WNA Report

Inside the Black Box - Exploring the Assumptions within Nuclear Power Forecasts

A Report by the World Nuclear Association's Working Group on Energy Futures

World Nuclear Association

Title: Inside the Black Box - Exploring the Assumptions within Nuclear Power Forecasting
Produced by: World Nuclear Association
Published: April 2013
Series: WNA Report
Report No.: 2013/003

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1 Introduction

Energy policy is critical to the evolution of electricity supply systems. The energy policy objectives of different countries usually include meeting the needs of households and contributing to the competitiveness of industry in a secure and environmentally responsible manner, with varying levels of emphasis placed on each element. Energy scenarios, projections and forecasts (hereafter all referred to as 'scenarios') are important tools for policy-makers wishing to understand the options for designing future energy systems and the consequences of these options in terms of costs, energy security and environmental impact. In the absence of such scenarios, policy-making is severely handicapped in attempting to gauge the possible impacts of specific measures.

A considerable number of energy scenarios, of varying degrees of quality, have been published by a range of organisations over the years. Energy systems are characterised by complex interactions between their constituent parts and attempts to understand the consequences of different policy options often make use of integrated quantitative economic models that aim to mimic the workings of these complex and interacting energy systems.

This report aims to review some of the best-known recent energy scenario studies using integrated models. It aims to map the variation between studies and to seek to account for it. The report examines the different assumptions that the studies make about the way the energy system works in order to identify the drivers for common tendencies and divergences amongst these studies. The intention is to inform better the public debate about energy policy in general and in particular to highlight optimal approaches for reconciling energy demand growth with ambitions for greenhouse gas emission reduction. The report concludes with some recommendations to future energy scenario builders.

2 Scope of the Study

Only a limited number of organisations have the mandate, ambition and budget to produce energy scenarios using integrated energy models. This report limits its coverage to five well-known scenario studies (see Table) comparing in each case the baseline scenario (ie, business-as-usual) with the principal greenhouse-gas reduction scenario.

Organisation	**Study**	**Scenarios**
International Energy Agency, an intergovernmental agency of the OECD	*World Energy Outlook* (WEO) (Nov 2012)	*Current Policies Scenario* (CPS) – government policies enacted by 2012 remain unchanged *450 Scenario* – policies are enacted that lead towards a 50% chance of limiting global temperature increase to 2 degrees Celsius
As above	*Energy Technology Perspectives* (ETP) (July 2010)	*Baseline Scenario* – no new policies are enacted and follows the 2009 WEO Reference Scenario to 2030 (as does the *Blue Map Scenario*) *Blue Map Scenario* – global energy-related CO_2 emissions fall to half their 2005 levels by 2050 and is optimistic for the development of all generating technologies
European Commission	*Energy Roadmap to 2050* (Dec 2011)	*Reference Scenario* – 'is a projection … of developments in the absence of new policies beyond those adopted by March 2010' *Diversified Supply Technologies Scenario* – reaches an 85% energy-related CO_2 emission reduction by 2050 … 'with no specific support measures for energy efficiency and renewables and assumes acceptance of nuclear and CCS'
Energy Information Agency, an agency of the US Department of Energy	*International Energy Outlook* (IEO) (Sept 2011)	*Reference Case* – 'Projections are … based on existing laws and policies.'
Eurelectric, the European electricity producers' trade association	*Power Choices* (June 2010)	*Baseline Scenario* – no new policies are enacted after Spring 2009 *Power Choices Scenario* – sets a pathway for a carbon neutral EU power sector by 2050 and in accordance with a 450ppm global scenario

The outputs of the studies are not always directly comparable, with varying terms of time period, regional focus and technical parameters. Moreover, the *ETP* and *Power Choices* studies included in this report were published prior to the Fukushima accident, the long term effects of which remain uncertain. However, sufficient commonality exists between the five studies for interesting observations to be made. The intention is to focus on the period to 2050 and to review the global and European results (which reflect the particular focus that scenario builders have placed on the European energy system).

3 Parameters of Interest

Our study is concerned with two parameters for which all the above studies produce scenarios.

1. Total electricity generation
2. Nuclear power generation

In many cases, organisations define only two or three scenarios but sometimes a higher number is produced. Comparison of all these scenarios would be cumbersome and the approach taken is to compare two from each study, namely a baseline scenario and a carbon reduction scenario. The baseline scenario is taken as the expected or most probable scenario in the absence of any additional measures to reduce greenhouse gas emissions and often referred to as the business-as-usual scenario. Carbon reduction scenarios make the assumption that additional CO_2 emission reduction measures are implemented, although there remain significant differences between the scope of these measures (geographical, technology) and the rate of application (ambition of the reduction target).

The results are presented in graphical form in the text; the underlying figures may be found in the appendix. It should be noted that the 2010 values attributed to the studies are often not the initial year used in the different studies. This reflects two principal considerations: first, that the Energy Technology Perspectives (ETP), Power Choices and Roadmap scenarios have baseline years of 2007, 2005 and 2005 respectively and the 2010 values have been generated by interpolation; and second, that the ETP and International Energy Outlook (IEO) refer to OECD Europe and the other studies to the EU27. It should also be noted that the IEA WEO and EU studies give figures for gross electricity generation whereas the IEA ETP, the EIA and the Eurelectric studies mostly give figures for net electricity generation or electricity demand. The figures for net generation have been converted to gross generation by an assumed five per cent increase. The aim of this study is to compare the overall direction of the different scenario projections rather than to achieve absolute calibration between them so it is hoped that the reader will accept these differences as second order considerations.

