Key Factors Affecting the Deployment of Electricity Generation Technologies in Energy Technology Scenarios

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List of abbreviations

Abbr.	**Organization**
EC	European Commission
EREC	European Renewable Energy Council
GP	Greenpeace
IEA	International Energy Agency
OECD	Organisation for Economic Co-Operation and Development
WEC	World Energy Council

Abbr.	**Report**
ETP	IEA Energy Technology Perspectives 2008
GR	Greenpeace/EREC Energy Revolution 2008
WEC	WEC Energy Policy Scenarios 2007
WEO	IEA World Energy Outlook 2007
WETO	EC World Energy Technology Outlook 2006

Abbr.	**Scenario**
ETPACT	ETP ACT Map Scenario
ETPBASE	ETP Baseline Scenario
ETPBLUE	ETP BLUE Map Scenario
GRREF	GR Reference Scenario
GRREVO	GR Energy Revolution Scenario
WEC1LEO	WEC Scenario 1, Leopard
WEC2ELE	WEC Scenario 2, Elephant
WEC3LIO	WEC Scenario 3, Lion
WEC4GIR	WEC Scenario 4, Giraffe
WEOAPS	WEO Alternative Policy Scenario
WEOREF	WEO Reference Scenario
WETOCC	WETO Carbon Constraint Case
WETOREF	WETO Reference Projection

Abbr.	**Source**
BIO	Biomass
COA	Coal
GAS	Gas
HYD	Hydro
NUC	Nuclear
OIL	Oil
REN	Other renewables
TOT	Total

Abbr.	**Technology**
+	CCS
FC	Coal
FC+	Coal CCS total
FCE	Coal Existing
FCE+	Coal CCS Retrofit post-combustion
FCHP	Combined heat and power
FCIC	Coal Integrated Gasif. Comb. Cycle
FCIC+	Coal Integrated Gasif. Comb. Cycle with CCS

FCN	Coal New plants
FCN+	Coal New with CCS
FCP	Coal supercritical pulverized
FCP+	Coal supercritical pulverized with CCS
FCT	Coal Conventional Thermal
FG	Gas
FG+	Gas CCS
FGC	Gas turbine combined cycle
FGC+	Gas turbine combined cycle with CCS
FGD	Gas distributed generation
FGE	Gas Existing
FGG	Gas turbine (gas cycle)
FGT	Gas Conventional Thermal (steam cycle)
FL	Lignite
FLT	Lignite Conventional Thermal
FO	Oil/Diesel
FOD	Oil distributed generation
FOGC	Oil used in gas turbine combined cycle
FOT	Oil Conventional Thermal
N	Nuclear
NLW	Nuclear LWR
NND	Nuclear new design
OTH	Others
RB	Biomass & waste
RB+	Bio CCS total
RCHP	Combined heat and power
RGEO	Geothermal
RH	Hydro
RH2	Fuel Cell
ROC	Ocean energy
ROTH	Other renewables
RSP	Solar PV
RST	Solar Thermal
RW	Wind
RWF	Wind Offshore
RWN	Wind Onshore

Abstract

This report presents the findings of a survey of key factors affecting the deployment of electricity generation technologies in selected energy scenarios. The assumptions and results of scenarios, and the different models used in their construction, are compared. Particular attention is given to technology assumptions, such as investment cost or capacity factors, and their impact on technology deployment.

We conclude that the deployment of available technologies, i.e. their market shares, can only be explained from a holistic perspective, and that there are strong interactions between driving forces and competing technology options within a certain scenario. Already the design of a scenario analysis has important impacts on the deployment of technologies: the choice of the set of *available technologies,* the *modeling approach* and the definition of the *storylines* determine the outcome. Furthermore, the quantification of these storylines into i*nput parameters* and c*ost assumptions* drives technology deployment, even though differences across the scenarios in cost assumptions are not observed to account for many of the observed differences in electricity technology deployment. The deployment can only be understood after a consideration of the i*nterplay of technology options* and the s*cale of technology deployment*, which is determined by economic growth, end-use efficiency, and electrification. Some input parameters are of particular importance for certain technologies: CO_2 prices, fuel prices and the availability of carbon capture and storage appear to be crucial for the deployment of *fossil-fueled power plants*; maximum construction rates and safety concerns determine the market share of *nuclear power*; the availability of suitable sites represents the most important factor for electricity generation from *hydro and wind power* plants; and technology breakthroughs are needed for *solar photovoltaics* to become cost-competitive.

Finally, this analysis concludes with a review on how energy systems in the selected scenario studies deal with risks related to energy security and greenhouse gas emissions, and recommendations for improving the usefulness of scenario development for decision-makers.

Executive Summary

Aim of the study

This report presents a review of energy scenario studies, focusing on the uptake and diffusion of technologies and the extent to which governance issues related to climate change and energy security are accounted for in the representation of technology deployment in this scenario literature. Accordingly, this report pays particular attention to the level of technology deployment and the factors driving this deployment across the scenario studies. This represents one of the first studies to analyse and review scenarios in terms of detailed technology representation and assumptions regarding deployment.

The study focuses on the electricity generation sector, which poses potentially one of the greatest challenges to the management of climate change since it is the largest source of CO_2 emissions globally. Guided by the different sets of electricity generation technologies that make significant contributions to future electricity production in the scenarios studied, this review focuses on the following technologies:

Table ES.1 Range of electricity generation technologies assessed

Coal fired	Gas-fired	Carbon capture and storage	Nuclear	Hydropower	Wind power	Solar
▪ thermal ▪ IGCC ▪ SC pulverized	▪ Steam cycle ▪ Gas cycle ▪ Combined cycle	▪ Coal retrofit ▪ Coal IGCC ▪ Coal pulverized ▪ Gas CC	▪ Light-water reactors ▪ Generation IV designs	▪ Large scale ▪ Small scale	▪ Onshore ▪ Offshore	▪ Photovoltaics ▪ Thermal plants

It is important to note that this by no means covers all possible technologies that could play a role in the global electricity system in the future. Other technology options such as oil- and biomass-based generation, geothermal, wave and tidal generation are included in some of the scenarios, but do not play a significant role in electricity production, while others such as nuclear fusion and ocean thermal generation are generally not included (in addition to other unanticipated technological breakthroughs).

Energy scenario studies under review

To address the particular research objective of assessing technology deployment, it was necessary in this report to focus on those scenarios with a detailed representation of technology, accounting for engineering and economic factors explicitly and quantitatively (or semi-quantitatively). In general, this means we focus on scenarios that have been developed or interpreted with technology-rich energy models.[1] The other criteria adopted include that the scenarios feature a global coverage and a time horizon until 2030 or beyond, and have been developed in the last few years. Additionally, in order to assess different viewpoints, publications prepared for governmental, industrial, scientific, and environmental interests have been considered. Based on these criteria, five studies were selected, as briefly described in Table ES.2 below. The first column of Table ES.2 shows the author and name of the study; the second column indicates the model used to provide the technology representation and some other elements of the scenario; and the third column indicates the key focus or uncertainty of the study. Across these studies we have analysed 13 scenarios, listed in the fourth column of the table (noting that scenarios in parentheses have not been analysed), with the fifth column indicating specific features of the scenarios.

We also considered the scenarios in the US Department of Energy's International Energy Outlook, the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios, the scenarios referred to in the IPCC Fourth Assessment Report, scenarios from the US Electric Power Research Institute, the Shell scenarios, and scenarios in the European Commission ADAM and NEEDS projects. However, all were excluded from this review because they did not satisfy the criteria outlined above or were yet to be published.[2]

For the selected scenarios, a comprehensive review and data collection was performed. This comprised review of published reports, and related working papers, journal articles and so on, followed by contact with the report authors to request additional data on technology deployment

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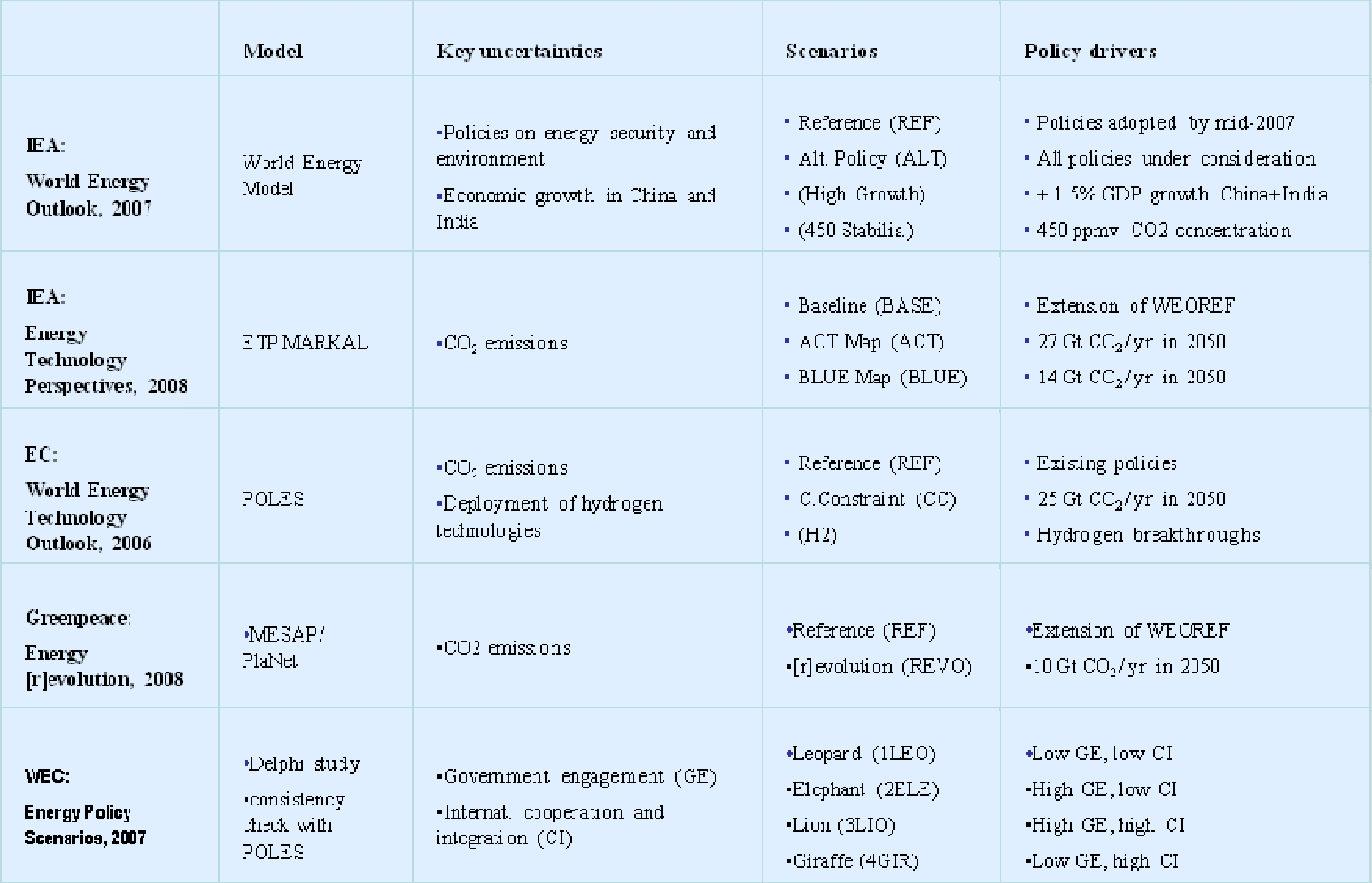
[1] It is useful to note the distinction between scenarios and models in this context. To quote and paraphrase IPCC (2000): ***Scenarios** are images of the future, or alternative futures. Scenarios are often formulated with the help of formal **models**, and specify some elements of the future in quantitative terms. Scenarios can also be less quantitative and more descriptive, and in a few cases they do not involve any formal analysis and are expressed in qualitative terms.*

