Incorporating Environmental Externalities into the Capacity Expansion Planning: An Israeli Case Study

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Abstract

The state of Israel is on the verge of a massive investment plan for the next 20 years in terms of its energy planning. One important factor that should be taken into account in the planning process is the environmental aspect of the program. In this paper we use the WASP-IV model and developed methodology to estimate the impact of several environmental externalities costs on the planning process. It was demonstrated that in most cases the compliance costs are too high to justify major changes in the development plan of the energy sector in Israel. The major impact is on the fuel use. More natural gas is used instead of coal. The Benefit cost ratio is about 4.5 while the net benefit is about 200 million USD (depending on the scenario). While this results seems promising as to the use of such model to inform Decision Makers (DM) about the different choices they face, it lack a cost effectiveness with other alternative programs, such as demand management (energy conservation, peak-load pricing etc.,).
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1. **Introduction:**

Electricity consumption is Israel is growing in a substantial rate (60% from 1997 – 2007, 6.82% in 2007). In recent years it almost reached its peak capacity. The demand is expected to grow as the population and income per capita are expected to grow. Future planning can hardly be based on demand side management but rather on supply expansion to meet future demand.

The aim of this paper is to describe the potential impact of emission reduction on the long run planning phase of the Israeli electricity sector. To this end we use a methodology that can inform Decision Makers (DM) about possible trade-off between costs and pollution.

The point arising from the paper is that there should not be a clear cut preference to supply management but rather to compare it to demand side management such as conservation program and peak load pricing.

With respect to the near future the choice is between alternative electricity production technologies. This may include supply management options only. The criterions for choosing one alternative over the other are cost efficiency, national dependency and environmental externalities. The environmental costs are not fully considered in the planning system in Israel because the damage values of the major pollutants are not a part of the electricity cost per se. Major pollutants are Sulfur Dioxide (SO$_2$), Nitrogen Oxide (NOx) and Particulate matters (PM) from a local point of view and Carbon Dioxide (CO$_2$) from a global point of view.

The algorithm used in this paper was WASP-IV in a modified version. Originally, WASP-IV was designed to handle only one or two pollutants. In reality, however, planners (regulators) of generation capacity systems may choose to regulate (control)
a larger number of pollutants. There are four pollutants regulated in the Israeli electricity system: PM (particulate matter), NO\textsubscript{x}, CO\textsubscript{2}, and SO\textsubscript{2}. Regulators may also choose to account for possible trade-offs between the level of emissions and technical (capacity factor, LOLP) and/or economic (capacity cost, fuel costs) characteristics of the electricity generation system. Hence, this paper extends WASP-IV by using a methodology (and software) which can represent several taxes and/or quantity constraints on emissions of several pollutants (Soloveitchik and Olshansky, 2006).

This paper is taking these environmental considerations into account in the capacity expansion plan for the electricity sector in Israel for the years 2008 – 2025. We used the WASP-IV model and developed methodology including additional module and software to estimate the impact of 5 different scenarios on the generation cost, environmental cost and also energy dependency.

We see the major advantage of our methodology is that it provides a working tool for implementing decision making process. Such tools can be used later on to change expansion plans, charge externality taxes etc.

The paper proceeds as follow: The next section describes the electrical sector in Israel; section 3 presents a brief literature review. Section 4 describes the methodology. Section 5 describes the results while section 6 summarizes and concludes the paper.

2. The Electricity sector In Israel:

Israel’s geographic size is about 22,000 square kilometers. Its population in June 2008 was 7.3 million and GDP was US$185.9 billion (2007 est.). Thus, the GDP - per
capita is about US$25,800 (2007 est.) The economy grew at an estimated rate of 5.4% in 2007, the fastest pace since 2000.

By the end of 2007 the total installed capacity in Israel was 11323 MW. This is decomposed of 42.7% generation by coal, 15.2% generation by natural gas, 36.8% by fuel oil and 5.3% by residual fuel oil.

Coal-fired power plants generate 69.5% of total generation, gas-based power plants – 19.7%, fuel oil and residual fuel oil-based power plants – 7.4% and 3.4% respectively. A detailed description of Israel’s electricity sector is available in IEC (2008).

Expansion plans should aim to adequately achieve electricity demand forecasts while meeting several criterions. Until recently the major criterions were cost efficiency and energy dependency. In recent years environmental criterions started to play a bigger part and different green NGO’s push forward in order to meet also stricter air pollution standards. One of the current major debates in Israel is about the expansion plans. While the electrical company pushes forward another coal-fired power plant, green organizations would rather go with cleaner production such as natural gas, solar energy etc.