4 Electricity Generation

4.1 GLOBAL ELECTRICITY GENERATION SCENARIOS

Baseline Scenarios

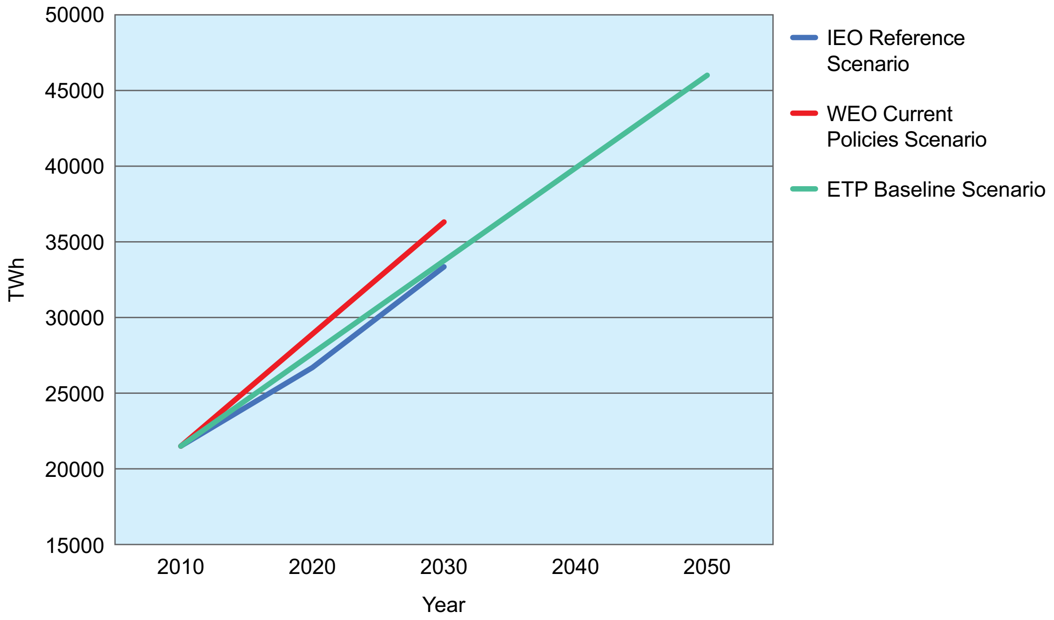

Figure 1: Global Electricity Demand (TWh) – Baseline Scenarios

Carbon Reduction Scenarios

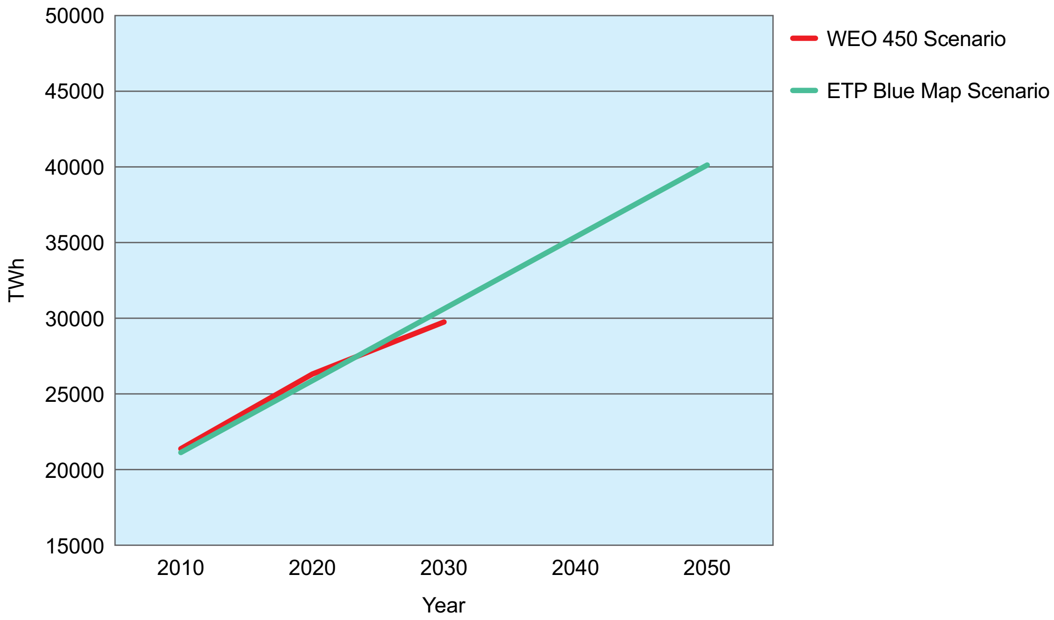

Figure 2: Global Electricity Demand (TWh) – Carbon Reduction Scenarios

At the global level, the EIA and IEA are in substantial agreement regarding the baseline or business-as-usual (BAU) growth of electricity generation, projected at 2.3-2.7%/year to 2030. The IEA's ETP projects this rate to 2050. The main driver for electricity demand growth is primarily the assumed continuation of growth in several developing countries' macro parameters, namely population growth, economic growth and urbanisation.

The same general result applies to the IEA's carbon reduction scenarios: the WEO 450 Scenario and the ETP Blue Map Scenarios. The WEO 450 Scenario "sets out an energy pathway that is consistent with a 50% chance of … limiting the increase in global average temperature to two degrees Celsius"[1]. "The ETP Blue Map scenarios are consistent with a long-term global rise in temperatures of 2 to 3 degrees C"[2]. A number of Blue Map scenario variants are developed in order to examine ways of achieving the 2 to 3 degree objective at least cost, assuming an 'optimistic' evolution for all technologies[3]. The rate of growth of electricity generation in these scenarios is lower at 1.7%/year.

4.2 EUROPEAN ELECTRICITY GENERATION SCENARIOS

Baseline Scenarios

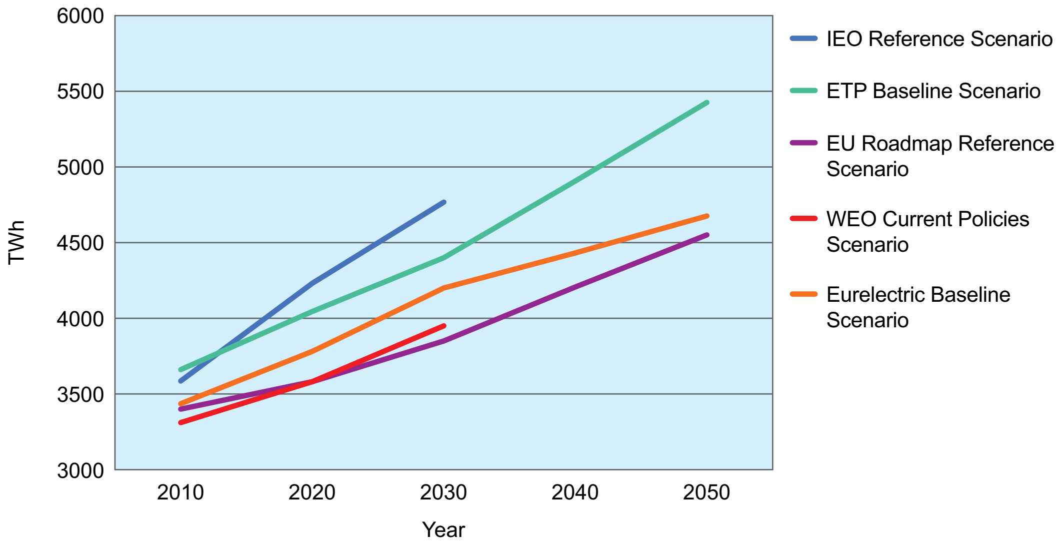

Figure 3: European Electricity Generation (TWh) – Baseline Scenarios

[1] p55, WEO 2011
[2] P69, ETP 2010
[3] The IEA's two carbon reduction scenarios show a small degree of difference. This is due to the 2011 ETP scenarios being based on those in the 2009 WEO whereas this report takes the 2012 WEO as the current scenarios.

