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THE ECONOMIC AND POLICY INTERNALIZATION OF EXTERNALITIES FROM POWER PLANTS AS A TOOL FOR PROGRESSING TOWARDS SUSTAINABILITY THE CASE OF BAHRAIN

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The Economic and Policy Internalization of Externalities from Power Plants as a Tool for Progressing Towards Sustainability
The Case of Bahrain

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1. Introduction

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

Reliable and reasonably priced sources of energy are essential for the economic and national security of the Kingdom of Bahrain, Recent Failures in energy Management such as Monday blackout in August 2004, the high demand for electricity and governmental subsidy for electricity and water, and the critical shortage of gas reserves, brought the critical role of energy to the public eye and underscored the need for a comprehensive energy strategy to ensure a sustainable supply of energy for the people of the Kingdom of Bahrain.

Full cost accounting quantifies the environmental externalities associated with electricity production is essential for the welfare of the society and the flow of market mechanism if we want to obtain the highest benefits for the society. Externalities related to energy production are in general defined as costs imposed on society that are not accounted for by the producers or consumers of energy, in other words damages not reflected in the market price. Normally, thinking of externalities related to energy, the externalities are environment, an often-cited example is the loss of production in fisheries due to the spill of pollutants and thermal stresses in the marine environment caused by energy use. Public health, agriculture and ecosystems, are another examples of parameters affected by the use of energy by others.

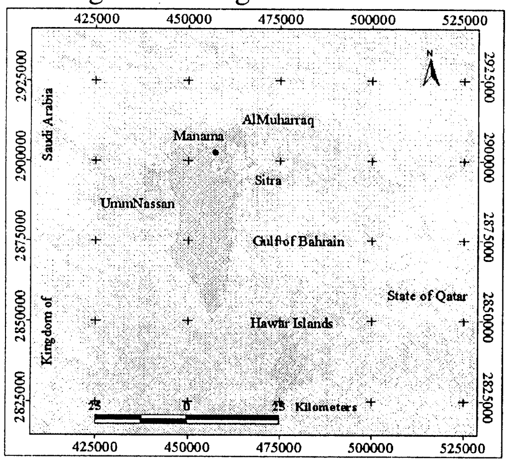
In this paper the review of externality valuation will focus on the assessment of environmental externalities, and the solutions would have to be adopted in order to achieve the concept of sustainable development.

A. <u>The Geographic profile</u>

The Kingdom of Bahrain considered one of SIDS, the kingdom consist of an archipelago of 36 low-lying islands and shoals, the total land area of the Kingdom in 1999 was about 706 square kilometers (km^2). It is located in the Arabian Gulf stretching between latitudes 25^0 32' N and 26^0 20'N and Longitudes 50^0 20'E and 50^0 50'E. There are approximately 534 km of coastline. The highest point in the country is *jabal Dukhan* at about 134 meters above sea level. The capital city, Manama, is located on the largest island, Bahrain, which accounts for about 84 percent of the total area of the country. Other islands include Al Muharrah (4% of total land area), Sitrah (2%), Umm

Nassan (3%), Nabih Saleh (0.1%) and Jiddah (0.05%). The southern chain includes Hawar, Sawad and other small islets (7%). Figure 1 shows a physical map of the country.

Figure 1- Kingdom of Bahrain



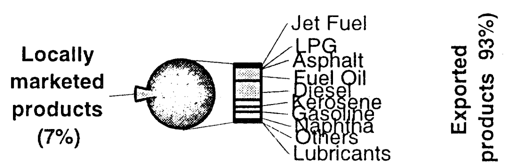
B. The Bahraini Energy Sector at a Glance

The turning point in the economic and social history of Bahrain was the discovery of oil in 1932. Since then, crude oil production, processing, distribution and consumption became major economic activities and significant sources of national income. Production of crude oil continues to increase to meet the growing demand for energy by all sectors of the economy. Most local crude production is consumed locally in refined oil products.

