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Document downloaded from:

<http://hdl.handle.net/10459.1/60274>

The final publication is available at:

<https://doi.org/10.1016/j.rser.2017.09.073>

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Comparison of past projections of global and regional primary and final energy consumption with historical data

Luisa F. Cabeza^{1,*}, Anabel Palacios^{1,2}, Susana Serrano¹, Diana Ürge-Vorsatz³, Camila Barreneche²

¹ GREA Innovació Concurrent, INSPIRES Research Centre, Universitat de Lleida, Pere de Cabrera s/n, 25001, Lleida, Spain.

² Department of Materials Science & Metallurgical Engineering, Universitat de Barcelona, Martí i Franqués 1-11, 08028, Barcelona, Spain.

³ Center for Climate Change and Sustainable Energy Policy (3CSEP), Department of Environmental Sciences and Policy, Central European University (CEU), Nádor utca 9, 1051 Budapest, Hungary

*Corresponding author: lcabeza@diei.udl.cat

Abstract

Energy planning is fundamental for energy planners to accurately plan for the future and to utilize the sustainable and renewable energy resources to a larger extent. But how well are we able to project the future? In this paper, past projections of global and regional energy consumption are compared to real data. The conclusions found that when comparing energy consumption projections with real registered data projections in 1977 substantially overestimated energy demand in the future, while later projections in the 80s and 90s were closer to reality, slightly underestimating real growth in demand. Although projections made in these two decades for total demand were typically slightly underestimated, per capita projections were still overestimating real trends. Considering the building sector, residential and commercial, energy consumption was underestimated in WEO 1982 and WEO 1994; and again, when per capita values are considered, higher values than reality were projected.

Keywords: primary energy consumption; final energy consumption; global and regional; projections; OECD countries.

1. Introduction

All nations are interested in accurately planning the future energy consumption and using sustainable and renewable energy resources to a larger extent. To achieve this goal, models are fundamental tools to energy planners because models will facilitate policy makers and administrators to take decisions for a greener tomorrow. Sustainable development and energy generation planning need data on the energy demand of a country/area/city in the future. For example, Suganthi and Samuel [1] reviewed the energy demand forecasting models for commercial and residential buildings. It is found that energy intensity is determined to find the relative energy utilization by a nation. Similarly, institutions like the International Energy Agency (IEA) started to do projections on the energy consumption and energy demand in buildings in the 70s. Brounen et al. [2] analysed how the use of gas and electricity is determined by the building, and compared it to the demographic characteristics of residents in 300 000 Dutch homes. They combined these results with projections on future economic and demographic trends. Nejat et al. [3] reviewed the energy consumption, CO₂ emissions and polity in the residential sector in the top ten CO₂ emitting countries (China, USA, India, Russia, Japan, Germany, South Korea, Canada, Iran, and UK). This review suggests that the driving factors for energy consumption increase are population, urbanization and economic growth. Finally, Ürges-Vorsatz et al. [4] presented the drivers of thermal energy use in buildings, and their past, present, and future trends on a global and regional basis.

Projections on residential energy demand can be found in the literature. Suganthi and Samuel [5] reviewed the models used for energy demand forecasting. The review demonstrates that traditional methods such as time series, regression, econometric, ARIMA as well as soft computing techniques such as fuzzy logic, genetic algorithm, and neural networks are being extensively used for demand side management. Loftus et al. [6] reviewed global decarbonisation scenarios, but this scenarios are not focussed in building energy consumption. Moreover, Fazeli et al. [7] reviewed the models of residential energy demand to temperature. One of the main conclusions of this review is that while the studies reviewed only tested the impact of changes in the temperature thresholds and the shape of temperature response functions, a comprehensive understanding of changes in energy demand patterns and climate adaptation potentials requires knowledge of building stock turnover rates and associated changes in technology and behavioural responses of building occupants, and this is not integrated in the models developed in the literature.

But how well are we able to project our energy future? How well do we know in advance how much energy we will need? It has been rarely compared so far, especially in the peer reviewed

literature, how close the projections are to the real data. Therefore, the objective of this paper is the comparison of past projections of total final energy consumption in the world and major regions, especially OECD countries since there is more available data for those countries.

An evaluation of the energy history of OECD countries is necessary in order to explain the differences between real and projected energy consumption. At the beginning of 1970, after the oil crises, the international community became more aware to dependency of fuel resources [8]. On that account, industrialized countries adopted several policies to rationalise energy use and to improve energy efficiency [9].

