a cost for the damage to an ecosystem or to a human life. In spite of many factors not completely included yet, quantification and internalization of currently externalized costs could be an important tool for decision makers in order to achieve more sustainable societal development. External costs, as a quantitative measure of impacts, have the advantage of being more objective than other approaches, even when not all the impact are included.

Many efforts have been made to do this, especially in developed countries. Within the framework of ExternE project (ExternE 1998[124]) the Impact Pathways Methodology and the corresponding software EcoSense were developed. It has been applied in the European countries, US, Thailand and in other countries, around the world. This methodology was created by and for developed countries and its application is limited for developing countries due to the complementary studies and large data requirements needed to estimate the impacts.

Rowe *et al.* 1995[125] used the EXMOD model in his study to evaluate and assess the New York electricity externalities; this model is similar to the European EcoSense model. The EXMOD model is an American model that was used to model air dispersion from locations in New York to receptor cells throughout the north-eastern U.S. and eastern Canada. The air dispersion models in EXMOD are annual average or simple peak models used by U.S. regulatory agencies; the two models are used to predict short-range changes (<50 km) and long-range changes (50-1500 km) covering local and regional range. Also ozone models are included that are driven by changes in NOx concentrations. So far the model does not compute CO2 damages (i.e. EXMOD implicitly assumes 0$/ton CO2).

Impact calculations are based on dose-response parameters in EXMOD with default high, central and low parameter values. Based on a review of the literature, the EXMOD model uses a central VSL estimate of $ 4.0 million for individuals under 65 years, and a central estimate of $ 3.0 million for individuals 65 years or older(Schleisner, 1998)[126]. The argument that VSL decreases with age is that years of expected remaining life decrease with age. Thus life expectancy and health status tend to decrease with age also the quality of life is reduced.

Monlar *et al.* (2008)[127] used The EcoSense model in calculating the equivalent monetary value of health damage, i.e. external cost, for two types of fossil fired power plants, located in Croatia, with the analysis covering Croatian- and European-wide scope of effects.

RiskPoll model has been used by Humbert *et al.* (2011)[128] on the integration of human exposure to PM into life cycle impact assessment (LCIA) to facilitate incorporating regional impact into LCIA for human health damage from PM.

Within the framework of ExternE project, a simplified model, RiskPoll, was developed; it is offered free of charge through the web to all countries around the world (Spadaro 1999)[129].

The RiskPoll model employs a simplified impact assessment methodology that is transparent, easy to use and requires limited input data. In the simplest approximation, only the population density for a circle centered at the source of the pollutants, with a radius of 500 to 1000 km is needed to predict the impacts. By contrast, detailed environmental impact analyses are data, resource and time intensive. Compared to detailed assessments, RiskPoll results are typically accurate to a factor of two. The simplified models provide estimates of the impact based on limited input information. Their role is not to replace a detailed analysis, but rather to complement detailed assessments by providing a *sanity* check of the results, and to obtain estimates in cases when the available input data are insufficient to perform a detailed analysis (Spadaro 1999).

The RiskPoll program assesses the consequences to human health, agricultural crops and man-made environments (building materials) from exposure to atmospheric emissions from routine or steady state processes. For crops, there may be losses or gains in yield, whereas, for materials, pollutants cause building soiling, structural damages and loss of detail due to acidic erosion due to some air pollutants. Monetization of the physical impact gives rise to the damage costs or social burdens.

The Kingdom of Bahrain is now expanding its power generation capacity, using environmentally friendly technologies such as low NOx burners in order to reduce the associated impact on air quality to a feasible minimum. However, older plants are still being operated in Bahrain; they have been documented to produce elevated NOx emissions.

The power stations, which contribute the main portions of NOx emissions in the eastern central area of Bahrain are gas turbine units installed at the Riffa power station, the Bahrain Petroleum Company (BAPCO) refinery, and the Bahrain Aluminum smelter (ALBA). The impact and corresponding damage costs related with health effects and building material damages (Man-made environments) due to air emissions from these facilities were calculated using the RiskPoll model. The impact on agricultural crops was not evaluated, because in Bahrain, agriculture is a marginal sector and its contribution (Agriculture and Fisheries) does not exceed 1% in GDP.

Many studies have concluded that in terms of costs, health impact contribute the largest part of the air pollution damage estimates i.e.Friedrich &Kallenbach (1991); Friedrich & Voss (1993). The most effort in this study was dedicated to evaluate health impacts.

Because usage of RiskPoll in this study does not require hourly data, the dispersion treatment was very simple. The main efforts were devoted to evaluating the impact and monetary valuation steps of the impact pathway approach. The basic methodologies for these steps are explained in Section 4.1.

The results of the simplified analysis regarding the externalities related to global warming are also included. The assessment was performed based upon data from 2004.

4.1 Methodologies

4.1.1 Impact Pathway Methodology

The economic burdens to human health and materials are assessed by an analysis of impact pathways (IPA). The ‘Impact Pathway Approach,’ (IPA) was used to quantify the environmental impact as defined in Figure 7. The principal steps can be grouped as follows:

- Emission: specification of the physical characteristics of the source and preparing a detailed inventory of airborne releases, e.g. kg of oxides of nitrogen (NOx) per year emitted by a power plant at a specific site;
- Dispersion: calculation of increased pollutant concentrations in all affected regions, e.g. incremental concentration of ozone, using models of atmospheric dispersion and chemistry for ozone (O_3) formation due to NOx;

  Separate atmospheric dispersion models were used to calculate the marginal increment in air pollutant concentrations. Locally (< 50 km from the source), dispersion of primary air pollutants (species emitted at the source) is influenced by stack parameters and weather data. Usually a Gaussian plume model is used to estimate concentrations. Beyond 50 km, chemical transformation, dry deposition and precipitation deplete the pollutant from the air. Regional concentrations can be predicted using Eulerian or Lagrangian transport models such as the Wind Rose Trajectory Model used in the EcoSense program of the ExternE Project (Krewitt et al., 1995[130]). RiskPoll includes a Gaussian plume model to estimate local concentrations when hourly meteorological data are available and regional dispersion is treated in a simplified way.

- Impact: calculation of the cumulated exposure from the increased concentration followed by calculation of impact(damage in physical units) from this exposure using an exposure-response function, e.g. cases of asthma due to this increase in O_3;

  Impact were quantified using Exposure Response Functions, (ERF) (really Concentration Response Function because the real exposure is rarely evaluated), which relate pollutant concentration to the resulting impact on a receptor (human health, crop productivity, etc.). ERFs for health impact are derived from epidemiological studies (Rabl, 2001[131]). In view of the available evidence, it is assumed that ERFs for health are straight lines with no threshold, at least not on a population-wide level and at current ambient concentrations. Impact on human health includes respiratory effects (asthma attacks, hospital admissions, etc.) and premature deaths. Mortality impact could be quantified in terms of the reduction in life expectancy, expressed as cumulative Years of Life Lost (YOLL) for the population at risk (Leksell and Rabl, 2001)[132].

- Cost: valuation of this impact in monetary terms, e.g. multiplication by the monetary value of a case of asthma.

Monetization is convenient for aggregating health impact and environmental burdens with different physical units. To obtain the costs, the impact (e.g., cases of asthma) are multiplied by the cost per case or unit cost (e.g., US$ per asthma attack). Unit costs for health impact include cost of illness, wage and productivity losses and non-market costs that consider the individual's WTP to achieve an environmental benefit. Ideally, country-specific cost data should be used to monetize the impacts. When these results are not available, the ExternE values may be scaled according to the ratio of Purchasing Power Parity GNP for the new location and Europe ($PPPGNP_{EU15}$). The adjustment accounts for income differences between countries, and consequently, in the WTP regarding to valuation of health impact by individuals in different parts of the world.

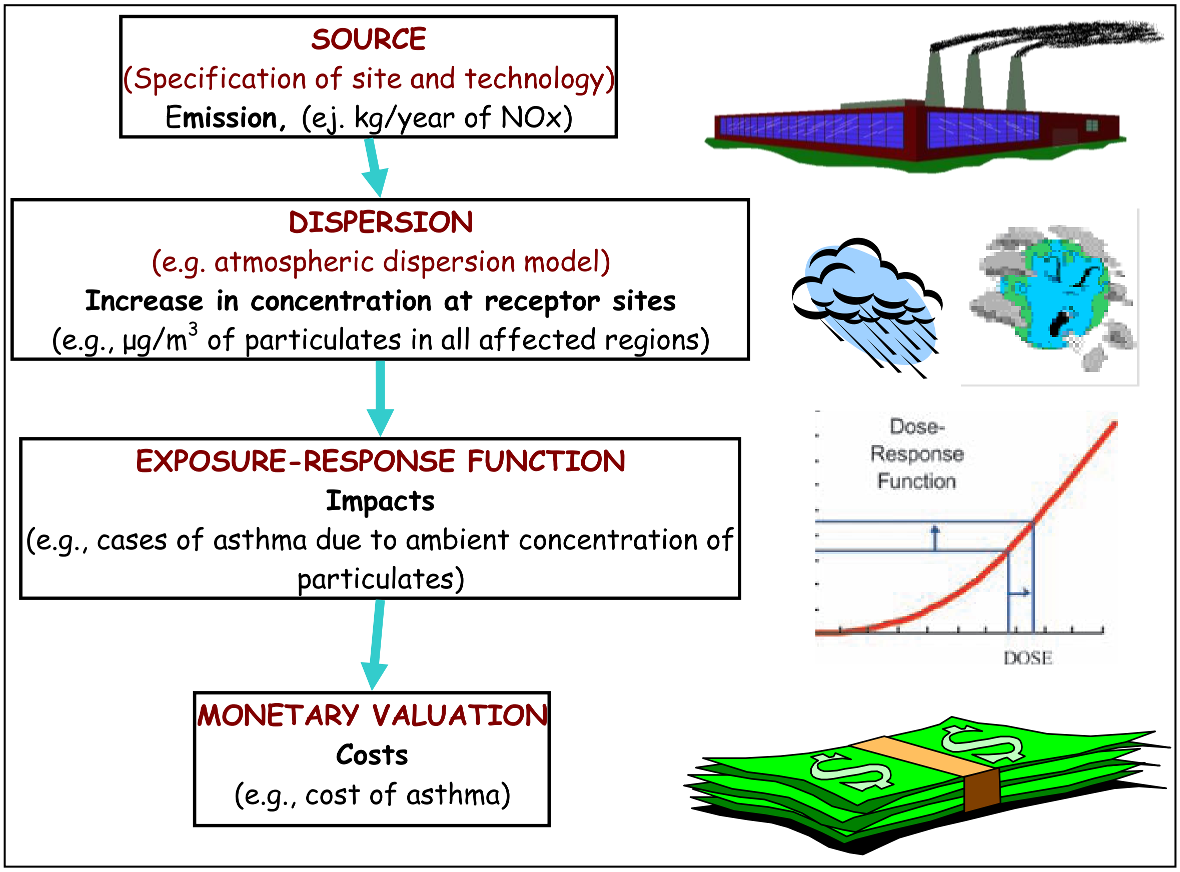


Figure 41. The Principal Steps of an Impact Pathway Analysis, for Air Pollution.

Source: Centre for Energy and Process[133]

Damages are aggregated over all receptors impacted by air pollution; the spatial boundary of the analysis extends up to thousands of km from the point of emission for the classical pollutants and it is global for greenhouse gases. This involves a difficult multidisciplinary system analysis (dispersion modelers, epidemiologists, ecologists, economists, etc). The uncertainties are large because the present knowledge about the effects of air pollutants is not sufficiently detailed. Despite the uncertainties, damage estimates are valuable since many policy decisions do not require great accuracy of the damages, and in many cases, firm recommendations can be made despite the large uncertainties (Spadaro 2001)[134].

4.1.2 The RISKPOLL Model

The RiskPoll program calculates the physical impact and the associated damage costs for the following type of pollutants: particulate matter (PM), sulfur dioxide (SO2), nitrogen oxides (NOx), carbon monoxide (CO), and secondary species such as nitrate and sulfate aerosols. The primary or precursor pollutants (PM, SO2, NOx and CO) are emitted directly into the air at the source location. The damages are very sensitive to local conditions, particularly meteorological data (wind speed and wind direction) and receptor distribution (population, crop or material density). Secondary pollutants, those species formed in the atmosphere because of chemical transformations of primary pollutants, are rather insensitive to local characteristics because they typically form in the air tens of km downstream of the source. SO_2 is the precursor pollutant for sulfates and NOx for nitrates.

The RiskPoll model contains a set of models and tools whose starting point is the *Simple Uniform World Model* (SUWM). It is assumed that the population density, atmospheric dispersion parameters and the exposure-response functions are constants and independent of the actual source parameters and location. In addition to this elementary model, the *Robust Uniform World Model (RUWM)* is available. In these, site dependence (characterized by the actual local population distribution) and real source parameters (in particular, stack height and exhaust flow values) are accounted for by a more rigorous, yet simplified, mathematical treatmentjaasspadaro@aol.com

QUERI is another model and tool, which adds appropriate scaling factors obtained when transferring the impact estimates from a known site to a different location provided that the local receptor densities are properly represented. QUERI includes up to three separate estimation procedures. The number of impact estimates calculated by the program depends entirely on the input information available to the user.

URBAN computer tool provides an approximate estimate of the physical impact and health damage costs from primary pollutants release from a single point source, and assumed to be located in the proximity of a city.

A general principle for all such tools is that a more detailed analysis is possible, as more data are available. Detailed descriptions of these models are available in Spadaro, 1999[135].

4.1.3 Uncertainty analyses

Unlike most engineering and traditional science calculations, uncertainty estimates for impact and damage cost values are quantitatively difficult to assess due to present gaps in our knowledge. Moreover, estimates are numerically large by comparison to the calculated values themselves.

Confidence interval (range, limit or level), CI, is a statistical concept designed to help researchers to increase their understanding of the likelihood or probability that the value of a random event will lie within a well-defined interval about its mean value. For most experiments, the 68% and 95% confidence limits are normally reported.

The structure of the 'Impact Pathways Analysis,' is essentially a multiplicative process that is based upon the product of the following four independent random variables: incremental concentration, ERF, receptor density and monetary cost. For such a function, the natural distribution is a lognormal distribution, which is characterized by a median value (best guess) μ_g and a geometric standard deviation σ_g. Together these factors define the 68% and 95% confidence intervals, dividing and multiplying the estimated damage cost by σ_g ,and by σ_g^2 respectively.

- 68% confidence interval: $\mu_g / \sigma_g, \mu_g \sigma_g$
- 95% confidence interval: $\mu_g / \sigma_g^2, \mu_g \sigma_g^2$

The σ_g values assumed in RiskPoll depend of the type of impacts: three for morbidity, four for acute mortality, six for chronic Mortality, and four for cancer.

4.2. Data and Assumptions

4.2.1 Study Case, Facilities' Data, Pollutant Inventories

The facilities included in the studies contribute the main portions of NOx emissions in the eastern central area of Bahrain:

1. Gas turbine units installed at the Riffa power station,
2. The Bahrain Petroleum Company (BAPCO) refinery, and
3. The Bahrain Aluminum smelter (ALBA).

In 1999 Emission measurement were carried out by the independent and certified German Consultant called LAHMEYER International (Since there has been no corrective action taken since then, the author assumed that the current situation is the same), the measurement results showed that the highest NOx emission concentrations were found in the flue gas of the large gas turbines without NOx reduction equipment at Riffa (255-344 ppm) and ALBA (264-313 ppm). The NOx levels measured at these units greatly exceeded the emission standards of Bahrain, The Metrological and

Environmental Protection Agency of Saudi Arabia (MEPA), The World Bank, and of Germany. In Table 17, the main parameters of those facilities are presented and Figure 43 shows their locations.

Table 17. Main Parameters of the Facilities

Characteristics	Unit	Riffa	BAPCO	ALBA
Pollutant Inventories				
SO_x	Tons/year	-	-	70,59.0
NO_x	Tons/year	38,763.0	884.8	33,069.0
PM_{10}	Tons/year	-	-	1,275
Stack Parameters				
Exhaust gas speed	m/s	40	20	14
Exit gas temperature	K	758.95[a]	691.85 [a]	465.15
Stack height	m	30-45	9.6 [b]	30-45
Stack diameter	m	4.7-5.6	3	3
Location				
Latitude		26.12	26.12	26.08
Longitude		309.42	309.40	309.40
Index Site		0	0	0

Source: Lahmeyer (1999).

[a] In the calculation, the upper bound of the RiskPoll was used: 600 K

[b] In the calculation, the lower bound of the RiskPoll was used: 25 m

Index Site or Source location ID code is relevant for QUERI model. Different sites are distinguished on the basis of the ratio of the local-to-regional population densities. For example, if the ratio is less than two, the site is treated as a rural location. The default values are:

- 0 (rural site),
- 1, 2, 3 (near small, medium, large city),

- 4 (within 25 km from large city),
- 5 (within 40 km from large city),
- 6 (more than 40 km from large city)

For all studies case the index Site was taken equal 0 (rural location) taking into account that for sites near large water bodies, surrounded by large uninhabited areas or for islands, different rules apply.

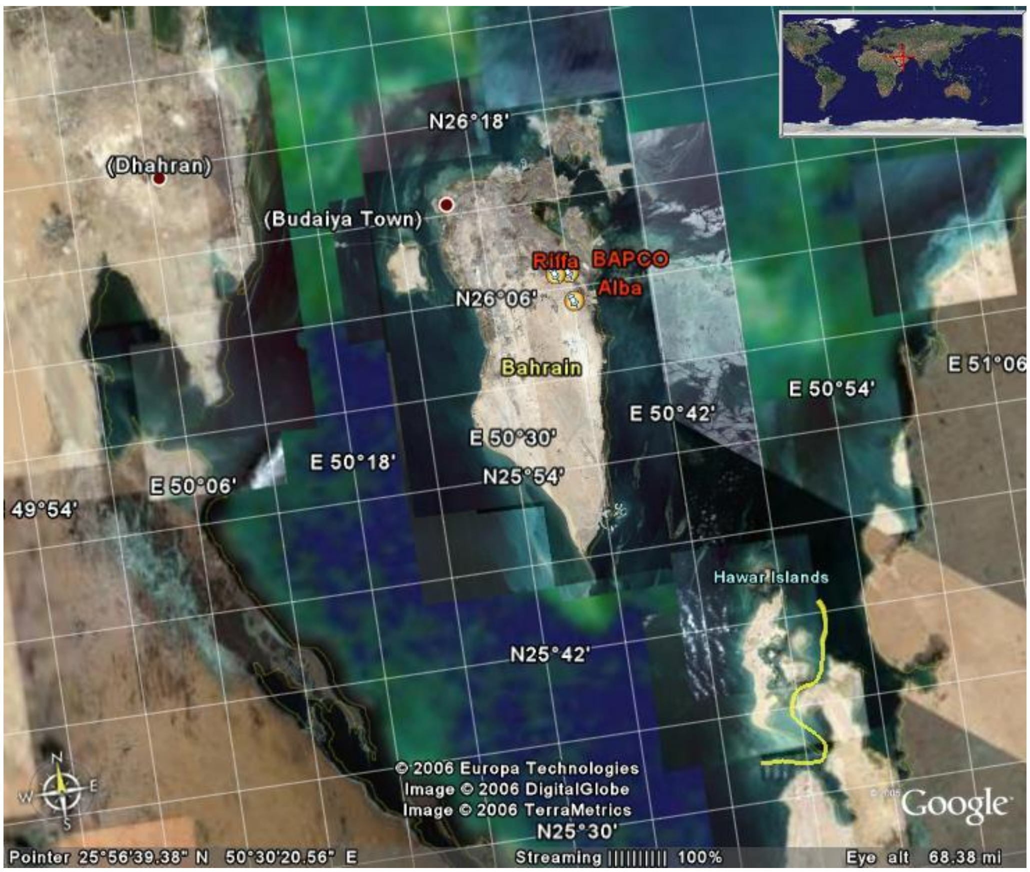


Figure 42. Facilities Location and Local Domain

4.2.1.1 Depletion Velocities

Using the reported depletion velocities around the world as reported in Spadaro, 1999 and the average meteorological conditions (precipitation rate and wind speed) for these locations, the author calculated the correlations between the depletion velocities corresponding to different pollutants and precipitation rates and wind speeds.

Table 18. Correlations Factors Between Depletion Velocities, Precipitation Rates (PR) and Mean Wind Speed (WS)

	WS, m/sec	PR, mm/yr	k_{PM10}	k_{SO2}	k_{NOx}	$k_{Sulfates}$	$k_{Nitrates}$
WS,m/sec	-		0.14	-0.18	0.53	0.20	0.56
PR, mm/yr		-	0.78	0.33	0.26	0.72	0.78
k_{PM10}	0.14	0.78	-	0.78	0.12	0.85	0.82
k_{SO2}	-0.18	0.33	-0.18	-	-0.05	0.74	0.48
k_{NOx}	0.53	0.26	0.12	-0.05	-	0.40	0.26
$k_{Sulfates}$	0.20	0.72	0.85	0.74	0.40	-	0.75
$k_{Nitrates}$	0.56	0.78	0.82	0.48	0.26	0.75	-

Source: Spadaro, 1999

Taking into account the Bahrain conditions; average precipitation rate (77mm to 80mm) and mean wind speed (6.22 m/sec), the followings results were obtained for the depletion velocities. All correlations used were acceptable except for NOx, a detailed assessment is strongly recommended, at least in the local domain which will allow a more accurate estimation of the depletion velocities for primary pollutants and then only the depletion velocities for secondary pollutants were estimated using correlation factors.

Table 19- Air Pollutant Depletion Velocities

	WS, m/seg	PR, mm/yr	k_{PM10}	k_{SO2}	k_{NOx}	$k_{Sulfates}$	$k_{Nitrates}$
WS,m/seg	-		0.14	-0.18	0.53	0.20	0.56
PR, mm/yr		-	0.78	0.33	0.26	0.72	0.78
k_{PM10}	0.14	0.78	-	0.78	0.12	0.85	0.82
k_{SO2}	-0.18	0.33	-0.18	-	-0.05	0.74	0.48
k_{NOx}	0.53	0.26	0.12	-0.05	-	0.40	0.26
$k_{Sulfates}$	0.20	0.72	0.85	0.74	0.40	-	0.75
$k_{Nitrates}$	0.56	0.78	0.82	0.48	0.26	0.75	-

Source: RiskPoll Model outputs

4.2.2 Population Data

By default, in RiskPoll, the local domain includes the impact area centered at the source and extending in all directions up to a maximum distance of 50 kilometers. In this study, for the local domain, only Bahrain's territories were considered and therefore, the radius of this domain is limited to 30 km resulting in a local population density of the 250.11 persons/km^2 (See Figure 43).

In the case of Bahrain, an island located in the Persian Gulf, the regional population density is low: 32.9 inhabitants for km^2. This value was obtained with Geographical Information System (GIS) considering the total population of Bahrain in comparison with Iran, Iraq, Kuwait, Saudi Arabia, Qatar, Unit Arabs Emirates, Oman and Yemen included in the radius equal to 1000 km, through proportional sum of intersected area, to include 103,351,428 inhabitants (See Figure 44).

Figure 43- The Impacted Area by the Emissions from the Bahraini Electricity Production Sector within the Regional Domain

Source: Google earth

4.2.3 Meteorological Data

Statistical meteorological data were used in the calculation. Anemometer height was at 10 m.

Table 20.The Meteorological Data for Bahrain's Territories

Parameter	Representative Values
Ambient temperature	**32 °C**
Mean Wind Speed	6.22 m/s
Pasquill Stability Class, Frequency of occurrence	
A	5%
B	10%
C	20%
D	30%
E	20%
F	15%
Mean Mixing layer height	840 m

Source: Bahrain Metrological Data

The precipitation rate in Bahrain ranges between 77mm to 80mm/year 2006. These figures are about the same for the entire region, which does not exceed 100mm/year. The mean relativity humidity is 52%.

4.2.4 Exposure Response Functions

Tables 21, 22, & 23 shows the FER (*IRR, Iref*, *fpop*) selected for the primary pollutants included in the study: PM10, SO_2 and NOx. The FER for NOx should be considered very carefully because, in most recent studies, the direct effects of NOx were not taken into account. Some studies, such as ExternE 2005, also did not include the direct effects of SO_2.

For the last update of the ExternE methodology, the assumptions about the toxicity of the different PM types were changed after a careful review of the latest epidemiological and toxicological literature. Evidence has been accumulating to underline the high toxicity of combustion particles and especially of particles from internal combustion engines, especially in the sizes smaller than 10 μg. For the secondary particles the evidence is less convincing. In particular for nitrates there is still not much evidence for harmful effects, whereas for sulfates, quite a few studies, including the very important cohort study of Pope *et al*. (2002), found associations. Therefore, ExternE now treats:

- nitrates as equivalent to 0.5 times the toxicity of PM_{10};
- sulfates as equivalent to PM_{10} (or 0.6 times $PM_{2.5}$);

Table 21. Increase Risk Ratio for Selected Exposure Response Functions

Health end points	IRR (%/μg/m³)			Reference
	PM_{10}	SO_2	NO_2	
Morbidity effects				
Chronic Bronchitis	0.82	-	-	Abbey (1995)[136]
Restrictive Activity Days	0.30	-	-	Ostro (1987)[137]
Respiratory Hospital Admissions	0.10	0.04	0.0396	Atkinson (2001)[138]/ Spix (1998)[139]/Ponce de Leon (1996)[140]
Cardiovascular Hospital Admissions	0.17	-	-	Chesnut, 1998[141]
Mortality effects				
Acute Mortality	-	0.034	0.034	Stieb (2002)[142]/ APHEA (1997)[143]
Chronic Mortality	0.3	-	-	Pope (2002)[144]
Infant Mortality	0.0039	-	-	Woodruf et al, (1997)[145]

Source: Abbey (1995), Ostro (1987), Atkinson (2001), Spix (1998), Leon (1996), Chesnut (1998), Stieb (2002), Pope (2002), and Woodruf & Schoendorf (1997).

For NOx, respiratory hospital admission was considered the ERF reported by Ponce de Leon (1996) and for acute mortality, the result of APHEA (1997), both recommended in the RiskPoll model.

The following ERF were selected From Ostro (1996)[146], because the national baseline levels are not available in order to transfer only the IRR. These values already include the I_{ref}

Table 22. Slope of the ERFs (IRR x I_{ref})

Health end points	Receptors	Pollutant	IRR x I_{ref}, Cases/(year-person-µg/m^3)
Emergency Room visit	Total population	PM_{10}	2.35 E-05
Acute asthma attack	Asthmatics	PM_{10}	0.059

Source: Ostro (1996).

The baseline incidence rate for chronic bronchitis and restrictive activity days were taken from reference studies because the national values were not available. For the remaining health end points, the national statistics were used (Bahrain Health Statistics 2004[147]). The corresponding population fractions were also obtained from population data for different age groups.