Production of crude oil reached a peak of 15.7 million barrels in 1988, dropping to 13.7 million in 2003 and continuing to drop slightly after that. Large quantities of crude are also imported from Saudi Arabia for processing in Bahraini refineries and eventual export to international markets, the total crude oil run to Bahrain refinery from Saudi Arabia reach about 80 million barrels in 2003.

Bahrain's crude oil refining capacity has steadily increased over the past decades. The vast majority of refined oil products, over 93%, are exported to international markets (see Figure 2).

Figure 2 - Refined oil products, 1994 (Thousands of tones of oil equivalent)

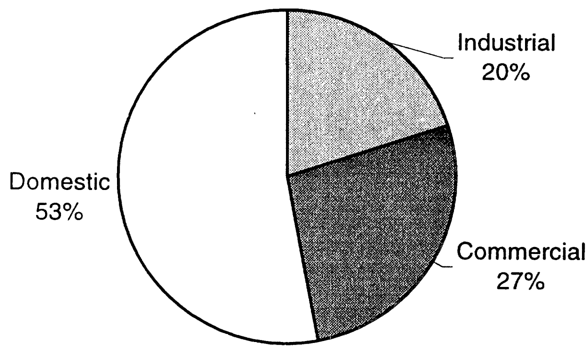


In recent years, natural gas has become more widely used, with consumption rising to 1194 million cubic feet per day in 2003 and continuing to increase since then. Most of the natural gas consumed in Bahrain is used to generate electricity and to satisfy heat demand from the manufacturing industries, mostly in the aluminum industry.

Electric power generation has shown steady increase 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 available electric generating capacity in Bahrain in 2004 was 1849 MW and consists of five publicly owned power stations (i.e., Manama, Muharraq, Riffa, Sitrah, and Hidd). The annual output from these plants typically account for about 83% of total electricity generated, with the remainder (17%) imported from the power station of the aluminum smelting plant (ALBA) which generates 1,527 MW and in the near future with the new expansion will reach 3,613 MW.

The demand for electricity is relatively high compared to the region, as well as compared to the world. Average annual per capita electricity consumption increased from 8,162 kWh in 1994 to 9,714kWh in 2004, an overall increase of about 20% (or 2.0%/year) increase during the same period. Total generation to satisfy rising industrial, household, and other demand increased from 4,550 GWh in 1994 to 7,522 in 2004, an overall increase of 65% (or 6.5% per year) Most of the electricity consumed is in the household sector which accounts for about 53% of total electricity demand. Figure 3 summarizes electric consumption patterns.

Figure 3 - Electricity Consumption by Sector in 2004 7522 GWHrs.



2. Power Generation and Conservation

A. Energy Conservation

The Kingdom government realizes the importance of energy conservation as a major thrust of the power policy, and for this reason an administrative restructuring for the ministry of Electricity and Water was initiated in 2000. But absence of an effective and clear conservation policy and regulations, with addition to the subsidy in this sector undermined the government efforts. Therefore, there is a need to have a system that encourages energy conservation and provides disincentives for the inefficient use of energy. In order to achieve this:

- Energy audit should be made compulsory for all major industrial and large commercial establishments.

- The responsible authority should periodically carry out consumers' guidance and education programme for energy conservation.
- Government is acutely aware of the fact that the subsidized-tariff for all sectors has led to inefficient use of energy by users. Therefore, the responsible authority should take comprehensive steps to induce users to adopt energy conservation measures.

