Comments on the electricity demand scenario in two studies from the DLR : MED-CSP & TRANS-CSP

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Abstract

What will be the electricity demand in 2050 ? Some authors assert that, while people income (i.e. GDP per capita) is growing, the current trends show that their energy consumption will begin to decrease, making it easier to satisfy their demand in the future. This idea can be found in papers written by researchers from the DLR which were then used by some NGOs and policy think tanks.

However, the derivation of the relation between electricity demand and GDP in the DLR papers depends on a wrong mathematical assumption, made at the very base of the electricity demand analysis. The authors of these papers assumed, without any justification, that the value of a coefficient related to the GDP/cap could linearly decrease with time instead of exponentially. This conducts to the non-credible consequences that in the future, the more income you have, the less electricity you consume. This trend is supported neither by any physical consideration nor by any real observation.

It should be noted that the electricity demand scenario has usually a major impact on the prospective economical models and that an unrealistic decreasing assumption can profoundly affect the results.

Introduction

There is a growing concern on how the world should satisfy his increasing energy demand as the consumption of fossil fuels produces more and more CO_2 and as fossil fuels reserves become gradually exhausted. To answer these issues, and following the recommendations of the IPCC[2], an initiative was founded in 2003, the TREC[3], that campaigns for the transmission of clean power from deserts to Europe, the Middle East and North Africa.

In order to validate its DESERTEC[4] concept, the German Aerospace Center[5] was commissioned by the TREC initiative to produce two studies. The first one, MED-CSP[6], focuses on bringing technology and deserts into service for energy, water and climate security in Southern Europe, North Africa, Western Asia and the Arabian Peninsula. The second one, TRANS-CSP[7], analyses the renewable electricity potentials in Europe and their capability to provide firm power capacity on demand.

Both studies examine the electricity production side as well as the electricity demand side, each for its geographical scope, to figure out possible scenarios. The correct anticipation of the electricity demand is thus a major question. A significant error in its estimation could affect the entire project.

The DLR method

In the two studies[8], the method used to build a scenario of electricity demand until the year 2050 for the set of countries involved in the TREC project is based on two main points. First, an assumption of the gross domestic product per capita (GDP/cap) future evolution for each country and, second, a simple correlation between their GDP/cap and their electricity consumption per capita (EC/cap) derived from data gathered between 1960 and 1999, as showed in the example below (figure 1) reproduced from the TRANS-MED study.

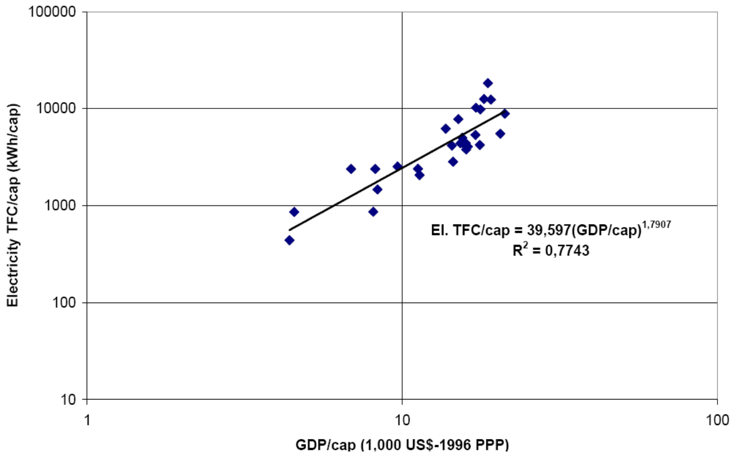

Figure 1: Electricity consumption versus GDP for a set of countries in year 1980 (from TRANS-MED, p. 90)

The assumption for the main variable GDP/cap is of the type of a constant growing rate (e.g. 3% per year, as in the example given below). Comment on this assumption is out of the scope of the present paper.