The first petroleum crisis (1973) confronted North America and Europe allies with OAPEC (Organization of Arab Petroleum Exporting Countries) countries. Since the OECD countries oil imports relayed totally on OAPEC, it was required to find another source. Therefore OECD countries became strongly dependent on imports from the Middle Eastern OPEC countries [10]. What had started as an oil crisis developed in each case into a deep economic crisis. As a result, the recession affected economies more severely than expected at first. Within months, oil prices escalated sharply, imposing a lasting financial drain on industrialized countries which, in both cases, accounted initially to about 2% of their annual economic output [10]. In the meantime, the erratic oil price increases depressed overall demand, economic activity and employment.

Against this background in 1974 the International Energy Agency (IEA) was founded, through the union of developed OECD countries. The member countries aimed at reducing their dependence on oil sources and minimizing the damages in case of another oil crisis. One of the measures was to increase domestic oil production, replacing much oil use in electricity generation and to improve energy efficiency. In the middle of 1980 OECD net oil imports were reduced by 27 Mb/day in the mid-1970 to 16 Mb/day in the mid-1980 [10].

While OECD countries were recovering from the previous crisis, in 1986 a second petroleum crisis appeared [11]. In 1985 the price collapse (falling by more than 50 percent) due to Saudi Arabia and some of its neighbours decision to release the surplus oil generated through the low economic activity and driven energy savings. This decision was a strategic movement of Arabian lobby in order to recover the leadership in the world oil market.

After the crisis of 1986, the prices recovered the normal levels and the developing countries were less dependent to oil prices. One reasonably explanation is that the measures undertaken by IEA and the agreements and protocols signed by the industrialized countries, such as Kyoto

protocol (1994) and the Energy Charter Treaty (1991) in order to improve energy efficiency, reduce greenhouse gas emissions, and increase the share of renewable energies.

2. Data sources

All data used in this paper was published by the International Energy Agency (IEA). Every year IEA publishes the World Energy Outlook (WEO), which is a document that incorporates all the latest data and developments to produce a comprehensive and authoritative analysis of medium and longer-term energy trends. It includes a full set of energy projections with strategic insights into their meaning for energy security, economy and environment. The World Energy Outlook was first published in 1977 in five year intervals, and is now published annually; so it was published in 1977, 1982, 1993-1996, 1998-onwards. Essentially, in this paper the issues included are WEO of 1977 [12], 1982 [13], 1994 [14], 1998 [15], and 2004 [16] taking as present 2013. Besides, the real data used to compare projections are extracted from the IEA data base, beyond 2020 [17]. The annual GDP growth and the population development are extracted from the statistics data base of OECD countries [18]. Moreover, the countries considered in each WEO for the regions under study are reported in Table 1. The additional countries joined to founders OECD countries during the period under study (1977-2004) are represented in Table 1 with (+). The OECD total is the addition of OECD North America, OECD Europe and OECD Pacific.

Table 1. Countries considered in each World Energy Outlook per region.

Region	WEO 1977	WEO 1982	WEO 1994	WEO 1998	WEO 2004
OECD North America	Canada and United States				+ Mexico
OECD Europe	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, and United Kingdom.			+ Czech Republic and Hungary	+ Poland and Slovak Republic.
OECD Pacific	Australia, New Zealand, and Japan				+ Korea

3. Results

The energy projections reviewed in this paper are based on the GDP growth assumptions that are reported in Table 2. The GDP growth projections were updated in every WEO [6,10]. For the period 1974-1980 the GDP projections were very optimistic, giving always values higher than the real growth (for example, all OECD countries were projected to grow 4.3% while the real growth was only 2.8%; similar differences can be found for the different OECD regions presented). For the period 1980-1985, GDP growth was projected in WEO 1977 and in WEO 1982. Again the projections in 1977 were very optimistic, with a growth for the OECD countries of 4.1% while the real growth was 2.5%; but in 1982 the projections were more realistic, all OECD countries were projected to grow 2.6%, very close to the final real value 2.5%. For the period 1985-2000 projections were presented in WEO 1982 again only for the OECD countries with a value of 3.2%, when the real value was 3.3%. In WEO 1994, projections for 1991-2000 were presented for the different OECD regions and for China (for the first time this region was included). New projections did underestimate the real GDP growth in all regions (for example, for OECD projections were 2.3% growth while the real growth was 2.8%, for China projections were 8.8% and real growth was 10.3%). Projections up to 2020 were presented in WEO 1998 and WEO 2004. Comparison with real data cannot be done, but the projections are all very similar to those for 2000 done in WEO 1994, lower than the real values for the year 2000.