B. Environmental Conservation

The kingdom of Bahrain heavily dependent on gas as a prime fuel for its power plants, this dependence is likely to increase further due to additions in generating capacity as envisaged in the government policy to cope with the high demand trend. The indigenous gas has greater sulphur content. And if we add to this problem lack of environmental friendly technologies in most of power plants like electrostatic precipitators, desulphurisation technologies and other technologies / equipments. We can imagine the magnitude of the environmental issues in power generation sector, currently three out of six power plant namely, ALBA, BABCO, and RIFA violating the environmental standard for NO_x. In 1999 an independent assessment conducted by LAHMER Int., to study the contribution of power stations on pollutants emissions revealed that the highest NO_x emission concentrations are found in the flue gas of the large gas turbines without NO_x reduction facilities at RIFA (255-313 ppm), and ALBA (264-313 ppm). The NO_x levels measured at these units exceed the considered emission standards of Bahrain, MEPA, World Bank, and Germany, which are all in the range between 39 and 49 ppm.

The corresponding total NO_x emission rates at full base load are of similar magnitude at RIFA (4425 kg/h) and ALBA (3775 kg/h), whereas the contribution from BAPCO (101 kg/h) and ALHIDD (502 kg/h after full extension of all 3 phases expected 2007) are presently negligible in comparison.

On the basis of the measures NO_x emission rates dispersion calculation were performed in order to show the present ambient air impact caused by the considered power plants, as well as their individual contributions to the overall situation. Assuming all considered plant at base load operation, 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 concluded that, any improvement of the ambient air quality in Bahrain will be achieved by retrofit measures at ALBA (phase 1) and RIFA (phase 2) together reducing the calculated annual average NO_2 levels from 58 $\mu g/m^3$ to 15 $\mu g/m^3$ and the highest peak levels from 1544 $\mu g/m^3$ to 274 $\mu g/m^{3.}$ However in order to comply with the stringent Bahrain standard of 200$\mu g/m^3$ for short term exposure also the Siemens units at RIFA (phase 3) would have to be rehabilitated.

C. Tariff structure and subsidy

Tariff rationalization is necessary if one has to improve the operational efficiency of power generation, the tariff structure for electricity in kingdom of Bahrain was not based on consumer-specific long-run marginal cost but was used as an instrument to achieve political and socioeconomic objectives. This resulted in a uniform tariff structure for MOEW, the overall production cost per kWh range between 18.7 to 12.0 fils, and the average sale price is 10.5 fils/kWh, in year 2000 the total production cost reach B.D 67.2 Million (equal U$ 178.2 Million) and the sales revenue from electricity not exceed B.D 50.3 Million (equal U$ 133.3 Million). However, the subsidy for electricity sector account for about B.D 17 Million (U$ 45 Million) or about 25% from the total production cost.

Similarly, the tariff structure in the natural gas and petroleum products that required for power generation does not reflect the true cost of exploration, production, transmission, and distribution. The gas prices are linked to the international price of crude and fuel oil. The retail gas prices set by the Government for Ministry of Electricity and Water (MOEW) have been without any adjustment for a few years. As a result, natural gas is sold indirectly to consumers below the cost of supply; to remove these distortions the Government should correct the prices. Currently, the government charge MOEW U$ 1.12 per 1000 cubic meter of gas (personal communication with senior planner in MOWE), and the world gas prices range between U$ 100 – 75, which is well bellow world market prices.

D. Power Generation and Air Pollution

Most of electricity in Kingdom of Bahrain as stated earlier produced by gas-fired stations, the major air emissions released from the combustion of gas include carbon dioxide (CO_2), nitrogen oxides (NO_x), and Nitrous oxide (N_2O). 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 health.

NO_x and SO_2, collectively known as acid gas, are largely responsible for the formation of acid precipitation that damages aquatic ecosystems, plants and structural materials such as limestone buildings and monuments. 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.

Table 1 shows the calculated GHG emissions in the energy sector (Bahrain Greenhouse Gas Inventory, 2000). As can be seen in this table, carbon dioxide emissions and Nitrogen Oxides are dominated by power supply, mostly in the form of electricity production from public power stations and heat production. Substantial levels of carbon dioxide are also emitted by the transport sector consisting mostly of on-road transportation.