For the second point, the method used in the two studies to establish the link between GDP/cap and EC/cap can be summarised as follows :

1) Plot bilogarithmic graphs of past final electricity consumption per capita (EC/cap) as a function of the gross domestic product per capita (GDP/cap), one point for each country (as shown in figure 1). Draw such a graph for each year ranging from 1960 to 2001.

Use a regression to find, for each year, the coefficients $a(t)$ and $b(t)$ of the power function,

$$EC/cap = a(t) \, . \, (GDP/cap)^{b(t)},$$

that best fits these points.

2) Plot the evolution of these coefficients $a(t)$ and $b(t)$ over time, ranging from 1960 to 2001. Then, find the best exponential fit for the pre-exponential coefficient $a(t)$:

$$a(t) = a_1 \, . \, exp(a_2 \, . \, t).$$

The best fit obtained in the TRANS-MED study has the following expression (see also figure 2) :

$$a(t) = 13.65 \; e^{\,0.0531\, t}.$$

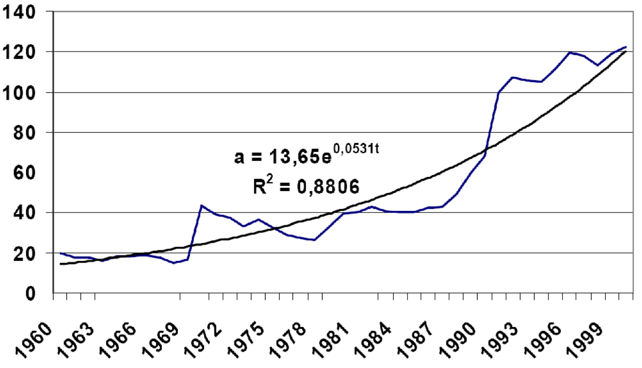

Figure 2: Evolution of the pre-exponential factor $a(t)$ with time (from TRANS-MED, p. 91)

The same approach can be used for coefficient *b(t)*, leading to the expression

$$b(t) = b_1 \,.\, \exp(b_2 \,.\, t).$$

In the two studies, this scenario is then labelled "low efficiency" (LE) as the electricity demand remains high.

Alternatively, a linear regression can be defined for the coefficient *b(t) :*

$$b(t) = b_1 + b_2 \,.\, t.$$

This second scenario is then labelled “high efficiency” (HE) because it predicts lower electricity demand levels than the previous one. The two options are illustrated in figure3, where the coefficients obtained in the TRANS-MED study are also given.

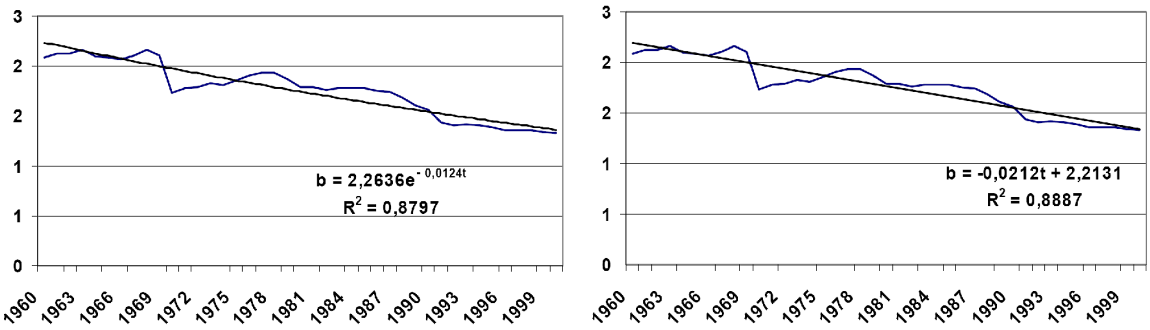

Figure 3: Evolution of the exponential factor *b(t)* with time and approximated by an exponential function (left) or by a linear regression (right) (from TRANS-MED, p. 91).