Carbon Reduction Scenarios

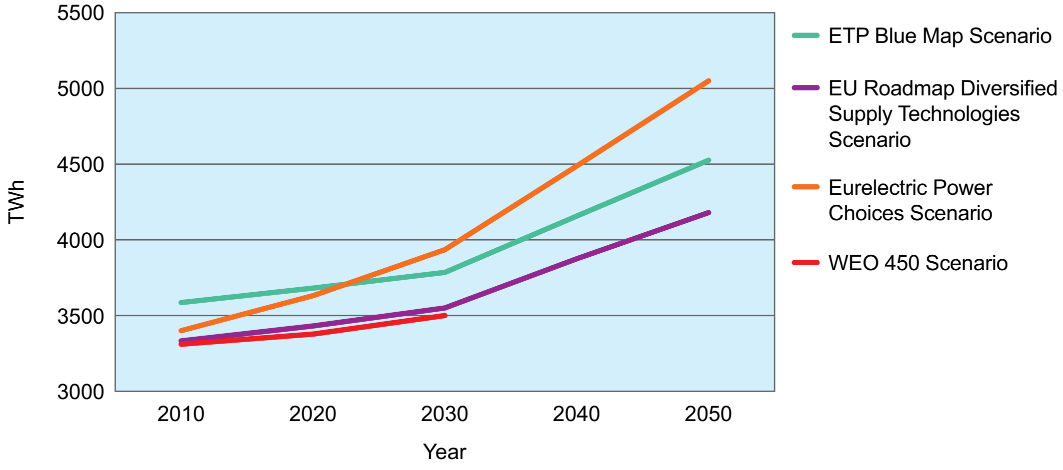

Figure 4: European Electricity Generation (TWh) – Carbon Reduction Scenarios

As with the global scenarios for electricity generation, there is a large degree of similarity between the European scenarios, at least until 2030. In the baseline scenarios, European electricity demand continues to grow at a relatively rapid pace (between 0.8-1.4%/year).

The European carbon reduction scenarios are characterised by a relatively slow rate of electricity demand increase to 2030 of 0.3-0.8%/year, reflecting the presumed efficacy of energy efficiency measures taken within the EU, followed by a period of higher growth for 2030-2050 of 0.9-1.2%/year. This acceleration of demand growth would appear to reflect a more pronounced electrification of transport in the post-2030 period, for example, in the IEA's *Blue Map* scenarios, half of the growth in electricity demand to 2050 is due to transport electrification[4].

[4] 'Power Choices' assumes that electrification is the lowest cost way of decarbonising transport and that 80-90% of European transport will be electric by 2050 (p53). Transport demand for electricity would rise from a share of <2% in 2005 to 31% in 2050.
The ETP 'Blue Map' scenario projects that half of global transport will be zero carbon by 2050 (p255). In OECD Europe, electricity use in transport rises from 76 TWh in 2007 to 360 TWh in 2050. The share of transport in electricity demand rises from 2.5% in 2007 to 9.9% in 2050 (p313).
'Roadmap' states that it takes a conservative view regarding electric mobility and does not assume strong policies in its favour (p76).

5 Nuclear Generation

5.1 GLOBAL NUCLEAR GENERATION SCENARIOS

Baseline Scenarios

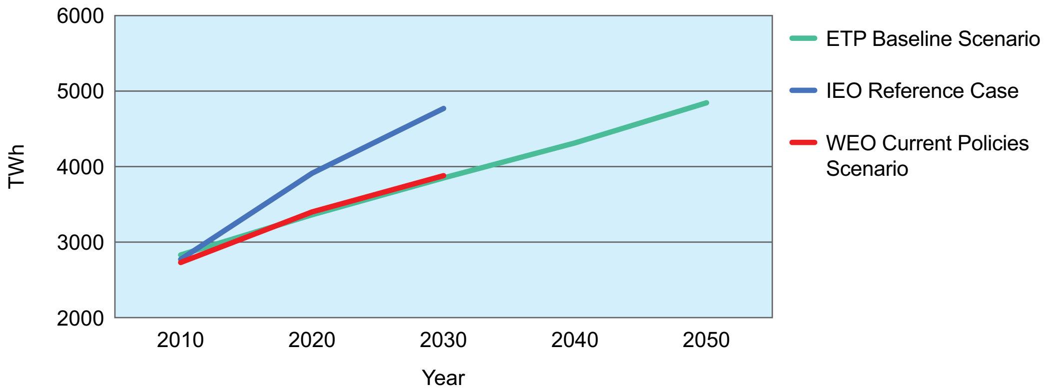

Figure 5: Global Nuclear Generation (TWh) – Baseline Scenarios

As might be expected, the degree of difference between the scenarios increases when nuclear generation is examined separately. In the global level baseline scenarios, nuclear generation grows at between 1.3-2.7%/year, which is nevertheless insufficiently rapid to maintain market share in the ETP *Baseline Scenario* where nuclear drops from 14% to 10% of global generation between 2009 and 2050[5].

Carbon Reduction Scenarios

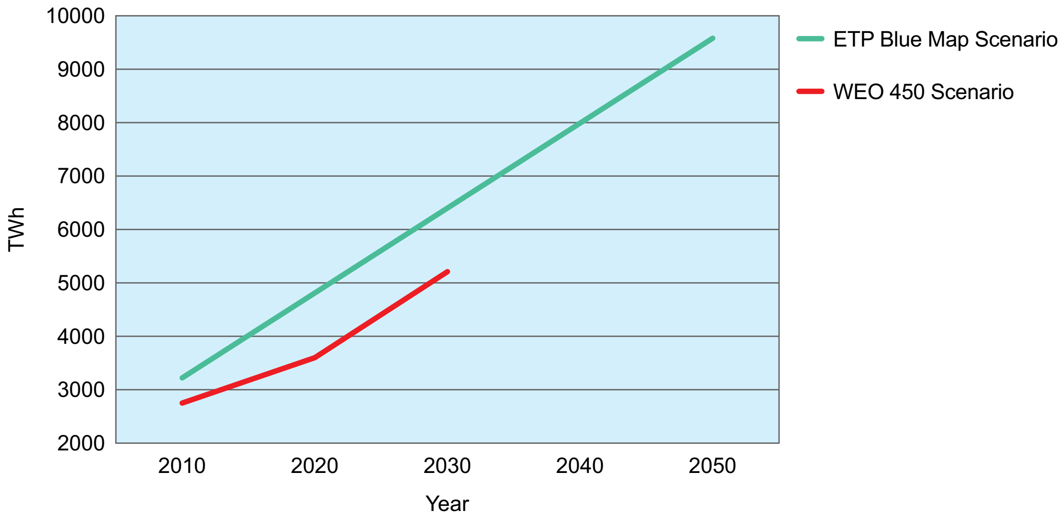

Figure 6: Global Nuclear Generation (TWh) – Carbon Reduction Scenarios

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[5] The EIA and IEO global nuclear generation scenarios may be compared with the WNA's 2011 Reference Scenario for the same years (TWh):

2010	2020	2030
2721	3510	4619

The WNA nuclear generation scenarios are compiled by expert industry opinion rather than integrated energy system modelling.

In the carbon reduction scenarios, nuclear generation increases at a much greater pace (3.1-3.5%/year). The implementation of carbon control measures clearly makes a significant positive difference to nuclear prospects as the nuclear share of generation increases steadily, for example in the ETP Blue Map Scenario from 14% to 24% in the period 2007 to 2050.