Given our interest in the specific factors driving technology deployment, we focus on those scenarios formulated with formal models specifying technology characteristics and deployment in quantitative terms. Importantly, these scenarios include both qualitative and quantitative elements.

[2] This is discussed in more detail in Chapter 2 in the main report.

and assumptions regarding technology characteristics (which were generally not available in the published reports). We then analysed systematically the available information on key factors, often following up with further discussion with the authors of the studies to fill in gaps, or to gain a better understanding regarding the scenario development process. Draft copies of the report were also provided to authors of the scenario studies for comment. Despite the cooperation of these authors, it was nonetheless not possible to obtain the complete sets of inputs and assumptions likely to affect technology deployment, given the proprietary nature of some models and datasets, the large number of factors potentially affecting deployment, and the limited time available in the study.

Table ES.2 Scenario studies selected for detailed analysis



	Model	Key uncertainties	Scenarios	Policy drivers
IEA: **World Energy Outlook, 2007**	World Energy Model	•Policies on energy security and environment •Economic growth in China and India	• Reference (REF) • Alt. Policy (ALT) • (High Growth) • (450 Stabilis.)	• Policies adopted by mid-2007 • All policies under consideration • +1.5% GDP growth China+India • 450 ppmv CO2 concentration
IEA: **Energy Technology Perspectives, 2008**	ETP MARKAL	•CO_2 emissions	• Baseline (BASE) • ACT Map (ACT) • BLUE Map (BLUE)	• Extension of WEOREF • 27 Gt CO_2/yr in 2050 • 14 Gt CO_2/yr in 2050
EC: **World Energy Technology Outlook, 2006**	POLES	•CO_2 emissions •Deployment of hydrogen technologies	• Reference (REF) • C.Constraint (CC) • (H2)	• Existing policies • 25 Gt CO_2/yr in 2050 • Hydrogen breakthroughs
Greenpeace: **Energy [r]evolution, 2008**	•MESAP/ PlaNet	•CO2 emissions	•Reference (REF) •[r]evolution (REVO)	•Extension of WEOREF •10 Gt CO_2/yr in 2050
WEC: **Energy Policy Scenarios, 2007**	•Delphi study •consistency check with POLES	•Government engagement (GE) •Internat. cooperation and integration (CI)	•Leopard (1LEO) •Elephant (2ELE) •Lion (3LIO) •Giraffe (4GIR)	•Low GE, low CI •High GE, low CI •High GE, high CI •Low GE, high CI

The reviewed studies are targeted at different audiences and have different objectives. According to the published material available, the IEA's World Energy Outlook (WEO) and Energy Technology Perspectives (ETP) aim at supporting governmental decision making on a global level, while the European Commission's World Energy Technology Outlook (WETO) particularly discusses the role of Europe in the future energy system (although it considers the global energy system). ETP and WETO explore CO_2 emission targets in so-called emission scenarios, whereas the WEO scenarios are based on a database of existing and prospective policies. The Greenpeace study

(GR), on the other hand, is produced jointly with the European Renewable Energy Council, and propagates a radical change towards a low-emission energy system with a phasing out of nuclear and fossil-fueled technologies. The scenario study of the World Energy Council (WEC), as a representative of the energy industry, considers future worlds according to the levels of government engagement and international cooperation and integration.

Some distinctions in the approaches used to develop the scenarios of technology deployment in the different studies are important to bear in mind. As mentioned above, although technology-rich energy models are generally used for all of these studies, there are some important differences: the ETP scenarios were developed with a MARKAL model—an optimization model that seeks to determine the least cost combination of technologies and fuels over the entire modeling time horizon. In contrast, technology deployment in the GR scenarios was developed using an analytical tool called MESAP PlaNet, in which the user can more directly select technology outcomes based on expert judgment. A further approach was adopted for the technology scenarios in WEC, WETO and WEO, which were developed and analysed with the POLES and World Energy Models. These are simulation-type models with optimization of the energy technology mix in each time period, whereas in addition, in the WEO and WEC studies the models are coupled to expert judgment.

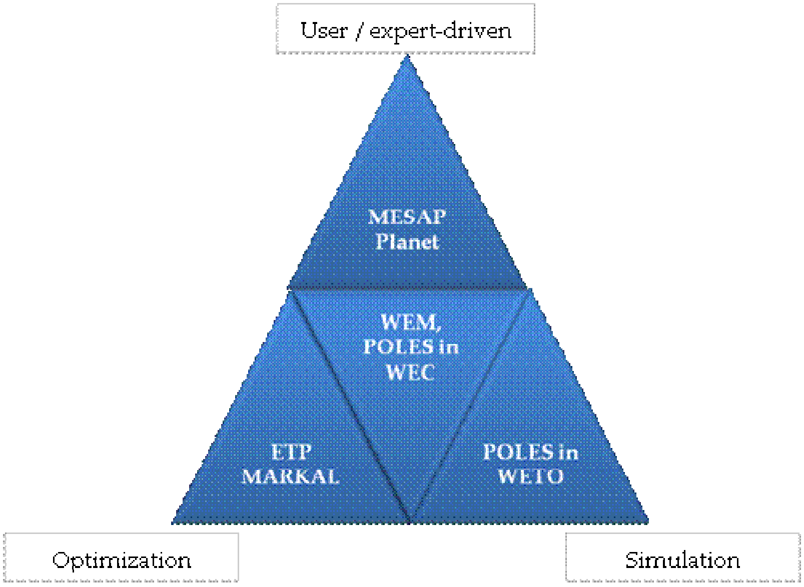


Figure ES.1 Approaches to detailed energy technology representation in scenario studies

Assessment of scenario input and output data

To address the objective of assessing technology deployment in the scenario literature (including how it is represented, which factors are important for the deployment of technologies, and what insights this provides regarding the extent to which this literature provides an appropriate representation of technology in the face of risks associated with climate change and energy security), this report compares in detail published documentation and additional data from the underlying scenario development and modeling work, focusing on the following anticipated drivers of technology deployment and scenario indicators:

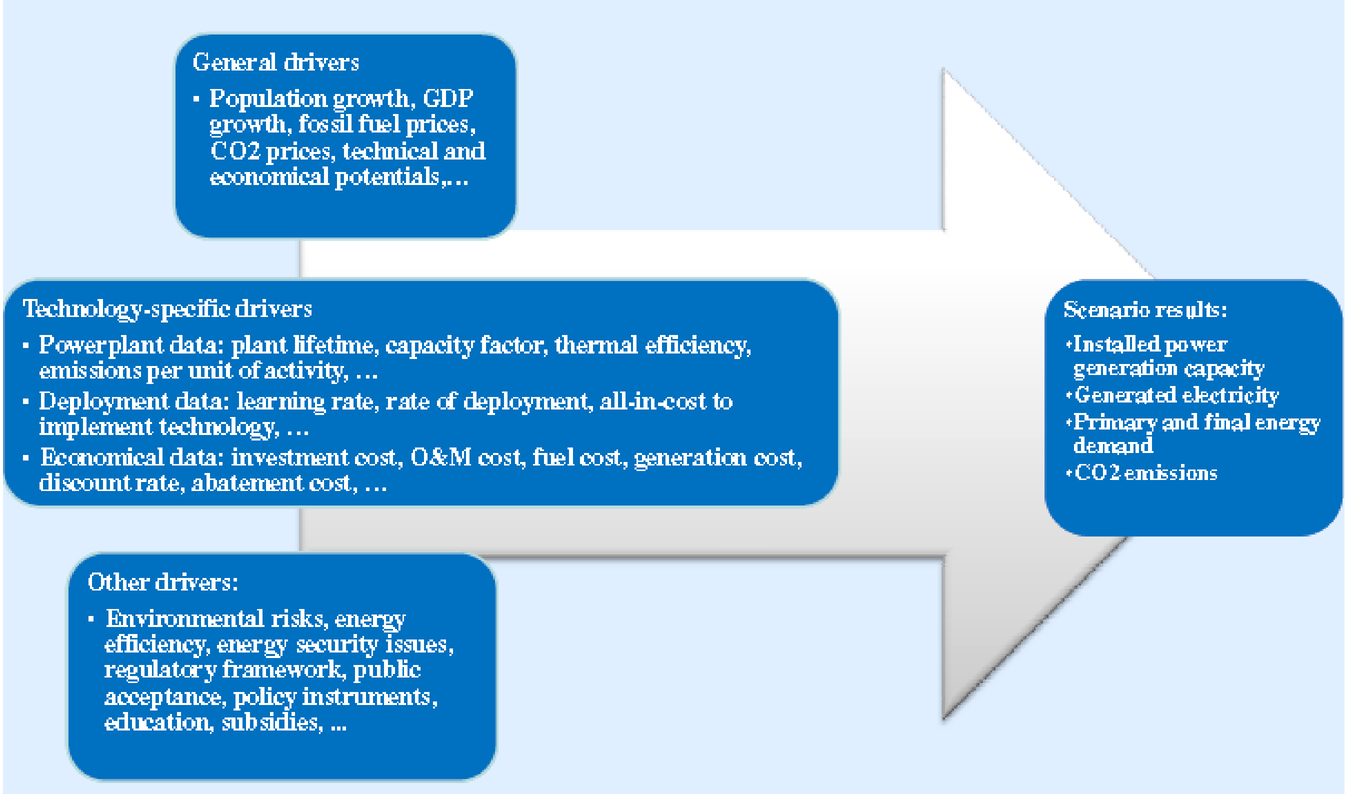


Figure ES.2 Anticipated factors affecting the deployment of electricity generation technologies in energy scenarios