This two steps procedure produces two scenarios, one with a low efficiency and another with a high efficiency. The latter (i.e. the high efficiency scenario) is considered by the authors of the DLR as the most promising for the entire project. Based on this choice, the regressions for coefficient *a(t)* and *b(t)* can be used to obtain predictive evolutions of the electricity demand as a function of the GDP/cap at different future times. This is illustrated in figure 4 for the LE scenario. This graph is very similar to a figure wrongly presented in the studies as that one corresponding to the HE scenario[9], while no graph was presented at all in the two studies for the LE scenario. It should be noted that in figure 4, we only have extended the scenarios until 2100 in place of 2060.

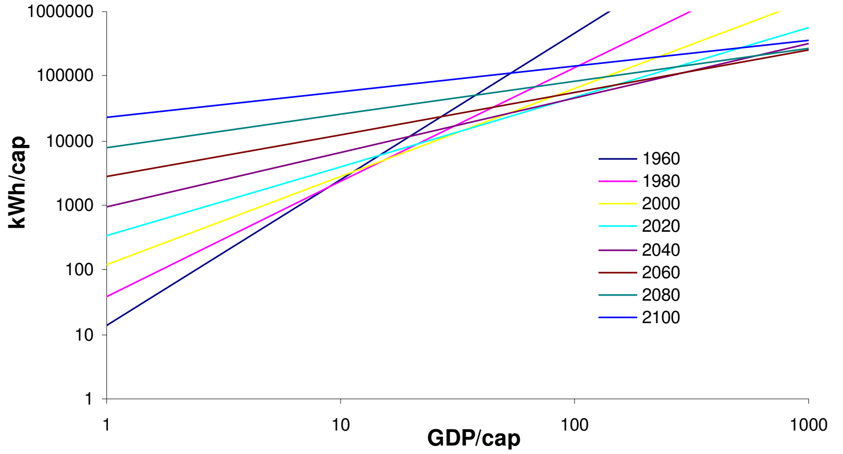

Figure 4: Predictive evolution of the electricity demand as a function of the GDP/cap for the “low efficiency” scenario.

This graph seems very sensible, as it shows that the electricity demand is always increasing with GDP, but that the rate of increase diminishes over time; probably due to technological progress.

The true HE graph

Unfortunately, values plotted in figure 4 do not correspond to the HE scenario as wrongly stated in the studies from the DLR. As mentioned in the previous section, we obtained such a graph for the LE scenario. The corresponding mathematical relation is trivially derived from the previous sections as :

$$EC / cap = 13.65 e^{0.0531(t-1960)} (GDP / cap)^{2.2636 e^{-0.0124(t-1960)}} .$$

This equation of the LE scenario, corresponding to figure 4, was considered by the authors of the DLR as not very appealing as they did not present the derived results and graphs for individual countries resulting from the LE scenario. They choose to derive their electricity demand scenarios from the sole HE assumption, by mean of a CG/HE (closing the gap/high efficiency) scenario (see TRANS-MED p. 71 for the concept CG/HE and p. 97 for the graphs). The concept "closing the gap", which refers to a scenario of convergence between the economies of the different countries involved, is out of the scope of the present paper.

The correct HE graph is given in figure 5. The corresponding equation is, using the coefficient from the previous sections :

$$EC / cap = 13.65 e^{0.0531(t-1960)} (GDP / cap)^{2.2131-0.0212(t-1960)} .$$

This last scenario and function, illustrated by figure 5, were used throughout the papers MED-CSP and TRANS-CSP to establish electricity demand in the various countries involved in the projects. After all computations and taking into account the population evolution, it finally produced graphs similar to figure 6.