5.2 EUROPEAN NUCLEAR GENERATION SCENARIOS

Baseline Scenarios

In contrast to the global picture, the situation for Europe shows a large degree of variation between the scenarios. The Eurelectric, EU Roadmap and EIA baseline scenarios project a continuing growth of nuclear generation, whilst the IEA projects a decline. The range of scenario projections is very wide which calls for an explanation of the differences. Possible reasons will be examined in Section 6, but it might be suggested that the IEA scenarios reflect ad hoc assumptions in view of the relatively optimistic expectations for nuclear capital costs that underlie the ETP scenarios, whilst the Roadmap *Reference Scenario* nuclear generation growth is puzzling in view of the very high nuclear capital costs assumed by the Roadmap scenario-builders (see below p14).

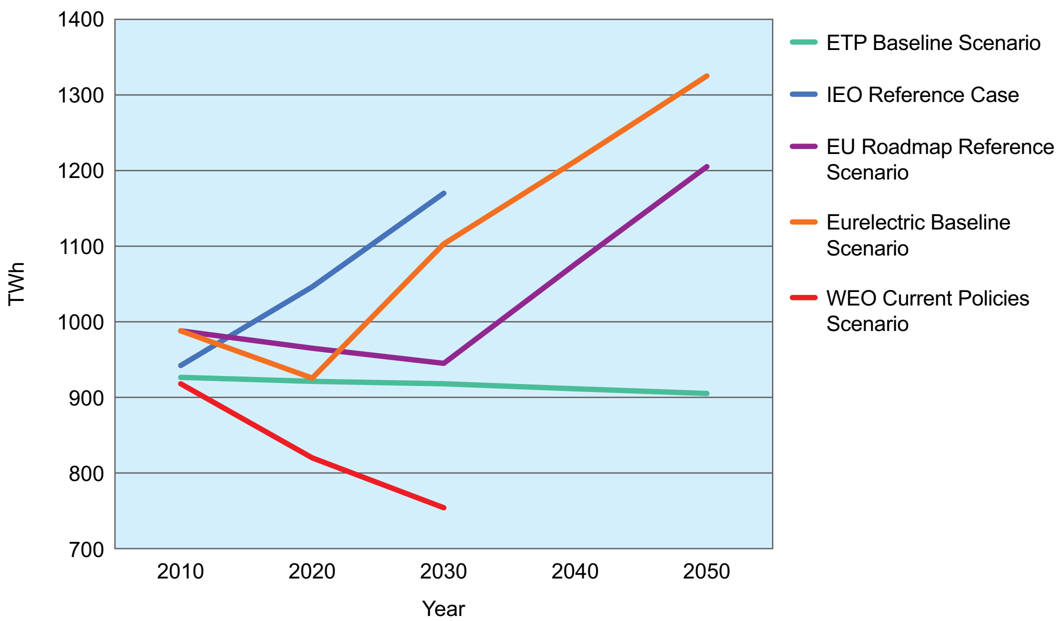

Figure 7: European Nuclear Generation (TWh) – Baseline Scenarios

Carbon Reduction Scenarios

In the carbon reduction scenarios, the IEA reverses its baseline picture of nuclear decline and projects a relatively rapid rate of growth in nuclear generation. The Eurelectric *Power Choices Scenario* projects an initial decline in nuclear before a rapid rate of growth is observed in the period 2020-2050. The outlier in this collection of scenarios is the EU's Roadmap *Diversified Supply Technologies Scenario* where low carbon technologies are incentivised in a technology-neutral fashion. However, instead of seeing a more rapid rate of growth of nuclear than in the Roadmap *Reference Scenario*, as might be expected, nuclear generation is projected to enter a steep decline. Such a result may be seen as an instance of an apparent inconsistency between scenarios appearing in the same study. The next section attempts to find explanations for the different scenario results in the assumptions made by the authors of the studies.

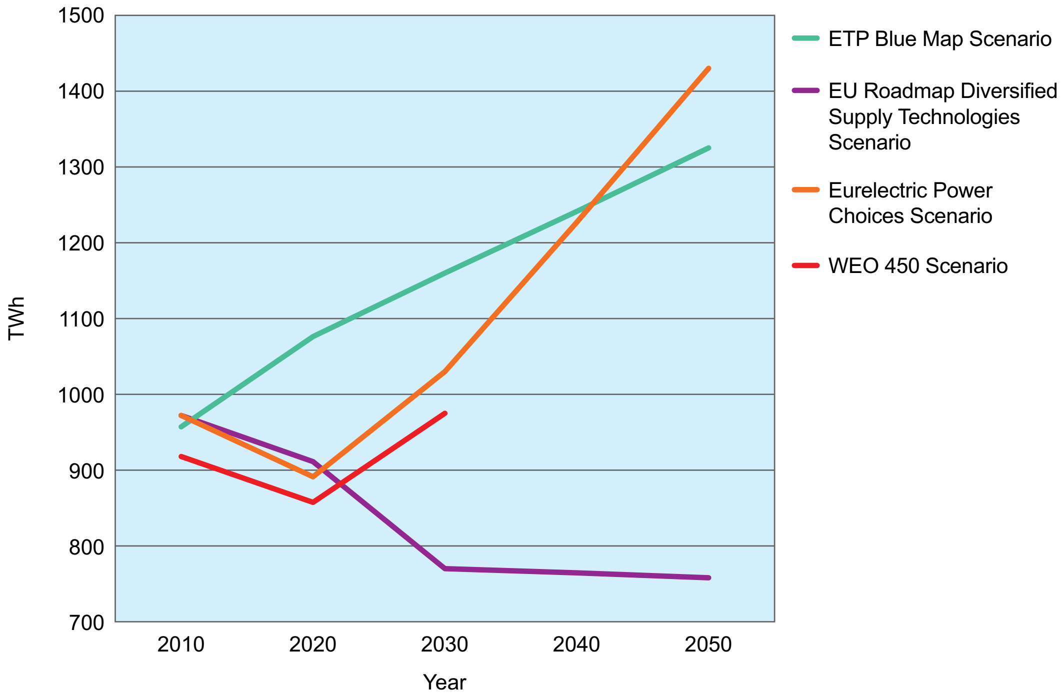

Figure 8: European Nuclear Generation (TWh) – Carbon Reduction Scenarios

6 Scenario Assumptions

A number of assumptions lie behind the values for electricity and nuclear generation produced in the scenarios: firstly, assumptions exogenous to the energy system, for instance population change and economic growth are often produced by econometric models of which the energy system is just one part; secondly, assumptions made about the cost of different generation technologies and the way in which these costs are expected to change over time; thirdly, 'ad hoc' assumptions that are often introduced, typically placing constraints on the rate at which different technologies can be deployed or the level of deployment that they can attain. In general, the current and future expected cost of generation (net of subsidies and carbon costs) should be a principal driver for any utility seeking least-cost generation. As far as nuclear generation is concerned, ad hoc assumptions are probably just as significant in determining the level of nuclear generation in the scenarios.