Each of these drivers is potentially important for the deployment of electricity generation technologies—for example, population and GDP growth have a strong impact on the overall demand for energy services (and hence the volume of electricity technology deployment, all other things being equal); whereas energy efficiency potentially has the opposite effect (net of any rebound), reducing the volume of required electricity generation deployment. Technology cost and energy prices (and any cost of pollution) are likely to affect both demand for energy and the competitiveness of different technologies for electricity generation. These are just a few examples, and we have examined how these factors are represented in the selected scenario literature,[3] and ultimately which factors are driving technology deployment.[4]

Among the above examples, it is interesting to focus here on a few to show some of the variation across the scenarios, and the extent to which these studies are addressing future uncertainties. For instance, some important differences in fossil fuel and CO_2 prices can be observed across the scenarios, which have, directly or indirectly, an impact on the deployment of electricity generation technologies and can be seen as general scenario drivers. As shown in Table ES.3 for the year 2030, comparatively high prices for fossil fuels are assumed in the GR study (and to some extent in the WEC study). In the ETP and WETO emission scenarios, high CO_2 prices are implemented (either directly or via an emissions cap) to achieve emission targets and to support the deployment of zero- or low-emission technologies.

Table ES.3 Fossil fuel and carbon prices in 2030 across the selected scenarios

	ETPACT	ETPBASE	ETPBLUE	GRREF	GRREVO	WEC1LEO	WEC2ELE	WEC3LIO	WEC4GIR	WEOAPS	WEOREF	WETOCC	WETOREF
Crude oil ($05/bl)	60	60	60	120	120	76	68	65	74	60	60	59	64
Natural gas ($05/boe)	43	43	43	110	110	55	48	48	55	43	43	56	57
Steam coal ($05/boe)	13	13	13	53	53	19	18	19	20	13	13	?	16
CO_2 Annex-B ($05/tCO2)	50	-	200	30	30	13	26	30	32	-	-	131	25
CO_2 non-Annex-B ($05/tCO2	25	-	50	30	-	10	10	20	10	-	-	37	9

bl: barrel; boe: barrel of oil equivalent; Annex B refers to countries listed in Annex B of the Kyoto Protocol.

Technology-specific characteristics are also important for technology deployment, and a range of perspectives about uncertain future developments is reflected in the scenario literature. To illustrate, Figure ES.3 below compares assumptions regarding thermal efficiency of different electricity generation technologies across the scenario studies. One can see that the scenario literature presents a relatively convergent view for some technologies (such as for gas combined cycle generation), but indicates a much larger degree of uncertainty regarding future characteristics and performance of other technologies (such as nuclear and conventional coal thermal generation). Given that there is substantial uncertainty regarding future performance characteristics of different technologies, this is not surprising and indicates that these scenarios can only be used as a tool to explore the impact of some uncertainties about the future technology landscape.

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[3] See Chapter 4 of the main report.

[4] See Chapter 5 of the main report.

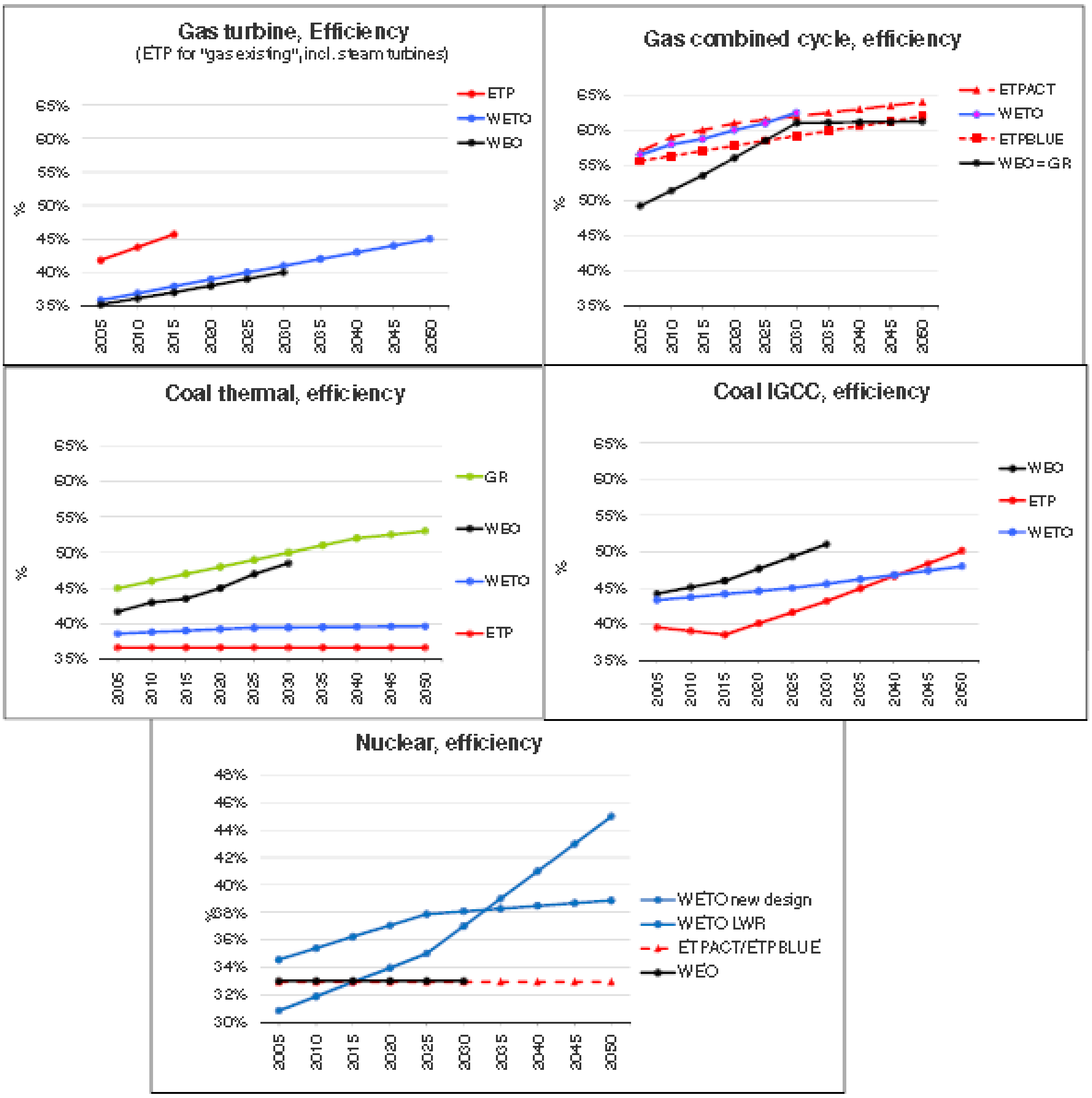

Figure ES.3 Comparison across scenarios of thermal efficiency assumptions for selected electricity generation technologies

It is also important to note that, in some cases, the studies diverge in their assumptions as early as 2005, and we can speculate that this is related to the choice of statistics used to calibrate the models, differences in calibration years, limited data availability for many countries, and potentially different technology definitions (for example, as indicated in Figure ES.3, the available data from the ETP study aggregates gas turbines and gas steam turbines together, whilst the GR scenario reports data for an aggregate coal technology).

For the analysis of technology-specific input data one further key factor expected to have an impact on technology deployment in many of the scenarios is the Levelized Cost of Electricity (LCOE) of different generation options. LCOE is the ratio of total lifetime production costs to total expected output, and indicates the cost-competitiveness of a particular technology. In this study, we focus on the most relevant components of LCOE for each technology, since only incomplete data were available for some of the relevant parameters. Fuel cost is currently the most relevant cost component for the LCOE of fossil-fueled technologies (especially generation plants using natural gas), while investment cost generally represents the most important component of LCOE for nuclear and renewable technologies.

An analysis of the technology and fuel cost assumptions in the scenario studies reveals some interesting differences. To illustrate, Table ES.4 summarizes the relative cost for key components of LCOE for selected technology options in 2030 across the groups of scenarios. In general, WEO and ETP have relatively lower estimates of cost (across all technologies shown here). Moreover, we can see differences in the relative ranking within scenarios—e.g., the WETO and WEC studies operate with high cost estimates for renewables compared to other studies, but for other technologies operate at average cost levels (implying a relatively less optimistic view on renewables relative to the other scenarios); whereas in ETP comparatively low cost assumptions are used for renewables, but average cost assumptions used for other technologies compared to other scenarios (implying a more optimistic view of renewables). Similarly, GR is characterized by uncommonly high cost assumptions for fossil-fired technologies, and average assumptions for a number of the renewables.

Table ES.4 Relative level of different cost components across the scenario studies (in 2030)

		ETP	GR	WEC	WEO	WETO
Gas	Lev. ann. fuel cost	low	high	medium	low	medium
Coal	Lev. ann. fuel cost	medium	high	medium	low	medium
Nuclear	Lev. ann. investment cost	medium		medium	low	medium
Wind onshore	Lev. ann. investment cost	medium	medium	high	low	high
Wind offshore	Lev. ann. investment cost	medium	high	medium	low	medium
Solar PV	Lev. ann. investment cost	low	medium	high	medium	high
Solar thermal	Lev. ann. investment cost	medium	medium	high	low	high
Hydro	Lev. ann. investment cost	low	high	medium	medium	high

Note: Lev. ann. = Levelized annual

Thus, the scenario studies provide alternative perspectives on the future economic characteristics of different technology options. Clearly, there is uncertainty regarding future cost and performance of different technologies (cost is illustrated here, but other factors are discussed further in the report), given uncertainties about the pace and direction of technological development and change, and future fuel availability and price. Scenario studies provide a means to explore such uncertainties, and the range of perspectives identified here shows, to a certain extent, that the scenario literature goes some way towards surveying possible future technology landscapes.