Table 23. Baseline Incidence Rate and Population Fraction of Health End Points

Health End Points	**Receptors**	**Baseline Incidence rate, cases /(person-year)**	**Reference**	**Population fraction**
Chronic Bronchitis	+ 30 years	0.00378	• Abbey et al. (1993, 1995a) • ExternE (2005)[148] • Abt (2005)	0.45
Restrictive Activity Days	Adult, 20+, 60-years[a]	19	• Ostro (1996), ExternE (2005)	0.60
Respiratory Hospital	Total Population	0.004139 [b]	Bahrain Health Statistics, 2004	1

Admissions				
Cardiovascular Hospital Admissions	Total Population	0.00082 [b]	Bahrain Health Statistics, 2004	1
Emergency Room Visit for respiratory illness	Total Population	ND		1
Acute asthma Crisis	Asthmatics	ND		0.084 [c]
Acute Mortality	Total Population	0.0031	Bahrain Health Statistics, 2004	1
Chronic Mortality	30 + years	0.0059	Bahrain Health Statistics, 2004	0.45

Source: Bahrain Health Statistics (2004), Ostro (1996), ExternE (2005)

[a] Indeed, the ERF must be evaluated for active population, in Bahrain from 18 to 60 years but the age groups are defined as 15 to 19 and 20 to 24.
[b] Only taking into account the numbers of patients Admitted to Salmaniya Hospital: the admissions due to Acute Respiratory Infections, Other Disease of Upper respiratory Tract, Chronic Obstructive Pulmonary Disease (COPD) and Asthma are included as respiratory hospital admission meanwhile Ischemic heart disease patients are considered as Cardiac hospital admissions.
[c] Value in Saudi Arabia

4.2.4.1 Mortality Impact

Using the methodology described in the Section 4.1.3.1, the RR reported by Pope et al (2002), $f\_{latency}$=0.45, the following results were obtained for Bahrainis population during 2004: $\alpha = 1.67\times 10^{-5}$, $\beta = 0.112$, T_L=73.5 (vs. 73.8 years reported in official statistic), ΔT_L=0.43 years and finally the slope of the ERF for Chronic mortality due to PM10 was S_{ERF}=1.6E-4 YOLL/ (yr-person-μg/m^3). It is the value used when the loss LE approach is considered, in place of 7.94E-06 Cases /(yr-person-µg/m^3) when the value of statistical life of 7.94E-06 Cases /(yr-person-µg/m^3) is the result of equation [5] if IRR = 0.003 (µg/m^3)$^{-1}$, Iref = 0.0059 cases/(year-person) and fpop = 0.448.

For acute mortality from direct exposure to SO_2 and NOx, the increased risk ratio is multiplied by the mortality rate to estimate the number of deaths. A loss of life expectancy of 6 months is assumed (equal to ExternE 2005) to get the ERF in terms of YOLLs.

The infant mortality is not considered when the loss LE expectancy approach is used.

4.2.5 Monetary Unitary Cost

The statistics of the World Bank, 2004, report the PPP_GNP in Bahrain equal to 19,670 of U.S $2004. For EU-15, the PPP_GNP is 27,923 of U.S $2004, and then using an elasticity factor of 1, the transferred rate for the transferring equation is 0.7, this mean; the VOS, YOLL (chronic), and YOLL (acute) for Bahraini's equal 70% of Europeans as stated in ExternE study.

4.2.5.1 Unitary Mortality Costs

The original and transferred values for mortality impact are shown in Table 24. The value of VSL and VOLY, both acute as chronic, were transferred.

Table 24. Mortality Unitary Costs for Statistical Life

	ExternE, €2000	Transferred to Bahrain, $2004
VSL	1,052,000	750,672
VOLY Chronic	50,000	35, 678
VOLY Acute	70,000	53,517

Source: Developed by this thesis author

$2000 = 0.92 €2000
$2000 = 1.097 $2004

The figures in Table 24 reveal a big difference between what are supposed to be the VSLs of Bahraini's compared with values from developed countries, and the actual figures that were obtained from the insurance companies' records, which don't exceed U.S $70,000 (Al-Hesabi 2002)[149]

4.2.5.2 Unitary Morbidity Costs

All of the components of the morbidity costs are considered and shown in the Table 25 as *Illness Costs* (IC), *Productivity Loss* (PL) and *Willingness-to-Pay* (WTP). The IC for Respiratory and Cardiovascular hospital admission were calculated upon the report from Salmaniya Hospital, multiplying the average numbers of health care days per patient, (five for respiratory and six for cardiovascular illness) by the daily health care costs for in-patients.

The productivity loss for Restrictive Activity Days was estimated from average daily wage in Bahrain; 7 Bahraini Dinar (BD), (1 BD equal U$2.65). Then the PL for Respiratory and Cardiovascular hospital admission is calculated starting from the PL in 10 and 11 days, considering five days at home after hospitalization. For emergency room visits, five days of productivity loss was considered.

The WTP was transferred from ExternE 2005.

Table 25. Morbidities Unitary Costs for Different Health Points, US $2004

Health End Points	IC	PL	WTP	Total
Chronic Bronchitis	N/A	N/A	163,619	**163,619**
Restrictive Activity Days	N/A	199	409	**599**
Respiratory Hospital Admissions	180	186	383	**749**
Cardiovascular Hospital Admissions	232.56	204.05	382.87	**819.48**
Emergency Room Visit for respiratory illnesses	28.63	92.75	197.98	**319.36**
Acute asthma crisis, Children	N/A	N/A	241.3	**177.5**
Acute asthma crisis, Adults	N/A			

Source: This table was developed by this thesis author

Figures shown above are an estimate of the morbidity unitary costs associated with pollution from the power plants in Kingdom of Bahrain. For example the willingness of chronic bronchitis patients to avoid and prevent such disease is estimated at more than U.S $163,000, while the estimates of the restrictive activity days of approximately U.S$59, and the respiratory hospital admissions at about $749. These figures should be taken into account when internalizing the currently externalized costs of power generation by incorporating them into the price of electricity.

4.3 Estimation and Valuation of Impact on Health

The three facilities, Riffa, BAPCO and ALBA, were evaluated using two of the models included in RiskPoll for classic pollutants: RUWM and QUERI, and the two existent approaches for mortality valuation: cases of death, valuated through the VSL; and loss of LE, evaluated through the VOLY. Then for each facility, four study cases were conducted, and in total 12 sets of results were processed.

The best estimation of the RUWM model was used for all facilities; meanwhile, the intermediate estimation of QUERI was used because the best estimation of this model requires hourly meteorological data, which were not available in this study. The total damage costs are presented in Table 26.

Table 26. Total Damage Costs, Millions of US $2004

Valuation Mortality Approach	RiskPoll	Riffa	BAPCO	ALBA
VSL	RUWM	**81.7**	**2.1**	**110.5**
	QUERI	**91.8**	**2.2**	**109.9**
	RUWM/ QUERI	88.97	97.38	100.54
VOLY	RUWM	**71.3**	**1.63**	**83.4**
	QUERI	**71.7**	**1.67**	**84.57**
	RUWM/ QUERI	99.48	99.87	98.64
VOLY/VSL	RUWM	87.25	76.61	75.42
	QUERI	78.03	74.70	76.88

Source: RiskPoll outputs

The total damage costs match very well with the emissions (See Table 17). The higher costs correspond to ALBA because it reports NOx, SO_2 and PM_{10} emissions. The results for BAPCO are lower because this facility only reports NOx emissions (884.8 ton/year). This reflects the importance of considering all emissions of the facilities in the evaluations because it is certain that there are SO_2 emissions from this refinery.

The total costs for Riffa are closer to ALBA than to BAPCO although in Riffa only NOx emissions are considered, but these emissions have increased from 31,786 in year 1990 to 38,763 ton/year in year 1999.

As other studies report, the evaluation of damage costs using the VSL approach is larger than for the VOLY method[150], as can be seen in the last rows of Table 26. The results using the VOLY approach range from 75 to 80 % of the results using the VSL approach, except for Riffa where they increased up to 87%.

This is due to the fact that when the VOLY approach is used, the results of RUWM and QUERI models are almost equal because with this approach, the contribution of the secondary pollutants (sulfates and nitrates) to the total are very high, more than 98% in ALBA and very close to 100 % in BAPCO and Riffa. It must be taken into account that for secondary pollutants both models, QUERI and RUWM use the same procedure based upon the basic equation of the Simple Uniform World Model (Equation [2] with R=1).

Using the VSL approach, the differences between RUWM and QUERI is higher in Riffa, (costs with RUWM smaller than with QUERI). This difference is related with the fact that the high exhaust gas velocity and the temperature, which increase the effective, stack height '*he'* in equation [4] and therefore, the calculated costs decrease. Using the VSL approach, the differences between RUWM and QUERI is higher in Riffa, (costs with RUWM smaller than with QUERI). This difference is related with the fact that the high exhaust gas speed and temperature, which increase the effective, stack height '*he'* in equation [4] and therefore, the costs decrease.

As in other international studies, the most important cost comes from chronic mortality, calculated on the basis of the method described by Pope*et al.* (2002), although the contribution of acute mortality due to SO_2 and NOx emissions are not negligible. Among morbidity effects, an important contribution comes from chronic bronchitis (Abbey *et al.,* 1995) and Restrictive activity days (Ostro et al,, 1996). In all study cases, the contribution of the secondary pollutants is higher than for the primary pollutant. The contribution of the mortality health end points and the secondary pollutants (sulfates and nitrates) to the total costs are reflected in Table 27. The contributions of the morbidity and the primary pollutants are the rest respect to 100 % respectively.

Table 27- Contribution of the Secondary Pollutants and the Mortality Health End Points to the Total Costs, %

		Riffa		BAPCO		ALBA	
		% Second.	% Mortal.	% Second.	% Mortal.	% Second.	% Mortal.
VSL	RUWM	93.7	58.5	81.8	63.8	67.9	64.4
	QUERI	83.4	63.1	79.6	64.7	68.3	63.7
VOLY	RUWM	99.7	52.5	99.1	52.7	83.4	63.1
	QUERI	99.2	52.7	99.0	52.8	82.5	52.7

Source: RiskPoll outputs

Table 28 presents the specific damage costs per ton of pollutants. The NOx specific costs for Riffa are smaller for the reason previously stated (high exhaust gas velocity and high temperature); it is intermediate for BAPCO and higher for ALBA.

Table 28. Specific Damage Cost, $2004/ per Ton of Pollutants

		Riffa	BAPCO	ALBA		
		NOx	NOx	PM10	SO2	NOx
VSL	RUWM	2,108	2,416	10,878	1,991	2,498
	QUERI	2,369	2,481	11,904	1,989	2,441
VOLY	RUWM	1,839	1,853	10,100	1,301	1,854
	QUERI	1,849	1,851	11,054	1,301	1,854

Source: RiskPoll outputs

4.3.1 Uncertainty Analyses

Figure 44 shows the results included in Table 26, and Figure 45 illustrates the same results with the confidence intervals. Figure 45 confirms that the uncertainties are large; the lower and upper costs are around a factor of four smaller or larger than the central estimates.

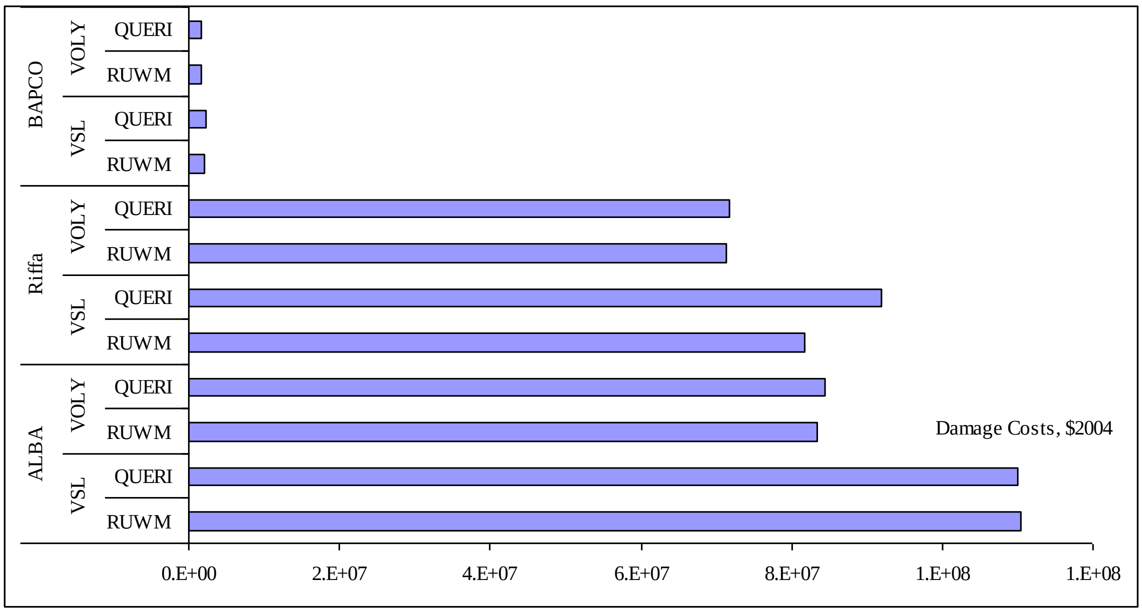


Figure 44. Total Damage Costs for ALBA, Riffa, and Bapco, US$2004

Source: RiskPoll outputs

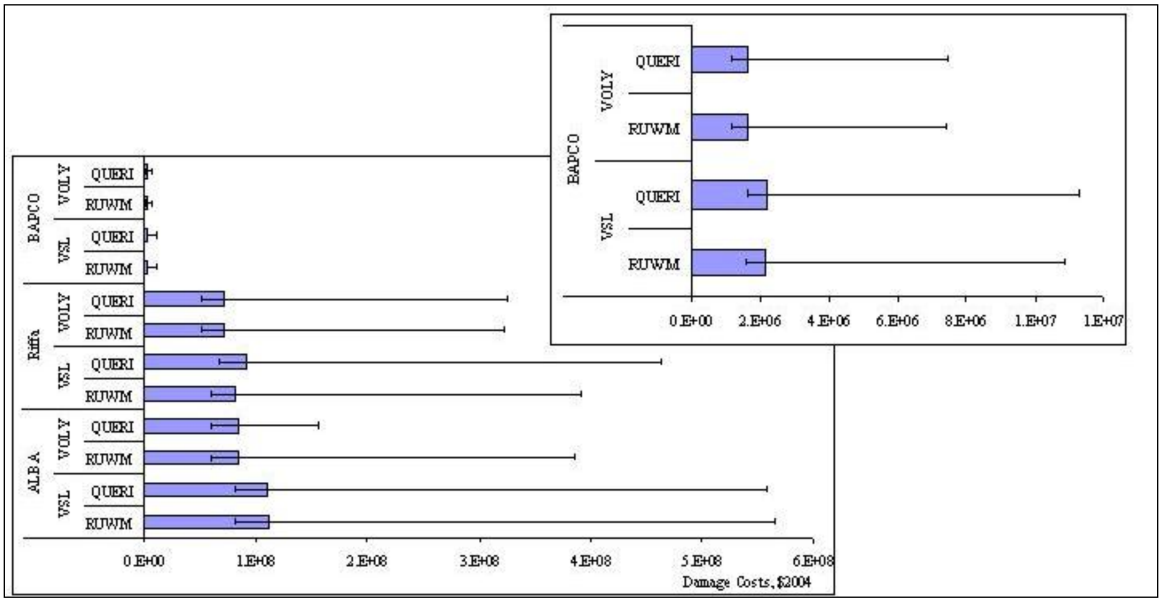


Figure 45. Total Damage Costs, with Confidence Intervals, US $2004

Source: RiskPoll outputs

4.4. Impact and Damage Costs on Building Materials (Man-made environments)

4.4.1 Methodology and Input Data

The AGRIMAT model assesses the impact to agricultural crops and to building materials (man-made environments) and the resulting economic costs from atmospheric exposure to SO2, not including wet deposition. Currently, the model can approximate the damages to the following types of receptors:

- *Agricultural crops*: Barley, Oats, Potatoes, Rye, Sugar Beets and Wheat;
- *Building materials:* Galvanized steel, Limestone, Natural stone, Paint, Sandstone and Zinc.

Damage assessments may be carried out separately for crops and materials. In this study, the impact on agriculture crops were not evaluated; in Bahrain the agriculture is a marginal sector and its contribution to GDP is very low. Only the impact on painted surfaces was estimated for Riffa because it reports SO_2 emissions.

As cells are very large, 100 x 100 km, the results have low precision and must be considered only from a methodological point of view. The input data used in the estimation were:

- Background SO_2 concentrations taken as the average of the mean value in different cities of Bahrain; Manama, Askar, Zallaq y Sitra: 12.1 ppb, 34.56 $\mu g/m^3$;
- Background ambient temperature: 305 K
- Background relative humidity: 52.1 %
- SO_2 emission rate: 7059 tons/year
- Depletion velocity: 0.61 cm/s
- The total residential units in Bahrain were about 110,000 units and the average total area for each residential unit is about 300 m^2 (Source: Statistical Abstract of Bahrain 2003). Then the total painted exposed surface is around 33,000,000 m^2.
- The maintenance cost of m^2 of paint ranges from \$ 5.00 to \$ 6.00/ m^2. (Source: Painting Companies).

Exposure Response Functions (ERFs) relate the impact to a receptor at risk (in this case, painted surface) to a change in the atmospheric concentration of SO_2. For both crops and building materials, the ERFs are non-linear relationships, which depend on the background SO_2 concentration at the location of exposure and other meteorological parameters, including background temperature, relative humidity, precipitation and ambient pH level.

$$S_{ERF} = 24 \times 10^{-4} \left(1 - exp\left[-\frac{0.121RH}{100 - RH}\right]\right), \text{ m}^2 \text{ damaged/ (year-m}^2 \text{ at risk } \mu g/\text{ m}^3) \quad \textbf{[15]}$$

ERF for painted surfaces quantifies the impact from direct ambient exposure to SO_2. The impact from wet deposition are typically greater than those calculated from direct exposure only, but simplification of the relevant ERF is not so simple, and has not been considered in RiskPoll. The slope of the ERF is also a function of the maintenance time period between repairs, which can vary greatly depending on the type of material, meteorological conditions and local cleaning practices.

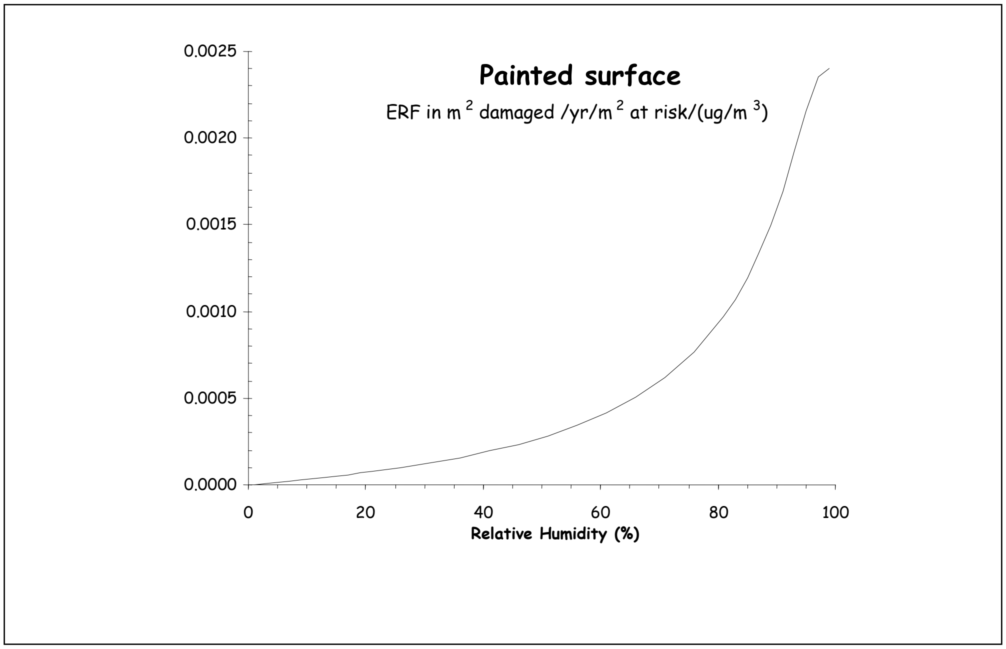


Figure 46. ERF for Painted Surface

Source: RiskPoll outputs

4.4.2 Results

AGRIMAT calculates impact of 1.77E+03 m^2/year of damaged surface and the costs ranges between \$2.44E+03 to 3.90E+04 per year (mean value equal to 9.76E+03).

4.5. Global Warming

For global warming, the Update to ExternE Methodology (ExternE, 2005) uses an avoidance cost approach for the central value. The avoidance costs for reaching the broadly accepted Kyoto target is roughly between €5 and €20 per t of CO_2 (ExternE 2005).

The emissions of CO_2, CH_4 and N_2O for the energy sector of Bahrain and the upper and lower bounds of avoidance costs are shown in Table 29. These costs were derived not only from the emissions of RIFFA, BAPCO and ALBA but also from the emissions of CO_2, CH_4 and N_2O from the whole energy sector.

The total emissions expressed as equivalent CO_2 were calculated using the following expression:

$$E_{Totales} = \sum_{i=1}^{3} E_i \times GPW_i \text{, Ton } CO_2 \text{ eq/year} \qquad \textbf{[16]}$$

Where:

$E_{Totales}$: Total emissions
E_i: Emissions of the greenhouse gases, CO_2, CH_4, and NO_2
GPW: Global Warming Potential
GPW is an index defined as the cumulative radiative forcing between the present and some chosen time horizon (i.e. 100 years) caused by a unit mass of gas emitted now, expressed relative to a reference gas. The values used are: 1 for CO_2, 21 for CH_4 and 310 for N_2O.

The upper and lower boundary of avoidance cost was estimated using the criterion of ExternE 2005 (€5 and €20 per t of CO_2).

Table 29. Lower and Upper Cost Estimates Related with the Global Warming of the Energy Sector in Bahrain

					Avoidance Cost	
GHG Source, Energy Sector (1994)	**CO_2 T/year**	**CH_4 T/year**	**N_2O T/year**	**Totals T/year**	**Lower Bound ($2004)**	**Upper Bound ($2004)**
Total Energy	**$1.46*10^7$**	**$2.65*10^4$**	**40**	**$1.52*10^7$**	**$6.37*10^7$**	**$2.55*10^8$**
Energy Industries	$1.33*10^7$	300	30	$1.33*10^7$	$5.59*10^7$	$2.24*10^8$
Fugitive emissions from fuels	0	$2.59*10^4$	0	$5.43*10^5$	$2.28*10^6$	$9.12*10^6$
Transport	$1.29*10^6$	300	10	$1.30*10^6$	$5.45*10^6$	$2.18*10^7$
Other Sectors (commercial, agricultural, residential, fishing)	$2.20*10^4$	20	0	$2.24*10^4$	$9.40*10^4$	$3.76*10^5$

Source: Bahrain's Initial Communications to the United Nations framework convention on Climate Change (2005), and RiskPoll outputs

Figures shown above are an estimate of the damage unitary costs associated with pollution from the energy industry in Kingdom of Bahrain. For the damage costs on the man-made environment the results have low precision and must be considered only from a methodological point of view, due to exclude the damage costs of agriculture sector, and limiting the impact on the man-made environment by one type of pollution i.e. SO_2 and one receptor i.e. the painted surface of buildings. The total costs range between U.S $ 2.44 – 39.0 million per year (mean value equal to U.S $ 9.76 million).

For global warming costs of the energy sector in Kingdom of Bahrain; the lower and upper avoidance costs approximately U.S $ 64 - 255 million per year, were 88% of this cost is related to power generation. Where the amount of emissions related to power generation i.e. CO_2, CH_4 and N_2O was obtained from Bahrain's Initial Communications to the United Nations framework convention on Climate Change (2005)[151] which was prepared by a working group including this thesis author; while the high damage cost of climate change in Bahrain attributed to the high per capita consumption of energy, and the heavy subsidy to energy.

Table 30. Summary of the Estimated Damage Costs Associated with the Pollution of Energy Industry in Kingdom of Bahrain:

Damage	NOx U$/ton	PM10 U$/ton	SO2 U$/ton	Total in U$/ million per year
Health				
Max.	2,498	11,904	1,989	
Min.	1,839	10,100	1,301	
Environment				
Max.	-	-	-	39
Min.				2.44
Global Warming				
Max.	-	-	-	255
Min.				64

Source: This table was developed by the author

Summary of Chapter 4

Chapter 4 presented the results of the empirical study on air emissions from three Bahrainis electrical power producing facilities. The author calculated the impact and corresponding damage costs related with human health effects and upon building materials(man-made environments) of atmospheric pollutions generated by fossil fuel related activities (electricity generation, fuel processing and aluminum smelter) in three Bahrainis facilities that were assessed using RiskPoll model.

Because many studies around the world report that health impact contribute the largest part of the damage estimates, the most efforts, in this study, were dedicated to evaluating them. For impact on building materials, the results have low precision and must be considered only from a methodological point of view, due to the lack of date for estimating the damage costs.

The facilities included in this work were: the Riffa power station, the Bahrain Petroleum Company (BAPCO) refinery, and the Bahrain Aluminum smelter (ALBA). Four study cases were conducted for each facility, using two of the models included in RiskPoll for classic pollutants (RUWM and QUERI), and two approaches for mortality valuation: cases of death, and loss of life expectancy.

The study results show the total damage costs related to the three power facilities (Table 26), and the specific damage costs per ton of pollutants (Table 28) that contributed to mortality and morbidity. The results presented in these two tables are linked with the main parameters of the facilities that were used to run the model that produced the results shown in Table 17.

The study includes a simplified analysis of the externalities in Bahrain's energy sector related with building materials (man-made environment) and global warming.

As in other international studies, the most important damage costs come from chronic mortality, although the contribution of acute mortality due to SO_2 and NOx emissions are not negligible. Among morbidity effects, important contributions come from chronic bronchitis and restrictive activity days.

Chapters 5 and 6present advise for policy-makers, and other official stakeholders, as well as report on the public's priorities for more sustainable energy production and usage policies. The author then reviewed an array of policy instruments that could be used to internalize the externalities of electricity generation and usage with the objective to reduce the negative human health and environmental burdens that are currently being experienced. The recommendations are based upon the feedback received from the questionnaires that were sent to 380 decision-makers, legislators, and to 600 public persons in the Kingdom of Bahrain during the period June-July 2007.

Chapter 5- Policy Selection for the Internalization of the Currently Externalized Cost of Electricity Generation and Usage in the Kingdom of Bahrain

Introduction:

This chapter is devoted to discussing the policy-makers (Members of the Parliament and of the Shoura Council) and stakeholder's choices for suitable policies and the related instruments to internalize the externalities of electricity generation and usage. The recommendations are based upon the feedback received from the completed questionnaires that were sent to 380 decision-makers and legislators in the Kingdom of Bahrain during the period June-July 2007. Out of 380 questionnaires sent to decision makers and other stakeholders concerned about the electricity production sector, 231 respondents completed the questionnaire. The SPSS software was used to calculate frequencies and percentages for the diverse variables.

The purpose of this "questionnaire" was to help the thesis author to gain insight into the attitudes and suggestions of public officials about the appropriate instruments of environmental policy to internalize the externalized costs of electricity generation and usage in the Kingdom of Bahrain, and to test if the prospective choices of market-based instruments are in line with the global policy trends.

Overall, market-based instruments are regulations that encourage behavior through market signals rather than through explicit directives regarding pollution control levels or methods. By way of contrast, conventional approaches to regulating the environment are often referred to as "command-and-control" regulations, since they allow relatively little flexibility in the means of achieving goals. Such regulations tend to force firms to take on similar shares of the pollution-control burden, regardless of the cost. Command-and-control regulations do this by setting uniform standards for firms, the most prevalent of which are technology- and performance-based standards (Stavins 2001)[152].

Market-based environmental policy mixes have been adopted by many OECD countries and by some developing countries such as Singapore, and China.

Goulder and Parry (2008)[153] present interesting evidence from several studies that addressed pollution externalities with different policy instruments. According to the estimates, pricing instruments (emission taxes, fuel taxes, or tradable permit systems) would reach the same level of pollution abatement with considerably lower costs (in the range of 40-95 % lower) than regulatory instruments (technology mandates or performance standards).

Chertow and Esty (1997)[154] called for a next generation of environmental policies because of the ineffectiveness of the “command and control” approach. They acknowledged that although the laws enacted in response to growing environmental activism in the late 1960s benefited the environment, they assert that further progress through “command and control” regulatory approaches will be limited. They contend that many current environmental problems cannot be addressed effectively by further tightening of emission standards.

