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Modeling the Future Electricity Demand of Europe, Middle East and North Africa

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Abstract

The paper presents a simple empirical method for the modeling of the future electricity demand of national economies in very different stages of economic development based on expectations for national economic growth and population and on a functional correlation of the historical per capita electricity demand and per capita gross domestic product. The model was applied to develop long-term scenarios until the year 2050 for the future electricity demand of 50 countries in Europe and the Middle East and North Africa (MENA). This approach delivers a valuable complement to the existing medium-term scenarios for Europe. The analysis shows that by the middle of the century the MENA region will probably consume as much electricity as Europe today.

Keywords: power demand, electricity consumption, long-term scenario, Europe, Middle East, North Africa

Introduction

Scenario analysis is a valuable tool to evaluate the sustainability of energy policies and supply strategies (International Energy Agency, 2002), (Trieb et al., 2005), (Trieb et al., 2006). As a basis for all scenarios in the electricity sector, the present and future demand must be assessed in a plausible, consistent way, in order to receive an estimate of the task to be solved. The report shows a simple method to estimate the future electricity demand in different economies that was applied to 50 countries in Europe, the Middle East and North Africa (Figure 1).

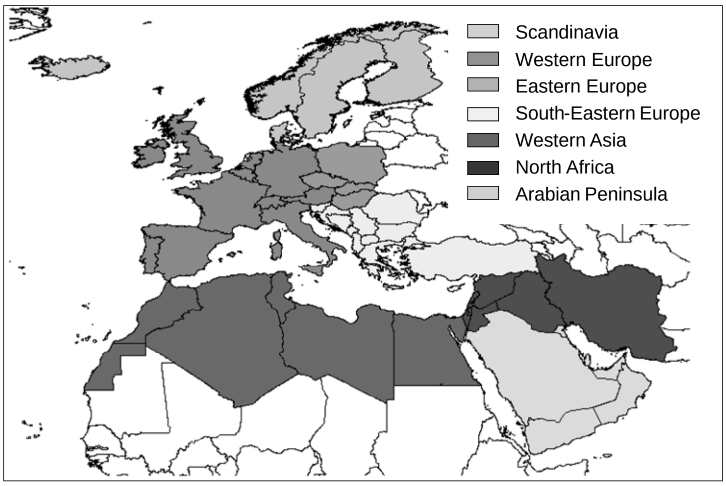

Figure 1: The fifty analysed countries in Europe, Middle East and North Africa

Relation of Population, Economy and Electricity Demand

The number and growth rate of population is one of the major driving forces for a national electricity demand. The scenario is based on the intermediate World Population Prospect of the United Nations that was revised in the year 2002. According to that analysis, the population in the total analyzed region will steadily grow from about 900 million people today to over 1200 million people in 2050 (Figure 2). The population in North Africa will grow from today's 140 million to 240 million in 2050. In terms of population, Egypt is the dominating country, accounting for 50 % of the population of the total region. The population in the Western Asian countries will grow from 120 to over 220 million people by 2050, Iran being the dominating country in this region. The population on the Arabian Peninsula will increase from today 50 million to over 150 million people in 2050. The dominating countries are Saudi Arabia and Yemen. The Saudi Arabian population will stabilize by the middle of the century, but Yemen's population will still be growing quickly by that time, becoming the most populated country in this region. While the European region shows a clearly stabilizing population just below 600 million, the population in MENA will grow from 300 to also 600 million within the same time span.