Of critical interest in this study is how the different representations of technology, and different assumptions regarding factors driving technology deployment across the scenarios affect the deployment of technology, the overall development of the electricity system, and the impact on key challenges of climate change and energy security. To answer this, we start with an aggregate overview of the scenarios in terms of some key indicators in Figure ES.4.[5] This figure presents six indicators: four of aggregate electricity technology deployment and one each of energy efficiency and CO_2 emissions. Each is presented as a relative indicator, as percentages of the highest value across the scenarios:

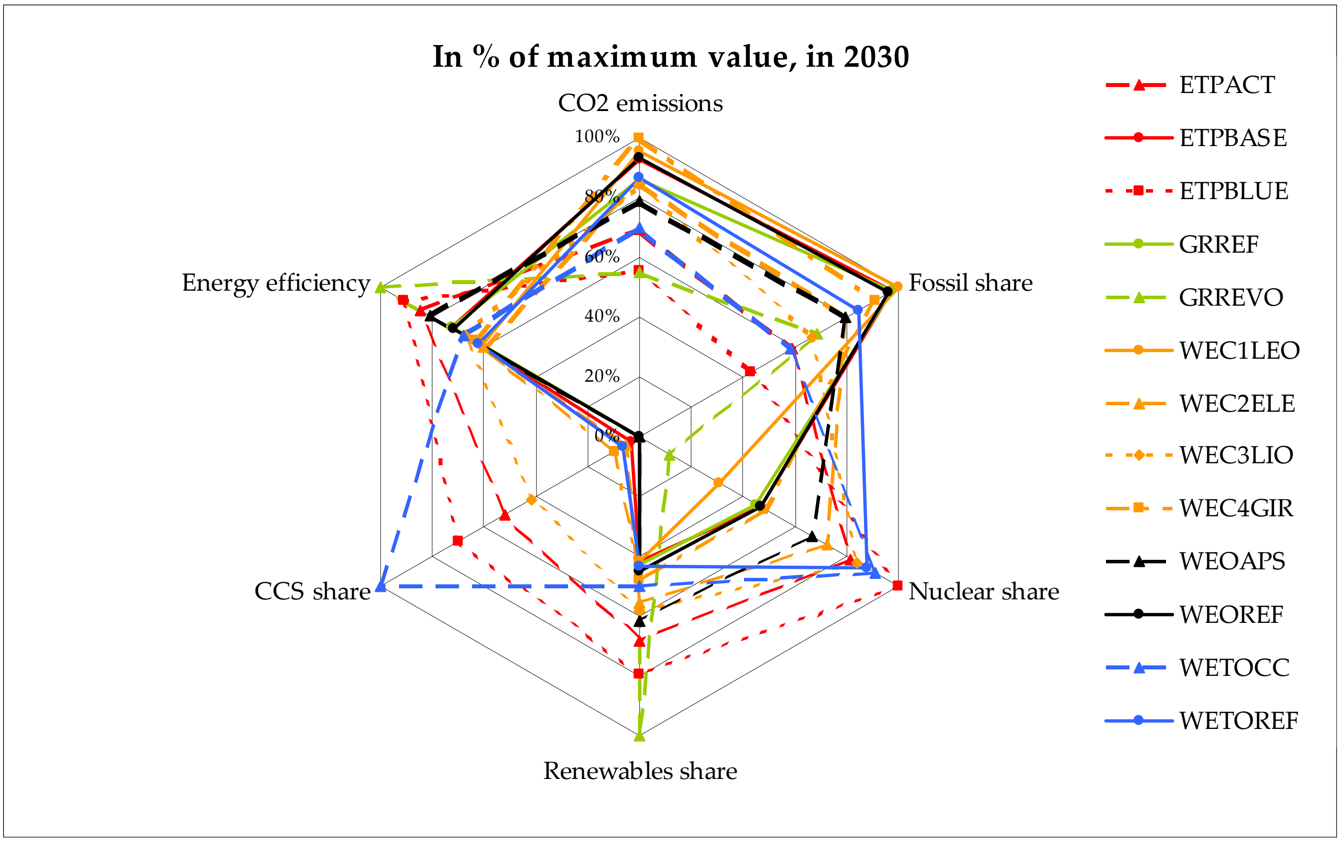

Figure ES.4 Scenario indicators of technology deployment, efficiency and CO_2 emissions

The scenarios depicted with solid lines in the chart above are business-as-usual scenarios. Each study considered such a scenario, primarily as a point of reference, before analysing the impact of alternative future developments often concerned with climate change mitigation. ETPBASE,

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[5] Further scenario indicators and disaggregated technology deployment data are compared in more detail and across time in Chapter 5 of the main report.

GRREF, WEC1LEO, WEC4GIR, WEOREF and WETOREF can all be considered business-as-usual scenarios. These scenarios generally exhibit higher CO_2 emissions, based on high shares of fossil-fueled power generation and only modest energy efficiency improvements. In addition to these business-as-usual scenarios, all studies examine policy-driven scenarios with lower CO_2 emissions. This category includes ETPACT, ETPBLUE, GRREVO, WETOCC, and to a certain extent WEC2ELE, WEC3LIO and WEOAPS. While most of these scenarios exhibit a wide deployment of renewables, only some scenarios incorporate a large contribution of nuclear, such as ETPACT, ETPBLUE, WEC3LIO or WETOCC, and the utilization of carbon capture and storage (CCS).

Turning to the actual levels of technology deployment, Figure ES.5 illustrates for two groups of electricity technologies (gas and nuclear) the level of generation over time across the scenarios. Figure ES.5 also shows historical trends in generation from these technology options, and shows how some of the scenarios envisage a very large increase in overall deployment. Information for all electricity generation technologies is presented in Table ES.5, which shows the share of each technology (grouped according to fuel) across the studies in the year 2030. Colours show where the level of deployment is significantly higher (green) or lower (red) than the average across the scenarios. The table illustrates that a range of energy technology futures are considered in the scenario literature, and that the combination of technologies identified as most optimal depends on many factors that vary across the scenarios. One can of course compare the relative deployment in this table with the estimates of relative cost in Table ES.3. Such a comparison does not reveal a clear causality between relative technology cost and relative deployment, although this is expected considering that a much larger range of factors affect technology deployment, and precisely the reason that detailed integrated energy models representing many of these influences are helpful for understanding technology deployment.

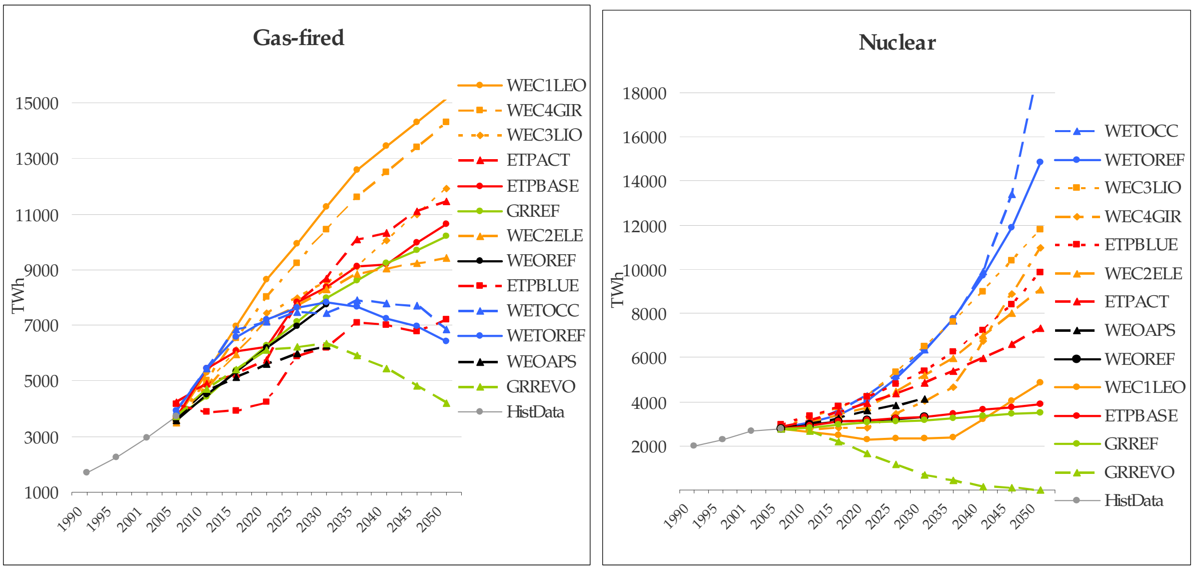

Figure ES.5 Deployment of gas-fired and nuclear generation plants, 1990-2050

Table ES.5 Electricity generation mix in 2030 across selected scenarios

	Current	ETP			GR		WEC				WEO		WETO	
	(in 2005)	ACT	BASE	BLUE	REF	REVO	1LEO	2ELE	3LIO	4GIR	APS	REF	CC	REF
Coal-fired	50.7%	18.7%	44.0%	15.8%	39.4%	26.0%	41.1%	33.1%	30.3%	39.1%	34.3%	44.6%	33.6%	35.8%
Gas-fired	9.3%	29.1%	23.3%	22.8%	22.5%	21.8%	29.6%	22.8%	22.0%	24.6%	20.1%	21.9%	21.1%	21.6%
with CCS		*9.4%*	*0.7%*	*12.6%*			*0.0%*	*0.8%*	*6.6%*	*1.5%*			*16.1%*	*1.0%*
Nuclear	15.2%	16.3%	9.2%	19.9%	9.0%	2.3%	6.1%	14.4%	16.7%	9.6%	13.3%	9.3%	18.0%	17.4%
Hydro	16.0%	14.0%	12.7%	15.9%	13.7%	15.2%	11.6%	13.0%	12.5%	11.3%	17.3%	13.7%	12.1%	11.4%
Wind	0.6%	9.1%	2.7%	9.8%	3.6%	15.1%	4.4%	6.8%	7.7%	5.8%	5.8%	3.6%	6.6%	5.2%
Solar PV	0.01%	0.8%	0.4%	1.1%	0.3%	4.6%	0.1%	0.1%	0.2%	0.1%	0.8%	0.4%	0.2%	0.1%

Key factors of deployment

Some main factors leading to different patterns of technology deployment across the scenarios can be summarized, including some examples on how these factors are represented in particular scenarios.