6.1 CURRENT COSTS

The current unit cost of generating electricity from different technologies varies considerably, depending on a range of variables. Unit costs are normally 'levelised' over the life of the plant and are conventionally disaggregated into capital costs, fuel costs and operations & maintenance (O&M) costs. Capital costs will in turn reflect the cost of constructing a plant net of any interest charged ('overnight' costs), the owner's costs of planning and organising the construction of a generating plant at a particular site and the cost of financing these requirements. All of these costs vary greatly, depending inter alia upon the country in which the plant is being constructed, the degree to which equipment may be purchased at world prices, the regulatory procedures required to permit the operation and the terms upon which finance may be secured.

Fuel costs for coal and oil plants will generally reflect world prices for coal and oil. Gas prices depend on local sourcing to a greater extent and are more variable as a result. Fuel costs are not such a significant part of the total nuclear cost structure. O&M costs depend on the complexity of the technology, local labour markets and regulatory requirements. In some countries, carbon costs will be imposed on technologies that emit greenhouse gases into the atmosphere.

The 'levelising' of costs allows comparison between generating technologies over the expected plant lifetime. The current levelised cost of a generating technology is an important consideration that bears on the degree to which utilities choose one technology in preference to another and is readily incorporated into economic models of power generation.

6.2 FUTURE COSTS

The understanding of current levelised generating costs is not the only consideration that a utility will evaluate when choosing between generating technologies. There are often other considerations that are in effect risks that the current structure of generating costs will change, such as:

- security of supply (for example, as relates to future fuel costs as well as availability)
- the risk that the current relative structure of levelised costs between technologies will not be maintained over time
- the risk that the expected levelised cost structure will not be realised (for example, as relates to nuclear construction duration)
- risks that the expected future prices for electricity will not be realised and the relative sensitivity of different technologies to power price volatility.

Electrical generating investments tend to have very long operating lifetimes, in the case of nuclear often of 60 years, and owners will want to estimate the degree to which expected returns on investment are affected by unexpectedly long construction times and changes in the costs of different inputs and of electricity prices over that period. The impact of such changes varies between different generating technologies; in broad terms, the principal risk for fossil fuel plants is the future cost of fuel and carbon; for renewable plants the confidence that subsidy levels will be maintained; and for nuclear plants the cost and time taken to commission the plant. Changes in the relative cost structure affect not only the relative profitability of different generating technologies but can also affect the future gross revenue stream. If the cost of the marginal producer falls, then, in a competitive market, the price of electricity would also be expected to fall. Thus expectations of the net revenue that might be earned by the deployment of different generating technologies and risks to those expectations should be significant factors incorporated into the development of different scenarios.

Although current and future costs are largely exogenous to the models used for scenario building, being determined by specific commodity, equipment and labour markets with important contributions from technological progress or public R&D programmes, there is often also an important endogenous consideration which relates to the relative potential economies of scale and scope available to different technologies. It is important that these endogenous factors are incorporated into energy models. Thus the costs of some technologies might be expected to fall to a greater or lesser extent depending on the extent to which these technologies are utilised.

Nuclear capital costs are thought to be sensitive to economies of both scale and in particular scope[6]. For example, first-of-a-kind (FOAK) plants are believed to be in the order of 20% more costly than nth-of-a-kind (NOAK) plants, as supplier fixed costs, including reactor design and permitting costs, decline per unit as numbers sold increase. The same is also claimed for some renewables technologies, for example, solar PV, where high development costs are amortised far more readily with mass deployment. Some studies are explicit about the assumptions made regarding current and future costs of different technologies, but others are not. The degree to which a study incorporates economies of scope may be expected to influence the resulting scenario projections, however, it is not clear that any of the studies have incorporated the impact of economies of scope on future nuclear overnight costs, as they use the same costs in all scenarios.

[6] Economies of scope refers to the lowering of average costs for a firm producing a long production run, eg, by recurrent use of proprietary knowledge.

The cost of generating electricity, where all externalised costs are included, gives a first approximation to the relative social desirability of different generating technologies. We therefore take the levelised cost of generating electricity (LCOE) and its expected change over time as the most important assumptions that need to be made by scenario-builders. Unfortunately, not all scenario studies reveal the cost information used in their scenarios and, where they do, it is not always complete. Information on capital costs is often included and, less frequently, expected future capital costs. The available capital cost information used in the different studies is tabulated below (see also figures 9-13):

Electricity Generation Capital Costs ($/kW)[7]

Organisation	Coal		Gas		Wind		Solar PV		Nuclear	
	2010	**2050**	**2010**	**2050**	**2010**	**2050**	**2010**	**2050**	**2010**	**2050**
IEA *WEO* Overnight cost[8]	807-3485		635-1622		1912-3716		3267-7381		1556-5863	
IEA *ETP* Investment cost	2100[9]	1650	900[10]	750	1450-2200[11]	1200-1600	3500-5600	1000-1600	3000-3700[12]	2700-3300
EU *Roadmap* Capital cost	3145[13]	2255	1224	1020	1582	1536	5962	1953	6266	5174
EIA Annual *Energy Outlook* Overnight cost[14]	2844		978		2438		4755		5339	
Eurelectric *Power Choices* Investment cost[15]	1859	1859	1144	1144	1859	1716	5720	2860	4290	3718

Despite the strong evidence for nuclear economies of scale and scope and for the fact that Generation III reactor designs represent a significant evolution from previous designs, no great allowance is made in the studies that quote future costs for nuclear unit cost savings, even where significant nuclear deployment is a feature of the scenario. More radical capital cost savings are in almost all cases made by other generating technologies, including those that should be seen as mature (such as coal-fired and hydroelectric generation).

7 All Euro amounts given in the EU and Eurelectric studies have been converted at $1.43/EUR.
8 The IEA does not give generating cost data in the WEO. However, the IEA collaborates with the Nuclear Energy Agency to publish a review of nuclear (and other) generating costs in 'Projected Costs of Generating Electricity – 2010 Edition'. The wide range of costs reflects differences in the costs reported for different countries whose estimates appear in the study. We assume that these costs are used by the IEA in their scenarios.
9 Supercritical Pulverised Coal Combustion
10 Natural Gas Combined Cycle
11 Onshore (mean value)
12 Generation III+
13 Supercritical
14 The overnight cost used by the EIA in its Annual Energy Outlook 2011 is US specific and was made available to the WNA through private correspondence.
15 The investment cost figures used by Eurelectric were provided by VGB, a power generation technical association, and made available to WNA through private correspondence.