A European Union study (CEC 1995)[155] written by a group of independent experts expressed alarm about the potential threats to Europe’s competitiveness posed by excessive environmental regulations. They present evidence that environmental regulations adversely impact their international competitiveness; such concerns continue to influence the industry’s approach to environmental policy. Regulatory standards are consistently opposed and market-based mechanisms such as removing subsidies, and emissions trading are the preferred alternatives.

In this questionnaire, the author investigated the perception and willingness to pay of Bahrain decision makers and stakeholders for different characteristics of energy policies that stimulate the production of renewable energy by using choice experiment (Longo *et al.* 2007)[156]. In a choice experiments-based survey, respondents were asked to choose between hypothetical public programs or commodities described by a set of attributes (see Hanley *et al.* 2001)[157]; hypothetical programs of commodities differ by the level that two or more attributes take. Respondents trade off the levels of the attributes of the programs or goods, one of which is usually its cost to the respondent, allowing researchers to infer the willingness to pay for public goods or programs and the implicit value of each attribute (see Hanley *et al.* 1998)[158].

In section 5.1, the author presents a list of policy options that could be used as parts of an integrated approach to internalize the currently externalized impact of electrical power production and usage within the Kingdom of Bahrain.

5.1 The Criteria of Policy Selection:

The first step in designing the policies was to identify the selection criteria (attribute) for the hypothesis, choosing the number of criteria and their levels is a very difficult exercise because it is important to identify the criteria that best describe the policy to be evaluated, and at the same time to limit the number of criteria and levels, because the higher number of criteria and levels, the more difficult and complex the choice exercise becomes.

1. Accordingly, the criteria were limited to nine elements considered as basis for the trade-offs among the designed policies (i) the cost of the policy (ii) the share of the cost of internalization that producers and consumers bear (iii) the security of the electricity supply (iv) the achievable percentage of energy efficiency (v) the achievable share of renewable energy (vi) the reduction percentage in air pollution and GHG emissions (vii) the potential avoidance of health costs (viii) the potential savings on fossil fuel consumption.

5.2 Questionnaire Description:

The questionnaire first provided an introduction of the respondents to illustrative questions by describing a hypothetical policy and its attributes for the internalization of currently externalized costs of electricity production and usage.

The questionnaire was divided into three parts:

a) The first part was comprised of seven multiple-choice questions. Each choice from the first six questions presented respondents with two hypothetical policies (policy A and policy b). Each policy was described by the nine previously stated attributes. In each exercise, policy A differs from policy B, in the level of attributes (criteria). For each pair choice, respondents were first asked to choose the policy they find more attractive and to then choose among two policies and the option of not implementing any policy. In the last question, they were asked to choose the most attractive policy from among the 12 policy options given in the six choices, and to then provide the reason(s) behind their selection.

b) The second part of the questionnaire included questions designed to engage the respondents that did not fully understand the choices in the first part of the questionnaire. The respondents were then asked to rank the importance of the criteria presented in the multiple-choice exercise in order to compare the results.

c) The last part of the questionnaire asked respondents to state which policy instruments they prefer to be used for the internalization of the externalized costs of electricity production and usage. They were asked if they agree or disagree to use the results of the RiskPoll model in designing policies for environmental regulation related to the energy sector.

Finally, the questionnaire was concluded by asking respondents the sector within which they work and if they filled in the questionnaire as a representative of the organization in which s/he works or if they filled it in as a private individual. (A copy of the questionnaire is attached in Appendix 1).

5.3 Methodology:

When policy makers and stakeholders were asked to choose the right policy and instruments to internalize the externalized costs of electricity generation and usage, they were required to propose a solution that would provide the best outcomes in terms of the evaluation criteria, described above. However, it was difficult to identify a single policy and related instruments that might outperform the others in terms of improved efficiency, decreased costs and reduced impacts. The choice of the policy and instruments will always require trade-offs among the criteria. Or an integrated, holistic approach must necessarily be multi-faceted in nature.

In this questionnaire, the main objective was to identify and to evaluate the possible policy alternatives to achieve the internalization of the currently externalized costs of electricity generation and usage. The choice of the policy instruments depends on how the instruments may perform in terms of the identified criteria.

5.4 Results:

Out of 380 questionnaires that were sent to decision-makers and other stakeholders concerned about the electricity production sector, 231 respondents completed and returned the questionnaire. (Appendix 2), the distribution of the respondents was: Academics 8.5% (19 respondents), Government policy-makers 29% (65 respondents), Researchers 2.7% (6 respondents), Policy-makers in the field of electricity 19.7% (44 respondents), Industry 21% (47%), and legislators about 19% (42 respondents). Also, 57% of the respondents answered the questionnaire as a representative of their organization, and 43% as private individuals.

Most of the respondents (84.8%) found the choice exercise clear and had no problems in filling in the questionnaire. Thirty-four persons (15%) however, judged the choices to be difficult because of the following:

- There were unknown bases for the calculations and unknown accuracy of them;
- There were unknown capital costs for solar/wind energy;
- There were too many indices and options to compare;
- It was difficult to convert the proposed rates into monthly average household consumption cost increases.

When asked which policy they found to be the most attractive among the 12 policy options provided in the questionnaire, 80 persons (36%) recommended adoption of **policy J,** and 46 persons (20.6%) selected **policy L** because the external costs of electricity for the two policy options are quite reasonable for industry and for the community with no power disruption being projected as a consequence of those policies.

According to the respondents, the current cost of electricity is high compared to other Arabian Gulf countries, and raising electricity costs further will make industry and other productive sectors non-competitive, and will add additional burdens on the poor people. The results show that respondents preferred policies with the lowest increases in prices.

One of the other explanations for this result is that the respondents preferred policies that require producers to bear the costs of the internalization, or at least require dividing the cost equally between the producers and consumers.

The comparison between each set of hypothetical policies in section 1 of the questionnaire revealed that the number and percentage of respondents who selected policy J, and policy L were 165 persons (74%) preferred policy J, and 156 persons (70%) preferred policy L (refer to Appendix 2).

Additional insights into the respondent's preferences to two hypothetical policies were obtained from their replies when asked to choose between the two policies and the option of not implementing any policy and therefore, to not internalize any currently externalized costs.

The results were that12.6% of the respondents preferred not to add any internalized costs in comparisons between policies I and J, and 28% preferred No Policy in comparisons between policies K and L**.**

The percentage of respondents who selected not to add any internalized cost was 35% when comparing policies E and F and 30% when comparing policies C and D (refer to Appendix 2).

Another important finding was that when the respondents were asked if they considered all the characteristics of the policies when comparing between the hypothetical policies, the results reveal that 165 persons (74%) considered the 9 criteria, which were presented in the questionnaire. However, the respondents who gave attention for only some of the characteristics were 26%, among these 12% gave attention to the cost of the policy, 7.5% gave attention to the impact on the health budget, and 4% gave attention to the possible increase in energy efficiency, while the remaining percentages were distributed among the other criteria (refer to Appendix 2).

In this context, 67 persons (30%) ranked the impact on the health budget as the most important element that should be considered when we seek to internalize the currently externalized costs. The challenge of greenhouse gas emissions was in second place with 22%. This is not a surprising result especially since most of the respondents were decision-makers who are aware of the impact of climate change can have upon small island nations such as Bahrain. The third most frequently selected element was selected by 20% of the respondents; it pertained to the importance of switching increasingly to renewable energy.

Another interesting insight was obtained when respondents were asked to select the policy instruments that might be used in the Kingdom of Bahrain to internalize the currently externalized costs of electricity; the analyses revealed that approximately 60% preferred the following instruments:

- Subsidies to be given to consumers to improve the energy efficiency of their system (60%).
- Subsidies to be given for producers to improve the energy efficiency of their system (60%).
- Subsidies to be given to commercial producers of energy from renewable sources (65%).
- Subsidies to be given to consumers to purchase and install renewable energy equipment (60%).

However, 57.4% suggested subsidies to be given to consumers who purchase renewable energy. This result suggests that the respondents appreciated a policy that encourages the production of electricity from renewable energy, and the use of the additional income from the higher cost electricity should be used by the Kingdom to improve the energy efficiency of the systems of producers and consumers.

Most respondents preferred policies that use other instruments such as the 'command and control,' approaches, tradable emissions, and pollution taxes. The results show that from a total of eight policy instruments proposed,67% support the command and control, and 64% preferred the tradable emission approach, while 50% preferred pollution taxes as a tool to internalize the currently externalized costs.

Finally, 58% of the respondents recommended the use of the RiskPoll methodology and results in designing policies for environmental regulations of the electricity production sector in Kingdom of Bahrain, while 17% did not agree, and 25% did not provide their opinions because they were not sufficiently knowledgeable about the suitability of the RiskPoll methodology.

The questionnaire results provided valuable insights about the respondent's relative lack of support for structural changes in the power generation policy in the Kingdom of Bahrain, most of which were consistent with the earlier analyses of Bahrain's electricity policy. The author is convinced that the results of such attitudes contributed to the worsening of the externalized costs related to electricity generation. These problems cannot be solved by only removing the heavy subsidies of electricity and water tariffs but must also include a more comprehensive package of economic, technical, and legislative tools.

The questionnaire results revealed the desire of respondents to maintain the subsidies for the electricity tariffs, and a gradual shift to renewable energy through their access to incentives in the form of subsidies to the renewable energy consumers and producers; this is a policy that would, in the long-term, mitigate the externalized costs of power generation.

The following are features of a new policy that could be drawn from the results of this questionnaire:

1- In the short-term, priority must be given to removing the subsidies on electricity tariffs. The respondents anticipated that the externalized costs would decline due to energy conservation and the use of renewable energy through the use of financial resources available from removal of the subsidies.

2- Internalizing the currently externalized costs of electricity generation and usage should be the second priority after confirming the results of the first priority.

3- Any policy aim to mitigate the externalized costs of electricity generation must contain multi- economic, technical and legal tools.

Summary of Chapter 5

Chapter 5 presented the answer to the sub-question posed within the research framework regarding the appropriate policies and the structural changes that can help to lead to adequate costing, pricing and taxing of electricity and thereby, help to remove subsidies and to internalize the currently externalized costs of electricity generation and usage, thereby helping the Kingdom of Bahrain to become more sustainable.

Results of 231 respondents to the questionnaire were used for the policy analyses. The respondents were invited to sequentially select a preference from each of multiple sets of two policy options.

Several hypothetical policies and policy instruments were proposed. The choice of the optimal policy should consider several criteria such as who will pay for internalizing the currently externalized costs and what should be the share of those costs that should be borne by producers, consumers, the government and other stakeholders. What emphasis should be placed on the value of energy security? What emphasis should be placed upon improvements in energy efficiency and on making the transition to renewable energy sources?

The analyses revealed that approximately 60% preferred the following instruments:

- Subsidies should be given to consumers to improve the energy efficiency of their system (60%).
- Subsidies should be given for producers to improve the energy efficiency of their system (60%).
- Subsidies should be given to commercial producers of energy from renewable sources (65%).
- Subsidies should be given to consumers to purchase and install renewable energy equipment (60%).

Additionally, 57.4% suggested that subsidies should be given to consumers who purchase electricity from renewable energy sources and personally install renewable energy systems on their buildings.

Chapter 6- Electricity and Environmental Considerations - Results of the Bahrain Island Public Citizen Survey

Introduction

For the purpose of supporting the data obtained with the questionnaire provided to public authorities that was discussed in Chapter 5, the author developed and used a second questionnaire to obtain insight into Bahraini's knowledge and concerns regarding the electricity generation issues as well as to assess their attitudes pertaining to the appropriate policy options that should be used. This questionnaire was different in form and substance from the previous one but was designed to complement it. It helped the thesis author to develop a more comprehensive picture of the public's opinions about the issue of internalizing the externalities of electricity generation. The survey was designed to obtain insight into the following issues:

- The level of awareness among Bahraini's regarding the environmental issues related to electricity generation;
- The willingness of Bahrainis to remove subsidies from electricity prices;
- The willingness of Bahrainis to pay to internalize externalities;
- The level of support for utilizing renewable energy;
- The willingness to pay to develop renewable energy;
- The level of support for the Bahraini legislators to require power plants to utilize renewable energy in electricity generation.

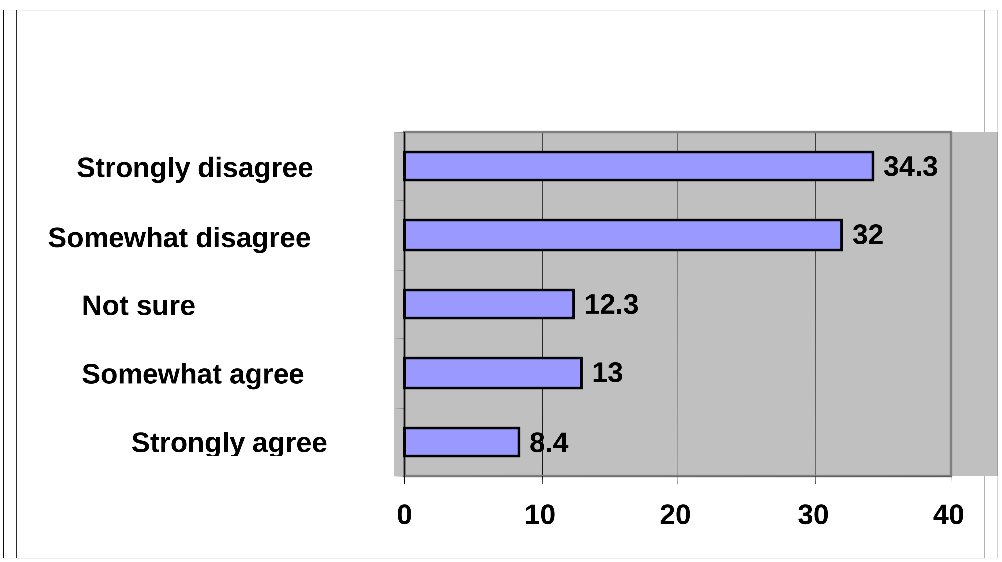
The survey designed to probe attitudes toward the environment and test the reception and viability of various proposed policies by using choice preference method (Appelbaum and Cuciti, 2003)[159], see also (The GfK Roper Yale Survey on Environmental Issues, 2007)[160].

Out of 600 questionnaires distributed to people from different regions, genders, ages, educational levels and different specializations, a total of 395 respondents answered the questionnaire between 28th September and 22nd October 2006. Copies of the questionnaire and of the statistics derived during analyses of the data are included in Appendix 3. The research methodology is presented in Appendix 4. Distribution of the respondents is reported by region, age, gender, and sector in Appendix 5.

6.1 Survey Results:

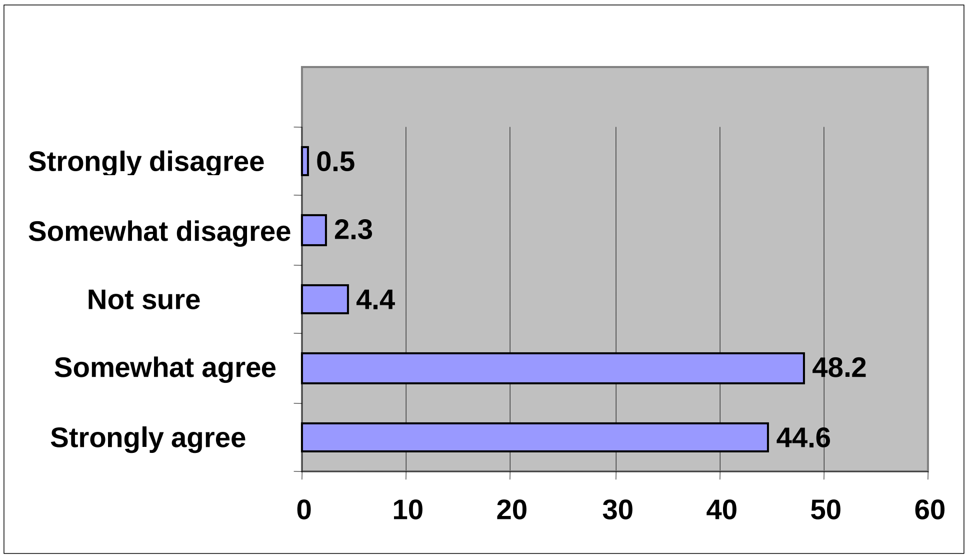
The survey first asked respondents if they agree or disagree on several environmental statements. The purpose of these initial statements was to determine if respondents were sufficiently aware of the environmental issues related to electricity to be able to provide meaningful responses. When asked to give their views about the following statement:“there is no relation between over-consumption of electricity and pollution,” the majority (66.3 %) said that they disagree with that statement. Their responses were subdivided according to 34.3% strongly disagreed, and 32% disagreed (See Figure 47). This means that the majority of respondents believed there is a positive relation between over-consumption of electricity and environmental pollution, while 33.7% were subdivided into 8.4% strongly agreed, 13% agreed, and 12.3% were not sure about the statement. This reveals that about one third of the people were not environmentally aware on this point. Therefore relevant authorities should work to enhance the citizen awareness through deliberate and sustained environmental awareness programs; either through the curricula at the different academic levels and/or through the media.

Figure 47. The Respondent’s Awareness about the Relationship Between Over-Consumption of Electricity and Pollution



Consistent with these responses, when the respondents were asked to agree or disagree with the statement “production of electricity from fossil fuel contributes to increasing air pollutants and deteriorating air quality”, 92.8% agreed with the statement, 4.4% were unsure, 2.8% disagreed with the statement (Figure 48).

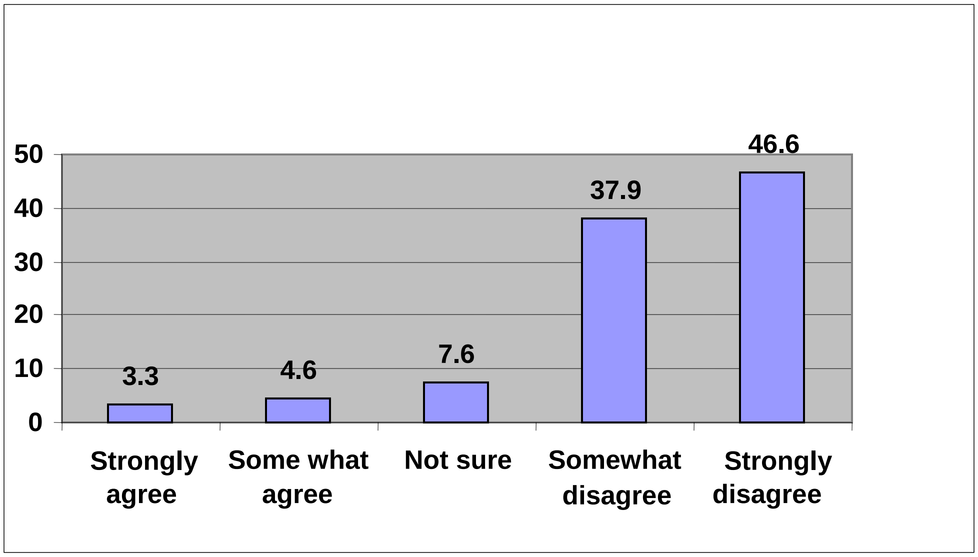
Figure 48- The Percentage of Responses of the Contribution of Electricity Generation to Air Quality Deterioration



More than 85% of the Bahrainis agreed with the statement “increasing emissions of carbon dioxide and other pollutants are the main reason behind global warming”, 11.9% were unsure, and 2.3% disagreed with the statement.

The percentages of answers to the fourth question, (will Bahrain Island be affected by global warming?) were similar to those for question three. In this case, 84.5% disagreed that Bahrain will not be affected by global warming, whereas 7.6% were unsure, and 7.9% agreed with the statement (Figure 49).

Figure 49.The Percentage of Responses Pertaining to the Impact of Global Warming on Bahrain



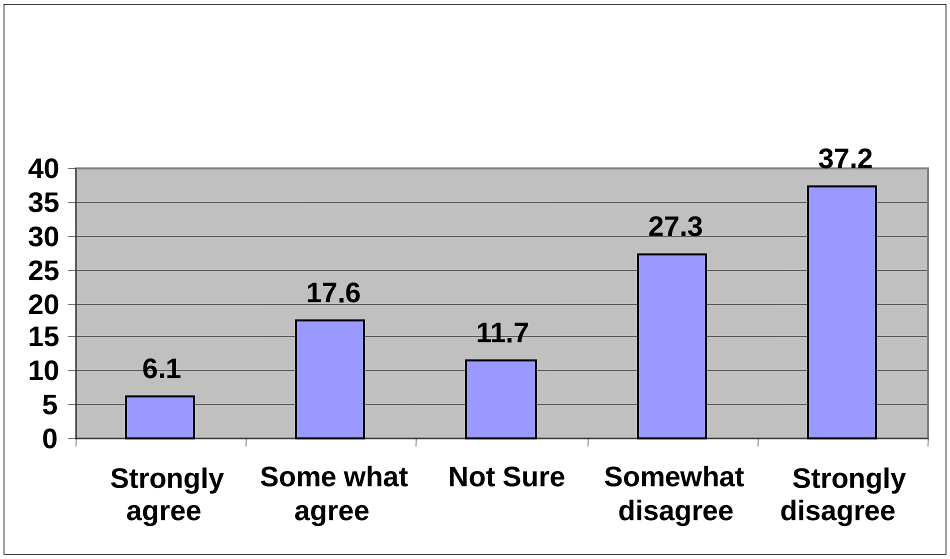
Bahrainis believe that the increasing demand for gas for the purpose of electricity generation will soon deplete the indigenous gas reserve in Bahrain. For this question, 59% agree with the statement, 30% were not sure and 10.9% disagreed with the statement.

The last question on the first part of the survey was, do you agree or disagree with the, statement "clean technology is a base for a clean environment?" The responses were, 91.3% agreed, 4.3% disagreed, and 4.1% were not sure.

After the first series of questions, the respondents were provided the following statement: "The government subsidy for electricity has significant impact on the environment." The results were: 46.9% disagreed 26.8% were not sure and 26.3% agreed.

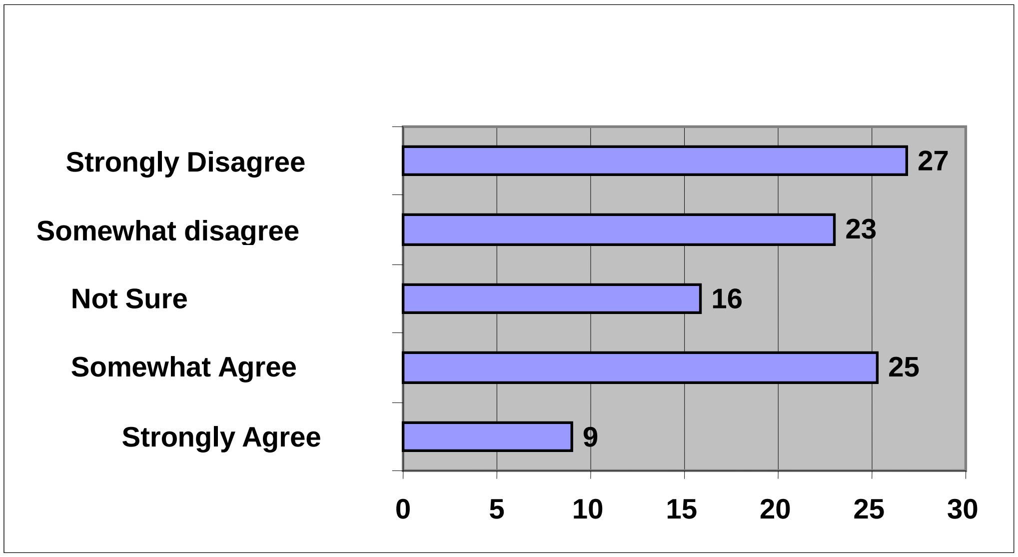
The next statement was: "To conserve resources and the use of electricity, the electricity prices should increase gradually." In response, 64.5% of the respondents disagreed, 23.7% support subsidy removal, and 11.7% were not sure (Figure 50).

Figure 50. The Percentage of Responses Pertaining to the Removal of Subsidies on Electricity Prices



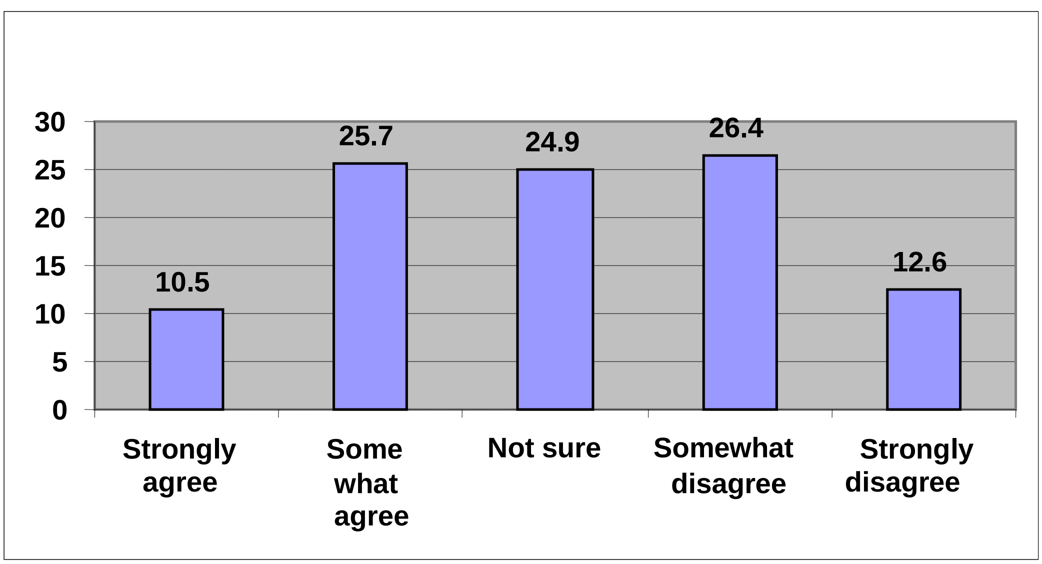
Despite their concern for the environment, the majority of Bahrainis responded to the question, “Do you support internalization of the environmental costs (Externalities) related to the production of electricity on the price of electricity?” it was found that (50%) were against the internalization of externalities in the price of electricity, 34% agreed to pay to internalize the externalities, and 16% were not sure (Figure 51).

Figure 51. The percentage of Responses Pertaining to the Question, Should Externalities be internalized Within Electricity Prices?



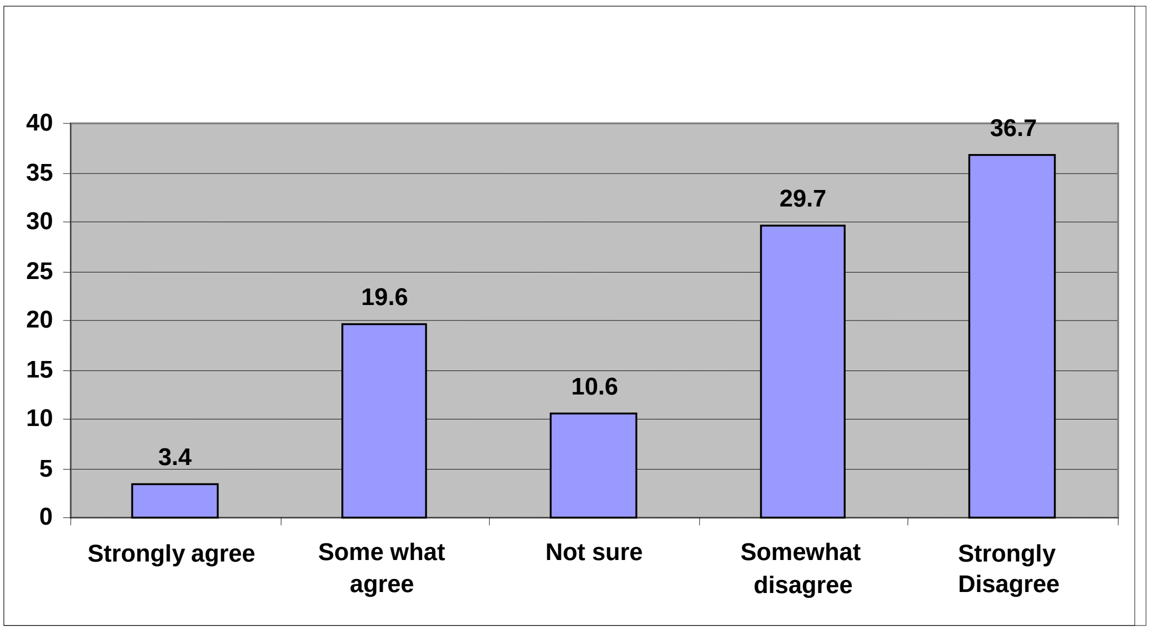
With regard to the question, "Is the 'polluter pays principle' an effective tool for environmental policy?" it was found that 39% disagreed, either strongly (13%) or somewhat (26%), while 25 % were not sure about their choice, 26% agree, and 11% strongly agree with the statement (Figure 52).