The design of a scenario already begins to determine the deployment of technologies: the definition of the *storylines*, the *approach used to quantify technological features* and the choice of the set of *available technologies* all have a strong impact on the outcome.

- **Storylines**: The storylines provide the basic elements of a scenario in a qualitative manner. All studies explore storylines describing business-as-usual worlds and alternative policy-driven (or perhaps normative) worlds, and there are important general distinctions that can be drawn between these two groups of storylines. Scenarios based on business-as-usual worlds include

WEOREF, ETPBASE, GRREF, WETOREF, and to some extent WEC1LEO and WEC4GIR, where a continuation of current energy system trends is assumed, e.g. in terms of technology characteristics and policy levers. In contrast, the storyline behind WEOAPS takes into account all policies under consideration which, for instance, leads to a moderate decrease in CO_2 emissions. The storylines of the policy-driven ETP scenarios are explicitly directed towards stringent emission reductions—translated into a stabilization (ETPACT) and a halving (ETPBLUE) of CO_2 emissions by 2050 compared to the 2005 level—which ultimately have a strong influence on technology deployment (we return to this below). The WETOCC storyline particularly emphasizes the need of early action of industrialized countries in achieving a long-term stabilization of CO_2 emissions. GRREVO is characterized by highest concerns about environmental impacts of the energy system, in which nuclear power and CCS are ruled out, and radical CO_2 targets are pursued. Finally, the WEC scenarios consider different emphases of government engagement and international cooperation, and we see later that these also coincide with the deployment of specific technologies.

- **Approach used to quantify technological features**: As discussed earlier, in the selected scenario literature detailed energy models are used to represent technological characteristics. The specific models or approaches themselves can have an influence on technology deployment. For instance, while technologies are deployed primarily on the basis of cost minimization in WEO, ETP, WETO and WEC in one way or another (as depicted in Figure ES.1, with optimization or simulation models, with differing involvement of expert judgment), expert judgment plays a much more dominant role in determining user-defined market shares in the approach of the GR study, where cost-efficiency of the electricity generation mix is not considered explicitly.

- **Availability of technologies**: The set of possible technologies selected by the scenario developers limits the range of technologies deployed in the scenarios—in some studies technologies are simply not considered or mentioned (for example, electricity from geothermal energy in the WETO study). The processes of technology invention and innovation, by which new or immature technologies could emerge and eventually be commercialized, are generally represented with simple assumptions about technology availability in the selected studies.

In addition to these design-related factors, the interpretation and quantification of storylines into specific *input assumptions* drives technology deployment. Critically, it is not necessarily assumptions about a specific technology or set of technologies that determines their deployment (for example, cost as discussed above), but rather the full set of assumptions including the interaction and interplay of technology and other assumptions. Importantly, the fact that the scenario literature on energy technology deployment applies approaches that are able to represent and integrate such a broad range of factors is, in general, an indication that such scenarios are well suited to provide insights regarding how specific systems and technologies can manage energy-related challenges and risks. However, there are some specific limitations, where the scenario literature could be improved to provide additional support to the management of such challenges, to which we return in the subsequent section.

Despite the range of factors affecting technology deployment, it is still possible to draw some robust conclusions from the scenario studies reviewed in this report. Some features of a scenario storyline and input parameters are clearly of particular importance for technology deployment, including both through direct effects and also through the interplay with other technologies. Key factors for the set of technologies covered in this study include:

- **CO_2 policy (and prices) and the availability of carbon capture and storage** (CCS), which appear to be crucial for the deployment of *fossil-fueled power plants* and, through competition, other technologies;
    - For instance, the comparatively high CO_2 prices or stringent policy targets applied in ETPBLUE or WETOCC discourage the deployment of fossil-fueled generation without carbon capture and thus support the deployment of zero- or low-emission technologies, particularly nuclear generation and CCS (which enables continued use of fossil fuels). The GRREVO scenario also assumes a stringent climate target, but in this case CCS and nuclear are fundamentally assumed not to be available (more below), and we thus see larger deployment of renewable technologies. ETPACT, with an intermediate climate policy, is less supportive of CCS and nuclear generation, with generation from natural gas remaining attractive in 2030. CO_2 policy is a strong determinant of technology deployment in these scenarios.

- **Maximum construction rates for nuclear power and assumptions about the response of policymakers to safety concerns (covering waste management, risk of catastrophic accidents and proliferation)**, which determine the market share of *nuclear power* directly, and indirectly the market share of other technologies;
    - For instance, the GRREVO scenario assumes that policymakers respond to concerns about nuclear power by phasing out this technology (globally), irrespective of the cost or other characteristics; whereas the ETP scenarios assume a maximum capacity of 1250 GW from nuclear by 2050 based on historical construction rates. In the WEC scenarios, a high level of government engagement coincides with more support for and deployment of nuclear generation, while in the WETO scenarios nuclear deployment is relatively unconstrained.

  These assumptions, together with assumptions regarding CO_2 prices, go a long way to explaining the level of nuclear deployment across the scenarios (see Table ES.5).

- **Availability of suitable sites for *hydro and wind power* generation;**
  - Across the scenarios, the deployment of hydroelectric generation exhibits less divergence compared to many other technologies (the difference in hydroelectric output between the scenarios with the highest and lowest generation is only about 30%, compared to 8-fold for wind and even more for nuclear). This appears to indicate that hydroelectric generation is roughly equally attractive under a range of different future worlds, and the level of deployment appears to be more affected by the availability of suitable sites. With wind generation we see more variation, with deployment of this technology more sensitive to climate policy. However, controlling for climate policy, we can see that deployment is consistent with assumed lower availability of suitable sites in the ETP and WEO scenarios, while the WETO, WEC and GR scenarios are more optimistic about both on- and off-shore generation potential.

- **Technology breakthroughs for *solar photovoltaics***, appear to be necessary for this technology to become cost-competitive for large-scale deployment.
  - Throughout the scenarios, solar PV plays only a very small role (with the exception of the GRREVO scenario, although it still remains below five percent of generation). This indicates that the factors leading to different levels of deployment of other technologies across the scenarios are less important for PV. In the case of the GRREVO scenario, the set of assumptions about climate policy, nuclear generation and CCS, combined with moderately optimistic assumptions regarding the cost of PV support the slightly higher deployment. Without such a combination, the implication is that major breakthroughs are needed to support larger-scale deployment of this technology.

In addition, it is worth noting that deployment of electricity generation technologies is also affected by the level of demand for electricity (which is determined by **economic activity**, **energy efficiency** and the degree of **electrification**). This affects not only the scale of deployment, but potentially also the mix, particularly if the rate at which technologies can be deployed is limited or there is a maximum potential for particular technologies (for example, a maximum number of suitable sites for hydroelectric generation). While it can be difficult to separate out the impact of different factors, one illustration is provided by the GRREVO scenario, which is very optimistic about energy efficiency, and thus exhibits a lower electricity demand. In this case, it is possible for this scenario to rely more on renewable sources of generation, despite limits to the potential of suitable sites for hydroelectric and wind generation. In contrast, in the WETO and WEC studies there is only a moderate reduction in energy intensity assumed in the scenarios, and thus electricity demand is higher and we see, on average, a larger share of generation from technologies not facing limited potentials (e.g. nuclear).

For a selection of the factors, Table ES.6 summarizes much of the above discussion on their role in the scenarios, along with repeating the information on technology deployment (shown earlier in Table ES.5). Table ES.6 provides a rough indication of the level (e.g., stringency of climate policy, or amount of energy efficiency) of the selected factors in the different scenario studies.

Table ES.6 Electricity generation mix in 2030 and selected key factors of deployment across selected scenarios

	Current (in 2005)	ETP			GR		WEC				WEO		WETO	
		ACT	BASE	BLUE	REF	REVO	1LEO	2ELE	3LIO	4GIR	APS	REF	CC	REF
Coal-fired	50.7%	18.7%	44.0%	15.8%	39.4%	26.0%	41.1%	33.1%	30.3%	39.1%	34.3%	44.6%	33.6%	35.8%
Gas-fired	9.3%	29.1%	23.3%	22.8%	22.5%	21.8%	29.6%	22.8%	22.0%	24.6%	20.1%	21.9%	21.1%	21.6%
with CCS		*9.4%*	*0.7%*	*12.6%*			*0.0%*	*0.8%*	*6.6%*	*1.5%*			*16.1%*	*1.0%*
Nuclear	15.2%	16.3%	9.2%	19.9%	9.0%	2.3%	6.1%	14.4%	16.7%	9.6%	13.3%	9.3%	18.0%	17.4%
Hydro	16.0%	14.0%	12.7%	15.9%	13.7%	15.2%	11.6%	13.0%	12.5%	11.3%	17.3%	13.7%	12.1%	11.4%
Wind	0.6%	9.1%	2.7%	9.8%	3.6%	15.1%	4.4%	6.8%	7.7%	5.8%	5.8%	3.6%	6.6%	5.2%
Solar PV	0.01%	0.8%	0.4%	1.1%	0.3%	4.6%	0.1%	0.1%	0.2%	0.1%	0.8%	0.4%	0.2%	0.1%

	ETP			GR		WEC				WEO		WETO	
Selected key factors	ACT	BASE	BLUE	REF	REVO	1LEO	2ELE	3LIO	4GIR	APS	REF	CC	REF
Modeling approach for technology selection	Optimization			User/ expert-driven		Simulation, expert-driven				Simulation, expert-driven		Simulation	
Level of technology detail	++			0/+		+/++				+		+/++	
Energy efficiency	+/++	+	++	+	++	0	0	+	0/+	+/++	+	+	0/+
Representation of energy security	0			0		++				+		0	
Stringency of CO_2 policy	+	0	++	0	++	0	0/+	0/+	0	0/+	0	+	0
Acceptance and potential of nuclear power	+	+	+/++	+	0	0/+	++	++	+	+	+	++	++
Potential sites for wind power	+			+/++		+/++				+		+/++	

Note: ++ high + moderate 0 low

Importantly, these and other findings in this report must be considered in light of some limitations and challenges faced in this project. The development of a scenario represents a major exercise, and this review has only been able to collect fragmentary data and deduce a limited understanding of the methodological approaches used in the various scenario studies. Nonetheless it has still been possible to gain a more in-depth understanding of 13 leading scenarios in terms of tendencies and broad drivers, and in a much more detailed, comprehensive and systematic way than has been attempted before. However, there are still a number of factors that are in reality important for the deployment of technologies which could not be assessed due to the limited access to and knowledge about the models. These include factors like construction times, manufacturing capacity, plant lifetimes, discount rates, or material and resources costs and availability (e.g. steel, water, skilled workforce). Other areas where this review has had limited success is in assessing some additional technology-specific factors such as assumptions regarding maximum penetration rates, and maximum potentials for renewable generation technologies.