Population projections are also interesting for the evaluation of the energy demand. Figure 1 shows the projection of the population in OECD countries for the period 1975 to 2020 one in 1982, 1994, 1998, and 2004. It can be seen that these projections did always underestimate the population growth. This phenomenon can be explained by the fact that life expectancy has strikingly increased over the years and the growing capacity has increased. Meadows [19] postulated the problematic of the non-limiting growth of population. According to this author, the advancement in medicine and the improvement in human quality of life stand for a reason of the life expectancy growth. It is interesting to see that projections in 2004 showed stagnation in population at about 1180 millions, but the real values shows constant growth at a rate of 3.7% since 1975.

Figure 1. Projections vs. reality of population for OECD countries from 1975 to 2020.

Table 2. GDP Growth Rates for the Reference and Accelerated Policy

(% per year)	Period 1974-1980		Period 1980-1985			Period 1985 - 2000		Period 1991 - 2000		Period 1995 - 2020	Period 2002-2020
	Real	Projected in 1977	Real	Projected in 1977	Projected in 1982	Real	Projected in 1982	Real	Projected in 1994	Projected in 1998	Projected in 2004
OECD North America	3	4.6	2.7	3.7	n.a	2.9	n.a	3.1	2.5	2.1	2.8
OECD Pacific	2.7	3.6	2.9	3.9	n.a	3.2	n.a	3.3	2.4	1.8	2.2
OECD Europe	2.5	3.4	1.7	4	n.a	2.1	n.a	2.3	2	2	2.3
Total OECD	2.8	4.3	2.5	4.1	2.6	3.3	3.2	2.8	2.3	2.2	2.4
China	6.2	n.a	7.6	n.a	n.a	9.4	n.a	10.3	8.8	5.5	5.6

n.a. – Not available

The WEO published projections of the total energy consumption for OECD countries, and the total energy consumption for the different identified OECD regions (North America, Pacific, and Europe). Later in time, other regions such as China were also included in the projections because China was identified as an emerging market.

Figure 2 shows the projections for total OECD countries of total final energy consumption. While in 1977 overestimated what really happened, all other projections were accurate enough, giving values very much close to the real ones. This trend is seen both in the OECD countries as a whole as well as in all the different OECD country groups considered. For China (Figure 2e), the projections started in WEO 1982, and were always underestimated; for example, it can be seen that the energy consumption projected for 2020 was already reached in 2010.

If the total energy consumption is considered per capita with the projections done by the IEA as shows Figure 3, the per capita total final energy consumption was overestimated, but here differences between regions are seen. If the total OECD countries are considered, projections in 1994 gave much higher total final energy consumption than the real one; and projections in 1998 were still high but not so much (real per capita energy consumption in 2010 was 0.035 GWh/person, while in 1994 was projected to be 0.066 and in 1998 0.046 GWh/person). On the other hand, projections for OECD North America were also too high in 1994 but quite accurate in 1998. For OECD Pacific and Europe a similar trend is seen but with less overestimation in 1994. Finally, China projections were the most accurate and with the contrary trend, since per capita energy consumption was underestimated in this case. It should be highlighted that these per capita differences between projections and real data are due to the lack of precision of the population growth data and not of the energy consumption projections.

Figure 4 shows the projections of total final energy consumption per GDP for OECD countries together and for OECD regions. Projections always overestimated the reality for all regions, with closer values to reality in latest projections, but still higher than reality. Projections in 1998 and 2004 show stagnation around 2 GWh per million USD for OECD North America, Pacific and Europe, while reality has reached values around 1 GWh per million USD in 2013. China has higher total final energy consumption than the OECD countries (projections of 3 GWh per million USD in 2010 and reality of around 1.4 GWh per million USD).

(a)

(b)

(c)

(d)

(e)

Note: different scale used in figures

Figure 2. Projections vs. reality of total final energy consumption for OECD countries from 1975 to 2020. (a) OECD; (b) OECD North America; (c) OECD Pacific; (d) OECD Europe; (e) China.

(a)

(b)

(c)

(d)

(e)

Note: different scale used in figure (e)

Figure 3. Projections vs. reality of per capita total final energy consumption for OECD countries from 1975 to 2020. (a) OECD; (b) OECD North America; (c) OECD Pacific; (d) OECD Europe; (e) China.