3. Literature Review

Past research has been concentrated on basic damage values of different pollutants (e.g., Sundqvist, 2004; Tol, 2005 and Longo et al., 2008). However, most research have taken a further step to use these estimates in the energy sector in general and in the electricity sector in particular (e.g., Spalding-Fechera and Matibe, 2003; Roth and Ambs, 2004; Tsoutsos, et al., 2005; Owen, 2006 and El-Kordy, et al., 2002). Most of these studies have applied the internalization of externalities to different countries.
Another set of papers have utilized the externalities into existing operational models. Such models include MARKAL (e.g., Nguyen, 2008; Rafaj and Kypreos, 2007), MESSAGE (e.g., Klaassen and Riahi, 2007) and WASP (e.g., Nakawiro et al., 2008). Our paper also uses WASP – IV model but contrary to Nakawiro et al. (2008) who limit his study to gas dependence and fuel import reliance, we concentrate on energy mixture due to the inclusion of several externalities.

Owen (2006) divides the external problems arising from electricity production into studies who uses damage value per KWh produced in different technologies and to studies who uses direct externalities by pollutant type. Sundqvist (2004) argues that this is one of the reasons that might cause disparity in applying the internalization process. In our study we use one scenario with damage cost per KWh while the 3 others apply to direct damage caused by different pollutants.

It should be emphasized that this study as the others listed above is taking the approach of minimizing costs subject to a set of constraints. However, an alternative approach is to bypass this cost minimization problem by using a multi-criteria approach (Tishler et al., 2007; Mirasgedis and Diakoulaki; 1997). A general framework would be to incorporate these two approaches in order to present decision makers with a clear crystal ball of the problem.

4. Methodology:

The Wien Automatic System Planning (WASP - IV) package was used in this study. WASP is one of the most common electricity planning programs in many countries. It finds the least cost electricity expansion plan subject to constraints which are determined by the user of the program. It calculates the discounted sum of yearly
costs which are decomposed out of fuel cost, fixed (capital) cost, operation and maintenance costs and the cost of unmet demand.

WASP-IV and our additional software were used to generate the set of scenarios (according to the Simplex Lattice Design approach – (Tishler et al., 2007). In our case study 140 different scenarios were calculated with the help of our software. To simplify the analysis at this stage we chose to consider 5 scenarios.

The paper concentrates on supply management to meet demand for electricity and by meeting several other restrictions (including environmental). The objective function of the BAU scenario in the regular WASP – IV software is to find the least cost expansion plan that meets the forecasted demand.

We compared this scenario to other 4 alternative scenarios in which environmental damages are taken into account by increasing the generation cost.

The planning period is from 2008 until 2025. The demand forecast is based on national energy forecasts which in turn are based on growth rates combined with income elasticity for electricity. We used 4 types of candidates for the expansion plan.

The first scenario is one in which a total external cost is converted from other studies and is presented in cents per KWh. The other three scenarios are based on tax per ton of pollutant. Two of them are associated with local pollutants (NOx and PM) while the third is associated with global worming (CO2).

It is well known that an ancillary benefit of taxing for CO2 reduction is associated with reduction in other local pollutants (Burtow, et al., 2003, Tishler et al.2007). Here we go in both directions, namely, the impact of reducing CO2 on local pollutants and vice versa.
Unit damage costs are taken from international sources since they are absent from an independent study for Israel of specific importance is the European Commission Extern E. The impact pathway was used in this project. That means that the pollution is traced from the release source to the point where it has an impact. The associated damage is estimated by dose – response functions. The monetary valuation was estimated by the \textit{willingness to pay} of individuals to avoid a negative symptom results from the operation of the plant. Finally, emission factors of the different pollutants in the different candidates are given and well known and documented (Sundqvist, 2004).

The estimates are the following:

- Coal fired electricity generation – 4 Ecents/kwh
- Natural gas – 1 Ecent/kwh
- NO\textsubscript{x} – 4868 US$/Ton
- PM – 16057 US$/Ton
- CO\textsubscript{2} – 22 US$/Ton

These damage values were added to the variable generating cost. In this way it is actually treated as tax on the production cost and increases the objective value more dramatically as the pollution coefficient is higher.

\textbf{5. Results:}

\textbf{5.1.1 Fuel Mix}

Here we assume continuation of the existing trend without taking into account externalities arising from electricity production.

The Fuel Mixture for BAU scenario is presented in Figure 1.
As can be seen clearly, only two types of energy sources play a major role: Coal and Natural Gas. Fuel Oil and Residual Fuel Oil plays only a negligible role. Under current conditions coal’s share is 62% but goes down to 39% by the year of 2025. The opposite of course holds for Natural Gas.