Management of energy-related risks

This review of factors affecting the deployment of electricity generation technologies in energy scenarios delivers insights about strategies for the energy system to deal with future challenges and risks. In broad terms, the review has explored scenarios illustrating a range of technological options for providing the energy services to support increasing global economic growth and development, identifying factors that may be important for fostering the deployment of technologies that can help to manage threats associated with climate change. In this context, two distinct groups of scenarios were analysed: business-as-usual scenarios (ETPBASE, GRREF, WEC1LEO, WEC4GIR , WEOREF , WETOREF), in which no significant measures are taken to reduce CO_2 emissions to the level necessary to avoid dangerous climate change; and climate policy-driven scenarios (ETPACT, ETPBLUE, GRREVO, WEC2ELE, WEC3LIO, WEOAPS, WETOCC), in which energy systems develop along a substantially different pathway over time to achieve emission targets, including ambitious targets. Policy measures to reduce greenhouse gas emissions represented in the scenarios include CO_2 targets and pricing measures that reduce the cost-competitiveness of emitting technologies, phasing out of high-emission technologies, support for zero- or low-emission technologies and the exploitation of energy efficiency options.

The review also found, however, that risks associated with energy security are addressed directly in only a small number of the scenarios in the reviewed studies. These include the WEC study, where energy security issues are clearly taken into account in the design of the scenarios. The scenario storylines in this study were built according to criteria encompassing accessibility, availability and acceptability of energy services. Furthermore, energy security is dealt with explicitly in WEO, which uses a policy database of current measures including those dealing with energy security, such as the *IEA emergency response mechanism* to manage the risk of a rapid oil price increase. In the other studies, energy security is not considered in detail, at least not in a way that provides substantial insights for governance. For example, in the GRREVO scenario, energy security is achieved as a consequence of a shift to a diversified renewable energy mix away from fossil and nuclear power generation, and by non-technological factors such as the adoption of principles of equity and fairness. Also in the ETP study, energy security is not defined explicitly, but is seen as a result of achievements with regards to climate change and energy efficiency.

It is noteworthy, however, that the scenarios which include a more explicit discussion of energy security do not exhibit significantly different patterns of technology deployment for electricity generation compared to the other scenarios. This may be because energy security is assumed to be managed through non-technological means (for example, the WEC scenarios are characterized according to the level of international cooperation), or the scenarios are concerned with security associated with energy resources that play a small role in the electricity sector (e.g. oil). Alternatively, the long time horizon of many of the scenarios (to 2050 or beyond, except for WEO) may mean that energy security challenges associated with global resource depletion become a major factor in all scenarios, even if only a few consider energy security in the conventional geopolitical-economic sense.

Implications for decision-making

This review and analysis has provided a number of additional insights for decision-making and the role of energy technology scenarios in supporting such processes. The scenario approach has strengths and limitations which affect its suitability for supporting public and other decision-makers. Some of these strengths and limitations are summarized in Table ES.7.[6]

We conclude that the deployment of electricity generation technologies is extensively covered in the scenario literature, with the methodologies employed able to account for a range of factors important for the future deployment of different systems and technologies. Despite this conclusion, it is almost certain that some real-world factors are not well represented, primarily related to the interface between the energy system and other human and natural systems (for example, related to non-energy resources, such as water, agricultural land (for biofuels), minerals, manufacturing and human capacity and so on). This represents a weakness not only from a methodological perspective, but also in terms of the credibility of the scenarios to the stakeholder audience. Other methodological approaches, such as life cycle inventory analysis, may complement scenario-based approaches to overcome such limitations. It is also worth noting that energy scenarios are less suitable for accounting for factors important for very immature or speculative technologies, where major technological breakthroughs are needed.

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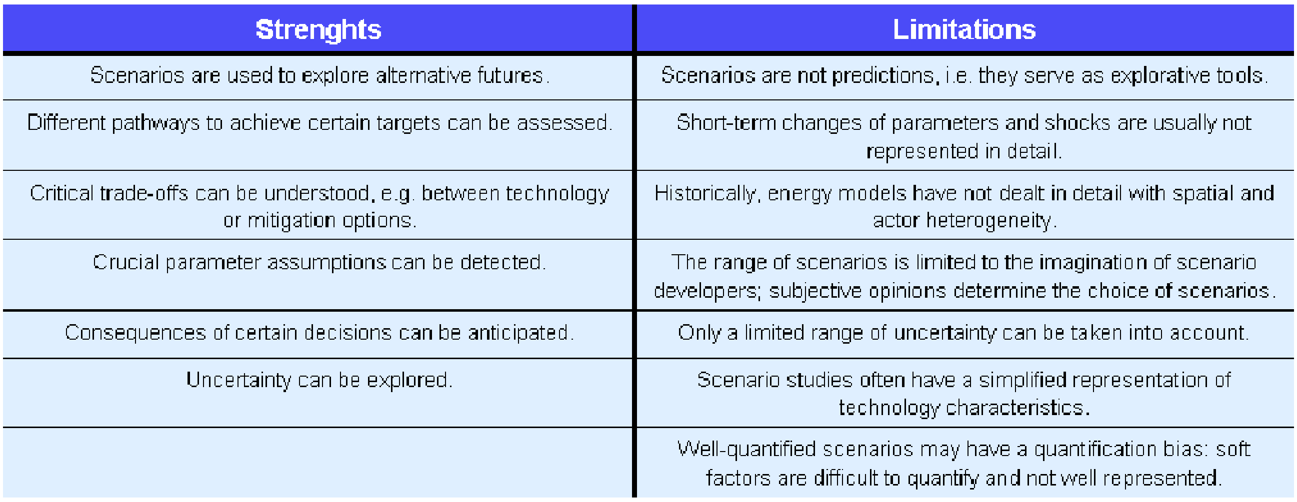
[6] This is discussed in more detail in Section 6.4 of the main report.

Table ES.7 Strengths and limitations of the scenario approach



Strenghts	Limitations
Scenarios are used to explore alternative futures.	Scenarios are not predictions, i.e. they serve as explorative tools.
Different pathways to achieve certain targets can be assessed.	Short-term changes of parameters and shocks are usually not represented in detail.
Critical trade-offs can be understood, e.g. between technology or mitigation options.	Historically, energy models have not dealt in detail with spatial and actor heterogeneity.
Crucial parameter assumptions can be detected.	The range of scenarios is limited to the imagination of scenario developers; subjective opinions determine the choice of scenarios.
Consequences of certain decisions can be anticipated.	Only a limited range of uncertainty can be taken into account.
Uncertainty can be explored.	Scenario studies often have a simplified representation of technology characteristics.
	Well-quantified scenarios may have a quantification bias: soft factors are difficult to quantify and not well represented.

The scenario literature also provides a fairly wide range of perspectives about how some future energy-related challenges and risks can be addressed. The breadth of this range of perspectives can be understood in the context of significant uncertainty about future technological development and political, social and economic factors. However, this wide range of views may detract from the usefulness and understandability of energy scenarios for policy- and other decision-makers, necessitating better communication and interaction between scenario developers and the audience of these studies. In the context of achieving reduced GHG emissions and enhanced energy security, the energy technology scenario literature provides many insights regarding systems and technology for management of climate change, although perhaps very ambitious targets are not well covered in the current literature (such as targets compatible with the European Commission's objective of restricting average temperature increases to below 2° C relative to preindustrial times). The scenario literature also supports the notion that there is no single option or single combination of options for responding to climate change and that policy makers have some flexibility to pursue different combinations of energy efficiency, electrification, renewables, nuclear power, and carbon capture and storage to meet long-term targets, at least during the period to 2030. One significant limitation for supporting governance of climate change risks, however, is that the scenario literature has a somewhat limited discussion of costs and trade-offs associated with different technology options (although some exceptions, such as ETP).

Unlike climate change, energy security is relatively less well covered and may represent the area in which energy technology scenarios are currently least able to support effective decision-making, possibly exacerbating governance deficits in this area. However, this statement is based on a definition of energy security related to concepts of import dependence and vulnerability to supply shocks. In contrast, energy technology scenarios are perhaps already suited to supporting governance concerned with managing the long-term depletion of energy resources and a shift to alternative resources and technologies.

Recommendations

One objective of this review is to advise IRGC on a niche project in the area of energy technology scenarios. In considering options here, it seems clear that IRGC's objectives are not most effectively served by taking a direct role in scenario development, nor in research on the process of technological change and deployment. However, IRGC could play a role in two key areas.

The first could be in enhancing information flow to policy and other decision makers regarding strategies for the management of energy-related risks. That is, IRGC could act as a clearinghouse for transferring knowledge from different studies and viewpoints on optimizing the energy mix to public decision makers. The comparative advantage of such a project would be that it utilizes the extensive and detailed analysis available in the energy technology scenario literature, but addresses weaknesses related to the dissemination, communication and interpretation of these scenarios. In such a project, IRGC would facilitate a better awareness and understanding among decision makers of the range of perspectives on how best to achieve a transition towards a sustainable, secure and efficient energy economy. IRGC would also be in a position to provide pragmatic and independent guidance with a global perspective to support urgent decisions on technology selection and the timing of deployment.