Table 1: Greenhouse gas emissions, 1994: energy sector (Gg)

GHG Source & Sink Categories	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2
Total energy	**14,633**	**26.50**	**0.04**	**57.45**	**121.12**	**23.07**	**1,177**
Energy Industries	13,320	0.30	0.03	45.27	6.04	1.51	0
Fugitive emissions from fuels	0	25.88	0.00	0.00	0.00	0.00	0
Transport	1,291	0.30	0.01	12.01	116.26	21.86	1,177
Other Sectors (commercial, agricultural, residential, forestry, fishing)	22	0.02	0.00	0.18	0.04	0.01	0

E. Power Generation Externalities

(1). Definition

Externalities are defined as benefits or 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 externalities are benefits or costs that manifest themselves through changes in the physical-biological environment. Pollution emitted by road vehicles and by fossil fuel fired power plants during power generation is known to result in harm to both people and the environment. In addition upstream and downstream externalities, associated with securing fuel and waste disposal respectively, 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, nor compensates people for harm done to them, they do not face the full cost of the services they purchase (i.e., implicitly their energy use is being subsidized) and thus energy resources will not be allocated efficiently (Owen, 2004).

The origin of an externality is typically the absence of fully defined and enforceable property rights. However, rectifying this situation through establishing such rights is not always an easy task. In such circumstances, at least in theory, the appropriate corrective device is a Pigouvian tax equal to marginal social damage levied on the generator of the externality. If the tax is subsequently used to compensate the sufferer(s), then the externality is said to have been "internalized."

(2). Externality Adders

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

- For public or quasi-public ownership of sources of electric power generation, the full social cost of alternative technologies could be used to plan future capacity with preference being given to that with the lowest social cost. ii. ii. Where electric power generation is privately owned, then regulators could use the full social cost to influence new investment, perhaps through an effective environmental tax.
- Environmental 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.
- Environmental adders could be used to adjust national accounts data to reflect depreciation of natural resources and damage to the environment arising from economic activity, yielding so-called "green" national accounts.
- Environmental 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.
- Environmental adders might assist in determining environmental policy priorities.

F. The Cost Of Electricity Generating Technologies

Power plants are most frequently compared on the basis of their levelised electricity cost (LEC), which relates the discounted capital cost of the plant, its annual operating and maintenance costs and fuel prices to the annual production of electricity to yield a value in cents per kWh. Renewable energy technologies that are, by their very nature, intermittent would incur fuel costs to the extent that backup capacity was used in order to maintain the desired supply of peaking power to the grid. At low levels of renewable penetration additional system costs would be negligible compared with generation costs, since variability would still be within normal tolerance levels for the system as a whole. Thereafter, higher levels of penetration will involve additional cost, since additional generation or electricity storage capacity would be required to meet peak demand if, for example, wind were unavailable. As a consequence, at a purely financial level, the value of intermittent generation should be less than that of conventional generation by approximately these additional costs Table 1.2 gives (indicative) levelised electricity costs in euro-cents per kilowatt hour (euro¢/kWh) for electricity generation by the major renewable and non-renewable technologies. Both coal and gas exhibit a clear absolute cost advantage over the bulk of renewable technologies, although electricity generated by "best performance" wind power has recently approached similar cost levels. Back-up generation costs associated with the intermittency of renewables to ensure reliability of supply are not included. Thus on purely financial grounds (inclusive of all forms of subsidy), renewable technologies would, in general, appear to be non-competitive. The cost "gap" has been narrowed significantly over the past two decades, a process that is expected to continue as reflected in projected cost levels for 2020 (Table 2). However, it is clear that significant policy actions to increase investment in research and development and to stimulate economies of scale in production and dissemination of renewables are required to meet environmental commitments on global climate change in any major way.