The fuel mix for two scenarios: “Health_impact” and “PM_tax” are presented in Fig. 2 and 3.

Under these scenarios, more than a half of electricity in each year will be generated from natural gas in the “Health_impact” scenario (see Fig. 2). The share of coal in this scenario will decrease to the 15%-20% in 2016 up to 2025. This is in opposite to the BAU scenario.

The energy mixture changes in the “PM_tax” scenario as well. As can be seen from figure 3, Coal occupies the largest share now.

Under the health impact which is the stringent scenario the coal share is being reduced from 78% to 16% in 2025. Natural gas, on the other hand, is being expanded from 22% to 84%. In the other scenarios the impact is more intermediate than the health scenario. Of specific interest is the PM scenario in which we can notice that despite the high externality caused by this pollutant, the impact on generation mixture is the modest, probably because the difference in the pollution coefficient of PM between coal and natural gas. The relative radical change in the generation mixture indicates
that it is more worthwhile to shift from coal to natural gas rather than pay the externality tax.

5.1.1 Capacity Mix.

It is interesting to know that there are no substantial changes in electricity capacity mix when external costs are included in the electricity production system. The changes in the generation mixture for BAU and “Health_impact” scenario are presented in Figures 4 and 5.

The only major change is the installation date for coal fired power plants in “Health_impact” scenario which is earlier than that of the BAU case (Fig. 5).

Emissions Reduction

Figure 6 presents the quantities of CO₂ emissions reduction for the four scenarios. The results also show that higher externalities taxes (like in “Health_impact” scenario) yield lower CO₂ emissions, as expected. However, the reduction in CO₂ emissions due to the taxes is rather limited, even when the taxes are
substantial. The externalities on CO\textsubscript{2} emissions mainly increases the cost of producing electricity by coal, which has the effect of reducing its share in electricity production and, thus, also reduces the emission of CO\textsubscript{2}, as well as the emission of other pollutants. It is called “the double dividend effect”. Figures 7 and 8 show the percentage reduction in CO\textsubscript{2}, NO\textsubscript{x}, and PM emissions (relative to the BAU) under the “Health\_impact” and CO\textsubscript{2} tax scenario.

**Figure 6 about here**

**Figure 7 about here**

**Figure 8 about here**

### 5.2 Integrating externalities into the expansion plan

#### 5.2.1 Treatment of External costs in WASP

Including external costs of electricity generation changes the expansion plan as well as the fuel mixture. We included the best estimates based on Owen (2006) and the European Commission (1998).

In all scenarios the damage costs per pollutant unit was added to the objective function as a tax on the entire energy system. This was done per pollution unit (e.g. 4868 USD per ton of NOx emitted etc.).

The WASP model may react to these external costs by different ways. It can deal only with change in the mixture of fuels. It can also make a switch to different power
plants over time and/or in a faster manner. The ultimate goal is to minimize the discounted total costs over the planning period.

5.2.2 Results of the different scenarios - Damage Costs

As to the benefit side, Figures 9, 10 presents the damage in the 5 scenarios. This was done by multiplying the damage per unit of pollution by the amount of the different pollutants. In the health impact scenario the damage was calculated by the amount of coal and natural gas multiplied by their associated externalities values.

As can be clearly seen, the damage in the BAU is the highest while the one in the health impact is the lowest. The difference is about 400 million USD annually depending on the scenario

Figure 9 about here

Figure 10 about here

It is worth noting that the relative share declines from 0.90% down to 0.49% for the business as usual scenario even without considering any pollution reduction. The reason is that GDP projections are higher than increase in electricity demand growth. Hence, the overall ratio declines. If we compare the Health impact scenario to the BAU one it can be seen that the damage is reduced by 0.21% at 2008 to 0.69% of the GDP. The damage is being reduced down to 0.38% by the year of 2025 for the health impact scenario.
5.2.3 Results of the different scenarios - Multi-criteria decision making

Multiple criteria decision making allows user to choose between different scenarios (see Fig. 11) in order to encourage more effective ways of pollutant reduction under different set of technical-economic restrictions. It is also possible to eliminate “unrealistic” scenarios of pollutant reduction and calculate the minimum cost of 1 ton reduction of each kind of pollutants when other technologies of electricity generation and emission control system are used.

This approach also allows DM to analyze the set of scenarios as multidimensional observations of the technical/economic parameters with using the Operational Research (OR) methods or methods of multivariate statistical analysis.

With this methodology and software DM could analyze how emissions reduction shapes the current level of major indicators of electricity system in the long run.