A complementary step would be for IRGC to establish a forum to bring public decision makers, industry, and civil society together with the developers of energy technology scenarios (along with other experts). The objective would be to foster understanding and ensure that developers of scenarios are aware of the important governance challenges and uncertainties most relevant to the audience of the scenario studies. This would help ensure that scenarios—which represent a powerful analytical tool for assessing technology deployment—can be exploited most effectively to support decisions on energy challenges. This may provide a means to address some of the specific areas identified in this review where the scenario literature could better support management of energy-related risks, in areas such as accounting for broader resource issues in energy technology deployment and more explicit analysis of energy security options.

1. Introduction

The world's energy system is likely to go through major changes within the next decades. Global warming caused by anthropogenic greenhouse gas emissions and major energy security issues due to the scarcity of fossil fuels require significant changes to today's energy system. Without a major transformation, fundamental risks will be faced by economic, social and natural systems.[7]

It is the purpose of the International Risk Governance Council (IRGC), the initiator of this project, to support the understanding and management of emerging global risks. In more detail, the IRGC describes its role as follows:

"Many risks, and in particular those arising from emerging technologies, are accompanied by potential benefits and opportunities. The challenge of better risk governance lies here: to enable societies to benefit from change while minimizing the negative consequences of the associated risks." (Summary information, 2008)

As a contribution to the above-mentioned risk governance process, this study investigates future developments of the power generation sector in selected energy scenarios. Contemporary energy scenario publications reveal very different developments of the scale and the technology mix of the power generation sector. To ease the interpretation and to increase the usefulness of energy scenarios for decision makers, the *rate* and the *driving factors* affecting the deployment of technologies are analysed, as defined by the terms of reference (see Appendix I). The study focuses on the electricity generation sector, as the largest source of CO_2 emissions (shown in Figure 1).

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[7] It is beyond the scope of this project to discuss the risks attributable to a continuation of the current energy mix. This has been done e.g. by Sims et. al. (2007).

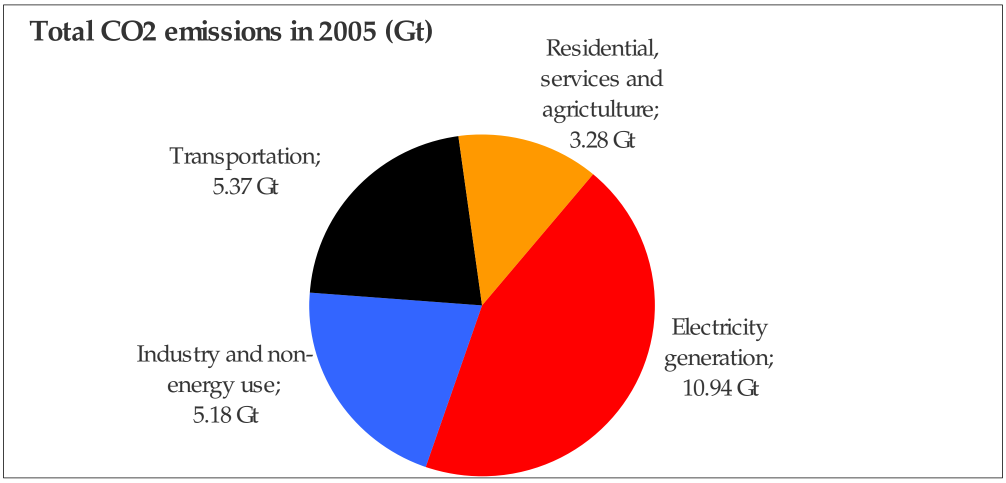

Figure 1 Total CO_2 emissions in 2005 (WEO, 2007)

The choice of technologies for the production of electricity therefore determines the future impact of the energy system on the environment, the economy, or human well-being in general. To analyse the technology choice, this study looks into the energy modeling efforts initiated within frameworks such as the Energy Technology Systems Analysis Programme (ETSAP)[8] or the Energy Modeling Forum (EMF)[9]. These models provide an integrated perspective on future energy system transitions based on a detailed representation of specific technologies, also known as the bottom-up approach. The next sections present an overview on the representation of technology deployment in bottom-up energy models.

Many different approaches are used to model the deployment of technologies, i.e. technological change. While in some models technological change is not dependent on any other model parameters, i.e. it is exogenous, other models attempt to endogenize technological change. Before describing these approaches in detail, some terminology on the typical life-cycle of technologies is presented, which can be found for example in Grübler, Nakicenovic and Victor (1999):

- Invention: the creation of ideas in basic research
- Innovation: the first practical application of an invention, including development and demonstration[10]

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[8] Implementing Agreement of the International Energy Agency, first established in 1976.

[9] Established at Stanford University in 1976.

[10] Following Shumpeter (1934) and Freeman (1982/1989)

- Niche market commercialization: due to performance advantages over existing technologies

- Pervasive diffusion: standardization and economies of scale

- Saturation: the exhaustion of improvement potentials and the appearance of more efficient competitors

- Senescence: domination by superior competitors

The rate of deployment of a technology, i.e. the evolution through the different stages of the life-cycle, is controlled by various barriers. Technical, cost and other barriers to the deployment of energy technologies are identified, for example, in IEA (2006): Technical barriers mainly occur before market commercialization and are resolved with further R&D and demonstration projects. Government funding is said to be essential in this early phase. Once a technology is technically viable it may still feature higher cost than existing technologies, which denotes the cost barrier. Cost barriers are reduced by R&D, learning-by-doing or the imposition of policies (e.g. a CO_2 tax). Finally, new cost-effective technologies may still face other barriers, according to the authors of IEA (2006): the lack of public acceptance, obstacles in planning and licensing (e.g. the difficulty of obtaining permissions for new entrants), higher risks in financing new technologies, which are sometimes unproven and small-scale, or the lack of information.

A similar set of barriers for renewable power generation technologies is presented by Kofoed-Wiuff, Sandholt and Marcus-Möller (2006)[11]:

- No level playing field: subsidies for conventional technologies and no internalization of externalities in energy and fuel prices cause disadvantages for new technologies

- Learning spill-overs: create incentives to wait for other stakeholders to develop technologies further

- Financing is more costly: due to higher capital-cost, the lack of experience, and the disproportionally high transaction cost

- Import tariffs and technical barriers to trade: e.g. certification and testing, or non-competitive public procurement

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[11] Being a synthesis of various studies on barriers for renewable technologies.

- Difficulty to obtain permits: e.g. approval procedures and spatial planning
- Unprepared energy infrastructure: integration of intermitting sources, grid connection and grid access
- Lack of knowledge and public acceptance

Traditionally, technological change is exogenously defined and modeled as a function of time only—technological change is thereby not linked to policy changes and must arise from sources that are largely unresponsive to policies. The debate about endogenizing technological change as a function of model variables is ongoing. Grübler, Nakicenovic and Victor (1999) demonstrate the possibility to endogenously generate technological change in energy models. Based on historical patterns in technological change they claim the need for modeling the following processes: learning curves should ideally include both learning-by-doing, which takes place in niche markets, and RD&D in the innovation stage; logistic models could be used to represent predictable patterns of technological diffusion and substitution; and the observed decarbonization of fuels provides evidence for a co-evolution of technologies in clusters. They conclude that it is increasingly possible to make quantitative observations and to model the stages of a technology's life-cycle, except for the invention and innovation stages.

A review of different approaches to model technological change can be found in Clarke, Weyant and Edmonds (2006). They argue that the statistical correlation between declining cost and cumulative production, which describes the so-called learning curve, reflects three major sources of technological learning, next to the inherent economies of scale:

- Learning-by-doing: represents efficiency increases and cost reductions over time, as a result of experience
- R&D: classified into basic or applied research, and publicly or privately funded
- Spillovers: defined as technological change in one industry/domain that arises from innovative activities in another

Furthermore, Clarke et al. (2006) provide an interpretation of models with endogenous technological change: the earliest and simplest approach only includes the first of the above sources, i.e. cost reductions only depend on cumulative installations or production[12], while R&D

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[12] As shown in Massner (1997) or Manne and Richels (2002).

and spillovers are neglected. As an advancement, "two-factor" experience curves[13] are used to represent both production-based and R&D-based technological change, but still focus on own-industry sources. Finally, several ongoing attempts to include also spillovers are discussed[14].

Turning back to the report at hand, the impact of different techniques to implement technological change is one factor considered to affect technology deployment. Furthermore, all available modeling inputs are compared and discussed with regards to their impact on the modeling output. Energy scenario studies have been compared before on an aggregate level, e.g. by Küster et al. (2007), who focus mainly on Europe and Germany, or by Hamrin, Hummel and Canapa (2007), who investigate the deployment of renewable technologies. The goal of this project is to go into more detail, and to assess the technology choice in some of the most relevant, contemporary energy scenarios, including the published documentation and additional data from the underlying modeling work. Many of the well-known energy scenario studies only publish the rough outcome of their scenario analysis, while the drivers behind technology choice are often not discussed in detail. In order to gain further insights into the factors driving technology choice across different scenario studies, the analysis in this present study is organized as follows:

Chapter 2 discusses the methodology applied in this study, the selection of scenario literature, and some of the anticipated key factors affecting technology deployment. **Chapter 3** summarizes the published information on the energy models that were used to create the selected scenarios, identifying methodological features important for the selection of technologies. The main modeling inputs (such as socio-economic drivers, technology characteristics and resource costs) are then cross-compared in **Chapter 4**, followed by the discussion of the modeling outcomes in **Chapter 5**. The deployment of the most relevant power generation technologies is compared in Section 5.2, including a discussion of the drivers behind the variation in deployment across scenarios. The key factors of technology deployment in energy models are then summarized in **Chapter 6**, along with recommendations to increase the usefulness of energy scenario analyses for policy and other decision makers, and a discussion of the limitations of this project.

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[13] See for example Barreto (2001) or Bahn and Kypreos (2003).

[14] E.g. Seebregts et al. (2000).

2. Methodology

The overall objective of this study was to identify key factors affecting technology deployment in the scenario literature. To ensure all relevant factors were considered, a panel of partners from industry and academia with some policy-relevant expertise was frequently consulted throughout the project. The assessment of energy scenarios was undertaken along the following work steps: first, a representative group of energy scenario studies was selected (as shown in Section 2.1), followed by the collection of relevant modeling data (Section 2.2). To analyse the impact of differing technology assumptions on the deployment across the scenarios, the available modeling parameters were compared and analysed, based on their contribution to the levelized cost of electricity (Section 2.3).