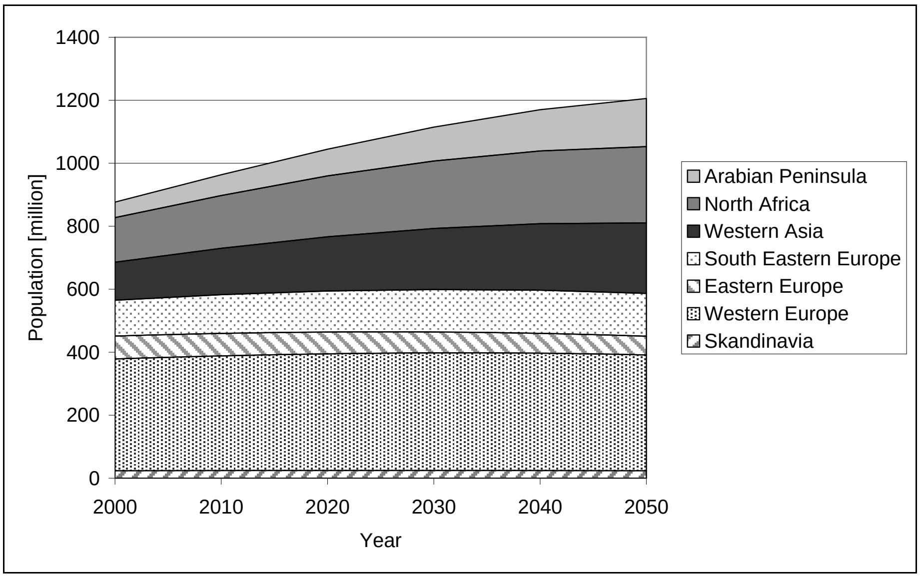

Figure 2: Growth of population in Europe and MENA aggregated by regions (Statistisches Bundesamt, 2003)

The second driving force for electricity demand is the economic growth, here represented by the change of the gross domestic product (GDP). The GDP is expressed in US$ 2001 purchasing power parity (PPP), defined by the basket of commodities of the Penn World Tables (Heston et al., 2002). Long-term average growth rates for the different countries are selected in a range of reasonable values, most countries closing the gap of GDP per capita to a certain reference country with very high GDP per capita – we have selected USA for this purpose – by 50 % in the year 2050. As the USA is a large country with very high GDP per capita, it represents something like an upper margin of productivity. Thus, the growth rate for the USA can be seen as reference case for a highly developed technical and organisational progress. The countries analyzed here reach higher GDP per capita growth rates as they are able to accelerate productivity growth by imitation, subsequently closing their gap to the USA.

Western Europe		**South Eastern Europe**		**Arabian Peninsula**	
Portugal	2.1	Cyprus	2.1	Oman	3.2
Spain	1.9	Malta	2.3	Kuwait	2.1
Italy	1.7	Greece	2.2	Qatar	1.9
Austria	1.6	Bosnia-Herzegowina	4.0	Saudi-Arabia	2.7
Belgium	1.6	Macedonia	3.9	UAE	1.8
France	1.6	Serbia & Montenegro	4.3	Yemen	6.5
Germany	1.7	Slowenia	2.1	Bahrain	2.3
Ireland	1.5	Croatia	3.1		
Luxembourg	1.2	Turkey	3.5	**North Africa**	
Netherlands	1.6			Morocco	4.6
Switzerland	1.5			Algeria	4.0
United Kingdom	1.7			Tunesia	3.6
				Libya	3.8
				Egypt	4.1
Western Asia		**Eastern Europe**			
Jordan	4.4	Bulgaria	3.7	**Scandinavia**	
Lebanon	4.2	Czech Republic	2.5	Norway	1.3
Syria	4.7	Hungary	2.7	Sweden	1.7
Iraq	5.6	Poland	3.0	Finland	1.7
Iran	3.8	Romania	3.8	Denmark	1.5
Israel	1.9	Slowac Republic	2.7	Iceland	1.6

Table 1: Average long-term per capita GDP growth rates in %/year selected for the scenario calculation.