G. Assessing The Externalities Of Power Generation

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 impacts from those with global impacts:

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

Table 2 - Cost of Traditional and Renewable Energy Technologies: Current and Expected Trends

Energy Source	Technology	Current cost (euro¢/kWh)	Expected future costs beyond 2020 as technology matures (euro¢/kWh)
Coal	Grid supply (generation only)	3-5	Capital costs to decline slightly with technical progress. This may be offset by increases in the (real) price of fossil fuels.
Gas	Combined cycle (generation only)	2-4	
Delivered Grid Electricity from Fossil Fuels	· Off-peak · Peak · Average Rural electrification	2-3 15-25 8-10 25-80	
Nuclear		4-6	3-5
Solar	Thermal electricity (annual insolation of 2500kWh/m²)	12-18	4-10
Solar	Grid connected photovoltaics (annual electrical output) · Annual 1000kWh per kW (e.g., UK) · Annual 1500kWh per kW (e.g., Southern Europe) · Annual 2500kWh per kW (e.g., lower latitude countries)	 50-80 30-50 20-40	 ~ 8 ~ 5 ~ 4
Geothermal	· Electricity · Heat	2-10 0.5-5.0	1-8 0.5-5.0
Wind	· Onshore · Offshore	3-5 6-10	2-3 2-5
Marine	· Tidal barrage (e.g. proposed River Severn Barrage) · Tidal stream · Wave	12 8-15 8-20	12 8-15 5-7
Biomass	· Electricity · Heat	5-15 1-5	4-10 1-5
Biofuels	Ethanol (cf. petrol & diesel)	3-9 (1.5-2.2)	2-4 (1.5-2.2)
Hydro	· Large scale · Small scale	2-8 4-10	2-8 3-10

Source: Adapted from (Owen, 2004)

(1). <u>Pollution Damage From Emissions Other Than CO_2</u>

Among the major external impacts attributed to electricity generation are those caused by atmospheric emissions of pollutants, such as particulates, sulphurdioxide (SO_2) and nitrogen oxide (NO_x), and their impacts on public health, materials and crops. The impact of these atmospheric pollutants on fisheries and unmanaged ecosystems are also important but have not yet been quantified. Emissions of SO_2 and NO_x have long-range Transboundary effects, which makes calculation of damages an imprecise exercise. Such calculations require measurement to be based upon the unique link between fuel compositions, characteristics of the power unit, and features of the receptor areas. Thus estimated damage costs may vary widely across continents, and even within individual countries. Estimated damages per tone of pollutant for SO2, NO_x, and particulates vary greatly because of a number of factors. Briefly these are:

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

However, damage estimates are dominated by costs arising from human health effects, which are largely determined by the population affected. Estimation of health impacts is generally based upon exposure response epidemiological studies and methodologies for placing a valuation on human life remain controversial. As might be expected, countries that are sparsely populated, or populated in largely non-receptor areas, tend to have relatively low health damage costs.

(2). <u>The External Damage Costs of Emissions of Carbon Dioxide</u>

This category refers to 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 agriculture patterns and other effects, all need to be taken into account. However, there is a lot of 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 this basis of limited knowledge is, at present, an imprecise exercise.

(3). <u>The External Damage Costs of Power Generation</u>

Fundamental work with respect to the valuation of External cost of electricity production in kingdom of Bahrain is essential to gain insight into this issue. However, this work is beyond the scope of this paper, and for the purpose of highlighting this problem, special attention is given to other studies in order to use it as proxy for the valuation of electricity production in Bahrain. Table 1.3 gives cost ranges (euro¢/kWh) for quantifiable external costs associated with the range of electricity generation technologies for countries within the European Union. However, the figures obtained from these studies should be used as signal for policy makers, and not reflect by all means the actual cost for the economy of kingdom of Bahrain, due to the non-conformity in terms of economic, geographic and technical issues.