Figure 52. Application of the Polluter Pays Principle as a Tool to Internalize Currently Externalized Impact of the Energy Generation and Use



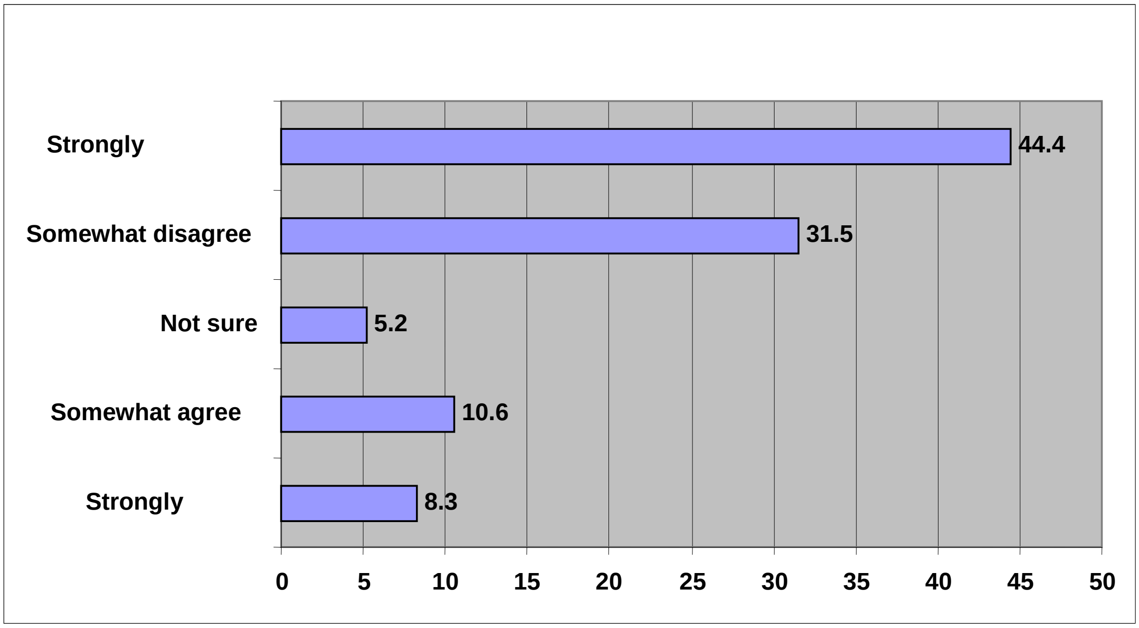
Responses to the next statement, “Electricity consumers should pay the actual price of electricity,” revealed that 66% disagreed, with 37% strongly disagreeing and 30% disagreeing. Further, it was found that 11 were not sure, 20 % somewhat agreed, and 3% strongly agreed to pay the externalities of electricity generation (Figure 53).

Figure 53. The percentage of Responses Pertaining to the Statement, “Electricity Consumers Should Pay the Actual Production Costs.”



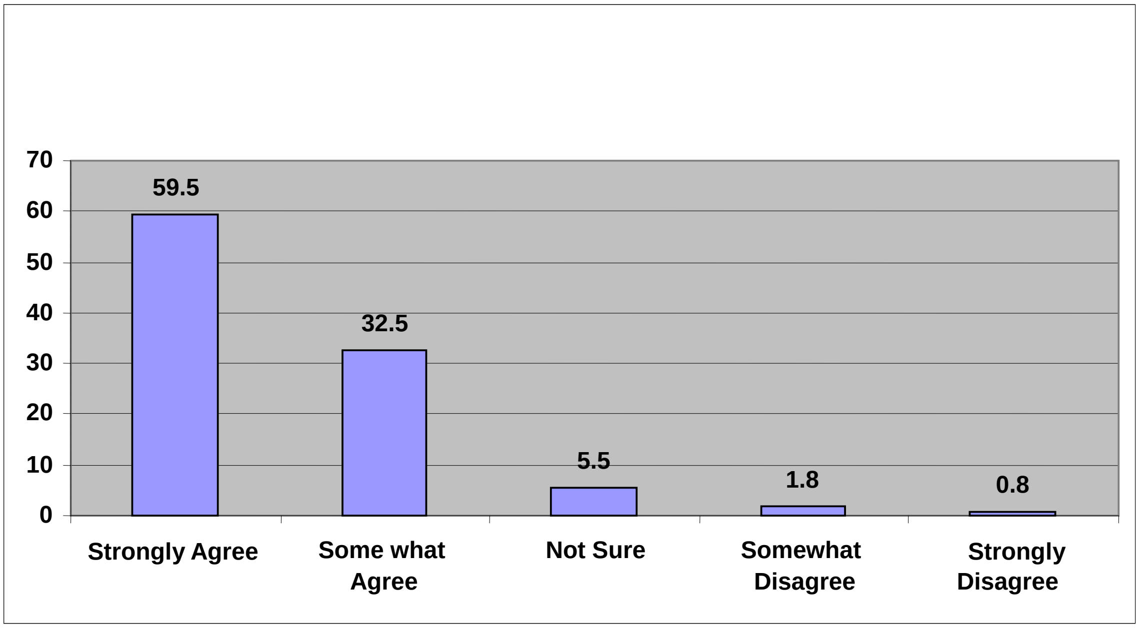
The last section of the survey asked respondents to give their views about their support for using renewable energy. First the respondents were asked to agree or disagree on the statement, “I don’t support a decision taken by the government to utilize renewable energy”. The results showed that there was substantial support for using renewable energy; 76% disagree with this statement, either 44% strongly, or 32% somewhat, 5% were not sure, 11% somewhat agree with the statement, wherein 8% strongly agree, which means they are against the utilization of renewable energy (Figure 54).

Figure 54. The Percentage of Responses pertaining to the Statement, "Do you Support a Decision Taken by the Government to Utilize Renewable Energy".



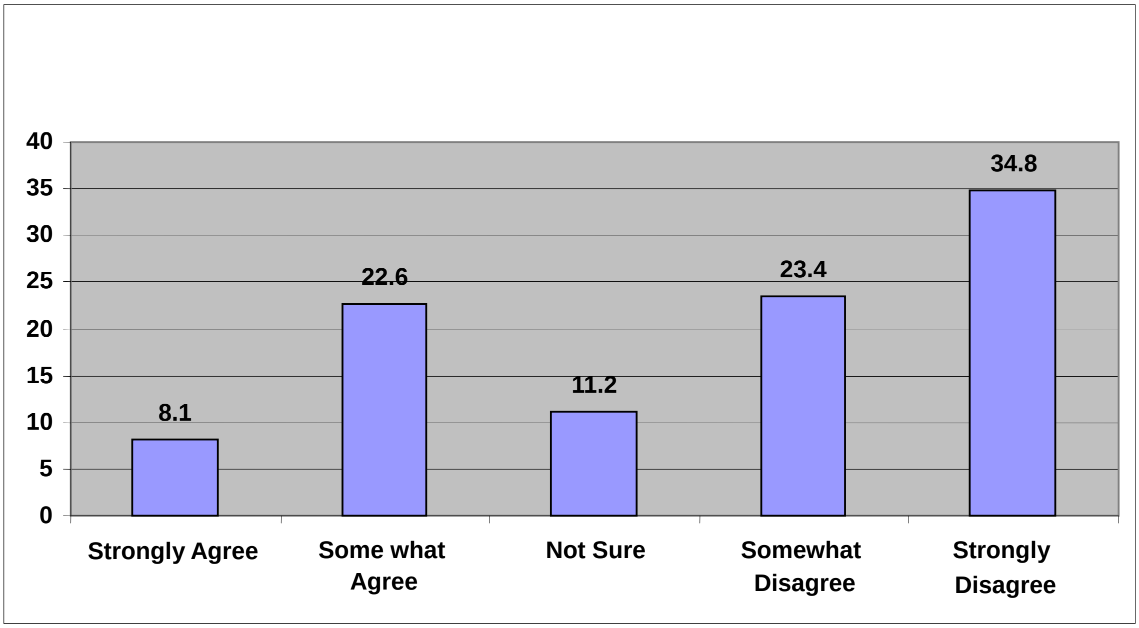
Responses to the statement, "Renewable energy contributes to resource conservation and environmental protection," revealed that 93% agree (60% strongly, and 33% somewhat) compared to 7% who do not agree (Figure 55).

Figure 55. The Percentage of Responses Pertaining to the Statement, "Renewable Energy Contributes on Resource Conservation and Environmental Protection."



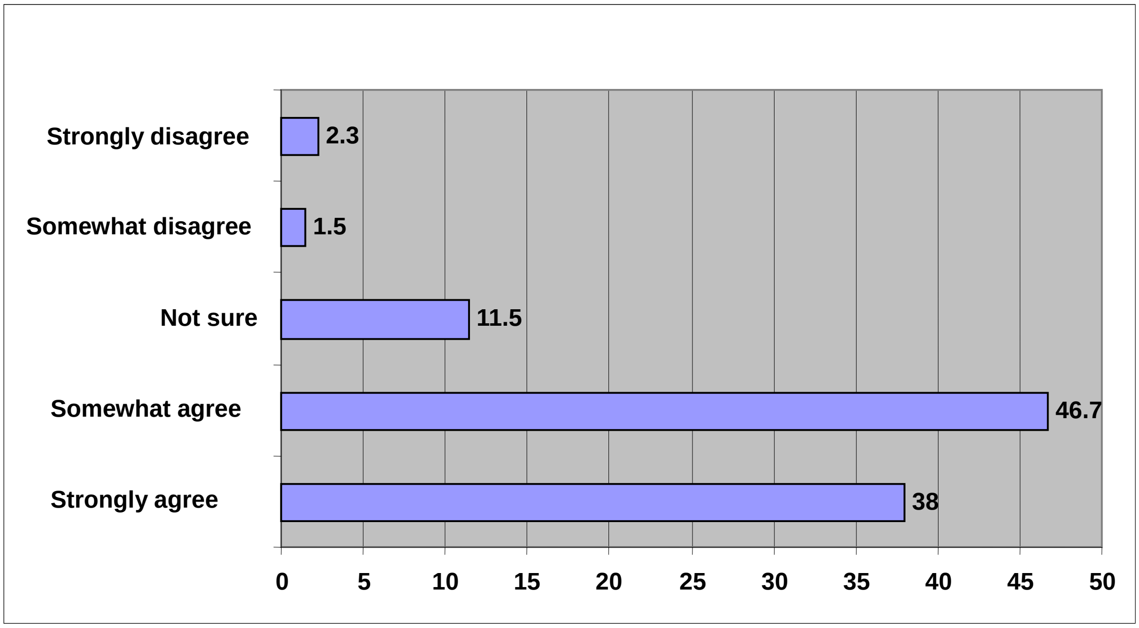
The responses to the statement, "I do not mind to pay monthly voluntary 5% from the electricity bill to support renewable energy development in Bahrain." revealed that despite their preference for renewable energy, the majority were not willing to pay to support renewable energy development in Bahrain. Fifty-eight %responded that they were not willing to pay a voluntary 5% extra per month on their electricity bill for investment in renewable energy, whereas 31% were willing to pay, and 11% were not sure (Figure 56).

Figure 56. The Percentage of Responses Pertaining to the Support to Renewable Energy Development in Bahrain.



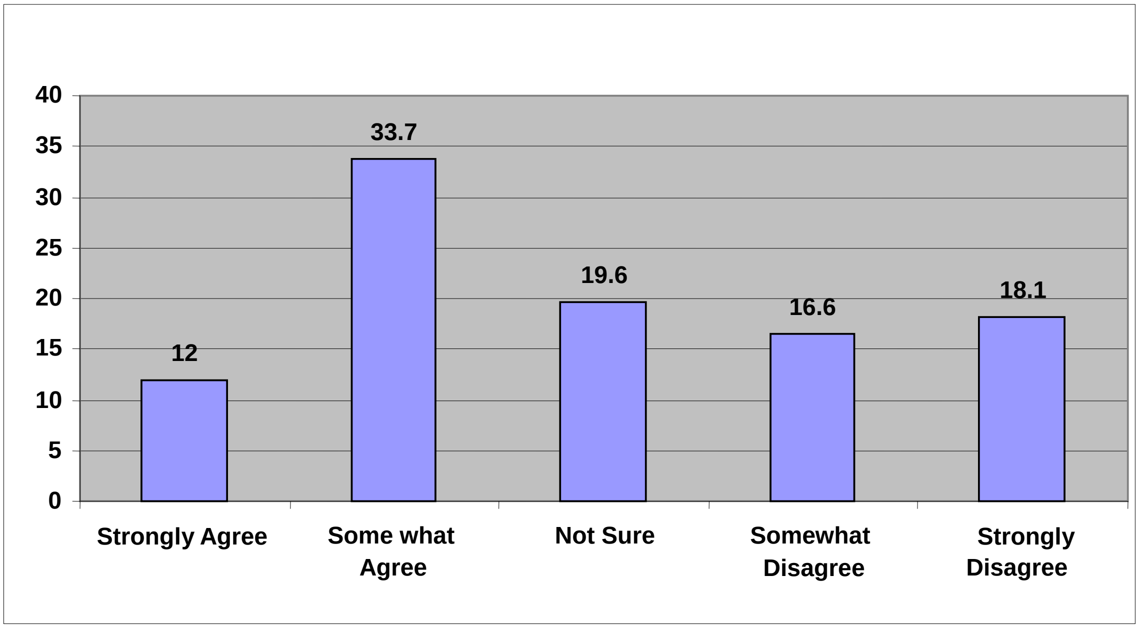
For the statement, “Bahraini legislators should require the power plants to produce 10% of their electricity from renewable sources within the next 10 years,” 85% supported it, 38% “strongly supporting” and 46% “somewhat supporting” it. Only about 4.0% expressed opposition, and 12% were not sure (Figure 57).

Figure 57. The Percentage of Responses Pertaining to the Statement, "Would you Support the Bahraini Legislators Requiring the Power Utilities to Produce 10% of their Electricity from Renewable Sources Within the Next 10 Years?"



It regard to the statement, "Bahrainis are willing to pay 5% more if electricity is generated from renewable sources," it was found that 46% of the respondents were willing to pay, with 12% strongly willing and 34 % somewhat willing. At the same time 20% were not sure, 18% strongly disagreed, and 17% somewhat disagreed (Figure 58).

Figure 58- The Percentage of Responses Pertaining to the Statement, "Bahrainis are Willing to Pay 5% More if Electricity is Generated with Renewable Sources."



Summary of Chapter 6

Chapter 6 presented results of the electricity and environmental consideration questionnaire. It was found that of the 395 respondents, the majority of Bahrainis are aware of and do care about the environment. The majority seems to understand the links between the electricity fuel source and environmental impacts.

The results provided evidence of Bahraini's support for the use of renewable energy through their expressed willingness to contribute voluntarily to develop and use renewable energy based upon their support for legislative action requiring power plants to produce 10% of their electricity from renewable sources during the next 10 years, and upon their willingness to pay 5% extra to have electricity from renewable sources.

However, Bahrainis do not support, even a gradual removal of the electricity price subsidies, as a way to internalize the currently externalized costs of producing and usage of electricity.

These results had to be employed in the decision-making process to adopt appropriate policies to improve the efficiency of the energy sector, and correct the price distortions associated with the price of non-renewable resources through the application of a package of economic, legislative, and technical instruments as stated in chapter 7.

Chapter 7- Approaches for Internalizing the Externalities of Bahrain's Electricity Production Sector: Action Plans, and Policy Measures

Introduction:

Concern has grown in recent years over the issue of the negative human health and environmental impact of the externalities from electricity production and usage. The concerns pertaining to these externalities revolve around the economic consequences of the market distortions for the price of goods and services, and lead to environmental and human health degradation.

Getting the prices right is a prerequisite for market mechanisms to work effectively towards sustainable development in the energy sector. This requires identifying and valuing external costs, and eventually reflecting them in the prices of the goods and services provided. Internalizing external costs can be designed so that the prices provide the "correct" price signals that drive consumers' choices towards an optimum, taking into account social and environmental aspects as well as direct economic costs (Bertel and Frazer 2002)[161].

Electrical Power authorities, in many places on the world, have been exploring ways to incorporate environmental considerations into their national policies and resource planning; most of the advanced nations developed their regulations to mitigate the negative impact of these problems. The adopted policy tools by power authorities in these countries include tools such as stringent environmental standards, emission taxes, tradable emissions permits, and externality adders.

Bahrain, as a small island developing state, with limited natural resources, is facing a very tough situation due to the intensive use of fossil fuels and its related environmental pollution, the absence of resource management planning, and because if its failure to add the externality costs to the price of goods and services such as power generation; all of which have caused extensive losses to the national economy and to human welfare.

The impact and corresponding damage costs related human health effects, environmental damages and destruction of building materials by atmospheric pollutants generated by fossil fuel related activities in the three Bahrainis power plants were assessed using RiskPoll model (refer to Chapter

3). The calculated external costs related to the electricity production and usage in Bahrain ranges from 4 to 6 U.S. $ cents/KWh.

Furthermore, in order to develop policy options for electricity production in Bahrain, a questionnaire was developed and used to assess the Bahrainis' knowledge and concerns regarding electricity generation issues. The results of the survey revealed that the majority of Bahrainis are aware of and care about the environment. They seem to understand the links between the electricity fuel source and environment.

The survey findings revealed: their support for the use of renewable energy as evidenced by: a. their willingness to pay voluntarily to develop and use renewable energy; b. their support for legislative action requiring power plants to produce 10% of their electricity from renewable sources during the next 10 years; c. their willingness to pay 5% extra to purchase electricity from renewable sources. On the other hand, Bahrainis do not support, even a gradual removal of the electricity price subsidies that are currently provided. Thus, they do not believe that they should have to pay the actual costs of electricity production and thereby contribute directly to internalizing the externalities of its production.

Two surveys that targeted the public and the decision-makers in Bahrain was conducted (refer to Chapter 5 & 6). The purpose of those surveys was to investigate the preference of electricity stakeholders for policy and policy instruments for internalization of the currently externalized costs in electricity production and use.

Analysis of the survey results revealed that most of the stakeholders preferred policies that internalize a *low percentage* of the total damage caused by externalized pollutants from electricity production, because they believe, raising the electricity cost further will decrease the competitive of industry and other sectors and will add additional burdens on the poor people.

The objectives of Chapter 7 are to clarify the issues for policy makers and to provide a discussion considering options and their likely outcomes. This Chapter reviews generic policy related to the issues of electricity generation and activities that have played a role in expanding the use of renewable energy, energy efficiency, and in internalizing externalities, in other countries. This thesis author then discusses these measures in the Bahraini context.

The method adopted by this thesis author to outline these proposed policies was based on the preference of the Bahraini citizens and the decision-makers as discussed in Chapters 5 & 6; he also took advantage of the successful policies that are being used in many other countries.

7.1 The Current Situation:

Bahrain is dependent on natural gas to support the current living standard. Natural gas is the primary fuel for most electricity production and, in turn, also for providing potable water. Use of natural gas is a significant element of Bahrain government's policy of providing subsidized electricity. Due to the advantages of cheap electricity, heavy industry contributes 34% of Bahrain's GDP.

Electricity demand is growing at a high rate (6.5% between 2003 and 2004) ; the existing and committed generation capacity is 2808 MW, with an expected growth to 5160 MW in 2020 (MEW, 2006). Both the transmission and distribution networks are loaded very heavily, with the transmission network operating nearing at full capacity during summer periods. Bahrain also uses its limited oil resources to heavily subsidize transportation.

7.2 The Forecast Situation:

As Bahrain's natural gas and oil reserves decline, it is estimated that both will be used up within 12-15 yrs, the ability to continue to provide low cost electricity will also decline. The committed long-term power plant investment is in line with the planned medium and long-term growth in electricity demand. Solutions to the constraints in the transmission network are also committed, although this is hampered by the lack of knowledge of future projects. Forecasts reveal that within increasing demands, the fault level on the current transmission network will rise above the rating of the current generating plant's capacity to produce.

The population is estimated to grow to approximately 1.2 million people from the present level of approximately 700,000 by 2020; this will cause increased demands for both electricity, and water. It will also increase demands for health care, education, food, shelter, transportation etc.

It is important to highlight that the dependence on low cost energy and the neglect of the environmental costs should be changed by developing and implementing a National Sustainable Energy Policy. However, for the purpose of this thesis research, the discussion in this Chapter is devoted solely to issues related to the electricity production sector and therefore, it does not address the similarly urgent issues pertaining to water or other services and commodities.

7.3 The Role of a National, Sustainable Energy Policy:

A National Electricity Policy (NEP) is a document produced by a government, which addresses the issues of electricity production, distribution and consumption. The NEP should serve as a roadmap, which details measures the country intends to implement in order to achieve its goals and targets, as stated in the policy.

Supporting reports/documentation should set the background by detailing the existing electricity situation including; the resources of electricity production which are currently being employed, any international or national agreements, e.g. the climate change convention, the state of the economy, the anticipated increases in demand, current and anticipated fuel costs and the electricity price structures for diverse users.

The NEP should be comprised of a set of measures to help to ensure that the government's plans are achieved. These measures can include legislation, international treaties, incentives, taxation, and improvements in efficiency, exemptions, subsidies, and instructions for state-owned and managed assets. For the NEP to be successful, it should be written with a broad view of the short and long-term issues that must be addressed, including economic development, the environment, and sustainability.

7.4 The Objectives of the National Electricity Policy (NEP):

The objectives of the NEP should be to develop a set of conditions which will lead, in the long-term, to more sustainable use of electricity on Bahrain Island, before the fossil energy supplies are utilized.

The way electricity is currently used is unsustainable; the policy must address how the usage of electricity should change, while maintaining the present standard of living.

The following issues will significantly impact this objective and will need to be addressed as a matter of urgency:

- Depletion of oil and natural gas reserves and security of future external natural gas supplies;
- Increased cost of imported gas and the impact on electricity prices.
- Continuing electricity subsidies by government.
- Neglecting the internalization of environmental externalities on the electricity prices and upon the human health impacts.

The Bahraini government's current practice of making it possible for a significant portion of the economy to be based on the availability of cheap and subsidized energy must be questioned as it presents considerable risks for a sustainable future, As can be seen from the experience of United States, and western Europe, national economies based on high energy prices can be tolerated, with the proviso that state aid is available to mitigate fuel poverty. In contrast, there are a number of examples in the former Eastern Bloc countries where increases in energy prices to bring them more into line with world prices by removing subsidies, caused serious disruption to their industrial base and to their overall economies.

The National Electricity Policy (NEP) should be developed with the following questions in mind:

Diversity of Supply and Supply Security:

- What is the extent of energy self-sufficiency?
- Future energy sources?

Electricity Efficiency:

- How will electricity be consumed and how can its usage are reduced?

- Goals for future energy intensity, i.e. benchmarked against international best practices?
- How to encourage purchase and usage of energy efficient devices and what can be done to support demand-side management to further encourage society-wide energy efficiency improvements?

Renewable Electricity:

- How should the Bahrain government encourage public and private investments in renewable energy sources?
- What should be the target percentages and the timetable for Bahrain to become increasingly reliant upon renewable energy sources?
- What specific mechanisms (e.g. taxes, incentives, and standards) should be used to implement the NEP?

These objectives were included in the 2030 Bahrain Vision, which emphasized the following:

- Conserving our natural resources for future generations to enjoy;
- Implementing energy-efficiency regulations (e.g., for buildings and electrical appliances);
- Directing investments to technologies that reduce carbon emissions minimize pollution and promote the sourcing of more sustainable energy.

The policy can be achieved via a number of methods including, regulatory means, voluntary and legal agreements, economic means, and information dissemination activities through training and awareness programs.

7.5 The Proposed Action Plans and Policy Measures:

The regional and international experiences have shown that the traditional way of government management in electricity generation, transmission, and distribution has not guaranteed a cost-effective and reliable electricity supply. For this reason many countries have chosen to reform their electricity production sector into commercially oriented and financially independent utilities in order to achieve the efficiencies of the private sector.

The Bahraini government recognizes the importance of commercially oriented utilities and is pursuing a similar course by privatizing some of the state owned power plants. However, in order to gain the benefits of this policy, an independent electric power authority must be established and maintained on a commercial and accountability footing, and committed with the following policy:

- To provide a reliable and cost-effective electricity supply to meet the developing demand for electricity within Bahrain;

- To ensure that the electricity production sector expansions are economically and socially justifiable, and are based on a least cost development strategy that incorporates demand-side management to reduce peak loads and to conserve power;

- To achieve full cost recovery from consumer groups for the provision of electricity and related services (refer to the government's social obligations in Chapter 2);

- To minimize the detrimental impact of the power generation, transmission and distribution system on the environment and the community, and to ensure that the pollution costs (externalities) from power generation are incorporated into the electricity end-use tariffs;

- To issue and enforce the required legislation, regulations, and guidelines to promote energy saving, renewable energy usage, and appropriate economic tools;

- To develop, promote and implement policy instruments to internalize the currently externalized costs of electricity production and usage;

- To promote investments in renewable energy options for power generation such as solar, wind and other feasible renewable sources;

- To support and finance renewable energy research, development and demonstration of renewable energy based projects.

7.6 General Action Plans:

- The power tariff for all consumer groups should reflect the full cost of supply, through the removal of price distortions (subsidies, externalities).
- Any subsidies for low-income households should be justified and financed from the governmental budget.
- Pursue demand side management programs that are shown to be technically and economically feasible as well as those which are

ecologically and support human health improvement outcomes for the short and long-term.

- Maintain efficient program for rehabilitating and maintenance of the generation and distribution system to minimize power failure in the short and long-term.
- Provide the government and the public with information related to conservation, efficiency, and more efficient technologies.
- Restructure and empower the existing customer services department to be capable to handle the energy auditing programs, inspection, and public awareness efforts that will be needed.
- Promote incentives for energy saving schemes.
- Promote the purchase and use of energy efficient electrical appliances.
- Protect the community through the enforcement of appropriate technical, consumer health and safety standards and procedures.
- Protect the environment through the implementation and enforcement of environmental regulations, and guidelines.
- Develop ongoing resource assessment processes with regard to optimal usage of national renewable energy resources.
- Increase public awareness on benefits of and procedures for utilizing renewable energy (Solar PV, wind, and biomass etc.) through educational and awareness programs.
- Carry out Environmental Impact Assessments before any project is undertaken.
- Minimize the impact of existing power plants through monitoring and proper enforcement of environmental standards.
- Secure funding to upgrade the existing out-of-date power plants to meet the environmental and safety standards.
- Establish and empower an environmental department within the national power authority to coordinate all awareness/education programs on all energy related issues.