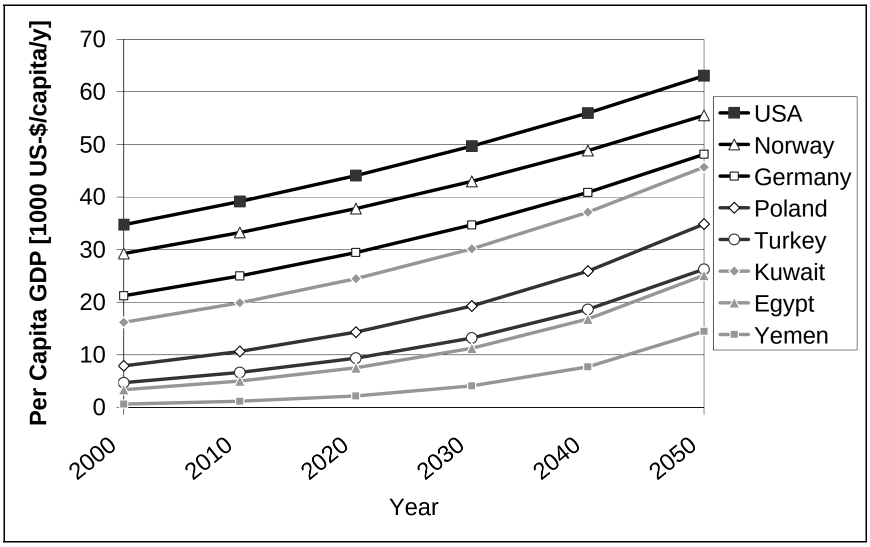

Figure 3: Outlook of per capita GDP in 1000 US-$/cap/year for selected countries in EUMENA. As a reference the per capita GDP of the USA is displayed growing with an average 1.2 %/year.

The effect of such a model is a relative convergence of the economies of the different countries. The literature on economic growth rejects that a convergence in this sense has been taken place in the past. However, for sub-samples of countries a convergence can not be rejected generally. If convergence exists, halving the difference in 50 years will be at the upper boundary (Baro, Sala-i-Martin, 1995). Following (International Energy Agency, 2002) the growth rate for the USA is assumed to be 1.2 %/year. Other sources assume a substantially higher growth rate.

The long-term average GDP growth rates used for calculating our scenario are given in Table 1. The resulting long-term development of the per capita GDP is given in Figure 3 for a selection of countries. The GDP per capita $x_{i,t}$ and the total final per capita electricity consumption $\hat{y}_{i,t}$ were correlated using a simple regression for a data sample of 25 selected countries (International Energy Agency, 2003), (Heston et al., 2002)[1]. For this purpose we have used a simple power function with two fit parameters a_i and b_i. This regression has been repeated for each year from 1960 to 2001, with the time index t = 1960, 1961, ..., 2001 and the country index i = 1, 2, ..., 25 (Equation 1):

$$\hat{y}_{i,t} = a_t \cdot x_{i,t}^{\,b_t} \qquad \text{Equation (1)}$$

This approach leads to a set of parameter estimates $\{a_{1960}, b_{1960}\}$, $\{a_{1961}, b_{1961}\}$, ..., $\{a_{2001}, b_{2001}\}$ across all countries for each year. Comparing the data from the years 1960 and 2000 in Figure 4 it becomes clear that in a time span of 40 years the per capita GDP in the analysed countries has grown considerably, but the per capita power consumption has grown at a slower rate. Also the relative difference of per capita power consumption between low and high income countries has decreased with time, varying by 2 orders of magnitude in 1960 and only by 1 order of magnitude in 2000.

The parameters *a* and *b* can be used for an extrapolation of the future per capita power consumption based on the experience of the past 40 years, if their transition in time is modelled, too. We now explicitly consider *a(t)* and *b(t)* as a function of time. Time trends of those two parameters were estimated using power functions and alternatively linear functions. Power functions gave a significantly better fit for the first term *a(t)* (Figure 5). For the second term *b(t)* it was hard to distinguish a linear trend from a power trend. The linear trend used here gives a scenario with high efficiency gains, while an exponential trend would result in low efficiency gains[2]. The result is an empirical time dependent model for the total final consumption of electricity as function of the per capita gross domestic product with the parameters

$$a(t) = 13.65 \cdot \exp(0,0531 \cdot (t - t_o)) \qquad \text{Equation (2)}$$

$$b(t) = 2.2131 - 0.0212 \cdot (t - t_o) \qquad \text{Equation (3)}$$

being t the time variable and t_o = 1960 the first reference year[3]. Applying the model, a future extrapolation for the original sample of 25 countries can be made (Figure 6). As a countercheck, the model was additionally applied to a sample of 150 countries for the year 2001, showing an acceptable correlation, too. Therefore, it was assumed to be acceptable for general modelling (Trieb et al., 2005).