Figure 11 about here

5.3 Cost benefit analysis

In order to estimate the overall efficiency of the different policy options vs. the BAU scenario, one should take into account both benefits (as given by the damage reduction) vs. the cost increase in the electricity production process. The results are depicted in Figure 12 for the total costs for the different scenarios and Figure 13 and Table 1 for the cost benefit results.

Since the BAU scenario does not take externalities into account, its private cost is the lowest (generation cost) but its social cost is the highest. The reason is that all other
scenarios increase the generation cost in order to decrease the total cost combined out of generation and externalities costs.

The highest increase in the generation cost occurs in the “Health impact” scenario and is estimated at 103 million USD per year. It also provides the highest benefit by reducing pollution. This is estimated by 341 million USD.

It is interesting to note that while the health impact provides the highest net benefit, it also provides the lowest benefit cost ratio. From a theoretical point of view the net benefit provides the correct cost – benefit result. However, these 4 alternative scenarios are NOT different projects but rather different assumptions as to how to look at the damage caused by different pollutants.

A possible better way is to look at how dealing with one pollutant abatement will cause reduction in the damage by the other pollutants and by that creates an optimal tax. This is, however, outside the scope of the current research but might be the basis for a future one.

6. **Conclusions:**

The paper tries to contribute another piece of an empirical case study for the state of Israel of dealing with an optimization program (WASP – IV) in order to internalize externalities caused by the electricity system.

The analysis was carried with respect to a long term planning problem until the year of 2025. Currently the Israeli authorities are considering different planning options.
Using such models as the one developed in this paper might prove to be useful for decision makers.

There were 5 scenarios analyzed. One was the business as usual (BAU) while the other four tried to take the externalities into account. One tried to internalize the externalities by considering external costs per KWh while the other 3 aimed at 3 major pollutants, namely CO$_2$, NOx and PM. Out of the 4, only the first one is taking the entire spectrum of damages into account. However, policy makers might not judge all pollutants equally as important. For example, CO$_2$ might be considered differently since its major impact is global.

The results show that the added costs to the generation system ranges between 18 and 103 million USD depending on the scenarios. That means a maximum of 3% increase out of the current generation cost. The benefits range from 100 and 444 million USD per year depending on the scenario. Most of the impact is by using natural gas rather than coal. Hence, it gives another benefit to policy makers since there is almost no need to change the power plants installments but rather only the use of them.

The benefit cost ratio ranges from 4.32 to 5.57 indicating a clear advantage to either one of the alternative scenarios and also by the opposite token the current inefficiency of the Israeli electricity system.

These results should be compared however to other programs to perform a cost effectiveness analysis. Such alternative programs might include energy conservation, peak-load pricing among others.

Another possible path of development is to use the results as a benchmark for a multi-criteria analysis (Soloveitchik et al., 2002) and by doing so bypass the issue of externalities estimation.
References:


Figure 1: Fuel mixture under the BAU scenario
Figure 2: Fuel mixture under the “Health_impact” scenario

Coal • Residual Fuel Oil • Fuel Oil • NG
Figure 3: Fuel mixture under the “PM_tax” scenario
Figure 4: Capacity Expansion Plan (BAU scenario) 2011 – 2025
Figure 5: Capacity Expansion Plan ("Health impact" scenario) 2011 – 2025
Figure 6: Total CO₂ emissions reduction vs. BAU scenario
Figure 7: Percents of CO₂, NOx, PM emissions reduction vs. BAU scenario

(“Health_impact” scenario)
Figure 8: Percents of CO₂, NOx, PM emissions reduction vs. BAU (CO₂_tax scenario)
Figure 9: Total pollutants damage

<table>
<thead>
<tr>
<th>Scenario</th>
<th>CO2 (Mton)</th>
<th>Nox (Ton)</th>
<th>PM (Ton)</th>
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<tbody>
<tr>
<td>BAU</td>
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<td>9168</td>
<td>1013</td>
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<tr>
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<td>5433</td>
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<tr>
<td>PM_tax</td>
<td>20279</td>
<td>8516</td>
<td>912</td>
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Figure 10: Total damage as share from GDP
Figure 11: Multi-criteria decision making
Figure 12: Comparing generation cost, externalities and social cost for the 5 scenarios (million $ annually)
Figure 13: Graphical representation of the CBA results (million $ annually)
Table 1: Benefit cost summary (in million USD)

<table>
<thead>
<tr>
<th>From BAU to:</th>
<th>Damage reduction</th>
<th>Total generation cost increase</th>
<th>Net benefit</th>
<th>Benefit cost ratio</th>
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<tr>
<td>Health impact scenario</td>
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<td>5.57</td>
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