7.7 Proposed Policy Measures for the Bahrain Electricity Production Sector:

The study of the external costs of electricity generation in the Kingdom of Bahrain revealed that the reasons behind the high externalities as illustrated in Chapters 2, 3& 4 are a number of factors associated with the current energy policy; therefore, having consumers pay these costs without treating of the main causes, would prevent the success of any future policy.

This thesis authors believes that one of the priorities for the government of Bahrain as a first step is to remove the subsidy on energy prices and to charge producers and consumers the real cost of resources. But this must be clearly justified and have institutional support.

The proposed policy can be divided as follows:

7.7.1 The Proposed Immediate Action:

7.7.1.1 Gradual Subsidy Removal:

Subsidies to the power sector In Kingdom of Bahrain are a political decision as stated in Chapter 1, from economic point of view electricity should not be subsidized as the case for the other private goods. Moreover, subsidies to the power sector tend to lead to economic distortions and usually have significant adverse impact on the society welfare, national economy, and environment. The main impact of electricity subsidies include increasing demand for electricity and investment in capacity beyond the socially optimum level, adversely affecting the balance of payments, and environmental degradation and negative human health impacts.

The justifications for the existing subsidy system in Bahrain include ensuring security of Electricity supply from indigenous resources (mainly fossil fuel), increasing competitiveness of industries, most of which is electricity-intensive (Bahrain has the second largest aluminum smelter in the world, it produces about one million tons per year). The final policy justification for the current subsidy is that it supports the Kingdom's social and economic development.

The estimated annual government subsidy to the power sector for operations based on electricity production of 9.1 million KWh in 2005 are over 170 million BD (U$ 460 million) assuming power generations fuel is valued at $40/barrel oil.

Gradual subsidy removal to electricity tariff could help in reducing the current over consumption per capita; it was assumed that subsidy removal could achieve at least a 10% reduction in power demand (about 300MW); this would annually reduce emissions of carbon dioxide and other pollutants by 1.5 million tones. This calculation is based on ~500gCO_2eq/kWh (Parliament office of Science and Technology, 2006).[162]

Removing fossil fuel and electricity subsidies from the low-income population would have strong impact on their living standard, therefore; policy-makers must understand the impact of the existing subsidy system, and any reform must take these issues into consideration to create a comprehensive policy package to balance the potentially negative effects of subsidy removal. While the environment and economic effects of subsidies are fairly well understood, social impact on welfare and employment are not as well evaluated due to difficulty of measurement.

Although 64.5% of households oppose any increase in the electricity tariff, about 31% state that they would accept to pay a voluntary 5% increase per month (approximately U$ 2.65 assuming the average monthly consumption for a household consisting of five people is around KWh 4000) of their electricity bill to support renewable energy development in Bahrain. This evidence indicates an electricity tariff increase, although unpopular in general, might be considered more publicly acceptable if substantially focused at supporting renewable energy. It is important to highlight that, some of the required funds to support and finance the electricity policy option could be fully financed by a tariff increase of US$ 31.80/year for all power users.

Removing subsidies that are both economically costly as well as harmful to the environment would be a win–win policy reform. The Bahrain government needs to take account of national circumstances in reforming subsidy policies and/or in designing new ones.

There are a number of basic principles that the Bahrain government should apply in designing subsidies and in implementing reforms to existing programs. Experience shows that, when applied, subsidy programs and their reform should meet the following key criteria (UNEP, Electricity Subsidies, 2004):

- **Well targeted:** Subsidies should go only to those who are meant and deserve to receive them;
- **Efficient:** Subsidies should not undermine incentives for suppliers or consumers to provide or use a service efficiently;

- **Soundly based:** Subsidies should be justified by a thorough analysis of the associated short and long-term costs and benefits;
- **Practical:** The amount of subsidy should be affordable and it must be possible to administer the subsidy in an efficient, effective and equitable manner;.
- **Transparent:** The public should be able to see how much subsidy programs cost and who benefits from them;
- **Limited in time**: The subsidy programs should have a limited duration, preferably set at the outset, so that consumers and producers do not get hooked on the subsidies and the cost of the program does not spiral out of control.

From the results of the survey, conducted for this thesis research to assess the attitudes of the Bahraini public, it was obvious that there is strong public resistance to have the current subsidy removed in order to pay for the currently externalized environmental costs related to electricity production and use.

Therefore, reforming existing electricity subsidies will require strong political will to take the tough decisions that will benefit society as a whole in both the short and the long-term.

Certain approaches can help in this process. Implementing reforms in a phased manner can help to soften the financial pain of those who stand to lose out and give them time to adapt. This is likely to be the case where removing a subsidy has major economic and social consequences. The pace of reform, however, should not be so slow that delaying its full implementation involves excessive costs and allows resistance to build up. The authorities can also introduce compensating measures that support the real incomes of targeted social groups in more direct and effective ways. That goal may be considered socially desirable. It may also be the price that has to be paid to achieve public and political support for removing or reducing the subsidy and for reducing the human health costs due to the air pollution caused by the current generations of electricity generating facilities.

Whatever the precise design of reform policies, politicians need to communicate clearly to the general public the overall benefits of subsidy reform to the economy and to society as a whole, and consult with stakeholders in formulating reforms to counter political inertia and opposition. Stakeholder consultation helps to ensure transparency and adds legitimacy to the proposed reforms, thereby increasing the chances of the policy being accepted.

7.7.1.2 Demand Side Efficiency Measures:

Air conditioning and lighting are significant electricity end-uses in Bahraini households. Lighting efficiency measures, including automatic controls for exterior lighting, higher-efficiency fluorescent lighting fixtures, ballasts, lamps, and controls, and compact fluorescent lamps (CFLs) in place of incandescent bulbs, can significantly reduce lighting electricity consumption and peak power use. High efficiency air conditioning, including higher-than-standard efficiency compressors, heat-exchangers, fans, control systems, and other associated equipment also have great potential to reduce space cooling power requirements, which represents almost half of the total power generation in Bahrain.

The assessment of the options focused on the introduction of CFLs and high efficiency air conditioners in the context of the existing electricity supply system. For both measures, this would involve a complete replacement of existing inefficient technology, phased-in over a 10-year period. The combined effect of these measures would result in a combined reduction in carbon dioxide emissions by 2015 of about 1.2 million tons/yr. (0.95 million tons for air conditioners and 0.21 million tons/yr. for CFLs).

The cost of saved carbon for implementing this option is negative (i.e., –$33.0/tons of carbon dioxide avoided) indicating its attractiveness from an economic perspective. The major impediments to implementation of high efficiency technology in Bahrain are likely to be the current low electricity tariffs, the high initial cost of many of the technologies relative to the less costly alternatives, and the current lack of availability of the efficient products themselves. Moreover, the introduction of lighting and space cooling efficiency improvement measures requires supply and demand for the technologies to be built up at the same time.

Households are responsible for the high percentage of the aggressive demand on electricity in Bahrain, but they could contribute positively on the energy efficiency programs; the power authority should adopt an energy policy for households that contain the policy instruments addressed in the following paragraphs.

7.7.1.2.1 Energy Performance Standard

The current Bahrain building policy lacks an Energy Performance Standard (EPS) that can/should be designed to provide requirements regarding the energy performance of a house or commercial building. According to this instrument, project developers and other parties to the project, are obligated to take energy-saving measures in all new developments. Also, some countries have developed requirements for energy efficiency improvements for retro-fitting existing buildings..

Bahrain could benefit from the international experience in this field, for instance, in The Netherlands, its energy efficiency action plan for 2007 has very stringent EPS, and the Energy Performance Coefficient (EPC) has been decreased from 1.4 in 1995 to 0.8. As a result of these measures, newly built houses save an average 30% in energy, additional EPC measures could result in tightening the standards by 25% around 2012 and 50% around 2015 with respect to the current standard. Such stringent standards could mean that the EPC for buildings would shift to 0.4; this would mean that the energy consumption for space heating & cooling could be comparable to that of passive houses (15 kWh/m^2)[163].

7.7.1.2.2 Subsidy Scheme to Low Income Households:

In order to encourage and remove the barriers facing the low-income households with respect to energy efficiency measures, the Bahraini power authority should initiate a subsidy program to provide the technical measures, advice and information for the rational use of energy. Low-income households generally face two barriers; financing the investments on energy efficiency, and having access to the right information.

The Power authority could subsidize projects to provide advice and information to low-income households, and to provide technical assistance, e.g. automatic controls for exterior lighting, higher-efficiency fluorescent lighting fixtures, ballasts, lamps, and controls, and compact fluorescent lamps (CFLs) in place of incandescent bulbs.

The required seed money to finance this scheme might be obtained from the gradual subsidy removal, internalizing the currently externalized costs of electricity, or other economic tools could be applied to remove the current price distortions.

7.7.1.2.3 Establish a Green Investment Scheme:

The government should seriously study the proposal to make arrangements with banking sector to offer financial means to invest in energy saving measures. Such green investments can be supported and financed with special loans with low interest rates. The green mortgage could be one of these tools, when the building meets the demands that were formulated by the regulatory authority for the sustainable building, the owner can receive a discount on the interest rate. However, in order to make this program successful, the government needs to remove barriers for building owners to invest in their building, currently, many barriers prevent building owners from actually improving their own real estate. Implementation of an effective plan could overcome the following barriers (The Netherlands Energy Efficiency Action Plan 2007):

- **Unawareness of the financial savings that can be made by energy savings.** This barrier can be removed by information campaigns;

- **Uncertainty and distrust about the quantity of financial savings that will be achieved.** Certification and quality management can help to increase the confidence in the results of energy saving measures. Smart meters can help to inform the dweller on his present energy consumption;

- **The home-owners are unable to finance the necessary investments in energy saving measures.** Banks should offer attractive financing programs and government should set up supporting programs, and financially stimulate home owners, industrial and commercial buildings owners to invest in energy efficiency. A subsidy for renewable options such as solar boilers, and solar PV should be considered.

7.7.1.2.4 Effective Energy Saving Campaigns

The Bahraini government needs to strengthen the existing energy saving programs and create new instruments and activities to bring the subject of energy saving to the attention of consumers by adopting the following instruments:

- Effective information centre for consumers to obtain answers to questions by telephone and via electronic mails that are sent to the centre, and to use different media to show the importance of the environmental issues and the roles of energy and environment;

- Provide energy advice through lectures and websites for the interested consumers groups; these approaches can provide consumers with tips and instructions on how to make their energy consumption more efficient & sustainable;

- Provide television programs targeted to different age groups such as children, using the theme of energy saving;

- Inform prospective buyers of household appliances by providing information about the energy efficiency of appliances through different media such as website, and booklets;

- Support a subsidy scheme to replace incandescent light bulbs and switches with energy saving bulbs and smart systems. The government has a subsidized and financially supported water-saving campaign to replace the regular water showerheads and taps with water saving devices. That campaign could be extended to also focus upon energy saving.

7.7.1.3 Electricity Efficiency of Power Generation:

The overwhelming majority of GHG emission in the electricity supply sector is from the combustion of natural gas for electric power generation. Numerous small and large units operating at low efficiencies characterize the Bahraini electric power supply system. Replacement or upgrading to achieve greater combustion efficiencies would considerably reduce annual natural gas consumption levels.

While several options were considered, the policy options assessment focused on upgrading existing systems with a combination of combined cycle units and co-generation (power and heat for water desalination). As part of a mitigation scenario, it was assumed that combined cycle units achieving at least 50% combustion efficiency, an improvement from the current level of ~35% (where only 35% of the fuel energy is converted to electricity) would be installed at eight inefficient single cycle power stations and cogeneration would be installed at one station. These changes would reduce emissions of carbon dioxide by about 2.3 million tones, annually.

There are no major costs, institutional, or social barriers envisioned for a more widespread use of electricity efficient technology in the electricity supply system. The cost of saved carbon for implementing these options at nine stations is negative (i.e., –$19.6/tone of carbon dioxide avoided) indicating its attractiveness from an economic perspective. Moreover, direct surveys among a range of individuals, confirmed its attractiveness from a social perspective.

7.7.1.4 Electricity Strategy and Climate Change Policy:

Bahrain should not wait until tomorrow to start adapting to climate change. It is currently vulnerable to climate variability and climatic extremes, and adaptation is already being practiced independently of the global climate change framework. Those practices could be fine-tuned by determining risk levels through more formal adoption approaches. The responses, however, must be institutionalized. The current adoption approaches in most SIDS recognizes the impact of extreme climatic events and are motivated by an appreciation of the consequences of non-adoption. Many SIDS have already experienced the effects of climate variations, such as variations in rainfall, soil moisture, winds, sea levels and patterns of wave intensity and action.

Bahrain has experienced increased temperatures, changes in rainfall patterns, and sea level increases are anticipated[164]. Various studies, such as those being undertaken by the climate change studies group, have shown a significant warming trend during the last 15 years.

SIDS, in general and Bahrain, in particular, are facing very serious problems. Climate change is really *"the dark side of fossil fuel."* About 70 to 80 per cent of greenhouse gas emissions come from the energy sector; it was not possible to solve climate change on any level if energy is not made to be more sustainable, especially by shifting to energy efficient, renewable energy-based systems.

There are many opportunities for implementing renewable energy and for dramatic increases in energy usage efficiency. Only by attaining sustainable energy within the context of sustainable development will it be possible to address climate change issues within The Kingdom of Bahrain.

There are several options and opportunities that have been analyzed to determine their environmental reduction potential and associated costs. Given the prominence of energy supplies, all of these options are focused on this sector. The paragraphs below summarize the options considered.

7.7.2 The Proposed Medium and Long-term Actions

7.7.2.1 Market-Based Mechanisms

The government of Bahrain has broad power to establish economic instruments for environmental protection; any legal framework must be based on the mandated power listed within the constitution of the Kingdom of Bahrain. Ministries, municipalities, and governorates have powers that are delegated to them by law.

Economic instruments can be used by the government to help solve local, regional and global environmental problems, require a coordinated national approach. A combined national system of command and control, and market-based instruments such as tradable emission permits for pollutants that cause environmental and health hazards or global warming would likely be justified if the command and control approach alone failed to deal with these issues. Externality adders and a discharge taxes system for discharge into the environmental media may also be justified under the constitution and the governmental laws. These systems must be carefully designed and implemented. The following economic instruments could be adapted in order to help to internalize the currently externalized costs of electricity generation in the Kingdom of Bahrain:

7.7.2.2 Externality Adders:

Many researchers who have addressed the ‘externality adders’ including Owen, 2004[165] who defined ‘externality adders" as units of externally added costs to the standard resource cost of energy to reflect the social costs of its use. For power generation, the externality adder would generally be specified in terms of U.S $ c/kWh. Usually ‘externality adders,’ used in an

Integrated Resource Planning (IRP) process, provide a strong and simple mechanism for internalizing the externalized costs of electricity generation and can encourage the adoption improved energy efficiency and implementation of electricity generation via renewable energy sources.

Greacen, 2005[166] defined 'externality adders' as an accounting tool that forces utility planners to account for environmental and social externality costs. As per the IRP process, the technology option with the lowest total cost is the one that must be built, even if the money for social and environmental costs does not have to be paid for by the generator. Currently the IRP is practiced in a number of US states. Because socially optimum outcomes identified by the IRP process are not always the same as outcomes that a utility would chose if left to its own planning process, the IRP requires an empowered and capable regulatory authority; unfortunately most developing countries lack the open and public process that is needed for an IRP, according to Greacen the IRP. Therefore, in order for it to function properly, the community, utility companies, and governmental agencies must be provided opportunities to participate in the development and implementation of the IRP.

The IRP approach differs from strategic supply planning because it includes not only the costs incurred by the individuals/organizations, but also the societal costs, such as environmental impact mitigation necessitated by some resource choices. Secondly, IRP is technologically neutral, treating demand-side options, end-use efficiency improvements and demand side management (DSM) with the same weight as supply side approaches, so that deferred or avoided end-use demand is equivalent to "delivered supply" of electricity (D'Sa 2004)[167]. IRP is therefore, intended to make an integrated assessment of supply and demand-side options for increasing energy services, for attempting to minimize all costs, and for creating flexible plans that allow for uncertainty and adjustment in response to changing circumstances (Fig. 59).

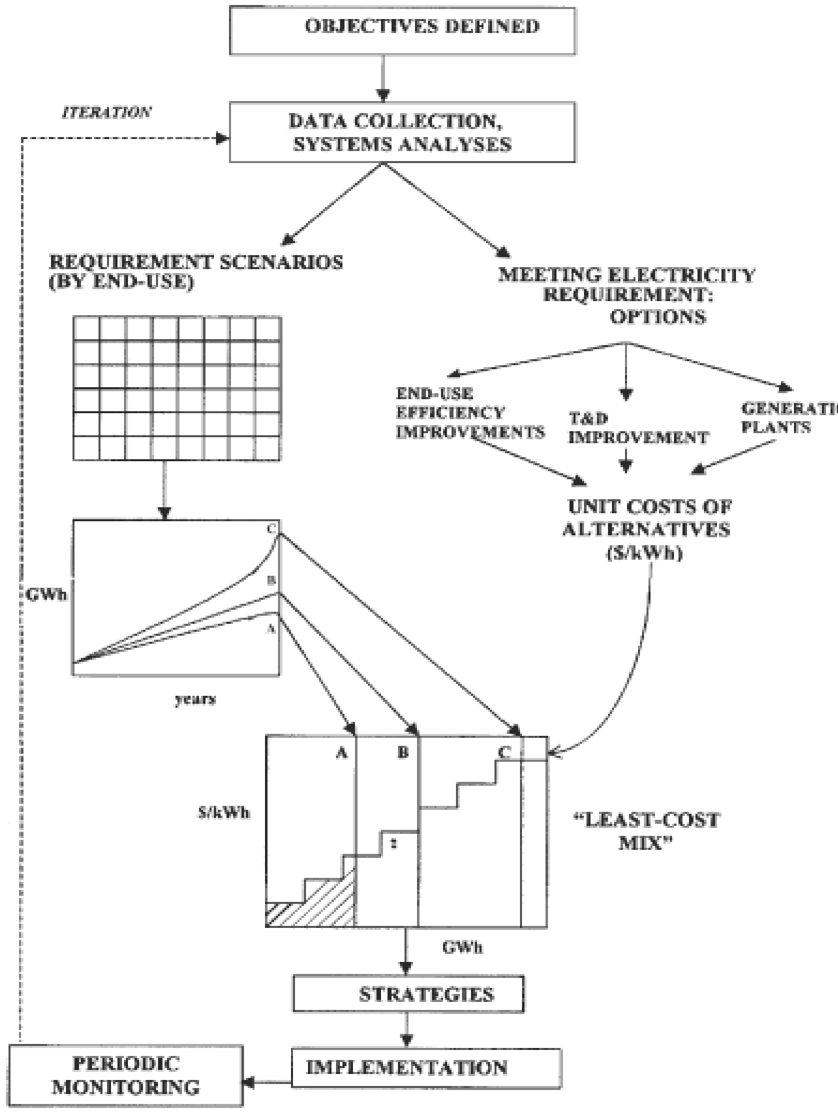


Figure 59. Steps in the Integrated Resource Planning Process.

Source: (D'Sa, 2004)

Bahrain does not currently have an IRP process. Currently the Ministry of Electricity and Water (MEW) decision-making framework only considers the commercial costs borne by the ministry rather than also the economic costs borne by the society. It doesn't take into account a full range of renewable energy options, choosing instead to consider only fossil fuel options**.**

For Bahrain, the IRP would be/could be an effective way for encouraging increased investments in diverse renewable energy and for internalizing part of the currently externalized costs of power generation, through the collection "Externality Adders," where most of the power generation sources are fossil fuel. Such a policy would be very close to the decision-makers perspective to promote renewable energy, with the potential to satisfy about 74% of surveyed decision makers in Bahrain, where most of them preferred policies that internalize a low percentage of the total damage caused by external costs from electricity production.

Bahrain should benefit from international experiences either in developing or developed countries, for instance, there are a few cases of IRP exercises that have been engaged academics or research organizations for the power sectors of a state of a country, for example, the Indian states of Karnataka and West Bengal, or for efficiency measures, for example, the conservation supply curve for Brazil (D'Sa 2004).

Additionally, the U.S Clean Air Act Amendment of 1990 as well as the US Energy Policy Act of 1992,contains provisions designed to motivate state commissions to adopt standards requiring utility participation in IRP.The adoption of an IRP is therefore, driven by the need for greater efficiency in the use of energy and due to concerns for the environment(Gallachoir 1997)[168].Through 1994, 38 U.S. states had formally adopted IRP to guide utility resource planning and 19 states had codified IRP into their legislation.

Among European Countries, only Denmark's 1994 Electricity Act has an effective IRP obligation. Distribution/supply companies are required to prepare demand side management (DSM) plans, generation and transmission companies and the independent system operators must develop scenarios for generation and transmission, and the ministry must provide guidelines and co-ordination of the overall 20-year plan. Few experiences with IRP have been reported in other European Union countries (Wuppertal Institute[169] cited from D' Sa 2004).

Though not yet practiced in Bahrain, 'externality adders' and IRP arewell-established frameworks that can help Bahrain's economy to lower energy costs and improve competitiveness while reducing environmental and social impacts. Bahrain policy makers should consider making IRP mandatory for all power sector planning. However, full benefits from IRP would probably only accrue with the formation of a truly empowered, capable, independent regulatory authority. The IRP would require supporting studies including a study of externality costs of electricity generation, and the economic cost of fuel prices; these studies should be conducted in an open and public process.

7.7.2.3 Tradable Emissions Approach

For many years legislators have struggled with the task of reducing air pollution and its associated health and environmental impacts. Command and control regulations, which persisted for over two decades, have made significant progress, but have failed to accurately internalize the total costs of pollution into utility decision-making. Emissions trading programs go much farther towards monetizing these costs and incorporating them into planning and technology development.

Tradable emission markets have recently evolved as a decision-making tool for internalizing the externality of air pollution from electricity production. A tradable emission, also known as “cap-and-trade,” enables those who can reduce pollution cheaply to earn a return on their pollution reduction investment by selling extra allowances. It allows those who cannot reduce pollution as cheaply to purchase allowances at a lower cost than the cost of reducing their own emissions. It also enables all participants to meet the total emissions cap, cost-effectively. It also provides all polluters incentives to innovate to find the least-costly solutions for total pollution control (Larsen *et al* 2005)[170].

The advent of emission trading programs provides a method for the monetization of emissions. Emission trading is consistent with the marginal cost of control approach of environmental externality theory.

There is an opportunity in Bahrain to adopt the tradable emission permits beside the Clean Development Mechanism (CDM). CDM is an arrangement under the Kyoto protocol allowing industrialized countries with greenhouse gases reduction commitments (called annex 1 countries) to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reduction in their own countries. The most important factor of the carbon project is that it would not have occurred without the additional incentive provided by emission reduction credits. The CDM allows net global greenhouse gas emissions to be reduced at a much lower global cost by financing emissions reduction projects in developing countries where costs are lower than in industrialized countries (Wikipedia

Encyclopedia 2007)[171].

Tradable shares and bankable coupons are two tradable instruments; a coupon would permit its owner to emit a prescribed quantity of effluent (for example, one ton of nitrous oxide) during a prescribed period of time (for example, one year). A share would entitle the owner to a prescribed proportion of the coupons allocated each year. Unused coupons could be banked for use in future years.

However, to explore the possibility of applying this concept, the Bahraini government needs to build upon the international experience. The concept of emissions trading has grown from a theoretical curiosity to a central idea in environmental regulation. The theory is well developed (Tietenberg, 1985[172], 1992[173]) and case studies and summaries of actual practice are available (Hahn 1989[174]; Tietenberg 1992).

Introducing the tradable permit systems in any society needs to be carefully examined to ensure that it will actually reduce pollution, at a lower cost than command and control strategies. The government should discuss any draft legislation with all stakeholders including the representatives of the civil society before any system is adopted.

7.7.2.4 Use of Green Taxes

The environmental taxes are one of the most popular tools of reducing external costs of electricity. Charging power producers a price to emit pollutants is necessary to reduce power plants emissions quickly to prevent the environment from reaching an irreversible situation; a green tax would internalize the pollution externalities associated with pollutants emissions and their contribution to the environmental deterioration, human health hazard, and global warming. If the price of electricity doesn't reflect these external costs, too much SO_2, NOx, and CO_2 will be emitted.

The green tax assigns a specific cost for each ton of pollutant produced by power plants, since this cost is known, the utility planners can make efficient decisions on minimizing the costs, and as a result the pollution emitted to the air. The cost of pollution produced would be passed on to the consumers of the electricity. Power plants would benefit on a return of investment for pollution reduction equipment, thereby, directing green tax revenues towards the development of more efficient power producing and using technologies and power conservation programs could lead to improved, more sustainable economic development in Bahrain.

The government of Bahrain should involve the public, industry and governmental decision-makers in carefully considering the options. In this regard, the results of this thesis author's survey revealed that 51% of the surveyed decision-makers in Bahrain support imposing tax on polluters. However, most of the industry opposes any kind of taxes to internalize the currently externalized cost of electricity generation in Bahrain. Their justification is that, raising electricity costs will not make industry and other productive sectors non-competitive, and will add more burdens on the poor people.

7.7.2.5 Provide Financial Support for Research and Development

Providing grants for research and development and demonstration play an important role in bringing promising but non-commercial renewable energy technologies to economic sustainability (Greacen, 2005). Limited use of demonstration projects can play important roles in developing local capacity to install, maintain, and repair renewable energy generation equipment. Currently, Bahrain does not have a policy supporting the R&D in the field of renewable energy. Thus, in order to stimulate the development of a sustainable market for renewable energy, the government should establish a fund to support a variety of programs such as supply solar energy for selected projects, demonstration of roof-top grid connected PV, establishing an energy centre in one of the local universities to develop teaching show cases of renewable energy technologies and to provide the renewable energy market with skilled expertise. They should also explore the possibility of manufacturing some of the renewable technologies such as PV cells and solar batteries, and to subsidize construction of a small PV station. However, in order for R&D to be successful, decision-makers should focus much more on the promising technologies, commercialization of technologies to encourage broad-based community and private sector participation, and support joint government and industry R&D programs.

There is extensive literature on the relationship between R&D and renewable energy dissemination. It is useful to consider that the USA, which has dedicated large sums of money to renewable energy research and development, has a smaller renewable energy industry than Denmark, which spent less on R&D but carefully nurtured domestic industries and concentrated on proven technologies (Greacen, 2005).

7.7.2.6 Renewable Electricity Systems for Power Supply

This initiative involves adding zero-carbon, renewable resources to the electric system. Bahrain is well endowed with solar energy with an annual average solar insulations level of about 400 W/m2, making it one of the highest in the world. Wind energy is less attractive as average wind speeds are well below 5 meters per second for large periods of the year over large portions of the country. Tidal energy is also not considered an attractive option due to land use required for the installation of turbines and the resulting adverse ecological impacts.

Despite abundant levels of solar insulation available in Bahrain, there is no serious initiative to utilize solar electricity technologies. Based on the mitigation analysis, solar troughs are a particularly relevant mitigation option for Bahrain that could lead to huge reductions in annual GHG emissions, and result in reductions in human illnesses caused by air pollutants.

The mitigation assessment focused on solar thermal combined cycle systems to meet about 10% of the electric demand within the next 10 years. This would involve the installation of two 150 MW solar thermal stations (with no natural gas backup), and would annually reduce emissions of carbon dioxide by 1.5 million tones.

The cost of saved carbon for implementing this option is negative (i.e., –$5.0/tone of carbon dioxide avoided) indicating its attractiveness from an economic perspective. However, using substantial levels of intermittent renewable electricity technologies in Bahrain would represent a departure from business as usual by requiring new coordination among different institutional entities. Indeed, one of the key technical issues was how intermittent resources can be integrated into the electric system given system interfacing, stability, and operability concerns. While these issues will require further review for the specific circumstances posed by the Bahraini electric system, it is unlikely that they represent unsolvable technical problems. In every country with significant installed renewable energy capacity there are laws that guarantee that renewable energy generators have access to the grid. These do not require subsidies. They only require fair treatment by the utilities that control the transmission and distribution system (Greacen, 2005).