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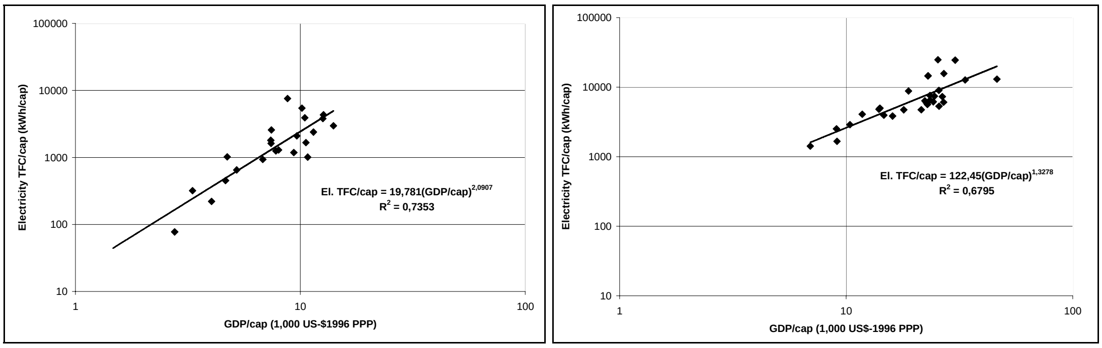
[1] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States. For some of these countries the time series start later than 1960. In the regression shown here, these were included as soon as data were available. Additionally for subsets of countries and/or shorter time series similar regressions were calculated. The results are very similar.

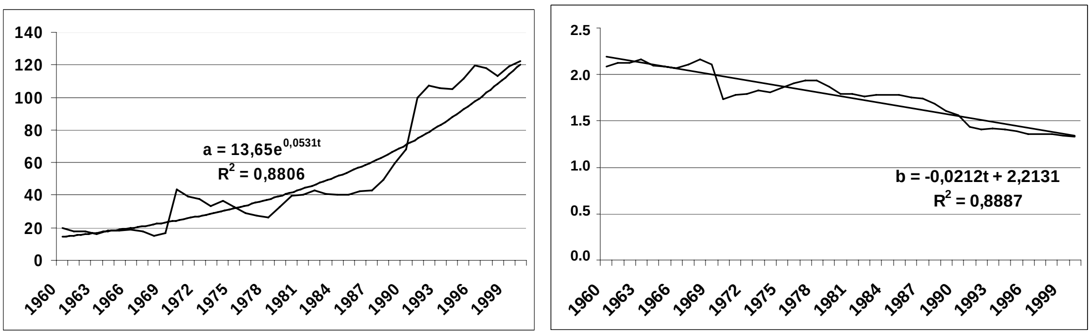
[2] Fast economic growth can increase the adoption and development of new machinery which is likely to be associated with high efficiency gains. Experience shows that it is not imperative that this kind of efficiency gains will be achieved without determined policy measures. There realisation requires technical, financial, social and political effort.

[3] Note that in line with the past experience the income will be less and less an explaining factor for differences of electricity consumption in cross country comparisons.



a) In the year 1960 **b) In the year 2000**

Figure 4: Examples for correlation between total final consumption per capita and GDP per capita. Data sources: (Heston et al. 2002), (IEA 2003-1,2), (Statistisches Bundesamt 2003)



a) Exponential regression for absolute term *a* **b) Linear Regression for exponent *b***

Figure 5: Regressions for the time dependency of the parameters *a* and *b* (Trieb et al., 2005).

Knowing the time dependence of *a* and *b*, Equation 1 can now be formulated as a function of time. From the resulting total final electricity consumption $\hat{y}(t)$, the gross electricity demand $\tilde{y}(t)$ is modelled in Equation (4) using data from (International Energy Agency-1, 2003) on distribution losses, consumption in the energy sector and the so called "own use". These parameters were aggregated into a proportional and a fixed term. The fixed term (fixed additional consumption $\varphi(t)$) is meant to accommodate energy use for oil and gas production and for a possible future transition to new electricity applications, as e.g. space heating, hydrogen production, electric cars, etc. The proportional term representing the electricity distribution losses $\delta(t)$ was reduced from the present state of the art in each country to a level which is now common in most industrial countries (i.e. 8 %), using the linear weighing function $\varepsilon(t)$, with the starting year $t_S = 2001$ and the final year $t_E = 2050$ of the scenario (Equations 5-7).