(a)

(b)

(c)

(d)

(e)

Note: different scale used in figure (e)

Figure 4. Projections vs. reality of per GDP total final energy consumption for OECD countries from 1975 to 2020. (a) OECD; (b) OECD North America; (c) OECD Pacific; (d) OECD Europe; (e) China

Figure 5 to Figure 7 show the projections and real values for primary energy supply for OECD countries and China, and primary energy supply per capita and per GDP for the period studied. Projections in 1977 underestimated the primary energy supply, but later projections were accurate enough with corrections over the years. Again China is the exception, since all projections underestimated considerably reality. OECD countries grew in primary energy supply at a rate of 4.9% in the period 1975-2010, while OECD North America, Pacific and Europe's rates were 4.7%, 10.5%, and 3.0%, respectively. China growth was 19.4% between 1975 and 2000, and 36.1% in the period 2000-2010.

Primary energy supply per capita in OECD was projected quite accurately, with overestimations since 2000, probably due to an unexpected decrease in real values. Primary energy supply per capita in OECD has stagnated at around 0.05 GWh/person. Similar comments can be drawn for OECD North America and OECD Europe, with average stagnation values of 0.095 GWh/person and 0.05 GWh/person, respectively. But OECD Pacific showed a growth since 1985 to 2000, stagnating then at around 0.07 GWh/person; for this region, projections in 1994 and 1998 underestimated real values, while projections in 2004 overestimated them. Finally, China showed such a steep growth in 2000 (from 0.008 GWh/person to 0.022 GWh/person) that no projections could follow.

Projections for primary energy supply per GDP always overestimated the reality for all regions. Projections in 1998 and 2004 show stagnation from 4 to 2 GWh per million USD for OECD North America, Pacific and Europe, while reality has reached values around 2 GWh per million USD in 2013 (1 GWh per million USD for OECD Europe). China has higher total primary energy consumption than the OECD countries (projections of 5 GWh per million USD in 2010, projected in 2004, and reality of around 2 GWh per million USD).

(a)

(b)

(c)

(d)

(e)

Note: different scale used in figure (a)

Figure 5. Projections vs. reality of primary energy supply for OECD countries from 1975 to 2020.

(a) OECD; (b) OECD North America; (c) OECD Pacific; (d) OECD Europe; (e) China

(a)

(b)

(c)

(d)

(e)

Note: different scale used in figure (e)

Figure 6. Projections vs. reality of primary energy supply per capita for OECD countries from 1975 to 2020. (a) OECD; (b) OECD North America; (c) OECD Pacific; (d) OECD Europe; (e) China

(a)

(b)

(c)

(d)

(e)

Note: different scale used in figure (e)

Figure 7. Projections vs. reality of primary energy supply per GDP for OECD countries from 1975 to 2020. (a) OECD; (b) OECD North America; (c) OECD Pacific; (d) OECD Europe; (e) China

Comparing Figure 2 with Figure 5, it is clear that projections in 1977 did overestimate total final energy consumption in OECD countries with did underestimate primary energy supply. But as commented previously, later projections were in general quite accurate. When final energy consumption and primary energy supply are presented per capita and per GDP, similar figures are found for real values and for projections.

4. Conclusions

This paper compares past projections of total, per capita and per GDP primary and final energy consumption in the world to historic energy demand data, focusing on OECD countries. Energy prospects are based on the GDP and population growth assumption, therefore these projections are also presented in this paper:

- For the period 1974-1980 GDP projections were very optimistic, giving values higher than the real growth.
- WEO 1977 and 1982 GDP growth projections for the period 1980-2000 did match reality; however, WEO 1994 did underestimate the real GDP growth in all studied regions.
- Population projections always underestimated population growth in reality.

When comparing total final energy consumption projections with real registered data, the main conclusions are:

- WEO 1977 projections overestimated reality substantially demand, giving a total energy consumption growth much higher than reality; nevertheless, all later projections were quite accurate with a tendency to slightly underestimate demand.
- Per capita and per GDP total final energy consumption projections were consistently overestimated.

Finally, when comparing primary energy supply projections with real registered data, the main conclusions are:

- WEO 1977 projections underestimated reality to a big extent, but again later projections were more accurate with a tendency similar to the reality.
- Per capita and per GDP primary energy supply projections were consistently underestimated.

Acknowledgements

The work is partially funded by the Spanish government (ENE2015-64117-C5-1-R (MINECO/FEDER)). The authors would like to thank the Catalan Government for the quality accreditation given to their research group GREa (2014 SGR 123) and research group DIOPMA (2014 SGR 1543). GREa and DIOPMA are certified agents TECNIO in the category of technology developers from the Government of Catalonia. Dr. Camila Barreneche would like to thank Ministerio de Economía y Competitividad de España for Grant Juan de la Cierva, FJCI-2014-22886.

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