Interconnection requirements specify the safety equipment and procedural steps necessary for connecting a generator to the grid. The critical principle is that all generators of electricity, either large or small power producer, and regardless of the source (fossil fuel or renewable) should have fair and non-discriminatory access to the grid.

Under current Bahrain policies, the government does not allow reselling electricity to the grid, due to lack of technical and legislative structure. Therefore, in order to encourage the renewable energy investments in Bahrain the Power Authority should immediately implement the required legal framework to enable the Small Power Producers (SPP) and Very Small Power Producers (VSPP) to sell their electrical production into the national grid.

Bahrain should benefit from the international experience with regard to the grid connection for SPP and VSPP, for instance, Denmark has legislation called "Connection of Environmentally benign electricity and CHP production Plants,"[175]under this legislation, renewable energy generators and cogeneration facilities share costs of grid interconnections with the distribution utilities.

Germany has similar legislation, in which plant operators have to pay for the grid connection, but the grid operator has to bear the cost of grid reinforcement if necessary (IEA 2005)[176]. Based on international experiences, fair and non-discriminatory access to the grid requires an independent regulatory authority.

Promoting renewable energy in Bahrain would be publicly acceptable, with the potential to satisfy the 75% of the surveyed Bahraini residents, and 65% of the decision-makers (refer to the results of surveys presented in Chapters 5 and 6).

7.7.2.7 Feed-in Tariffs (Production Incentives)

Feed-in tariffs or production incentives are a fixed subsidy paid per kWh of electricity generated. Feed-in tariffs can be superior to investment incentives (payments per kWh of installed capacity) because they eliminate the temptation to inflate initial project costs and encourage developers to build reliable facilities, which maximize energy production. The shift from investment incentives to production incentives in the USA after 1994 was clearly influenced by this concern and the abuses encountered by early investment incentive schemes (Greacen 2005).

The feed-in tariff is a policy instrument preferred by many renewable energy project developers because it provides a guaranteed market for renewable energy at a guaranteed price. Because feed-in tariffs are paid per kWh generated, project developers and financers must rely on the assumption that the incentives will continue to be available in future years. Therefore, in order to be effective, feed-in tariffs must be guaranteed for many years (typically at least 10 years).

Feed-in tariffs are considered to be a safe, reliable, and effective renewable energy support mechanism. They are simpler and generally less resistant to abuse than other mechanisms. They can help lower barriers to entry to smaller renewable energy providers who lack sufficient financial resources or risk analysis to develop projects in which tariff and revenues are unpredictable.

The international experience shows that, one challenge lies in determining the price, in Germany, Spain and Denmark the philosophy has been to establish the feed-in tariff subsidies at a level sufficiently high that a well – managed company can make a reasonable profit. For instance, in Germany remuneration depends on the technology, with only € 0.07/kWh paid for large geothermal plants, wind turbines getting € 0.091/kWh and solar Photovoltaic (PV) up to € 0.5162/kWh (Mitchell 2003)[177].

There is currently no feed-in tariff in Bahrain. However, the government should consider this option to encourage renewable energy installations. The government may consider a flat feed-in tariff or could subsidize the renewable energy on the basis of the externality benefits that they provide. Conventional electricity plants have negative externality costs and because it is not included in the conventional prices, renewable technologies can get a subsidy (externality benefit) equal to the excess externality cost of conventional generation.

7.7.2.8 Renewable Portfolio Standards (RPS)

Under this approach, the RPS obligates each electricity producer to include in its resource portfolio a certain amount of electricity from renewable energy sources, the producer can satisfy this obligation by either (a) owning a renewable energy facility and producing its own power, or (b) purchasing power from someone else's facility. RPS rules can allow conventional producers to trade their obligations (Rader and Hempling 2001)[178].

The experience in countries applying the RPS legislation shows that. RPS has one main advantage it can lower the price of renewable energy in the short term by encouraging competition among producers. Proponents of feed-in tariffs argue that RPS only provides efficiency gains in the short term. They argue that prices under feed-in arrangements can actually be lower because there is less risk; with a fixed price, revenue streams are more predictable, allowing procurement of lower cost financing. In the long run, proponents argue, feed-in tariffs lead to lower renewable energy costs because they lead to larger installed capacity of renewable energy systems, which drive down the per unit costs through greater manufacturing experience (Mitchell *et al.* 2003)[179] .

There is currently no RPS in Bahrain, therefore, the government needs to study the cost-effectiveness of this approach and compare it with feed-in tariff. There is no doubt that issuing a regulation to require fossil fuel power plant managers to procure renewable energy equal to 3%-5% of their installed capacity, will help to begin to protect the environment, enhance sustainability, and improve resource conservation. However, committing independent power producers (IPP) to invest in renewable energy might affect the privatization process of electricity production sector.

The main challenge with implementing RPS is that RPS is a policy designed for a competitive "Power Pool" type electricity market. It has never been tried in a semi-regulated or regulated monopoly environment such as Bahrain, and this definitely will impact the effectiveness of this policy.

Bahrain can benefit from international experiences in this regard, especially the success stories in developing countries; in the developed countries there are 17 U.S states, United Kingdom, Sweden, Japan, Italy, Austria, and Australia, which have implemented RPS policies (Haynes[180], 2005 and EWEA[181], 2005). While there are examples of RPS failures in several U.S states, there is also evidence that, together with other incentives, a properly designed RPS (e.g. Texas) can be effective in encouraging substantial renewable energy investment.

China is similar to Bahrain in the sense that it is a growing developing country economy. China has a low percentage of installed renewable energy capacity. While China initially pursued establishing an RPS, and after considering the advantages and disadvantages the country chose a feed-in tariff mechanism instead of RPS (Greacen 2005).

The international experience shows that a successful RPS requires an effective and empowered regulatory body able to ensure that market transactions are fair, able to monitor compliance and levy fines against non-compliant generators. Bahrain unfortunately lacks such a regulatory body with experience and authority to handle this kind of program, the author recommends that the new electricity and water authority, which was established in December 2007, will develop and use new tools and programs for promotion of investment in renewable energy.

The renewable energy industry, in general, prefers feed-in tariffs over RPS mechanisms because under the feed-in tariff, a guaranteed price for electricity is provide, under the RPS the tariff is uncertain. Uncertain tariffs raise the uncertainty about future revenue streams, which makes it challenging to arrange favorable financing (EWEA 2005).

The regulatory body and decision makers in Bahrain need to study the RPS mechanism carefully and determine whether it is possible to come-up with tailored Bahraini RPS and ensure that obligations are met cost-effectively. The study should also review policy options under consideration by the Bahraini government in light of international experience and Bahrain's Industry structure and regulatory environment, the key international renewable energy experts can help in this regard.

7.7.2.9 Investment Grants for Renewable Energy Systems

Direct grants are a widespread form of policy intervention to incentives increased use of renewable energy by reducing the direct capital cost of the project. From an economic perspective, such direct payments are a "second best" solution compared with tax relief (Mott MacDonald 2005)[182].

Taxes can more directly implement the "Polluter Pays Principle" for the external environmental costs. In practical terms, however, such "second best" measures may be more politically viable and just as effective as tax relief. In any case, few existing taxation schedules claim to represent the "true cost" of pollution as they should in a "Polluter Pays Principle" framework. Most are only a policy compromise that results in partial coverage of the true costs of the polluter's pollution emissions.

Examples of grant schemes include:

- Debt guarantees are approaches whereby, the government commits to underwrite third-party loans taken by a renewable project developer, promising to repay any outstanding balance in the event that the project goes bankrupt. The observed example of this measure is in Japan, where the government guarantees up to 90% of debt capital taken by renewable project developers;
- Subsidized interest on third-party debt financing for renewable generation investment. For example some of the EU countries provide soft loans with typical interest rates of 2% below market level, with a an observed range of 1%-5% (IEA database)[183];

- Capital contribution for renewable equipment purchase. In a SIDS such as Malta, this incentive already applies to household solar energy heating systems and electric cars (Mott MacDonald 2005);
- Making public funding available to conduct feasibility studies on potential installation sites;
- Provide assistance with the marketing of renewable products, such as through public awareness creation programs.

Investments subsidies may be more appropriate for small-scale auto-generation units, however where power is largely used on-site and investor confidence of outside power demand is not the central concern. For instance, Germany's "250MW" promotion of small-scale wind turbines from 1989 to 1998 assisted in facilitating the installation of 1560 units, with an average capacity 2kW, exceeding the program target. The "250MW" program offered either € 100/kW installed, or a premium of € 0.04/kWh for electricity fed into the public grid. The investment grant component was limited to 60% of total investment, up to a maximum of € 50,000 for installations below 0.5 MW capacities (EWEA 2003)[184].

Investment subsidies are also widely used as incentives for PV, with grants ranging between 30% and 70% of the investment costs in some of the EU countries (IEA, 2004)[185]. These subsidies have been more successful in Germany, where more than 70% of PV installation within the EU15 took place between 2001 and 2003; the subsidy varied between 50% and 70% of capital cost for householders who elected to invest.

For Bahrain, investment grants would be most effective for PV installations and small wind turbines, where most of the power generated would be for owner's usage. Such a grant scheme would be a publicly visible effort to promote renewable energy, with the potential to satisfy about 76% of surveyed Bahraini households that agreed with the indirect statement "*do you support a decision taken by the government to utilize renewable energy*" and 60% said yes to the question "*Do you prefer subsidies given to consumers who purchase renewable energy?"* in the policy selection survey (refer to Chapter 5). The scheme could also foster a sense of private ownership for renewable energy systems in Bahrain, contributing to the task of public education through demonstration projects. Grants are therefore, expected to have a high level of public acceptability in Bahrain.

The main obstacle to such an incentive program in Bahrain is the current low level of consumer electricity tariffs, which are significantly lower than generation costs as stated earlier. The low level of tariff means that all renewable energy systems are uncompetitive to end-users, with very long back periods even when subsidized.

Summary of Chapter 7

Chapter 7 presented an overview on different policies, programs, and action plans that could be adopted by the government of Bahrain to eliminate subsidies and internalize the currently externalized costs of electricity production and usage.

It described 1) the current and forecasted situation, 2) the roles and aims of the national electricity policy, 3) the proposed action plans and policy measures. It is important to understand the characteristics of these policies and their consistency with decision-makers, stakeholders, and the public opinions.

Chapter 8 summarizes the answers to the research questions addressed in this thesis. It also provides overall conclusions and recommendations for the future of the electrical energy sector in the Kingdom of Bahrain.

Chapter 8. Conclusions and Recommendations

The previous four Chapters summarized the results of the empirical research on the externalities of electricity generation in Kingdom of Bahrain and on the societal member's willingness to pay for internalizing those costs. This study evaluated the externalities of power plants, and the management and policy measures to internalize the currently externalized costs of electricity generation and usage.

This research addressed the following main question:

- To which extent can we use economic valuation of externalities in the policy making process in the electricity production sector?

In order to answer this question, the following five sub-questions were addressed:

1. What is the structure of the Bahraini electricity production sector?
2. What is the current electricity policy, and what are the key factors that influence it?
3. What are the environmental and human health impactof electricity generation and usage?
4. What are the currently externalized costs under the present electricity policy?
5. What policies and structural changes could lead to adequate costing, pricing, and taxing of electricity and thereby, help to internalize the currently externalized costs of electricity production and help the Kingdom of Bahrain to become more sustainable?

To answer the first research sub-question:

1. What is the structure of the Bahraini electricity production sector?

This study showed that the electrical power generation system in the Kingdom of Bahrain plays a vital role in the economics of the island; the installed electrical generating capacity in Bahrain in 2004 was 1849 MW.

The electrical utility industry consumes large volumes of fossil fuel; the publicly owned power stations consume over 3 billion cubic meters of natural gas/yr. to generate about 83% of the total electricity generated, with the remainder (17%) obtained from the power station of the aluminum smelting plant (ALBA) which generates 1,527 MW. In the near future, with the new capacity expansion, the total will be 3,613 MW.

The most recent electrical energy consumption forecasts project growth in demand of approximately 8%/year for the next 10 years. This consumption growth will require increasing the output capacity by at least 150 MW per year.

The research revealed that the tariff structure for electricity in the Kingdom of Bahrain is not based on consumer-specific, long-run marginal costs but is based upon a price structure that is used as an instrument to achieve political and socioeconomic objectives. Electrical prices in Bahrain are far below the total capital and operating costs of production and delivery, for instance at the oil prices in the international market which reached around US $ 110 per barrel, the power production subsidy estimated to be 97% to 83.8% of the total actual costs.

It is obvious from the results of this study that, the Kingdom of Bahrain is facing considerable challenges in terms of operational efficiency, cost recovery, and responsibility towards the community especially the environmental and human health impact caused by emissions of its power plants. Large investments are required to rehabilitate, modernize and expand the electricity production and distribution system to meet the growing demands and to optimize the development opportunities; without such investments, the supply of electricity and its negative impact on the people of Bahrain will continue to increase.

In order for the government of Bahrain to seek to address these problems made the decision to restructure the electricity production sector. However, the liberalization of the electricity production sector and the establishment of effective competition will depend on many actions among them, the removal of formal barriers to independent, small-scale generators to sell their electrical production into the grid, actions to remove the informal difficulties, and to be non-discriminatory. Therefore, any continued public ownership in the sector, particularly in generation and supply, must be on the basis of competitive neutrality with private sector entrants. Publicly-owned utilities should have equivalent policies, and generally be subject to an equivalent regulatory framework as private companies.

The answer to the second research sub-question: “What are the environmental and human health impact of electricity generation and use?” is:

The author found that the air quality has become an acute problem in Kingdom of Bahrain. Increasing air pollution occurs in urban areas due to transportation, and industrial activities, mainly electrical power generation. Emission measurements were performed by an independent and certified consultant. The measurements showed that the highest NOx emission concentrations were found in the flue gases of the large gas turbines without NOx reduction equipment at the Riffa power plant (255-344 ppm) and at the ALBA power plant (264-313 ppm). The NOx levels measured at these units exceed, by far, the established emission standards of Bahrain, Metrological and Environmental Protection Agency in Saudi Arabia (MEPA), World Bank, and Germany, which are in the range of 39 - 49 ppm.

There is extensive evidence from the literature that the air pollutants emitted by power plants cause many serious, human health, and environmental effects. The old power plants in Bahrain emit high levels of NOx. However, it has to be taken into account that NOx is a precursor of ozone in the atmospheric chemistry. Due to considerable emissions of volatile organic compound (VOC’s) at the BAPCO refinery, it can reasonably be assumed that enough VOC’s are contained in the ground level atmosphere around power plants mainly, Riff, BABCO, and ALBA, to efficiently catalyze the formation of ground level ozone. These results in synergistic effects of both NOx and ozone have to be considered, since both compounds lead to adverse health effects due to their oxidative potential.

The study revealed that the measurement of health parameters in Bahrain pose a challenge for the evaluation of health impact of environmental pollution, for instance, due to the absence of epidemiological studies, the cause of death and illness data are not routinely collected and the data that are collected are not very reliable. Additionally, due to varying quality of medical services, and as a result of poor diagnosis and record keeping, the study of health impact is difficult.

The study showed that the main governmental medical centre in the country treated about 0.6% of the population for respiratory illnesses in 2005, the number of respiratory patients admitted to Salmaniya hospital peaked at

3645 in 2005, the bulk of the patients (59.5%) were children (under 19 years of age). However, if the medical data for the private hospitals were available, that would push the percentage of the population afflicted by respiratory diseases closer to 2%.

An estimation was made of the medical costs for the care provided to respiratory patients in 2005were 3645 patients admitted to Salmaniya hospital for treatment. They spent about 17,339 person health care days in the hospital with an average of 4.76 health care days per patient. The cost per day was approximately BD 109.3, therefore the government paid BD 2 million (equal US$ 5.3 million), with the addition to the in-patient cost, about 2717 out-patients suffering from respiratory illness visited the specialized clinics in the same hospital with a cost of about BD 0.08 million (equal US$ 0.2 million) based on BD 27.30 for visit. Of course this may underestimate the actual cost if more expensive procedures, tests, and medications were involved.

Electricity generation was found to be the main source of the atmospheric pollution. The necessity of finding a balance between the costs of achieving a lower level of environmental and health injuries and the benefits of providing electricity and other services at a reasonable cost led to studies to estimate the external costs that are not currently included in the electricity prices. Even when there are large uncertainties involved, these costs can be used by decision-makers in the process of achieving an improved and equitable electrical pricing system, which can help it to make progress toward a more sustainable Bahrain.

> The answer to the third question: “What are the currently externalized costs under the present electricity policy?” is:

The impact and corresponding damage costs related with health effects and building materials(Man-made environments) of atmospheric pollutants generated by fossil fuel related activities (electricity generation, fuel processing and aluminum smelting) in three Bahrainis facilities were assessed using the RiskPoll model.

As many studies around the world report that health impact contribute the largest part of the damage, the most effort in this study was dedicated to evaluate them. For impact on building materials, the results have low precision and must be considered only from a methodological point of view.

The facilities evaluated included: the Riffa power station, the Bahrain Petroleum Company (BAPCO) refinery, and the Bahrain Aluminum smelter (ALBA). Four study cases were conducted at each facility, using two of the models included in RiskPoll for classic pollutants (RUWM and QUERI), and two approaches for mortality valuation: cases of death, and loss of life expectancy.

The study included a simplified analysis of the externalities in Bahrain's energy sector related with global warming.

As in other international studies, the most important damage costs come from chronic mortality, although the contribution of acute mortality due to SO_2 and NOx emissions are not negligible. Among morbidity effects, important contributions come from chronic bronchitis and restrictive activity days.

The empirical study revealed that the external costs assessed for the three facilities match very well with their emissions. The higher costs correspond to the ALBA power station, ($97,088,550, min/max: 26,547,274 / 319,346,794), because it reports high NOx, SO_2 and PM_{10} emissions. The results for the BAPCO power station were the lowest; (63,479,153, min/max: 17,490,289/222,230,511), because this facility only reports on NOx emissions (884.8 ton/year). The results for Riffa were 79,131,062, min/max: 22,010,741/297,013,910. *(All costs are in US $2004)*.

> To answer the last research question, "What policies and structural changes will lead to adequate costing, pricing, and taxing of electricity and help to internalize the currently externalize costs of electricity production and use, thereby help the Kingdom of Bahrain to become more sustainable?" the following was found:

The respondents to two separate questionnaires were invited to answer questions whereby s/he was asked to respond to several hypothetical policies for the internalization of the currently externalized costs of electricity production and usage.

the objective of the first questionnaire is foreseeing the policy-makers and stakeholder's choices for suitable policies and the related instruments to internalize the externalities of electricity generation and usage, while the second questionnaire aimed to know the opinions of the Bahraini's regarding the electricity generation issues as well as to assess their attitudes pertaining to the appropriate policy options that should be used.

The survey results from 231 respondents revealed that most preferred policies that internalize a low percentage of the total damage caused by the currently externalized costs from electricity production and usage, because they believe, raising electricity costs further will reduce the competitivity of industry and other productive sectors and will add more burdens on poor people.

The majority of respondents considered and looked at all criteria as a package in their selection of the suitable policy, and ranked the impact on the health budget as the most important element that should be considered in the process of internalizing the currently externalized costs. The issues of greenhouse gases emissions & climate change came in at the second-level of importance.

The results revealed that the majority of respondents preferred multi-policy instruments in order to internalize the externalities of electricity production and they supported the use of instruments such as granting subsidies to the consumers and producers of renewable energy, use of command and control, tradable emissions, and use of pollution taxes.

The second survey was targeted to the public, and was designed to address the following:

- The level of awareness among Bahraini's regarding the environmental issues related to electricity generation;
- The willingness of Bahrainis to have the subsidy removed from electricity prices;
- The willingness of Bahrainis to internalize externalities;
- The level of support for utilizing renewable energy;
- The willingness to pay to develop renewable energy;
- The level of support for the Bahraini legislators requiring power plants to utilize renewable energy in electricity generation.

The results from 395 respondents revealed that, the majority of Bahrainis are environmentally aware and do care about the environment and seem to understand the links between the electricity fuel source, the environment and the negative human health impact from air emissions from electrical power generation facilities.

However, despite their support for increased use of renewable energy through their willingness to contribute voluntarily to develop and use renewable energy and their support for legislative action requiring power plants to produce 10% of their electricity from renewable sources during the next 10 years, and the willingness to pay 5% extra cost monthly to have electricity from renewable source.

Bahrainis are very sensitive to remove even gradually the subsidy to electricity prices, paying the actual cost of electricity, and internalizing the externalities of electricity production.

Improving the sustainability of the energy systems by removing the subsidies and by incorporating energy externalities into the related policy making processes represents a key challenge that has been studied by the author of this thesis.

During this work, the author came to realize, based upon the findings of these two surveys, that the internalization of the externalized costs of electricity or the removal of subsidies are not currently acceptable from societal point of view in Bahrain.

Both of the targeted groups for the surveys looked at these issues from different angles. The decision-makers believe that internalizing the full, currently externalized costs will adversely affect the competitive advantages for Bahrain, for both the industrial and services sectors. While the public oppose changes in the price structure of electricity pricing, and any quick action from the government in this regards, because it might cause dramatic price changes for them and consequent political reaction. Therefore, solutions for the issues of externalities and subsidies should be made by taking the opinions of the community into consideration.

Based on these facts, the author of this thesis proposed a set of policies and action plans. He presented details about the relative social costs of these options, which include the external as well as the financial costs and provided a justification for governmental initiatives and a specific basis for assessing the relative desirability of the options.

The proposed policy measures represent a range of possible approaches to reduce or eliminate the environmental and health impacts caused by the electricity production sector in Kingdom of Bahrain. Most of the proposed policies have a number of societal objectives beyond of externalities, and subsidies including improvement in technical efficiency, industry development and promotion of investment in renewable energy and society-wide improvements in energy efficiency, at all levels.

Thus, it is the responsibility of the Bahraini government to assure that its electricity policies address the health and environmental impacts of its electricity generation facilities. There are many policy options available to the government for eliminating the externalities of such facilities and to use the national resources more efficiently.

Among such policy options the following are addressed within the thesis: a. externality adder, b. Green pricing of renewable energy, c. renewable energy portfolios, d. research, development, and demonstration of renewable energy and energy efficient technologies, and e. participation in emissions trading programs.

To wrap up the findings of this study with the main question of this research "*To which extent can we use economic valuation of externalities in the policy making process in the electricity production sector"*. This thesis author believes that the economic evaluation of power generation externalities became the basis for policy reforming and restructuring of energy sector and a support tool for the decision-making process, and the political will, as a scientific method (even if accompanied by some uncertainties) have acceptance from all the stakeholders.

The economic evaluation of power generation externalities, also provide the decision-makers with a solid platform to choice the best suitable economic tools to internalize the external costs of power generation.

8.1 Lessons Learned from this Thesis Research Study:

This researcher investigated the issue of internalizing the externalities associated with power generation in Kingdom of Bahrain with special consideration to the role of economic evaluation in influencing policies that would reduce the economic and environmental impactof energy production and usage. The author conducted this research in five parts:

- Analyzed the current electricity policy, and the key factors that influence it;

- Assessed the environmental and human health impactof electricity generation and use;

- Estimated the currently externalized costs under the present electricity policy;

- Conducted two questionnaire surveys to gain insights into the opinions and recommendations of the general public and of official governmental decision makers on the magnitude and dimensions of these problems and the possible solutions to them;

- Proposed policies and structural changes that can lead to adequate costing, pricing, and taxing of electricity and thereby, help to internalize the currently externalized costs of electricity production and usage. In this way, he hoped to help the Kingdom of Bahrain to become more sustainable.

The structure of power generation in the Kingdom of Bahrain was founded on the premise that the generation, transmission, and delivery of electricity are a public/governmental monopoly served by regulated entity. Revising electricity prices by removing subsidies and internalizing the currently externalized costs, introducing power generation technologies, and emergence of Independent Power Producer (IPP) in 2008 challenging this premise and resulting in industry restructuring.

Although the competitive market developed for partial generation and service delivery, a large share of production, transmission, and distribution net works are still under governmental monopoly. The governmental monopoly is characterized by high production costs, rapid depletion of resources, and social obligations that result in provision of heavy subsidies, and negative externalities. However the emergence of IPP questions the regulatory treatment of market failure to reflect subsidies and negative externalities in the electricity prices.

The power industry in Kingdom of Bahrain is suffering from problems that limit its efficiency as an industry that provides vital inputs to all other sectors; thus the essential question becomes "how can were-structure the electricity generation, distribution and usage system to optimize its short and long-term, net value to Bahraini society in the face of emerging factors such as the new business model i.e. independent power producers (IPP) that is based upon reduced dependence upon fossil fuel, increased reliance upon renewable energy sources and dramatically improved energy efficiency throughout society?".

This researcher analyzed the current electricity policy and the key factors that influence it; the external cost of power generation was also estimated. A set of policies was proposed based on random sample opinions of community and decision-makers. The following are lessons learned from this research journey:

1- **Avoid the Misuse of Resources:** the objectives of the current government's subsidy to the electricity prices is to support low-income people but the beneficiaries are beyond this class up to the middle and rich classes, consequently, government intervention is required to rectify the current situation to optimize the social benefits to the community in an equitable manner.

2- **Allocate Power Generation Costs Appropriately:** There is a fundamental principle in economics "beneficiaries and polluters should pay. This should be used here in Bahrain but that will be a difficult challenge based upon the current-willingness to pay and in-willingness to accept reductions in energy price subsidies that was found during the two surveys. Therefore, the government should intervene to mitigate the price distortion in the market and optimize the short and long-term social net benefits by using market-based tools.

3- **Standardize the Market Access for the Conventional and Renewable Energy:** standards should be developed and implemented that allow investors to invest renewable energy facilities and have access via feed-in-tariffs, to sell their electricity to the national grid.

4- **Encourage Renewable Energy by Enabling Return on Investment:** the investments on renewable energy will not occur unless investors have the opportunity to recover appropriate returns on their capital.

5- **Regulate the Electrical Energy Production System judiciously:** regulate the generation and use of renewable energy to create sustainable demand; and to encourage the efficient use of electricity.

6- **Avoid Price Distortions:** The current electricity price doesn't reflect the actual costs; there is substantial subsidy as well as external costs related to the generation and consumption of electricity; the government must have clear economic policy to remedy and prioritize this problem.

7- **Diversify Sources of Power:** In light of the increasing demand and reliance on fossil fuels to meet the requirements of development, it has become imperative for the government to diversify energy sources, especially renewable energy.

8- **Support R & D to Close the Current Knowledge Gap in the Field of Renewable Energy and of the Associated Externalities of Generation and Consumption of Energy, in General, and to Electricity in Particular:** Research is needed to help make the electrical grid ready for and responsive to decentralized electrical energy generation. Additionally, further investigations are needed on the valuation of the external costs of electricity generation. This R&D should be jointly funded by the government and by the private sector to provide support for universities and research institutions.

Although building upon these lessons will be challenging, it is essential that all stakeholders should bear in mind that the objective of addressing lessons is to optimize the short and long-term social value and welfare for the people of the Kingdom of Bahrain in ways that are environmentally sound and economically equitable. The public and all others must be involved in the discussions, new policies, and programs and monitoring of the results as the changes are made.

8.2 The Roadmap for the Next Ten Years in Bahrain

1- Prior to bringing the electricity prices close to the world price levels, the current subsidies and the effects of the externalities should be studied carefully at the micro and macroeconomic levels, because the electricity prices have significant effects on employment, GDP, and inflation because electricity is an intermediate commodity for most sectors and price increases can have negative effects on competitiveness.