$$\tilde{y}(t) = \hat{y}(t) \cdot (1 + \delta(t)) + \varphi(t) \qquad \text{Equation (4)}$$

$$\delta(t) = \delta(t_E) \cdot \varepsilon(t) + \delta(t_S) \cdot (1 - \varepsilon(t)) \qquad \text{Equation (5)}$$

$$\varphi(t) = \varphi(t_E) \cdot \varepsilon(t) + \varphi(t_S) \cdot (1 - \varepsilon(t)) \qquad \text{Equation (6)}$$

$$\varepsilon = \frac{t - t_S}{t_E - t_S} \qquad 2001 \le t \le 2050 \qquad \text{Equation (7)}$$

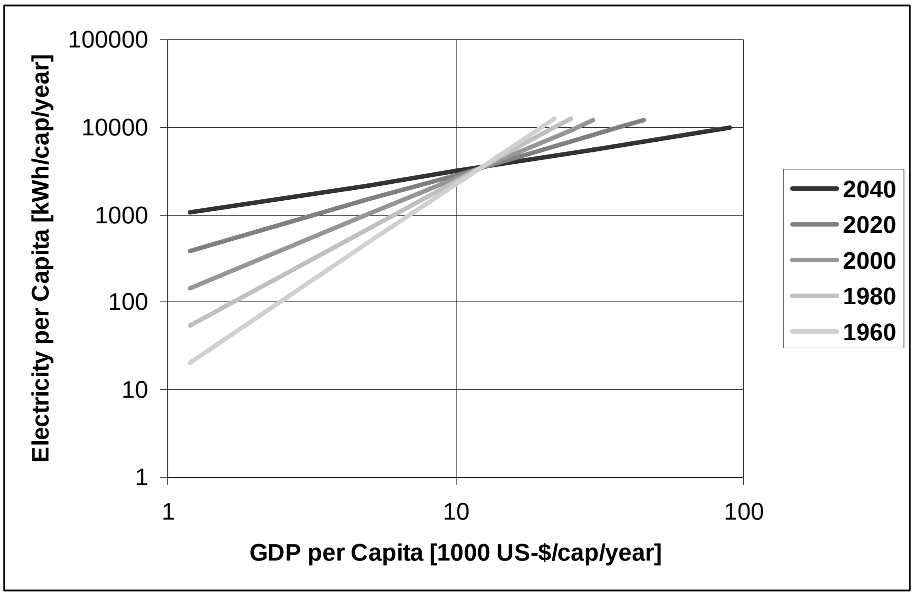


Figure 6: Simplified relation between per capita electricity consumption and per capita GDP. Each line follows a function of the type $\hat{y}(t) = a(t) \cdot x(t)^{b(t)}$ that was fitted to data of 25 selected countries for the years 1960 through 2001, where $\hat{y}$ is the net per capita electricity demand and x is the per capita GDP. The lines for 2020 and 2040 were extrapolated using an empirical time function of the parameters $a(t)$ and $b(t)$ as explained in the text.

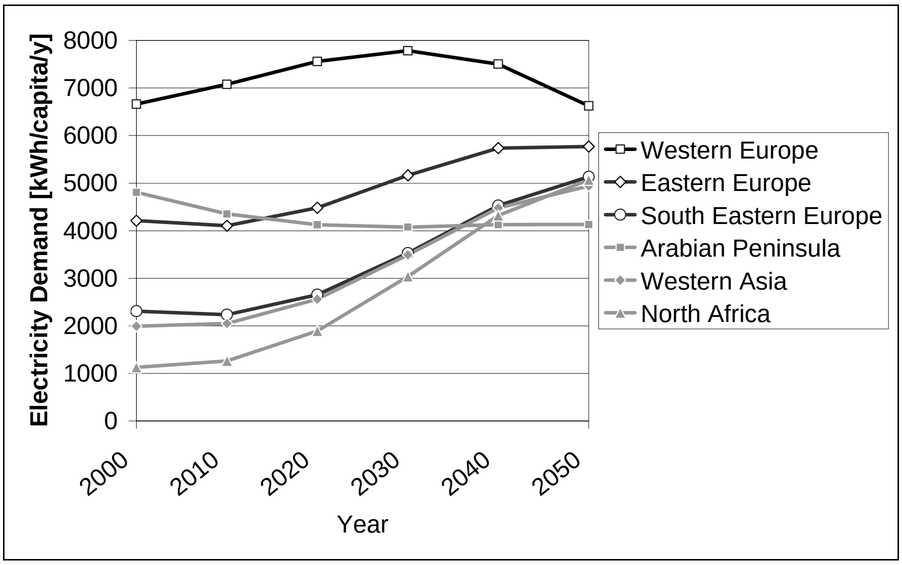


Figure 7: Per capita gross electricity consumption $\tilde{y}(t)$ aggregated by regions. The per capita electricity demand of Scandinavia stays relatively constant at 16,000 kWh/cap/y and is not displayed here. The Arabian Peninsula is very heterogeneous with values ranging today from around 15,000 kWh/cap/y in the smaller emirates to values as low as 200 kWh/cap/y in Yemen.