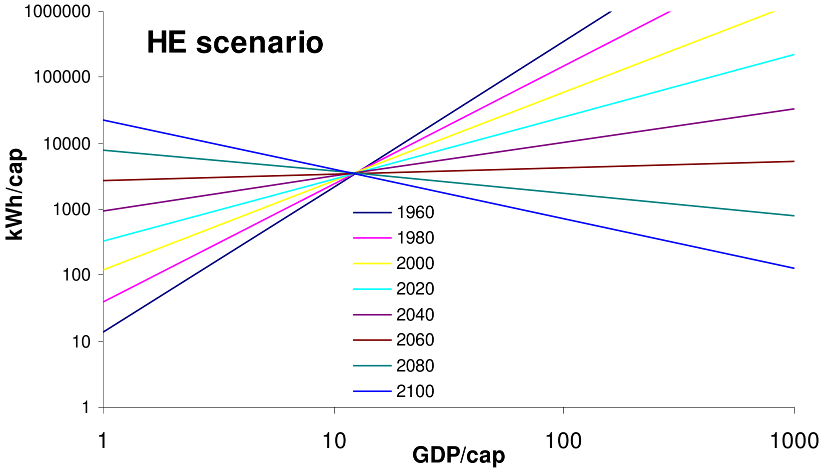

Figure 5: Predictive evolution of the electricity demand as a function of the GDP/cap for the "high efficiency" scenario.

Comments on the HE scenario meaning

The correct HE evolutions, shown in figure 5, have very interesting properties. All the lines intersect at one point, a special GDP/cap, for which electricity demand is not dependent on the time. Furthermore, in year 2064, technological progress will be so that people from poor countries will use the same amount of electricity as those from rich countries, as the line becomes horizontal. After that date, more wealthy people will use less electricity than poor ones (negative slope). These properties are only the consequence of the linear regression defined for the *b(t)* coefficient. It intersects the horizontal axis in year 2064. The coefficient then becomes negative meaning a decrease of electricity demand with increasing GDP.

These properties are against common sense and known relationships between GDP/cap and electricity demand per capita. It seems that the authors of the studies did not pay much attention to the physical meaning of their assumptions.

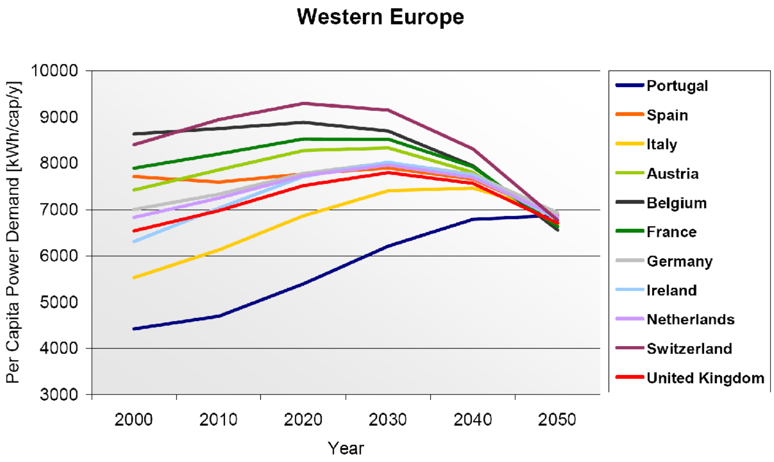

Figure 6: Time evolution of the EC/cap for different countries (from TRANS-CSP, p. 40).

An example of the electricity demand behaviour over time, corresponding to the HE and LE scenarios, is given in figure 7, in which, following the HE scenario, a country whose GDP/capita constantly grows at a rate of 3% will nevertheless no more need electricity at the end of the century ! This behaviour seems unnatural as far as, for human beings, growth corresponds structurally to an increase in material goods consumption.