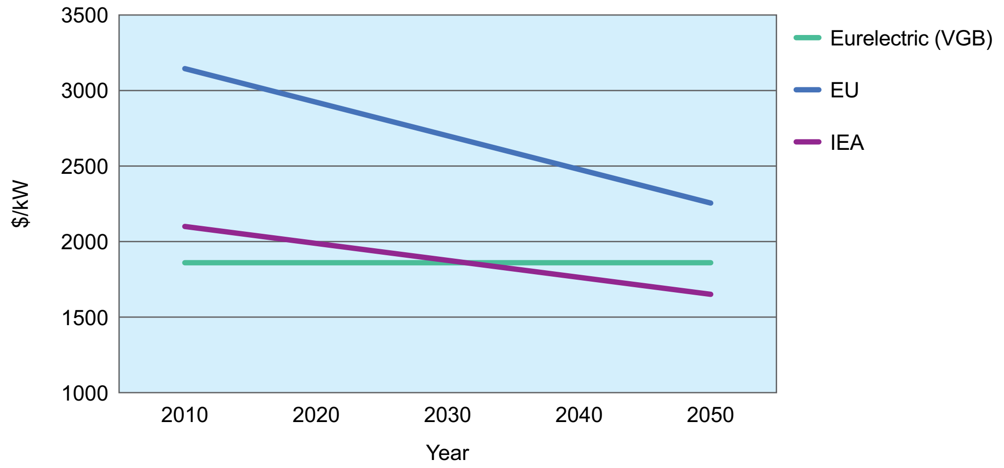

Figure 9: Capital Cost Projection – Coal ($/kW)

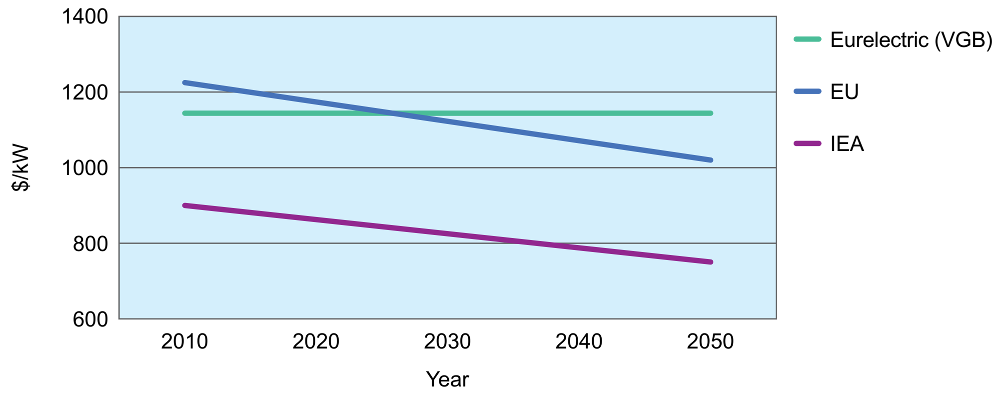

Figure 10: Capital Cost Projection – Gas ($/kW)

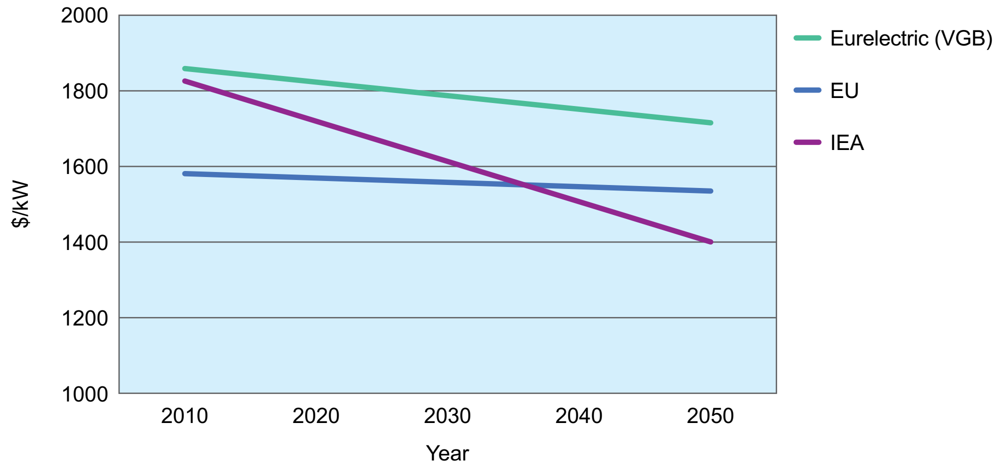

Figure 11: Capital Cost Projection – Onshore Wind ($/kW)

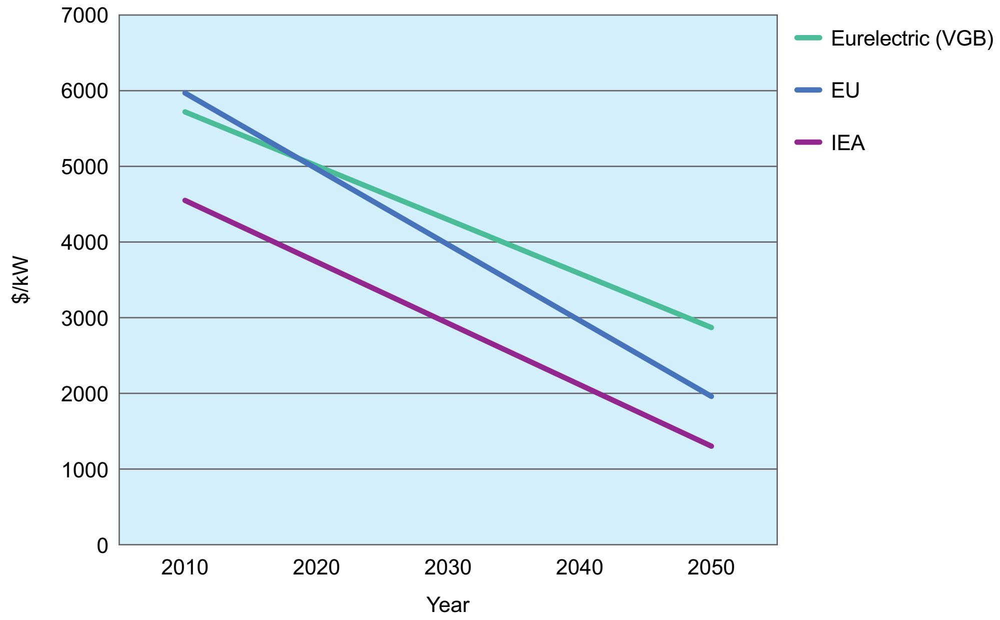

Figure 12: Capital Cost Projection – Solar PV ($/kW)