2- A systematic and comprehensive strategy for supporting investment in renewable energy should be integrated with the energy market liberalization processes. A renewable energy portfolio should be integrated within the overall energy and power sector targets. The government energy monopoly must be eliminated and a robust partnership between public and private roles in renewable energy development should be fostered.

3- In order to achieve real, society-wide energy savings, a program of energy conservation measures should be established and actively supported and implemented by all governmental departments and by all consumers.

4- It is essential that priority be given to provide policy and financial support for R&D in the entire energy industry as it applies to the short and long-term future of Bahrain and the surrounding region.

5- Take advantage of economies of scale in generation of electricity in Bahrain and in neighboring countries to reduce the economic and environmental burdens of the current system. This could be accomplished either through joint ventures or through the purchase of electricity from countries within the region.

6- Bridge the data and research gaps to undertake full cost accounting of all externalities. According to the research findings of this thesis, because the health damages dominate the impact of the externalities, therefore, the most accurate way of measuring the health impact of air pollution are to conduct epidemiological studies to establish dose-response relationships linking the observable health impact to the environmental variables.

7- Attract and support renewable energy technology producing industries to Bahrain, particularly companies that produce solar energy equipment such as PV cells.

8- A comprehensive study should be done to address the externalities of electricity production and usage, to address the uncertainties, omissions, and bias related to this thesis research..

8.3 Limitations of the Study:

It is appropriate to underscore that in a study such as this that combined policy and quantitative analyses to stress that the results of the calculations are only sound as the input data and assumptions from which they are derived. Therefore, the limitations and weaknesses of the findings and recommendations should understand and should not be taken simply without further studies and analyses. The figures in this study contain the following uncertainties, omissions and biases:

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Uncertainties: The economic burdens to human health and to the man-made environment were assessed by an analysis via the impact pathways approach (IPA) developed by RiskPoll model (Chapter 4). The (IPA) was used to quantify the environmental impact from power plants fired by natural gas through an inventory of each emission.

Estimates of pollutant dispersion were made using models and data from monitoring sites. The estimates of human health impact were based on the dose-response relationship with the impact measured essentially in terms of years of life lost. Those estimates were then used to develop an economic valuation of these impacts.

The results are subject to uncertainties that arise not only from data limitations on the numbers of in-patients and out-patients of some hospitals from which data were not consistently available. Also there is uncertainty over the applicability of the dose-response functions derived from European and American studies. Further there are difficulties in quantifying pollutant impact on the ecosystem and on the man-made environment.

Omissions: Many impact resulting from the emissions and waste of power plants, such as the occupational hazard to the workers of power plants, the impact of the co-generation water discharges on the marine ecosystems, and the impact of power plants on visibility and aesthetics were not quantified.

Biases: It is obvious that there are biases in this study due to omissions and uncertainties, which could result in underestimations of the actual environmental and health impact of power plants in the Kingdom of Bahrain.

Furthermore, in addition to shortcomings of the quantitative analyses, there are data limitations due to inadequate access to the required information and the statistics for the analyses of the current electricity policy.

Also, the findings that were obtained from the two surveys regarding the externalities, subsidies, and policies of electricity generation, may not adequately reflect the scientific background and knowledge of the respondents to the questionnaires.

Appendices

Appendix 1: Questionnaire on the acceptance of the Bahraini Society appropriate policies to internalized the externalized cost of electricity generation

Hypothetical policies for the internalization of the currently externalized costs of electricity production and use in the Kingdom of Bahrain

1- Background:

This questionnaire is part of Mr. Ali Jassim M. Al-hesabi's PhD research that is focused upon seeking ways to internalize the externalities of electricity generation in the Kingdom of Bahrain. The study, among other things, has looked to the magnitude of external costs (the monetary valuation of human health effects and negative environmental impacts) caused by air emissions from electricity generation.

The research utilized the RiskPoll model; this program is capable of assessing the consequences to human health, agricultural crops and man-made environments (building materials) from exposure to atmospheric emissions from routine or steady state processes.

Three site-specific case studies have been conducted to calculate the external costs associated with production of electricity. The facilities included in the studies contribute the largest proportion of the NOx, Sox, and PM_{10} emissions in the eastern central area of Bahrain:

1. Gas turbine units installed at Riffa power station;
2. Bahrain Petroleum Company (BAPCO) refinery, and
3. Bahrain Aluminum smelter (ALBA).

The external costs assessed for the three facilities match very well with their emissions. The external costs range between 6 $ cents to 4 $ cents per kWh (equal to 23-15 fils in Bahrain currency).

In light of these results, and in order to adjust the price of electricity in the Kingdom of Bahrain to eliminate price distortion, policy changes could be taken to price electricity production so as to internalize currently externalized costs and to encourage implementation of technologies with lower socio-economic and environmental costs. Such approaches could include improved energy efficiency as well as a shift of energy production approaches, both centralized and decentralized, to solar and wind energy production.

Governmental policies could be used to encourage the emergence of clean technologies and new sectors of activity derived from Bahrain-based-research and development that can result in new high value added enterprises and in helping Bahrain to become energy self-sufficient after the oil and natural gas supplies have been utilized.

The Objectives of this Questionnaire:

This questionnaire is designed to help in characterizing preferences of diverse stakeholders, and policymakers in relation to the potential effects of policies for the internalization of the costs of electricity production in the Kingdom of Bahrain.

In this questionnaire the respondent is invited to answer several questions whereby s/he will be asked to respond to several hypothetical policies for the internalization of the external costs of electricity production.

Each policy is described by seven characteristics. Policies differ in the magnitude of some of the policy approaches. For each question, the respondent is asked to choose the policy s/he prefers. Each respondent is invited to choose the policies as a representative of your organization, and not as a private individual.

I will share the results of this research extensively throughout Bahrain.

Please fill in this questionnaire and send it back to Mr. Ali Jassim M. Al-hesabi at the following address:

Mr. Ali Jassim M. Al-hesabi
General Directorate of Environment and Wildlife
Office of the Head of Environmental Assessment
Salmabad
P.O.Box: 28652
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Hypothetical policies for the internalization of the currently externalized costs of electricity production and use in the Kingdom of Bahrain

Section 1:
A new energy policy for the internalization of the costs of damages to human health and environment may be characterized by the following elements:

1- The cost of the policy: the internalization of the external costs of electricity production:

The internalization of the external costs could impact on producers to different degrees, according to the target level of internalization. For example, three different policies as presented in Table 1 are possible approaches.

Table 1- The Additional Costs of Electricity Production per kWh

Policy 1 =>	3 $ cent per kWh for oil	1 $ cent per kWh for gas	0 $ cent per kWh for Solar
Policy 2 =>	5 $ cent per kWh for oil	2 $ cent per kWh for gas	0.1 $ cent per kWh for Solar
Policy 3 =>	7 $ cent per kWh for oil	3 $ cent per kWh for gas	0.2 $ cent per kWh for Solar

The figures in the above table give the additional costs of delivery of electricity production per kWh that could result from environmental regulatory policies designed to internalize the currently externalized costs.

2- Who Pays for the Cost of the Policy?
At the end energy producers and/or consumers will pay the cost of the policy. The policy may be designed to impose higher costs on one group in comparison with another group.

3. The Security of Supply of Electricity:
The current situation of supply in Bahrain shows that there are energy supply disruptions especially during the summer, and the frequency of such disruptions is about 1 hour per week. Such disruptions currently affect about 25% of the population. One of the positive consequences of a policy for internalization of external costs of electricity would be a dramatic decrease in the frequency of such disruptions, thereby decreasing the number from 1 or 0 hours per week.

4- The Effects on Energy Efficiency:
The current low price of electricity in Bahrain has caused industries and households in Bahrain to put low priorities on energy efficiency, but this situation is likely to change in Bahrain in case the currently externalized costs of electricity production are internalized. Consequently, energy efficiency programs will become dramatically more important; such internalization of externalities will help in achieving at least 40-60% improvement in energy efficiency.

5- The Effects in Renewable Energy:
The electricity market in Bahrain is currently seriously distorted; therefore, governmental policy measures such as removing subsidies and internalizing the external costs of electricity production will promote enhanced investments in exploitation of renewable energies (Solar, Wind...Etc.). Therefore, developing and implementing an integrated renewable energy policy by the government, will help in generating 10-15% of the current electricity demand from renewable within the next ten years.

6- The Effects in Air Quality and Greenhouse Gases:
Air pollution and greenhouse gases that are emitted from electricity production in Bahrain rank among the highest in our list of local environmental problems. Many seem to accept these problems as the price we must pay for economic development. Under the present pricing structure, market failures have been considered responsible for air

pollution; internalizing these costs will help to reduce air pollution and greenhouse gases by at least 20-40% and will help to stimulate investments in energy conservation and renewable energy production methods.

7- The Effects on Human Health:

The RiskPoll model used in this research provided an estimate of the public health costs associated with fossil fuel combustion in the power plants in the Kingdom of Bahrain. The results show that, the society, insurance companies, and the public health budget bear most of the costs via increases in disease treatment and health care costs, productivity loses, and the consequences of increased mortality. Developing and implementing governmental policies that will help to internalize the currently externalized costs will help to improve human health and to reduce the societal costs by at least 50%.

8- Conservation of Resources:

The internalizing policy will positively affect the exploitation plans to conserve the finite resources of gas and oil in Bahrain, internalizing externalities will encourage the government to adopt an energy efficiency, and renewable energy policy; this will lead to a 30-50% reduction in the consumption of natural gas for electricity generation.

Choice between Hypothetical Policies:

The following 6 Tables compare hypothetical policies. For each Table, I invite you to choose between two hypothetical policies. Please compare only the two policies presented in each Table.

Do not compare policies among different tables.

Choice 1. Compare Policy A with Policy B

Characteristics	Policy A	Policy B
Cost of the policy: the internalization of the currently externalized costs;	3 $cent/kWh for gas 0 $cent/kWh for Solar or Wind power	6 $cent/kWh for gas 0.2 $cent/kWh for Solar or wind power
Share of the cost of the internalization that producers will pay;	65%	50%
Share of the cost of the internalization that consumes will pay;	35%	50%
Frequency of events of energy disruption in Bahrain;	0 hours every week	0 hours every week
Achievable percentage of energy efficiency;	20%	50%
Shares of renewable energy;	15%	10%
Reduction in air pollution and greenhouse gases;	20%	40%

Avoidance percentage of health costs;	25%	50%
Potential reductions of fossil fuel consumption.	30%	50%

1. Which policy do you find more attractive? □ **A or** □ **B**
2. If you were to choose between A & B and the option of not implementing any policy and therefore not internalizing any currently externalized costs, what would you choose? □ **A** □ **B** □ **NO POLICY** (no cost internalization)

Choice 2. Compare Policy C with Policy D

Characteristics	**Policy C**	**Policy D**
Cost of the policy: the internalization of the externalized costs;	5 $cent/kWh for gas 0.1 $cent/kWh for Solar or wind power	6 $cent/kWh for gas 0.2 $cent/kWh for Solar or wind power
Share of the cost of the internalization that producers will pay;	35%	35%
Share of the cost of the internalization that consumers will pay;	65%	65%
Frequency of events of energy disruption in Bahrain;	0 hours every week	0 hours every week
Achievable percentage of energy efficiency;	40%	60%
Shares of renewable energy;	10%	10%
Reduction in air pollution and greenhouse gases;	30%	40%
Potential avoidance of health costs;	40%	50%
Potential saving on fossil fuel consumption.	40%	50%

1. Which policy do you find more attractive? □ **C or** □ **D**
2. If you were to choose between C & D and the option of not implementing any policy and therefore, not internalizing any external costs, what would you choose? □ **C** □ **D** □ **NO POLICY** (no cost internalization)

Choice 3. Compare Policy E with Policy F do not compare the Policies in this Choice 3 with policies in Previous Choice

Characteristics	Policy E	Policy F
Cost of the policy for the internalization of the external costs of electricity production	2 $cent/kWh for gas 0.1 $cent/kWh for Solar or wind power	3 $cent/kWh for gas 0.2 $cent/kWh for Solar or wind power
Share of the cost of the internalization that producers will pay;	50%	50%
Share of the cost of the internalization that consumers will pay;	50%	50%
Frequency of events of energy disruptions in Bahrain;	0 hours every week	0 hours every week
Achievable percentage of energy efficiency;	15%	20%
Shares of renewable energy;	7%	10%
Reduction in air pollution and greenhouse gases;	15%	20%
Potential avoidance of health costs;	20%	25%
Potential saving on fossil fuel consumption.	25%	30%

1. Which policy do you find more attractive? □ **E or** □ **F**
2. If you were to choose between E, F and the option of not implementing any policy and therefore not internalizing any external cost, what would you choose? □ **E** □ **F** □ **NO POLICY** (no cost internalization)

Choice 4. Compare Policy G with Policy H do not Compare the Policies in this Choice 4 with Policies in Previous Choice

Characteristics	Policy G	Policy H
Cost of the policy for the internalization of the external costs of electricity production	6 $cent/kWh for gas 0.2 $cent/kWh for Solar or wind power	4 $cent/kWh for gas 0 $cent/kWh for Solar or wind power
Share of the cost of the internalization that producers will pay;	65%	35%
Share of the cost of the internalization that consumers will pay;	35%	65%
Frequency of events of energy disruptions in Bahrain	0 hours every week	0 hours every week
Achievable percentage of energy efficiency	55%	40%

Shares of renewable energy	10%	15%
Reduction in air pollution and greenhouse gases	40%	30%
Potential avoidance of health costs	35%	30%
Potential saving on fossil fuel consumption	45%	40%

1. Which policy do you find more attractive? □ **G or** □ **H**
2. If you were to choose between G, H and the option of not implementing any policy and therefore not internalizing any external cost, what would you choose? □ **G** □ **H** □ **NO POLICY** (no cost internalization)

Choice 5. Compare Policy I with Policy J do not Compare the Policies in this Choice 5 with Policies in Previous Choice

Characteristics	Policy I	Policy J
Cost of the policy for the internalization of the external costs of electricity production	1 $cent/kWh for gas 0 $cent/kWh for Solar or wind power	1.5 $cent/kWh for gas 0.1 $cent/kWh for Solar or wind power
Share of the cost of the internalization that producers will pay;	35%	65%
Share of the cost of the internalization that consumers will pay;	65%	35%
Frequency of events of energy disruptions in Bahrain;	1 hour every week	0 hours every week
Achievable percentage of energy efficiency;	10%	15%
Shares of renewable energy;	5%	5%
Reduction in air pollution and greenhouse gases;	15%	20%
Potential avoidance of health costs;	10%	15%
Potential saving on fossil fuel consumption.	15%	20%

1. Which policy do you find more attractive? □ **I or** □ **J**
2. If you were to choose between I, J and the option of not implementing any policy and therefore not internalizing any external cost, what would you choose? □ **I** □ **J** □ **NO POLICY** (no cost internalization)

Choice 6. Compare Policy K with Policy L Do not compare the policies in this Choice 6 with policies in previous choice

Characteristics	Policy K	Policy L

Cost of the policy for the internalization of the external costs of electricity production	1 $cent/kWh for gas 0 $cent/kWh for Solar or wind power	2 $cent/kWh for gas 0 $cent/kWh for Solar or wind power
Share of the cost of the internalization that producers will pay;	50%	50%
Share of the cost of the internalization that consumers will pay;	50%	50%
Frequency of events of energy disruptions in Bahrain;	1 hour every week	0 hours every week
Achievable percentage of energy efficiency;	10%	15%
Shares of renewable energy;	5%	7%
Reduction in air pollution and greenhouse gases;	10%	15%
Potential avoidance of health costs;	10%	20%
Potential saving on fossil fuel consumption.	15%	25%

1. Which policy do you find more attractive? □ **K** **or** □ **L**
2. If you were to choose between K, L and the option of not implementing any policy and therefore not internalizing any external cost, what would you choose? □ **K** □ **L** □ **NO POLICY** (no cost internalization)

Choice 7:
Among the 12 policies given in the above choices, which policy do you find more attractive? And Why?
□ **A** □ **B** □ **C** □ **D** □ **E** □ **F** □ **G** □ **H** □ **I** □ **J** □ **K** □ **L**

Section 2: What are your motivations or reasons for your choice?

1. Do you think the choice of options in the previous pages were clear? □ Yes □ No
2. Did you find the choice of options on the previous pages difficult to answer?
□ No
□ Yes → what were the main difficulties you found while comparing the hypothetical policies?

3. Did you consider all the characteristics of the policies when you were comparing each group of two policies, or have you paid attention only to one characteristic of that policy?

□ I considered all the characteristics
□ I only considered one characteristic → which one?
□ The cost of the policy
□ Who pays for the cost internalization
□ The effects on the health budget
□ The possible increase in energy disruptions
□ The possible increase in energy efficiency
□ The possible reduction in greenhouse gases
□ The consumption of fossil fuel

4. On a 1 to 7 ranking, where 1 means the most important element and 7 the least important element, please rank the importance of the following elements for a policy for the internalization of the external costs of electricity production:

___________________ Reducing the negative Human Health impacts.

________________ Developing and implementing a fair distribution of the costs among producers and consumers.

___________________ Guaranteeing the security of the supply of electricity.

___________________ Optimizing the level of the costs that are internalized.

___________________ increasing the total society's energy efficiency.
___________________ Reducing the greenhouse gases emissions.

_________________ Reducing fossil fuel consumption and increasingly relying upon renewable energy sources and technologies.

Section 3:

5. Which of the following policy instruments would you prefer for Bahrain to use for the internalization of the currently externalized costs of electricity production and usage? Choose one or more instrument(s).
□ Traditional command and control[5];

[5] The regulator sets an overall target for each firm, or plant, and gives the firms some discretion in how to meet the standard. Technology forcing standards demand a performance (energy consumption level, emission level) that is not feasible with the existing technology. The requirements induce firms to invest in developing and implementing innovative technologies. As an example, this instrument is being applied in some developed countries to stimulate the development and introduction of zero emission cars.

□ Tradable emission permits[6];
□ Pollution taxes[7];
□ Subsidies given to consumers to improve the energy efficiency of their system;
□ Subsidies provide for producers to improve the energy efficiency of their system;
□ Subsidies given to commercial producers of energy from renewable sources;
□ Subsidies given to consumers to purchase and install renewable energy equipment;
□ Subsidies given to consumers who purchase renewable energy;
□ Other approaches.
____

6. Do you think the RiskPoll methodology and results should be used in designing policies for environmental regulation of the Electricity production sector in Kingdom of Bahrain and if so how should they be used?

____

____

7. Are you a representative of?
□ University □ Government / Policy □ Electricity utility □ Other Industry
□ NGO □ Research institute □ Consultant □ Other, please explain

8. Did you fill in the questionnaire as a representative of your organization or as a private individual?

□ Representative of your organization □ Private individual

Thank you for having completed the questionnaire!

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[6] Each permit represents a fixed quantity of allowed emissions, typically 1 metric ton per permit. The number of permits in 'owned' by the firm represents the total permitted emission quantity; a penalty is applied in case the actual emissions of that firm are in excess of this quantity. Permits may be traded. Buyers will be those operators or countries, which lack permits for their emission needs (their marginal costs of reduction are high). Sellers will be those operators or countries, which have permits in excess (their marginal costs are low).

[7] The objective of a carbon tax is to internalize the external cost of pollution into the price of producing electricity based upon fossil fuels.

Appendix 2

Choice 1 Do you find policy (A) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	87	39.0	39.0	39.0
	Yes	136	61.0	61.0	100.0
	Total	223	100.0	100.0	

Do you find policy (B) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	134	60.1	60.1	60.1
	Yes	89	39.9	39.9	100.0
	Total	223	100.0	100.0	

If you were to choose between (A) and (B) and the option of (No Policy)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	A	82	36.8	50.6	50.6
	B	80	35.9	49.4	100.0
	Total	162	72.6	100.0	
NO	Policy	61	27.4		
Total		223	100.0		

Choice 2- Do you find policy (C) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	85	38.1	38.1	38.1
	Yes	138	61.9	61.9	100.0
	Total	223	100.0	100.0	

Do you find policy (D) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	138	61.9	61.9	61.9
	Yes	85	38.1	38.1	100.0
	Total	223	100.0	100.0	

f you were to choose between (C) and (D) and the option of (No Policy)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	C	91	40.8	58.0	58.0
	D	66	29.6	42.0	100.0
	Total	157	70.4	100.0	
No	Policy	66	29.6		
Total		223	100.0		

Choice 3- Do you find policy (E) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	141	63.2	63.2	63.2
	Yes	82	36.8	36.8	100.0
	Total	223	100.0	100.0	

Do you find policy (F) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	84	37.7	37.7	37.7
	Yes	139	62.3	62.3	100.0
	Total	223	100.0	100.0	

If you were to choose between (E) and (F) and the option of (No Policy)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	E	56	25.1	38.6	38.6
	F	89	39.9	61.4	100.0
	Total	145	65.0	100.0	
No	Policy	78	35.0		
Total		223	100.0		

Choice 4- Do you find policy (G) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	103	46.2	46.2	46.2
	Yes	120	53.8	53.8	100.0
	Total	223	100.0	100.0	

Do you find policy (H) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	120	53.8	53.8	53.8
	Yes	103	46.2	46.2	100.0
	Total	223	100.0	100.0	

f you were to choose between (G) and (H) and the option of (No Policy)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	G	87	39.0	50.3	50.3
	H	86	38.6	49.7	100.0
	Total	173	77.6	100.0	
No	Policy	50	22.4		
Total		223	100.0		

Choice 5- Do you find policy (I) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	214	96.0	96.0	96.0
	Yes	9	4.0	4.0	100.0
	Total	223	100.0	100.0	

Do you find policy (J) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	11	4.9	4.9	4.9
	Yes	212	95.1	95.1	100.0
	Total	223	100.0	100.0	

If you were to choose between (I) and (J) and the option of (No Policy)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NO	2	.9	1.0	1.0
	I	28	12.6	14.4	15.4
	J	165	74.0	84.6	100.0
	Total	195	87.4	100.0	
No	Policy	28	12.6		
Total		223	100.0		

Choice 6- Do you find policy (K) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	186	83.4	84.2	84.2
	Yes	35	15.7	15.8	100.0
	Total	221	99.1	100.0	
Missing	System	2	.9		
Total		223	100.0		

Do you find policy (L) attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	37	16.6	16.7	16.7
	Yes	184	82.5	83.3	100.0
	Total	221	99.1	100.0	
Missing	System	2	.9		
Total		223	100.0		

f you were to choose between (K) and (L) and the option of (No Policy)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	NO	2	.9	1.3	1.3
	K	2	.9	1.3	2.5
	L	156	70.0	97.5	100.0
	Total	160	71.7	100.0	
No	Policy	63	28.3		
Total		223	100.0		

Choice 7- Among the 12 policies given in the questionaire, which policy do you find more attractive?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Policy A	16	7.2	7.2	7.2
	Policy B	12	5.4	5.4	12.7
	Policy C	4	1.8	1.8	14.5
	Policy D	7	3.1	3.2	17.6
	Policy E	5	2.2	2.3	19.9
	Policy F	20	9.0	9.0	29.0
	Policy G	10	4.5	4.5	33.5
	Policy H	7	3.1	3.2	36.7
	Policy I	9	4.0	4.1	40.7
	Policy J	80	35.9	36.2	76.9
	Policy K	5	2.2	2.3	79.2
	Policy L	46	20.6	20.8	100.0
	Total	221	99.1	100.0	
Missing	System	2	.9		
Total		223	100.0		

Section 2-1 did you think the choice of options in the previous Pages were clear?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	32	14.3	14.5	14.5
	Yes	189	84.8	85.5	100.0
	Total	221	99.1	100.0	
Missing	System	2	.9		
Total		223	100.0		

Section 2-2 did you find the choice of options on the previous pages difficult to answer?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	189	84.8	84.8	84.8
	Yes	34	15.2	15.2	100.0
	Total	223	100.0	100.0	

Did you consider all the characterstics when you comparing policies?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	58	26.0	26.0	26.0
	Yes	165	74.0	74.0	100.0
	Total	223	100.0	100.0	

Number of Respondents pay attention for the cost of the policy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	1	.4	3.6	3.6
	1.00	27	12.1	96.4	100.0
	Total	28	12.6	100.0	
Missing	System	195	87.4		
Total		223	100.0		

Number of Respondents pay attention for the cost of internalization

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	24	10.8	100.0	100.0
Missing	System	199	89.2		
Total		223	100.0		

Number of respondents pay attention for the effects on the health budget

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	16	7.2	100.0	100.0
Missing	System	207	92.8		
Tota		223	100.0		

Number of respondents pay attention to the possible increase in energy disruption

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	2	.9	100.0	100.0
Missing	System	221	99.1		
Total		223	100.0		

Number of respondents pay attention to the possible increase in energy effeciency

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	9	4.0	100.0	100.0
Missing	System	214	96.0		
Total		223	100.0		

Number of respondents pay attention to the possible reduction in greenhouse gases

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	9	4.0	100.0	100.0
Missing	System	214	96.0		
Total		223	100.0		

Number of respondents pay attention to the consumption of fossil fuel

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	7	3.1	100.0	100.0
Missing	System	216	96.9		
Total		223	100.0		

Ranking of health impacts as important element

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	80	35.9	36.7	36.7
	2.00	62	27.8	28.4	65.1
	4.00	11	4.9	5.0	70.2
	5.00	65	29.1	29.8	100.0
	Total	218	97.8	100.0	
Missing	System	5	2.2		
Total		223	100.0		

Ranking of distribution of the cost among producers and consumers as important element

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	67	30.0	30.7	30.7
	2.00	17	7.6	7.8	38.5
	3.00	12	5.4	5.5	44.0
	4.00	20	9.0	9.2	53.2
	5.00	8	3.6	3.7	56.9
	6.00	48	21.5	22.0	78.9
	7.00	46	20.6	21.1	100.0
	Total	218	97.8	100.0	
Missing	System	5	2.2		
Total		223	100.0		

Ranking of security of supply as important element

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	59	26.5	27.1	27.1
	2.00	53	23.8	24.3	51.4
	3.00	43	19.3	19.7	71.1
	4.00	37	16.6	17.0	88.1
	5.00	19	8.5	8.7	96.8
	6.00	7	3.1	3.2	100.0
	Total	218	97.8	100.0	
Missing	System	5	2.2		
Total		223	100.0		

Ranking of level of the internalized cost as important element

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2.00	45	20.2	20.6	20.6
	3.00	39	17.5	17.9	38.5
	4.00	16	7.2	7.3	45.9
	5.00	30	13.5	13.8	59.6
	6.00	57	25.6	26.1	85.8
	7.00	31	13.9	14.2	100.0
	Total	218	97.8	100.0	
Missing	System	5	2.2		
Total		223	100.0		

Ranking of Energy effeciency as important element

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	5	2.2	2.3	2.3
	3.00	67	30.0	30.7	33.0
	4.00	55	24.7	25.2	58.3
	5.00	29	13.0	13.3	71.6
	6.00	41	18.4	18.8	90.4
	7.00	21	9.4	9.6	100.0
	Total	218	97.8	100.0	
Missing	System	5	2.2		
Total		223	100.0		

Ranking Reducing greenhouse gases emission as important element

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	24	10.8	11.0	11.0
	2.00	27	12.1	12.4	23.4
	3.00	31	13.9	14.2	37.6
	4.00	11	4.9	5.0	42.7
	5.00	28	12.6	12.8	55.5
	6.00	37	16.6	17.0	72.5
	7.00	60	26.9	27.5	100.0
	Total	218	97.8	100.0	
Missing	System	5	2.2		
Total		223	100.0		

Ranking Reducing fossil fuel consumption as important element

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.00	2	.9	.9	.9
	2.00	15	6.7	6.9	7.8
	3.00	26	11.7	11.9	19.7
	4.00	63	28.3	28.9	48.6
	5.00	34	15.2	15.6	64.2
	6.00	23	10.3	10.6	74.8
	7.00	55	24.7	25.2	100.0
	Total	218	97.8	100.0	
Missing	System	5	2.2		
Total		223	100.0		

Section 3-5 Do you refer the traditional command and control as a tool to internalized the currently externalized cost?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	74	33.2	33.2	33.2
	Yes	149	66.8	66.8	100.0
	Total	223	100.0	100.0	

Do you prefer the tradable emssions permits as a tool to internalized the currently externalized costs

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	80	35.9	35.9	35.9
	Yes	143	64.1	64.1	100.0
	Total	223	100.0	100.0	

Do you prefer pollution taxes as a tool to internalized the currently externalized costs

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	111	49.8	49.8	49.8
	Yes	112	50.2	50.2	100.0
	Total	223	100.0	100.0	

Do you prefer subsidies given to consumers to improve the energy effeciency of their system

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	90	40.4	40.4	40.4
	Yes	133	59.6	59.6	100.0
	Total	223	100.0	100.0	

Dou prefer subsidies provide for producers to improve the energy effeciency of their system

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	89	39.9	39.9	39.9
	Yes	134	60.1	60.1	100.0
	Total	223	100.0	100.0	

o you prefer subsidies given to commercial producers of energy fron renewable sources?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	79	35.4	35.4	35.4
	Yes	144	64.6	64.6	100.0
	Total	223	100.0	100.0	

Do you prefer subsidies given to consumers to purchase and install renewable energy equibments

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	91	40.8	40.8	40.8
	Yes	132	59.2	59.2	100.0
	Total	223	100.0	100.0	

Do you prefer subsidies given to consumers who purchase renewable energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	95	42.6	42.6	42.6
	Yes	128	57.4	57.4	100.0
	Total	223	100.0	100.0	

Do you think the Riskpol Methodology and results should be used in designing policies for environmental regulation of electricity sector in Bahrain

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	39	17.5	23.2	23.2
	Yes	129	57.8	76.8	100.0
	Total	168	75.3	100.0	
Missing	System	55	24.7		
Total		223	100.0		

affiliation of respondents

		Frequency	Valid Percent	Cumulative Percent
Valid	University	19	8.5	8.5
	Goverment/Policy	65	29.1	37.7
	Research Institute	6	2.7	40.4
	Electricity Utility	44	19.7	60.1
	Other Industry	47	21.1	81.2
	Legislators	42	18.8	100.0
	Total	223	100.0	

id you fill in the questionaire as a representative of your organisation as private individual

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Private	96	43.0	43.0	43.0
	Repre	127	57.0	57.0	100.0
	Total	223	100.0	100.0	

Appendix 3: Survey Text with Frequencies:

Energy and Environment in Bahrain
Adhoc Survey

Dear Respondent,

You have been selected to participate in a survey about energy and environmental issues in Bahrain, the survey is for academic purpose, your responses will be kept confidential, the survey aim to assess the Bahrainis knowledge and preference concerning electricity generation, fuels that may be used in the production process, and willingness to pay for environmental and actual production costs.