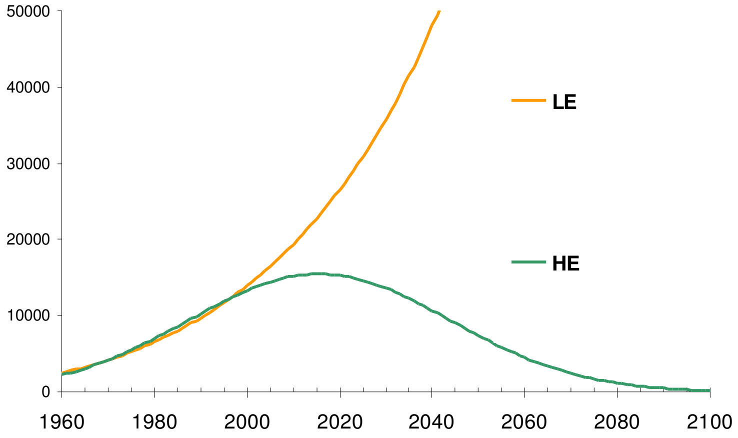

Figure 7: Examples of time evolution of electricity demand according to the low efficiency and high efficiency scenarios.

Therefore, we postulate that when such a power function is used to express the evolution of electricity demand over time, the power factor has to be less than one but cannot become negative. This express that, on the long run, as the GDP/capita progresses, the electricity demand per capita also progresses, but at a lower rate. One can admit that this "decoupling" phenomenon will continue to progress over time, due to technological progress and people efforts. But the lower positive limit of the decoupling coefficient is unknown.

Re-examining figure 3, it is patent that the difference between the two regressions is very tiny. The graphs give no evidence of which could corresponds to the evolution of real countries. But, over time, the linear regression will produce negative values as the exponential regression will not. This last regression will tend to zero which is slightly more rational but still unrealistic in our opinion. The only physical option would be to have an exponential decrease towards a constant positive value. Physically this would correspond to a limit where a high GDP still induces a high electricity demand.

Conclusion

The use of regressions, on limited data sets, to produce forecasting on the long term evolution of the real, physical world is very delicate, not saying very risky. Mathematical curve fitting tools give no indications on the most appropriate type of curve to be used, i.e. one that best corresponds to the real (physical) behaviour of the world system. One has always to keep in mind the physical reality underlying the studied problem. It seems that the authors of the DLR papers did not pay sufficient attention to these realities.

In our opinion, the real physical world, as well as the laws of physics and thermodynamics, must lay at the very base of all scenario building process. This kind of approach was brilliantly demonstrated in the 1970's at the MIT by D. Meadows et al. and presented in their 1972 book - "The limits to growth". In this work, commissioned by the Club of Rome[10], the researchers developed a lot of relations between the relevant physical aggregates, carefully verifying their agreement with the real world.

In the case of electricity, there are obviously many opportunities to raise the technological efficiency on both the production and the demand side. But technological efficiency cannot become infinite. The laws of conservation and of degradation of matter and energy are limiting factors. Therefore, on the long run, in spite of better efficiency, more material consumption will always imply more energy consumption.

The choice made by the DLR's authors has consequences of great importance as it implies that the electricity demand will "naturally" fall down in the future, making it easier to produce sufficient amounts of electricity. The DESERTEC concept is obviously a good one. It would be better if it was based on a more credible prospective of the electricity demand.

[1] **ORMEE** : Observatoire sur le Relais Médiatique des Enjeux Énergétiques.
[2] **IPCC,** International Panel on Climate Change, http://www.ipcc.ch.
[3] **TREC,** Trans-Mediterranean Renewable Energy Cooperation, http://www.trecers.net.
[4] **DESERTEC concept** for energy, water and climate security in EUrope, the Middle East and North Africa (EU-MENA), http://www.trecers.net/concept.html.
[5] **DLR** : German Aerospace Center, http://www.dlr.de/en/.
[6] **MED-CSP**, Concentrating Solar Power for the Mediterranean Region, http://www.dlr.de/tt/med-csp.
[7] **TRANS-CSP**, Trans-Mediterranean interconnection for Concentrating Solar Power, www.dlr.de/tt/trans-csp.
[8] MED-CSP, Chap 4 : Demand Side Assessment for Electricity and Water & TRANS-CSP, Chap 2 : A Scenario for Sustainable Electricity.
[9] MED-CSP, Chap 4, p. 92 & TRANS-CSP, Chap 2, p. 36.
[10] **Club of Rome**, http://www.clubofrome.org/.