The cost ranges in Table 1.3 are often relatively large, reflecting Variations in generation technology (and hence emission levels per kWh) and geographic location (and hence damage costs per kWh). Based upon the Rabl and Spadro estimates, a typical, average European conditions, new base load plant, would have total quantifiable damage costs of 7.27 euro¢/kWh for a coal fuel cycle, and 2.37 euro¢/kWh for gas. Both of these estimates fall within their respective "EU range" in Table 1.3, despite the relatively high-assumed damage costs relative to the ExternE study. These "typical" estimates indicate that total damage costs associated with the coal cycle are (approximately) three times those of gas and a very large multiple of those for renewable energy technologies.16 If these typical "externality adders" are combined with the lower bounds of the "current" cost data given in Table 1.2, the gas fuel cycle would exhibit a marked societal cost advantage over all other modes of generation with the exception of wind and hydro.

Table 3 - External Costs for Electricity Production in the EU (Euro ¢/kWh)

Country	Coal & Lignite	Peat	Oil	Gas	Nuclear	Biomass	Hydro	PV	Wind
Austria				1-3		2-3	0.1		
Belgium	4-15			1-2	0.5				
Germany	3-6		5-8	1-2	0.2	3		0.6	0.05
Denmark	4-7			2-3		1			0.1
Spain	5-8			1-2		3-5			0.2
Finland	2-4	2-5				1			
France	7-10		8-11	2-4	0.3	1	1		
Greece	5-8		3-5	1		0-0.8	1		0.25
Ireland	6-8	3-4							
Italy			3-6	2-3			0.3		
Netherlands	3-4			1-2	0.7	0.5			
Norway				1-2		0.2	0.2		0-0.25
Portugal	4-7			1-2		1-2	0.03		
Sweden	2-4					0.3	0-0.7		
United Kingdom	4-7		3-5	1-2	0.25	1			0.15
EU range	**2-15**	**2-5**	**3-11**	**1-4**	**0.2-0.7**	**0-5**	**0-1**	**0.6**	**0-0.25**

H. Internalizing The Externalities Of Electricity Production

(1). Internalizing Externalities

At least in theory, the most efficient process for imposing the "polluter pays principle" would be to internalize as many of the externalities of power generation as possible. Using the marketplace would permit energy producers and consumers to respond to such price signals in the most efficient and cost-effective way. However, it should be emphasized that only external damage costs associated with emissions from fossil fuel combustion have been considered in this paper. Security of supply and energy subsidies must also be incorporated into the analysis in order to achieve a reasonable internalizing for power generating, Once monetary values have been derived to reflect the external costs of power generation, the next step is to devise a mechanism for "internalizing" them into market prices. In theory, an energy tax would represent relatively straightforward solution; the worst of any social impact of energy taxes on poorer sections of society would have to be offset to ensure that the tax burden was not disproportionate in its incidence.

(2). Policy Options for "Internalizing" Externalities

Estimated damage costs associated with externalities of fossil fuel combustion tend to lack precision, which would make the imposition of environmental "adders" a very controversial policy option. Further, it should be remembered that valuation of externalities is predicated on the discipline of welfare economics, where economic (or a locative) efficiency is the guiding principle. Distributional assumptions are, at least at that level, ignored. In addition, most actions will be based upon control or abatement costs and therefore their relationship with the precise cost of damage arising from the externality may be very tenuous. However, a number of second-best options are available that could, at least partially, approximate the desired outcome.

(a). *Direct Government Actions:* The governments generally exercise effective control over many parts of the economy, including buildings, employees, vehicle fleets, infrastructure, government corporations, joint ventures, land and resource management, and the allocation of research and development budgets. Because externalities are a form of market failure, Government intervention is justified in order to minimize their impacts on the community. Where taxing polluters is deemed to be politically unacceptable, then environmentally benign technology could be encouraged through grants and subsidies.