Please answer the questionnaire and return it back to the following Address:

Public commission for Environment
P.O.Box: 28652
Fax: 17786012
E-mail: alih@environment.gov.bh

Please tick and answer the appropriate information:

Male/Female			**Level of Education**		**Field of Specialization**	
Age			Below secondary		Social Science	
Res. (Flat/Villa)			Secondary		Economics	
Monthly Income			Diploma		Physical Science	
Area			B.Sc.		Human Science	
Affiliation	government		Master		Information	
	Private		Ph.D		Legislation	
	NGO		Other (specify)		Environment	

Issue	**Questions**	**Strongly Agree**	**Some-what agree**	**Not Sure**	**Some-what disagree**	**Strongly Disagree**
Energy and Environment	1- There is no relation between over consumption of electricity and Pollution.	8.4%	13%	12.3%	32%	34.3%
	2- Production of Electricity from fossil fuel sources contributing on pollution and the degradation of air quality.	44.6%	48.2%	4.4%	2.3%	0.5%
	3- The reason behind global warming is the increasing levels of ambient CO^2 and other pollutants.	47.5%	38.3%	11.9%	1.3%	%1
	4- Bahrain Island will not affected by Global warming.	3.3%	4.6%	7.6%	37.9%	46.6%
	5- The growing demand on electricity will deplete the indigenous gas reserve on the near future.	23.9%	35.1	30%	8.4%	2.5%
	6- Clean Technologies is important for clean environment.	62.3%	29.3%	4.1%	2.8%	1.5%

Cost of Energy	7- The government subsidy for electricity has significant impacton environment.	8.4%	17.6%	26.8%	22.2%	24.7%
	8- To conserve resources and use of electricity the electricity prices should increase gradually.	6.1%	17.6%	11.7%	27.3%	37.2%
	9- The environmental costs (Externalities) related to the production of electricity should be included on the price of electricity.	9%	25.3%	15.9%	23%	26.9%
	10-polluter pay principle not effective tool for environmental policy.	10.5%	25.7%	24.9%	26.4%	12.6%
	11-Electricity consumers should pay the actual production cost.	3.4%	19.6%	10.6%	29.7%	36.7%
Renewable Energy	12- I don't support a decision taken by the government to utilize renewable energy.	8.3%	10.6%	5.2%	31.5%	44.4%
	13- Renewable energy contributes on resource conservation and environmental protection.	59.5	32.5%	5.5%	1.8%	0.8%
	14- I do not mind to pay monthly voluntary 5% from the electricity bill to support renewable energy development in Bahrain.	8.1%	22.6%	11.2%	23.4%	34.8%
	15- Would you support the Bahraini Legislators requiring the power utilities to produce 10% of their electricity from renewable sources within the next 10 years?	38%	46.7%	11.5%	1.5%	2.3%
	16- Bahrainis are willing to pay 5% more if electricity is generated with renewable sources.	12%	33.7%	19.6%	16.6%	18.1%

Thank you for your help.

The following demographic information are extracted from the survey results:

17- Gender:

Male: 63%
Female: 37%

18- Type of Residence:

Villa: 75.5%
Flat: 24.5%

19- Area (governorate):

Capital: 20.9%
Muharraq: 10.1%
Northern: 40.2%

Central:	21.2%
Southern:	7.6%

20- Occupation:

Government:	66.1%
Private Sector:	33.9%

21- Education Level:

Below Primary:	1.3%
Primary	12.5%
Diploma	25.3%
BSc.	52.6
Master	7.3%
PhD	1%

22- Specialization:

Socio:	13.8%
Economic:	27.6%
Science:	22.9%
Humanity:	17.8%
IT	12.1%
Law	1%
Environment:	4.7%

23- Age:

< 22	1.6%
23-27	15.1%
28-35	33.3%
36-50	43.1%
> 51	6.9%

24- Income (in Bahraini Dinars = 1 BD= U$2.65):

< 200	1.4%
200-375	14.9%
376-800	69.9%
801-1000	7.3%
> 1000	6.6%

Appendix 4: Survey Methodology:

The survey was conducted between 28th September and 22nd October 2006, with a random sample of respondents. Random sampling considered an excellent sampling frame to gauge public opinions. About 600 survey sheets were distributed among the employees of some governmental ministries, and private sector, because the workers in these institutions represent all Bahrainis from different areas, sexs, ages, and educational levels; also most of workers have families and represent a household.

Because the survey distributors were selected from the targeted entities, they made intense efforts to maximize the proportion of completed questionnaires, either by encouraging people to contribute to the survey, as well as by clarifying any misunderstanding.

Although the data are from the entire Bahrain region, the survey is not weighted by region, the respondents from the northern governorate are over-represented, and the respondents from southern governorate are under-represented. However, the representation are consistence with total population of these governorates, for instance the total population of northern governorate is over 140 thousands inhabitants and the population density per square kilometer is over 900 inhabitants, while the total population of the southern governorate is about 70 thousands inhabitants, and the population density not exceed 230 inhabitants/km^2 (refer to the population densities by area in chapter 4).

People of the ages between 35-50 years are over-represented, while people over 50 are under-represented. Furthermore, there is evidence that the answers were an honest reflection of the real attitudes and opinions of the people (some comments were observed throughout the questionnaires which stated that the government should not overtax people). The an honest reflection may result because energy was cited as the topic of the survey in the introduction; the effect of the an honest reflection is to understate support for removal of electricity subsidies, cost recovery, internalizing of externalities, the preference for renewable energy, and the concern regarding the local environmental issues.

After compiling the survey answer sheets, a serial number was given to each respondent, in order to ease the cross-checking to the input data, and to ensure that all input data are correct.

The statistical analyses were performed using the software SPSS version 14.0 was used, the data were first coded numerically, for instance if the sex of the respondent was male will give (1), and (2) for female. This approach was also applied for type of residence, area, occupation, educational level, specialization, and similarly for the answers for each question of the questionnaire. The analyses were then performed and the results evaluated to provide inputs to policy, information and training efforts that should be done.

Appendix 5- Results of the survey:

Frequencies

```
[DataSet1] F:\final_hessabi_Survey Analysis.sav
```

```
Summery statistics showing the number of respondents to each question
```

Statistics

		EE_Q1	EE_Q2	EE_Q3	EE_Q4	EE_Q5	EE_Q6	ES_Q7	ES_Q8	ES_Q9	ES_Q10	ES_Q11	RE_Q12	RE_Q13	RE_Q14	RE_Q15	RE_Q16
N	Valid	391	390	394	393	393	393	392	392	391	382	387	387	385	394	392	392
	Missing	4	5	1	2	2	2	3	3	4	13	8	8	10	1	3	3

Frequency Table

EE Q1: Is there any relation between over consumption of electricity and Pollution?

EE_Q1

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	33	8.4	8.4	8.4
	2	51	12.9	13.0	21.5
	3	48	12.2	12.3	33.8
	4	125	31.6	32.0	65.7
	5	134	33.9	34.3	100.0
	Total	391	99.0	100.0	
Missing	System	4	1.0		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

EE Q2: Do you think that Production of Electricity from fossil fuel sources contributing on pollution and the degradation of air quality

EE_Q2

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	174	44.1	44.6	44.6
	2	188	47.6	48.2	92.8
	3	17	4.3	4.4	97.2
	4	9	2.3	2.3	99.5
	5	2	.5	.5	100.0
	Total	390	98.7	100.0	
Missing	System	5	1.3		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

EE Q3: The reason behind global warming is the increasing levels of ambient CO^2 and other pollutants

EE_Q3

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	187	47.3	47.5	47.5
	2	151	38.2	38.3	85.8
	3	47	11.9	11.9	97.7
	4	5	1.3	1.3	99.0
	5	4	1.0	1.0	100.0
	Total	394	99.7	100.0	
Missing	System	1	.3		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

EE Q4: Bahrain Island will not affected by Global warming

EE_Q4

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	13	3.3	3.3	3.3
	2	18	4.6	4.6	7.9
	3	30	7.6	7.6	15.5
	4	149	37.7	37.9	53.4
	5	183	46.3	46.6	100.0
	Total	393	99.5	100.0	
Missing	System	2	.5		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

EE Q5: The growing demand on electricity will deplete the indigenous gas reserve on the near future.

EE_Q5

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	94	23.8	23.9	23.9
	2	138	34.9	35.1	59.0
	3	118	29.9	30.0	89.1
	4	33	8.4	8.4	97.5
	5	10	2.5	2.5	100.0
	Total	393	99.5	100.0	
Missing	System	2	.5		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

EE Q6: Clean Technologies is important for clean environment.

EE_Q6

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	245	62.0	62.3	62.3
	2	115	29.1	29.3	91.6
	3	16	4.1	4.1	95.7
	4	11	2.8	2.8	98.5
	5	6	1.5	1.5	100.0
	Total	393	99.5	100.0	
Missing	System	2	.5		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

ES Q7: The government subsidy for electricity has significant impacton environment.

ES_Q7

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	33	8.4	8.4	8.4
	2	70	17.7	17.9	26.3
	3	105	26.6	26.8	53.1
	4	87	22.0	22.2	75.3
	5	97	24.6	24.7	100.0
	Total	392	99.2	100.0	
Missing	System	3	.8		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

ES Q8: To conserve resources and use of electricity the electricity prices should increase gradually.

ES_Q8

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	24	6.1	6.1	6.1
	2	69	17.5	17.6	23.7
	3	46	11.6	11.7	35.5
	4	107	27.1	27.3	62.8
	5	146	37.0	37.2	100.0
	Total	392	99.2	100.0	
Missing	System	3	.8		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

ES Q9: The environmental costs (Externalities) related to the production of electricity should be included on the price of electricity.

ES_Q9

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	35	8.9	9.0	9.0
	2	99	25.1	25.3	34.3
	3	62	15.7	15.9	50.1
	4	90	22.8	23.0	73.1
	5	105	26.6	26.9	100.0
	Total	391	99.0	100.0	
Missing	System	4	1.0		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

ES Q10: polluter pay principle is not effective tool for environmental policy.

ES_Q10

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	40	10.1	10.5	10.5
	2	98	24.8	25.7	36.1
	3	95	24.1	24.9	61.0
	4	101	25.6	26.4	87.4
	5	48	12.2	12.6	100.0
	Total	382	96.7	100.0	
Missing	System	13	3.3		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

ES Q11: Electricity consumers should pay the actual production cost.

ES_Q11

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	13	3.3	3.4	3.4
	2	76	19.2	19.6	23.0
	3	41	10.4	10.6	33.6
	4	115	29.1	29.7	63.3
	5	142	35.9	36.7	100.0
	Total	387	98.0	100.0	
Missing	System	8	2.0		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

RE Q12: I don't support a decision taken by the government to utilize renewable energy.

RE_Q12

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	32	8.1	8.3	8.3
	2	41	10.4	10.6	18.9
	3	20	5.1	5.2	24.0
	4	122	30.9	31.5	55.6
	5	172	43.5	44.4	100.0
	Total	387	98.0	100.0	
Missing	System	8	2.0		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

RE Q13: Renewable energy contributes on resource conservation and environmental protection.

RE_Q13

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	229	58.0	59.5	59.5
	2	125	31.6	32.5	91.9
	3	21	5.3	5.5	97.4
	4	7	1.8	1.8	99.2
	5	3	.8	.8	100.0
	Total	385	97.5	100.0	
Missing	System	10	2.5		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

RE Q14: I do not mind to pay monthly voluntary 5% from the electricity bill to support renewable energy development in Bahrain.

RE_Q14

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	32	8.1	8.1	8.1
	2	89	22.5	22.6	30.7
	3	44	11.1	11.2	41.9
	4	92	23.3	23.4	65.2
	5	137	34.7	34.8	100.0
	Total	394	99.7	100.0	
Missing	System	1	.3		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

RE Q15: Would you support the Bahraini Legislators requiring the power utilities to produce 10% of their electricity from renewable sources within the next 10 years?

RE_Q15

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	149	37.7	38.0	38.0
	2	183	46.3	46.7	84.7
	3	45	11.4	11.5	96.2
	4	6	1.5	1.5	97.7
	5	9	2.3	2.3	100.0
	Total	392	99.2	100.0	
Missing	System	3	.8		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

RE Q16: Bahrainis are willing to pay 5% more if electricity is generated with renewable sources.

RE_Q16

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	47	11.9	12.0	12.0
	2	132	33.4	33.7	45.7
	3	77	19.5	19.6	65.3
	4	65	16.5	16.6	81.9
	5	71	18.0	18.1	100.0
	Total	392	99.2	100.0	
Missing	System	3	.8		
Total		395	100.0		

1 strongly agree - 2 somewhat agree – 3 not sure – 4 somewhat disagree – 5 disagree

Summary

The electrical power production industry in the Kingdom of Bahrain as a Small Island Developing State (SIDS) has come a long way from its beginnings more than seventy years ago when the government, in May 1931, commissioned the first electrical power station at Ras Romman with a capacity of 0.2 Megawatt. In 1932, another power plant, the Ras Romman plant was constructed on behalf of the Bahrain Refinery. Since then, electricity production capacity has been dramatically increased to the current installed capacity of 1849 MW for Bahrain, which has a population of 0.691million inhabitants.

Currently, the electrical tariff structure in Bahrain is not based on consumer-specific, long-run marginal costs, but is based upon a price structure that is used as an instrument to achieve political and socioeconomic objectives. At $40 per barrel of oil, the total power production subsidy was estimated to be 26.5 fils kWh (about 7 U.S ¢ per kWh), with consumers paying 22% of the total capital and operating costs. However, at oil prices, in the international market, which reached US $ 110 per barrel in 2007, the power production subsidy was estimated to be 83.8% to 97%of the total actual costs.

Most of the electricity in Bahrain is produced by natural gas-fired power facilities; the major air emissions released from the combustion of gas include carbon dioxide (CO_2), particulates (PM_{10}), nitrogen oxides (NOx), and sulphur oxide (SOx). Other air pollutants include methane (CH_4) and non-methane volatile organic compounds (NMVOC).

Recently, the ambient air quality status was studied via a network of four monitoring stations in Bahrain. It was found that while non-methane hydrocarbons (NMHC), PM10, and ozone were consistently at critical levels in many areas, the concentrations of NOx, and SOx, were also increasing from moderate to high levels. The old power plants in Bahrain emit high levels of NOx.

The impact and corresponding damage costs related to human health effects and impact upon buildings and upon other man-made structures due to atmospheric pollutants generated by fossil fuel related activities (electricity generation, fuel processing and aluminum smelter) of three Bahraini facilities were assessed using the Risk Poll model which calculates the physical impact and the associated damage costs for air pollutants. As many

studies around the world reported that health impact contribute the largest part of the damage from air pollutants emitted from such facilities, most of the work in this thesis research was dedicated to evaluate them and to develop recommendations of ways to prevent or to at least minimize such problems.

The electrical power production facilities included in this research were: the: Riffa power station, the Bahrain Petroleum Company (BAPCO) refinery, and the Bahrain Aluminum smelter (ALBA). Four case studies were conducted at each facility, using two of the models included in RiskPoll for classic pollutants (RUWM and QUERI), and two approaches for mortality valuation. The thesis studies also included a simplified analysis of the externalities from Bahrain's energy sector related with global warming.

The estimated external costs from the three facilities match their emissions very closely. The average annual emission costs from the ALBA power station wereUS$97,000,000, from the BAPCO power station, they wereUS$63,000,000and from the Riffa facility, they wereUS$79,000,000/year (*All costs are in US$2004)*.

In order to evaluate potential governmental policy options for electricity generation in Bahrain, a survey was done to assess the knowledge and concerns of the general public regarding human health and environmental concerns associated with electricity generation. The survey results revealed that the majority of Bahrainis are aware of and care about the environment and are concerned about negative human health impact of air pollution. They understand the linkages between electricity usage, environmental quality and human health. However, despite their support for the use of renewable energy, Bahrainis do not support the removal, even gradually, of the subsidies on electricity prices, in order to pay the actual costs of electricity, and to thereby internalize the externalities of electricity production.

A second survey performed by this thesis author, targeted decision-makers in Bahrain. The purpose of this survey was to investigate the preference of electricity stakeholders about policy instruments for internalization of currently externalized costs in electricity production and usage. The results revealed that most decision-makers preferred policies that internalize a low percentage of the total damages caused by the currently externalized costs from electricity production, because they believe, raising electricity costs further will make industry and other productive sectors non-competitive, and will add more burdens on poor people.

The thesis author evaluated nine policy options that have been used internationally for their potential applicability in helping Bahrain to make improvements in its energy policies and programs.

The proposed policies included legal and economic instruments that can be used by the government to help it solve local, regional and global environmental problems, which need a coordinated national approach. A national system of tradable emission permits for pollutants that cause environmental and human health hazards or global warming would be justified if the *'command and control'* approach fails to solve the problems. Externality adders and discharge tax systems for discharges into the environmental media may also be justified under the constitution and governmental laws. However such systems must be carefully designed and implemented.

The author concluded that the economic evaluation of power generation externalities should become the basis for reforming governmental policy and for restructuring the energy sector. It should also serve as a decision-making support tool and for enhancing the political will to make the needed changes. It provides decision-makers a solid platform for them to select and to implement effective economic tools to internalize the currently externalized costs of power generation.

The author developed a ten-year roadmap for gradually removing the energy price subsidies and for internalizing the currently externalized costs of power generation and usage.

The author recommended that the Bahrain government should study the subsidy and externality effects at the micro and macroeconomic levels and should develop and implement a strategy for private and national investments in renewable energy within the energy market liberalization process. He also proposed that the government should implement energy efficiency improvement programs throughout Bahrain and should invest in R & D on energy and climate change challenges.

Samenvatting

De electriciteitssector in het Koninkrijk Bahrein, een *Small Island Developing State (SIDS)*, is ver gekomen in zijn ontwikkeling sinds het begin, meer dan zeventig jaar geleden. In mei 1931 gaf de regering de opdracht tot de bouw van de eerste electriciteitscentrale bij Ras Romman. Die had een vermogen van 0.2 Megawatt. In 1932 werd nog een centrale gebouwd voor de Bahrein Raffinaderij. Sindsdien is het de productiecapaciteit dramatisch toegenomen tot de huidige omvang van het geïnstalleerd vermogen van 1849 mWe, bij een bevolkingsomvang in Bahrein van 0.691 miljoen inwoners.

De tariefstructuur voor electriciteit in het koninkrijk Bahrein is niet gebaseerd op de voor consumenten specifieke lange-termijn marginale kosten, maar op politieke en sociaal-economische doelstellingen van de overheid. In het verleden, bij een olieprijs van 40$ per vat olie, werd de totale subsidie op electriciteit geraamd op 26.5 fils per kWh (ca. 0.07$ per kWh). Daarbij betaalden consumenten 22% van de totale kosten (vast en variabel). Tegenwoordig echter, bij een olieprijs van 110$ per vat – in 2007 – wordt de subsidie geraamd op 83.8 á 97% van de feitelijke totale kosten.

De meeste electriciteit in Bahrein wordt geproduceerd met installaties die aardgas gebruiken als brandstof. De belangrijkste emissies door verbranding van gas zijn kooldioxide (CO2), fijn stof (PM10), stikstofoxiden (Nox) and zwaveloxiden (Sox). Daarnaast zijn er emissies van verontreinigende stoffen als methaan (CH4) en andere vluchtige oplosbare stoffen (VOC).

Onlangs werd de luchtkwaliteit bestudeerd met een netwerk van vier waarnemingsstations voor geheel Bahrein. Daarbij werd vastgesteld dat de concentraties van NOx en Sox aan het toenemen waren van matige naar hoge niveaus, terwijl de concentraties van VOC (exclusief methaan), PM10 en ozon kritisch hoge waarden hadden bereikt. De oudere electriciteitscentrales in Bahrein hebben een hoge uitstoot van NOx.

In dit onderzoek werd het Risk Poll model gebruikt om de gezondheidseffecten en de schade aan de gebouwde omgeving te ramen die veroorzaakt wordt door de luchtverontreiniging uit de conversie van fossiele brandstoffen (electriciteitsproductie, raffinage en aluminiumproductie) in drie productiefaciliteiten in Bahrein. Daarbij werden ook de schadekosten geraamd. Wereldwijd zijn er veel studies die melden dat

gezondheidseffecten de grootste bijdrage leveren aan de schadekosten van zulke installaties. Daarom wordt in dit onderzoek de meeste aandacht besteed aan de evaluatie van gezondheidseffecten, de economische waardering daarvan, en beleidsaanbevelingen om deze te voorkomen of te minimaliseren.

In dit onderzoek werden de volgende productiefaciliteiten in beschouwing genomen: de electriciteitscentrale in Riffa, de raffinaderij van de Bahrein Petroleum Company (BAPCO), en de Bahrein Aluminum smelter (ALBA). Voor elk van deze installaties werd een *case study* uitgevoerd met behulp van twee van de modellen in Risk Poll (RUWM en QUERI), en twee benaderingen voor de waardering van mensenlevens. Tevens werd een vereenvoudigde analyse uitgevoerd van de bijdrage van de energiesector in Bahrein aan klimaatverandering. De externe kosten veroorzaakt door deze drie installaties staan goed in verhouding tot hun emissies. De gemiddelde jaarlijkse kosten voor de electriciteitscentrale ALBA bedroegen 97 miljoen dollar. Voor BAPCO was dat 63 miljoen doller, terwijl het voor Riffa ging om 79 miljoen dollar (in Amerikaanse dollars van 2004).

Verder zijn er in dit onderzoek beleidsopties ontwikkeld voor de electriciteitsproductie in Bahrein. Daartoe is een enquete uitgevoerd waarin de kennis en de bezorgdheid van het publiek in kaart gebracht werden over de gezondheids- en milieu-aspecten van electriciteitsproductie. Uit de enquete bleek dat de meerderheid van de inwoners van Bahrein zich bewust is van milieuproblemen, en daarover ook bezord is. Ze maken zich zorgen over de risico's voor en schade aan de gezondheid van mensen. Ze zien in dat er een verband is tussen electriciteitsgebruikenerzijds en milieukwaliteit en volksgezondheid anderzijds. Ze zijn een voorstander van vernieuwbare energie, maar geven geen steun aan het beëindigen van de subsidies op electriciteit, en het internaliseren van de externe effecten in de kosten en prijzen van electriciteitsproductie. Ook niet als dat geleidelijk gebeurt.

Een tweede enquete in dit onderzoek vond plaats onder de beleidsmakers in Bahrein. Deze enquete had tot doel de opvattingen van verschillende stakeholders te onderzoeken op het gebied van beleidsinstrumten voor het internaliseren van de externe effecten van de electricteitsproductie. De resultaten lieten zien dat de meeste beleidsmakers een voorkeur hebben voor dergelijke beleidsinstrumenten. Zij geloven dat een verdere stijging van de kosten van electriciteitsproductie een negatief effect zal hebben op de (internationale) concurrentiepositie van bedrijven en op de draagkracht van mensen met lage inkomens.

Negen beleidsopties die eerder in andere landen werden ingezet zijn onderzocht op hun toepasbaarheid in Bahrein. Daartoe behoren zowel economische instrumenten als meer conventionele *command&control* instrumenten. Deze kunnen door de regering gebruikt worden om locale, regionale en mondiale milieuproblemen te adresseren, die een gecoördineerde aanpak vereisen. Een nationaal systeem van verhandelbare emissierechten zou gerechtvaardigd kunnen zijn als de *command&control* aanpak ontoereikend is. Milieuheffingen zijn ook gerechtvaardigd onder de grondwet en andere wetten van Bahrein. De inzet van dergelijke instrumenten moet echter zorgvuldig voorbereid en uitgevoerd worden.

Dit onderzoek komt tot de conclusie dat de economische waardering van de externe effecten van electriciteitsproductie de basis zou moeten zijn voor beleidshervorming en de herstructurering van de energiesector. Economische waardering zou ook een *decision-making support tool* moeten zijn in het proces van beleidsontwikkeling en het vergroten van politieke wil om de noodzakelijke veranderingen door te voeren. In dit onderzoek wordt een roadmap ontwikkeld waarmee in tien jaar tijd de subsidies op electriciteit kunnen worden afgebouwd, en de externe kosten van electriciteitsproductie geïnternaliseerd. De regering van Bahrein zou de effecten van de huidige subsidies en de externe effecten moeten analyseren op micro- en macro-economisch niveau. Verder zou de regering publieke en private investeringsstrategie moeten ontwikkelen en implementeren voor de introductie van vernieuwbare energiebronnen, passend binnen het liberaliseringsproces van de energiemarkt in Bahrein. Tot slot wordt voorgesteld dat de regering energiebesparingsprogramma's zou moeten invoeren in heel Bahrein, en onderzoek en ontwikkeling bevorderen op het gebied van energie en klimaatverandering.

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