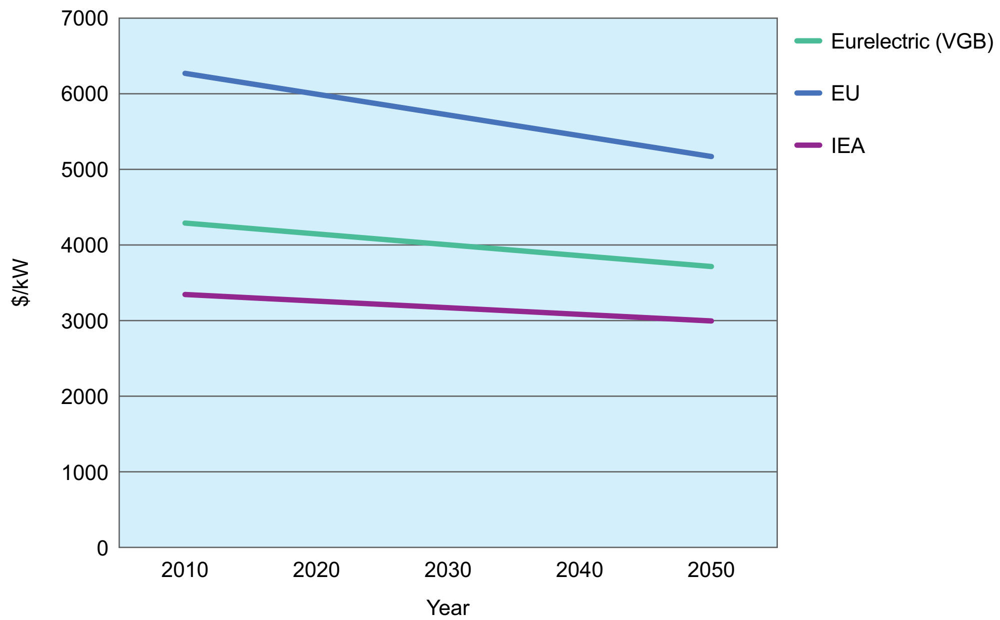

Figure 13: Capital Cost Projection – Nuclear ($/kW)

As previously noted, the cost of nuclear generation relative to the costs of alternative generating technologies will be a key consideration for utilities planning new generation facilities. The economics of fossil fuel generation are governed principally by the fuel and, where relevant, carbon cost. Fossil fuel cost assumptions are stated by the IEA, Eurelectric and the EU and included in the appendix. In most cases, the forecasters project rising fossil fuel prices. Nuclear fuel assumptions are not made explicit in any of the studies, presumably because they do not materially influence total costs.

6.3 AD HOC ASSUMPTIONS

A range of ad hoc variables have been introduced into the studies' scenario generation processes. Energy is of course fundamental to economic development and environmental integrity and as such is subject to greater political oversight and regulation than almost any other production sector. In the case of nuclear power, the model ad hoc assumptions appear to act uniformly to either restrict the rate of growth of nuclear or to cap the level of deployment. The principal stated ad hoc assumptions adopted in the different scenarios are given below:

IEA (Energy Technology Perspectives)

The IEA's ETP Blue Map scenario is stated as following a least cost approach to achieving the carbon reduction objective. However, the growth of nuclear capacity is assumed to be limited to a global maximum of 1200 GW in 2050. This appears to reflect a belief that the supply chain and, to a lesser extent, fuel supply could constrain the rate of expansion. The rate of annual increase in Blue Map of approximately 20 GW/yr in the period to 2030 is not unduly ambitious and was in fact matched during the growth of nuclear capacity during the 1980s[16].

In a high nuclear Blue Map variant scenario (*hiNUC*), the maximum global nuclear capacity for 2050 is raised to 2000 GW. It is of interest that the *hiNUC* scenario returns lower generating (and carbon) costs than in Blue Map, indeed total electricity prices are projected as only 6% higher than in the *Baseline Scenario*.

Other assumptions that are alluded to in the text, but whose influence on the projections is not made explicit include:

- Insufficient grid capacity in some cases to accommodate large scale nuclear power plants.
- Nuclear plant operating lifetimes of 40-60 years.
- Sufficient geological uranium resources, but higher incentive prices that would be required to discover new resources.

IEA (World Energy Outlook)

No specific global nuclear assumptions are given, only a discussion of general challenges to the deployment of nuclear technology. For Japan in particular, expected reactor lifetimes are set at 40 years for pre-1990 reactors and 50 years for more recent reactors. New Japanese reactors are limited to the two currently under construction.

[16] The Nuclear Energy Agency estimate the required new reactor construction as 16 GW/year up to 2020, 20 GW between 2020 & 2030, 35 GW between 2030 and 2040 and 42 GW between 2040 and 2050 assuming a uniform 60 year reactor life. (p44, *The Role of Nuclear Energy in a Low Carbon Future*, NEA/OECD Paris 2012)

Eurelectric (Power Choices)

- Nuclear power is ruled out for ten EU countries without historical nuclear experience and no plans for future development.
- Germany and Belgium phase out nuclear power.
- Nuclear power plant lifetime extensions are not permitted except in the case of Sweden.
- The availability of new nuclear sites is limited and development on these sites carries higher costs.
- Existing reactor designs only are considered.
- Nuclear costs are lower in countries with a mature nuclear industry.

EU (Energy Roadmap to 2050)

In the *Reference Scenario*, nuclear is modelled on its economic merit except for member states with legislative provisions to phase out nuclear. New nuclear power plants were included only for Bulgaria, Finland, France, Lithuania, Romania and Slovakia. The way in which these assumptions are flexed in the *Diversified Supply Technologies Scenario* is not stated.

Energy Information Administration (International Energy Outlook)

The EIA uses expert opinion to project nuclear capacity. It is assumed that nuclear power plants are built when favourable government policies are in place and the EIA's modelling disregards nuclear power plants cost assumptions.

7 Conclusions and Recommendations

This review compares a number of scenarios created by the IEA, EU, EIA and Eurelectric for electricity demand and the contribution of nuclear to meeting that demand. The scenarios in general exhibit considerable agreement on future electricity demand in both the baseline and carbon reduction cases at the global and European levels. The scenarios for nuclear generation in general present a view of continued growth, though the degree of divergence between the scenarios for nuclear generation is greater than those for electricity demand, especially in the case of the EU.

Divergence between nuclear demand projections in otherwise apparently similar scenarios are a cause for concern to those looking to inform prospective energy policy making. For instance, the reasons for the divergence between the IEA's nuclear generating baseline scenario projections globally and for Europe (cf. Figures 5 and 7) are not immediately apparent from information given in the *World Energy Outlook*. Only by referring to the cost information given in the IEA's *Projected Costs of Generating Electricity* is it clear that capital costs for nuclear power plants are significantly lower in non-OECD countries and this could be an important factor driving the divergence. It is possible that the divergence also reflects ad hoc assumptions governing the degree to which nuclear power can grow in Europe but which are unstated.

The existence of divergences that cannot be explained by close reading of the study or associated documents are of greater concern. For example, in the case of the EU's *Roadmap*, a counter-intuitive nuclear generation divergence exists between the baseline and the carbon reduction scenarios (cf. Figures 7 and 8). Nuclear generation grows in the baseline case despite the imposition of quite severe ad hoc restrictions. Strangely, in the carbon reduction case, nuclear generation falls sharply despite the more favourable relative cost position of nuclear vis-à-vis coal and gas (ie, the imposition of carbon constraints on fossil fuel generators which effectively increase their costs). The cost of nuclear in both *Roadmap* scenarios assumed by the European Commission's modellers was significantly higher than for estimates made by other expert organisations. In general, greater explanation of and justification for the choice of generating costs would be helpful to the reader.