The resulting general function of per capita gross electricity consumption $y(t)$ is finally calibrated to the present situation in each country assuming a linear mix of the current value $y(t_S)$ derived from national statistics (International Energy Agency-1, 2003), and the model value $\tilde{y}(t)$. The weight of the model value is assumed to increase linearly from 0 in 2001 to 1 in 2050. For this purpose, again the weighing function ε was used:

$$y(t) = y(t_S) \cdot (1 - \varepsilon(t)) + \widetilde{y}(t) \cdot \varepsilon(t) \qquad \text{Equation (8)}$$

This function was calculated for each country of the region. The aggregated results for the different analysed regions are displayed in Figure 7 (for single countries please refer to (Trieb et al., 2005) and (Trieb et al., 2006)). It is interesting to note a certain evidence of convergence of the different, initially very heterogeneous regions at values around 5000 – 6000 kWh/cap/year. This can be observed for most except for the Scandinavian countries, which also massively apply electricity to process- and space heating, and show values between 15,000 and 25,000 kWh/cap/year. In contrast to the other regions, the per capita consumption slightly decreases in the Arabian Peninsula. This is due to the possibility of huge efficiency gains in the usage of electricity. For the same reason the electricity demand in Eastern and South Eastern Europe declines during the first decade. A second reason applies for the Arabian Peninsula: Due to its fast growing population the low income country Yemen with its low electricity consumption substantially gains weight in the aggregate.

A Scenario for Europe, the Middle East and North Africa

As a final step, the per capita electricity consumption is multiplied with population for every year of the scenario analysis, yielding the absolute gross electricity consumption in each of the analyzed countries (Figure 8 and Figure 9). Electricity consumption in Europe will not grow as strongly as in MENA. By the middle of the century, with 3000 TWh/y, MENA will have a power demand similar to Europe today, while Europe will stabilize at a consumption of around 4000 TWh/y, respectively.