(b). *Voluntary Actions:* Governments may try to influence the actions of households and firms by voluntary means, such as information campaigns, advertising, environmental product labeling, demonstration projects, and facilitating voluntary environmental initiatives. There are several mitigation measures that have been analyzed to determine their environmental impacts reduction potential and associated costs. Given the prominence of energy supply, all of these options are focused on this sector. The followings summarize the options considered:

(1). Energy Efficiency of Power Generation:

The overwhelming majority of pollutants and GHG emission in the energy 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 mitigation 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 would be introduced at eight inefficient single cycle power stations and cogeneration was introduced at one station. These changes would annually reduce emissions of carbon dioxide by 2.7 million tones (Bahrain GHG inventory, 2000).

There is no major cost, institutional, or social barriers envisioned for a more widespread use of energy efficient technology in electricity supply. The cost of saved carbon for implementing this option at 9 stations is negative (i.e., –\$19.6/tonne of carbon dioxide avoided) indicating its attractiveness from an economic perspective. Moreover, direct surveys among a range of individuals confirm the attractiveness from a social perspective.

(2). Renewable Energy 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 insulation level of about 400 W/m^2, 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.

The mitigation assessment focused on solar thermal combined cycle systems to meet about 5% of electric demand. This would involve the installation of one 150 MW solar thermal station (with no natural gas backup), and would annually reduce emissions of carbon dioxide by 1.4 million tones. The cost of saved carbon for implementing this option is negative (i.e., –$5.0/tonne of carbon dioxide avoided) indicating its attractiveness from an economic perspective. However, using substantial levels of intermittent renewable energy technologies in Bahrain would represent a departure from business as usual requiring new coordination among different institutional entities. Indeed, one of the key technical issues was how intermittent resources can be integrated in 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.

(3). 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 energy and peak power use. High efficiency air conditioning, including higher-than-standard efficiency compressors, heat-exchangers, fans, control systems, and other associated equipment also has great potential to reduce space cooling power requirements, which represents almost half of the total power generation in Bahrain.

The mitigation assessment focused on the introduction of CFLs and high efficiency air conditioners in the context of the existing electric 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 tones (0.95 million tones for air conditioners and 0.21 million tones for CFLs). The cost of saved carbon for implementing this option is negative (i.e., –$33.0/tonne 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 alternative, and current lack of availability of the efficient products themselves. Moreover, the introduction of lighting and space cooling efficiency measures require supply and demand for the technologies to be built up at the same time (Bahrain GHG Inventory, 2000).

(4). Other Mitigation Initiatives:

In addition to the measures discussed above, several other measures can be considered as following:

Interconnection Of The Electric Transmission Grid: The Bahraini electric transmission system is currently not connected to region networks and is characterized by relatively high line losses. Integrating the transmission grid with that of the neighboring Gulf Cooperation Council (GCC) countries is potentially attractive for reducing pollutants and GHG emissions because it could mean the operation of larger power generation station with better electric system carbon emission rates (i.e., tC/MWh), as well as being able to tap into transmission networks which on aggregate have lower line losses. Further investigation is needed on the carbon emitting characteristics of regional electric systems.

Landfill Gas And Utilization In Power Generation: This option can reduce greenhouse gas emissions by preventing the direct release of methane to the atmosphere. Since the Bahrain electric supply sector overwhelmingly uses natural gas, there is no net gain in the carbon content of electricity on the grid. The amount of methane that can be captured annually from large sanitary landfills is about 12,000 tones. The cost associated with methane recovery is much higher than the cost of natural gas, which is available in Bahrain at relatively low cost. Further investigation is needed on site-specific characteristics of the landfills, as well as the additional pipeline costs for the transport of methane to local power stations.

3. Conclusions

This paper has considered the externalities of power generation in Kingdom of Bahrain, through highlighting in different elements related to this issue, it has been shown that ceasing subsidy and internalizing the external cost of electricity production could lead to sustainability, optimizing the use of resources, and removed market distortion. The removal of both direct and indirect subsidies to power generation, and the appropriate pricing of gas the main fuel for power generation, electricity tariff to reflect the environmental damage are essential for policy strategies in the long run. However, different Policy Options for "Internalizing" Externalities could help in mitigation the impact on the national economy.

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