Energy scenarios can and should inform policy making. If they are to perform this role in a credible manner, it behoves the authors to clarify to the greatest extent possible the basis upon which the scenarios have been formulated. Such clarification empowers stakeholders to participate more meaningfully in the policy-making process. Therefore, best practice in scenario construction would indicate a more complete description of the variables driving the projection of nuclear generation and the justification for the particular values assumed, for example, future nuclear investment costs especially where such assumptions are not in line with commonly accepted values. Counter-intuitive results should be explained and ad hoc assumptions fully outlined.

8 References

International Energy Agency, World Energy Outlook 2012 (Paris, Nov 2012)

International Energy Agency, Energy Technology Perspectives 2010 (Paris, July 2010)

Energy Information Agency, Annual Energy Outlook 2011 (Washington, 2011)

Energy Information Agency, International Energy Outlook 2011 (Washington, 2011)

Eurelectric, Power Choices – Pathways to Carbon-Neutral Electricity in Europe by 2050 (Brussels, June 2010)

European Commission, Energy Roadmap to 2050 – Impact Assessment (Brussels, Dec 2011) SEC (2011) 1565/2

World Nuclear Association, The Global Nuclear Fuel Market – Supply and Demand 2011-2030 (London, Sept 2011)

Appendix[17]

Electricity Generation – Baseline Scenarios

Organisation / Study	Regional scope	Base Year TWh	2020 TWh	2030 TWh	2050 TWh
International Energy Agency (WEO Current Policies)	Global	21408 (2010)	29194	36492	
International Energy Agency (ETP Baseline) p112	Global	19756 (2007)			46186
Energy Information Agency (Reference Case Central Producers only)	Global	20345 (net) (2009) 21362 (gross)	25462 (net) 26735 (gross)	31943 (net) 33540 (gross)	
International Energy Agency (WEO Current Policies)	EU	3310 (2010)	3588	3944	
International Energy Agency (ETP Baseline) p308	OECD Europe	3387 (net) (2007) 3556 (gross)		4200	5168 (net) 5426 (gross)
Energy Information Agency (Reference Case Central Producers only)	OECD Europe	3418 (net) (2010) 3588 (gross)	4040 (net) 4242 (gross)	4550 (net) 4777 (gross)	
European Commission (EU Roadmap Reference Scenario) p38	EU	*3274 (2005)*	*3584*	*3865*	*4558*
Eurelectric (Baseline) p61	EU	3100 (net) (2005) 3255 (gross)	*3600 (net)* *3780 (gross)*	*4000 (net)* *4200 (gross)*	*4450 (net)* *4672 (gross)*

Electricity Generation – Carbon Reduction Scenarios

Organisation / Study	Regional scope	Base Year TWh	2020 TWh	2030 TWh	2050 TWh
International Energy Agency (WEO 450)	Global	21408 (2010)	26497	29841	
International Energy Agency (ETP Blue Map) p112	Global	19756 (2007)			40137
International Energy Agency (WEO 450)	EU	3310 (2010)	3373	3500	
International Energy Agency (ETP Blue Map) p308	OECD Europe	3387 (net) (2007) 3556 (gross)		3612 (net) 3792 (gross)	4306 (net) 4521 (gross)
European Commission (EU Diversified Supply Technologies Scenario)	EU	*3274 (2005)*		*3540*	*4182*
Eurelectric (Power Choices)	EU	3100 (net) (2005) 3255 (gross)	*3473 (net)* *3646 (gross)*	*3750 (net)* *3937 (gross)*	*4800 (net)* *5040 (gross)*

[17] Figures in italics have been estimated from tables and graphical material in the relevant reports.

Nuclear Generation – Baseline Scenarios

Organisation / Study	Regional scope	Base Year TWh	2020 TWh	2030 TWh	2050 TWh
International Energy Agency (WEO Current Policies)	Global	2756 (2010)	3397	3885	
International Energy Agency (ETP Baseline)	Global	2719 (2007)			4825
Energy Information Agency (Reference Case Central Producers only)	Global	2648 (2010) 2780 (gross)	3731 (net) 3917 (gross)	4546 (net) 4773 (gross)	
International Energy Agency (WEO Current Policies)	EU	917 (2010)	819	752	
International Energy Agency (ETP Baseline) p308, 311, 314	OECD Europe	926 (gross) (2007)			863 (net) 906 (gross)
Energy Information Agency (Reference Case Central Producers only)	OECD Europe	898 (net) (2010) 942 (gross)	998 (net) 1047 (gross)	1111 (net) 1166 (gross)	
European Commission (EU Roadmap Reference Scenario)	EU	999 (2005)		*943*	*1201*
Eurelectric (Baseline)	EU	967 (net) (2005) 1015 (gross)	882 (net) 926 (gross)	1048 (net) 1100 (gross)	1259 (net) 1322 (gross)

Nuclear Generation – Carbon Reduction Scenarios

Organisation / Study	Regional scope	Base Year TWh	2020 TWh	2030 TWh	2050 TWh
International Energy Agency (WEO 450)	Global	2756 (2010)	3601	5218	
International Energy Agency (ETP Blue Map)	Global	2719 (2007)			9608
International Energy Agency (WEO 450)	EU	917 (2010)	861	972	
International Energy Agency (ETP Blue Map) pp 308, 311, 314	OECD Europe	926 (gross) (2007)			1262 (net) 1325 (gross)
European Commission (EU Diversified Supply Technologies Scenario) p38	EU	*999 (2005)*		*770*	*758*
Eurelectric (Power Choices) p61	EU	*967 (net) (2005)* *1015 (gross)*	*849 (net)* *891 (gross)*	*979 (net)* *1027 (gross)*	*1363 (net)* *1431 (gross)*

Gas and Coal Prices Used in the IEA, Eurelectric, EIA and EU Studies

				Baseline Scenario		**Blue Map Scenario**	
			2008	**2030**	**2050**	**2030**	**2050**
ETP	Natural gas $/mBTU	US	8.3	11.4	11.9	10.2	7.9
		Europe	10.3	14.0	14.7	11.0	8.6
		Japan	12.6	15.9	16.7	12.5	9.7
	Steam coal $/t	OECD	121	109	115	65	58
				Current Policies Scenario		**450 Scenario**	
			2010	**2030**		**2030**	
WEO	Natural gas $/mBTU	US	4.4	7.2		7.6	
		Europe	7.5	13.4		10.0	
		Japan	11.0	15.6		12.5	
	Steam coal $/t	OECD	99	122.5		78.0	
				Baseline Scenario			
			2009	**2030**		**2050**	
Eurelectric	Natural gas $/mBTU	EU	6.3	12.5		16.1	
	Steam coal $/t	EU	84	142		146	
				Reference Scenario			
			2010	**2030**		**2050**	
EU	Natural gas $/boe	EU	53	77		98	
	Steam coal $/boe	EU	23	33		34	
				Reference Case			
			2010	**2030**			
EIA	Natural gas $/mBTU	OECD Europe	5	10			
		World	<8	<13			
	Steam coal $/mBTU	OECD Europe	5.5	7.4			

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