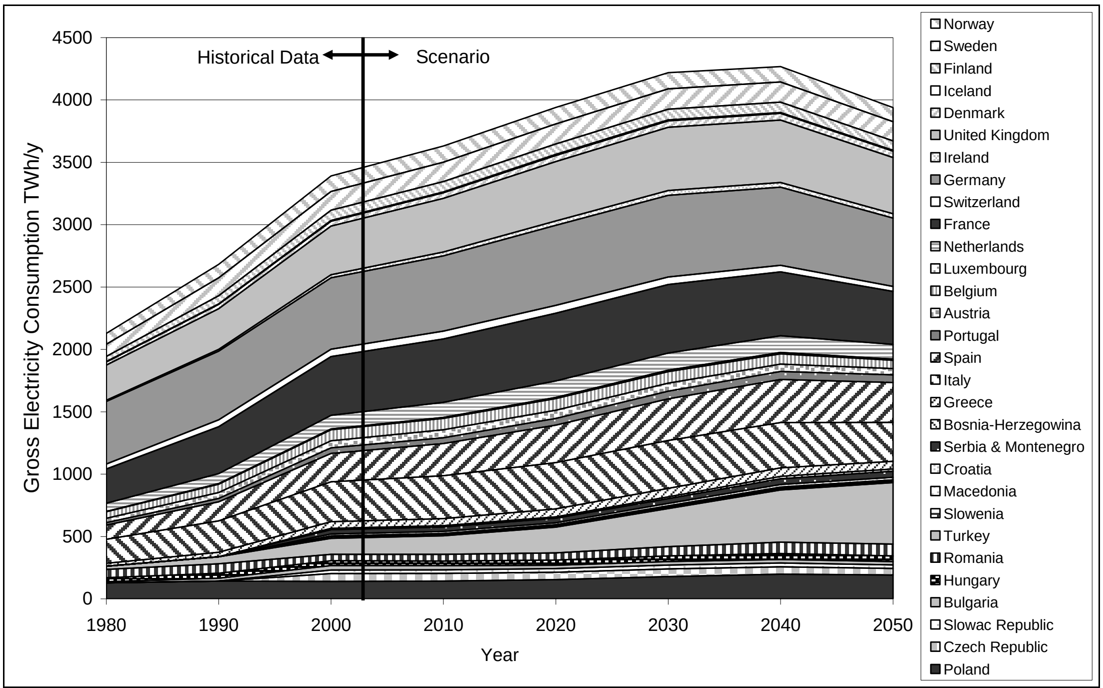


Figure 8: Scenario of electricity demand for the analysed European countries

In the long-term, most European countries show a slowly growing, stagnating or even retrogressive electricity consumption, except for some south-eastern European countries like Turkey that still will be growing substantially. The same is true for all MENA countries, some of them showing exceptional growth rates in the power sector. Germany, France, United Kingdom, Italy and Spain remain the leading electricity consumers of the European region, while the principal consumers in MENA will be Egypt and Iran, both arriving by the middle of the century at the same order of magnitude of demand as the major European countries.

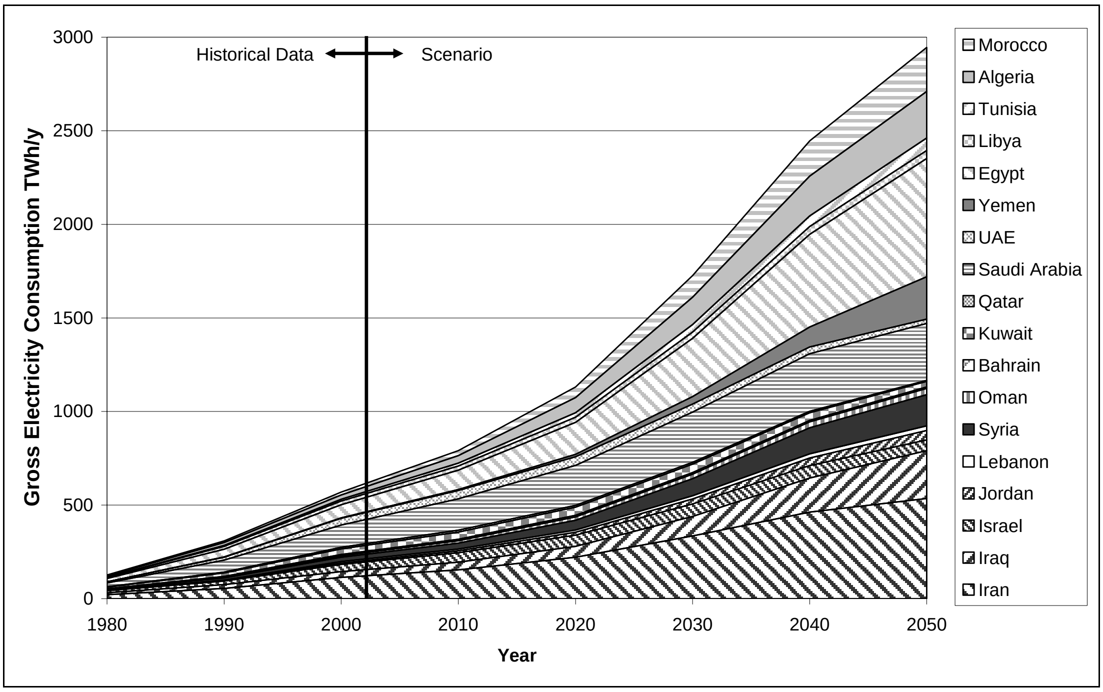


Figure 9: Scenario of electricity demand for the Middle East and North African countries

Conclusions

A method for long-term scenario analysis of electricity consumption was developed and applied to 50 countries in Europe, the Middle East and North Africa for an in depth analysis of the potential of different electricity supply technologies (Trieb et al., 2005), (Trieb et al., 2006). The scenario only considers the development within the classical power sector. Sharp changes of paradigm in other sectors like an eventual production of hydrogen for the transport sector are not included. A simple analysis like the one presented here cannot reproduce the exact growth rates and even less the short term fluctuations of the real electricity market. It is also difficult to reproduce sharp changes in energy policy, dealing e.g. with the introduction of new efficiency measures, the depletion of resources or international conflicts. A scenario of the type presented here is therefore not a prediction.

However, it can be useful to estimate the order of magnitude of future electricity demand related to a specific set of reasonable economic and demographic guard rail assumptions, and to show a consistent path to a future energy demand situation. Varying the input parameters for the scenario (e.g. different GDP and population growth rates), different results can be achieved and different pathways to the future can be evaluated in terms of plausibility and desirability. Especially for scenario analysis, different paths can be analyzed at the same time. The method offers the opportunity to derive consistent paths for different assumptions of the key parameters GDP/capita and population. Furthermore, as single countries are important actors it is important that not only large regions are analyzed. The extension of grids is likely to link the electricity market of a number of states. Thus, to supply decision-makers with the necessary information, a simultaneous and consistent analysis of many countries as introduced above is required.

The analysis shows that by the year 2050 electricity consumption in the developing economies in the Middle East and North Africa will probably achieve a value of around 3000 TWh/year comparable to the demand of Europe today, while Europe will stabilize at a consumption of around 4000 TWh/year. This result was obtained although efficiency gains experienced in the past 40 years were fully incorporated in our model. This is of course relevant for the sustainable development of the total region, being a challenge for security and affordability of energy resources, environmental compatibility, fair access to energy, and international relations.

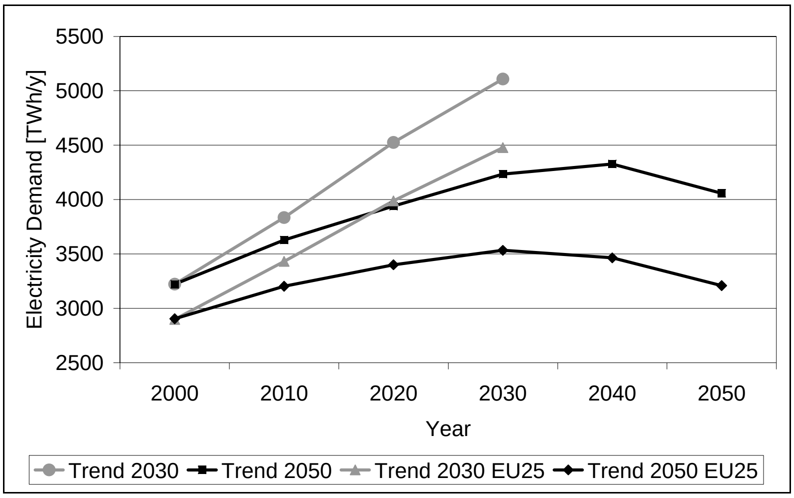


Figure 10: Comparison of our scenario (Trend 2050 and Trend 2050 EU25) with the European Energy and Transport Trends 2030 (European Commission-1, 2003) for all European countries and for a selection of the EU 25.

In the medium term, our results show a slower growth of electricity demand than the scenarios of the European Commission (European Commission-1, 2003), (European Commission-2, 2003) in Figure 10, which however in its latest update have been corrected significantly downwards (European Commission 2005). The time frame of those scenarios until 2030 leads to the impression of a monotonously growing electricity demand in Europe and MENA, neglecting the probably stagnating trend in Europe after that date due to stagnating population numbers and energy efficiency, and thus neglecting a fundamental difference between both regions. With typical investment cycles of over 40 years in the power sector, a long-term view of at least 50 years is necessary to derive meaningful results of scenario analysis.

Most medium term scenarios are based on a continuously growing electricity intensity which leads to the impression that all regions will in the long term achieve high per capita electricity consumption similar to North America, neglecting the fundamental infrastructural, geographic and meteorological differences given. In the medium term, our method yields a growing demand too, but in the long term it converges at 5000 – 6000 kWh/cap/year for most of the analyzed regions except for Scandinavia, where it remains at rather constant 16,000 kWh/cap/year. This is due to the fact that similar to North America, Scandinavia is intensively using electricity in the domestic and process heat sector due to its specific situation as a northern region with low population density.

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