2.1. Selection of studies

A representative selection of energy scenarios stood at the beginning of the analysis. The following selection criteria were applied to the broad field of scenario literature:

- Global scope
- Time horizon until 2030 or beyond
- In-depth technological representation of the electricity generation sector
- Recently published
- Recognized in the energy policy community

The first two criteria from the list above regarding the geographical and temporal coverage were defined in the initial proposal (see Appendix), while the other criteria support the collection of reliable technology data. Additionally, the representation of different viewpoints was ensured by considering publications prepared by or for industrial, scientific, governmental or environmental interests. Based on these criteria and a preliminary review of the scenario literature, five studies were selected as briefly described in Table 1.

These comprise the International Energy Agency's (IEA) World Energy Outlook (WEO) and Energy Technology Perspectives (ETP) studies, which represent a rather neutral, scientific viewpoint, the European Commission's World Energy Technology Outlook (WETO) as a governmental perspective, the World Energy Council's (WEC) energy scenarios, representing an industrial viewpoint, and the Greenpeace Energy Revolution (GR) study. Each of these studies presents between two and four main scenarios, while ETP even explores a more extensive range of uncertainty[15]. To characterize the studies in some more detail, ETP, WETO and GR present emission abatement scenarios, i.e. these studies project the impacts of different emission targets and the causally determined CO_2 concentrations in the atmosphere[16]. ETPBLUE (one of the ETP scenarios) presents an emissions profile consistent with a long-term concentration of 450 ppm, assuming that emissions are stable from 2050 onwards, whereas ETPACT leads to 520 ppm. The WETO carbon constrained scenario (WETOCC) describes a world which achieves a CO_2 concentration of 480 ppm in the long term, with emissions at 13 Gt/yr in 2100. GR presents a world in which fossil fuels are phased out by 2085, without any further deployment of nuclear energy or any application of carbon-capture and storage, which leads to emissions as low as 0.5 Gt/yr at the end of the 21st century.

WEC, on the other hand, explores desirable futures with respect to what they call the *3 A's* covering *Accessibility* to modern and affordable energy, *Availability* of continuous and high quality energy, and *Acceptability* in terms of social and environmental goals. The political dimensions of government engagement (GE) and international cooperation (CI) are seen as the critical drivers of the future energy system and are therefore used to define the scenarios.

In contrast to many of the other studies, the WEO scenarios are based on a policy database of actual and prospective measures on energy security and environmental sustainability. Among the WEO scenarios, the *Reference* and *Alternative policy* scenarios were analysed in this study. The *High Growth Scenario* was not assessed due to data limitations. After discussion with the authors of WEO, the *450 Stabilisation Case* was also excluded since it is published in extracts only and not developed in an integrated framework. The 2008 World Energy Outlook, which includes a much more integrated low stabilization case, was published too late to be included in this study.

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[15] Namely five variants of the *ACT* scenario and 12 variants of the *BLUE* scenario. These variants are only published partially, so that only the *Map* variants are selected for this study.

[16] According to Carter et. al. (2007), a long-term stabilization at 450 ppmv would result in a 2°C temperature increase, and prevent most serious damages due to climate change.

The WETO hydrogen (WETOH2) scenario was also not assessed because it concludes that 90% of hydrogen production is consumed in the transportation sector, and thus is expected to provide fewer additional insights about technology deployment in the electricity generation sector.

It should be mentioned that in addition to these studies we considered the scenarios in the US Department of Energy's International Energy Outlook, the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios, the scenarios referred to in the IPCC Fourth Assessment Report, scenarios from the US Electric Power Research Institute, the Shell scenarios, and scenarios in the European Commission ADAM and NEEDS projects. A preliminary assessment was conducted on some of these scenarios but all were excluded because either they lacked a global scope or did not provide sufficient detail in the representation of technologies; or because insufficient data were available, the scenarios were not yet published/available or the scenarios were developed prior to the last few years. These criteria for exclusion do not necessarily represent criticisms of the scenarios, since in many cases they were developed to answer different questions. For example, although a much lower level of technology detail in some of these other scenarios precludes analysis of deployment of specific technologies, such scenarios may be more suitable for considering very long-term developments, given significant uncertainty regarding characteristics of specific technologies in the very distant future. Similarly, studies with a limited geographical scope may provide more insights regarding specific factors affecting technology deployment within the geographic region covered, although the insights may not be applicable to the global scale of interest here.

Table 1 Overview of selected studies

Abbr	Study	Date	Lead authors	Modeling teams	Contact person
WEO	World Energy Outlook 2007	2007	Fatih Birol, Economic Analysis Division, IEA Noé van Hulst, Long-Term Office, IEA	IEA Economic Analysis Division	Bertrand Magné
ETP	Energy Technology Perspectives 2008	2008	Neil Hirst, Office of Energy Technology and R&D, IEA Robert Dixon , Peter Taylor, Energy Technology Policy Division, IEA Dolf Gielen, Office of Energy Technology and R&D, IEA	IEA Office of Energy Technology and R&D	Dolf Gielen
WETO	World Energy and Technology Outlook- WETO H2	2006	Bruno Lapillonne, Enerdata Domenico Rossetti di Valdalbero, Supervisor, EC DG Research Patrick Criqui, LEPII-EPE Dominique Gusbin, Federal Planning Bureau, Belgium	LEPII-EPE (P. Criqui, S. Mima, Ph. Menanteau) Enerdata (B. Chateau, A. Kitous)	Silvana Mima
WEC	Energy Policy Scenarios to 2050	2007	Brian Statham, Study Group, WEC Robert Schock, WEC	Enerdata (B. Chateau, A. Kitous)	Alban Kitous Robert Schock
GR	Energy Revolution	2008	Sven Teske, Climate & Energy Unit Greenpeace Arthouros Zervos, Oliver Schäfer, EREC	DLR, Dep. of Systems Analysis and Technology Assessment (W. Krewitt, S. Simon, St. Kronshage) Ecofys (W. Graus, M. Harmelink)	Wolfram Krewitt

Abbr	Model	Key uncertainties	Scenarios	Policy drivers
WEO	World Energy Model	Policies on energy security and environment Economic growth in China and India	Reference (REF) Alternative Policy (APS) High Growth (HG)	Policies adopted by mid-2007 All policies under consideration 1.5% higher GDP-growth China+India
ETP	ETP MARKAL	CO_2 emissions	Baseline (BASE) ACT Map (ACT) BLUE Map (BLUE)	Extension of WEOREF 27 Gt CO_2/yr in 2050 14 Gt CO_2/yr in 2050
WETO	POLES	CO_2 emissions Deployment of hydrogen technologies	Reference (REF) Carbon Constraint (CC) H2	Existing policies 25 Gt CO_2/yr in 2050 Hydrogen technology breakthroughs
WEC	Delphi study; Consistency check with POLES	Government engagement (GE) International cooperation and integration (CI)	Leopard (1LEO) Elephant (2ELE) Lion (3LIO) Giraffe (4GIR)	Low GE, low CI High GE, low CI High GE, high CI Low GE, high CI
GR	MESAP/PlaNet	CO_2 emissions	Reference (REF) Revolution (REVO)	None; extension of WEOREF 10 Gt CO_2/yr in 2050

2.2. Data collection

At first, published scenario assumptions and results were collected and compared. A survey template was used to assess the following anticipated drivers of deployment for each technology, across the studies:

- General drivers:
    - Population growth, GDP growth, fossil fuel prices, CO_2 prices, theoretical, technical and economical potentials,…
- Technology-specific drivers:
    - Powerplant data: plant lifetime, capacity factor, thermal efficiency, emissions per unit of activity, ...
    - Deployment data: learning rate, rate of deployment, all-in-cost to implement technology, ...
    - Economical data: investment cost, O&M cost, fuel cost, generation cost, discount rate, abatement cost, ...
- Other drivers: environmental risks, energy security issues, regulatory framework, public acceptance, policy instruments, education, subsidies, ...
- Scenario results: installed capacity, generated electricity, primary and final energy demand, CO_2 emissions

This data is in most cases not on the necessary level of technology detail for the purposes of the present study. For instance, assumptions on technology parameters are often not presented at all, while the results are mostly aggregated by fuel, rather than disaggregated by technology. Accordingly, additional data that were clearly assignable to the core study were collected. This included numerical data received upon request from the authors of the studies, as well as papers on the modeling work.

2.3. Comparison of technology assumptions

One key factor expected to have an impact on technology deployment in many of the scenario studies described above is the cost of the technology. Accordingly, in the data collection phase, emphasis was placed on ensuring that sufficient data on technology-specific assumptions were obtained to estimate Levelized Cost of Electricity (LCOE). The LCOE is the ratio of total lifetime expenses versus the total expected output, in terms of discounted present values. This approach facilitates the comparison of the economics of different plant types, as suggested by Drennen et al. (2002) or the IEA (2005). The resulting average price would repay the investors expenses and can be calculated as follows:

$$LCOE = I*CRF/Q + O\&M/Q + F/Q + E/Q \qquad (\$/MWh)$$

(as applied for example in Rafaj and Kypreos, 2007)

$I*CRF/Q$ = Levelized annual investment cost ($/MWh)

I = Capital investment cost ($/kW)

CRF = Capital recovery factor

$= dr * [(1+dr)^{n}]/[(1+dr)^{n} - 1]$

, where dr = Discount rate, n = Plant life time

Q = Annual plant output (MWh)

$O\&M/Q$ = Levelized annual operation & maintenance cost ($/MWh)

F/Q = Levelized annual fuel cost ($/MWh)

E/Q = Levelized annual external cost ($/MWh)

It can be seen that the *CRF* represents that annualized return on investment necessary to amortize the full investment cost over the lifetime of the technology. Hence, a higher discount rate or a shorter plant lifetime increases the levelized investment cost. Accordingly, it is not necessary to discount O&M, fuel or other future cost with this formulation. Some models incorporate a learning process for certain technologies, particularly renewables and carbon capture and storage (CCS), which leads to a decline of *I* over time, as suggested for example by Grübler et al. (1998).

The annual plant output (*Q*) is usually calculated as the product of installed capacity, capacity factor and the yearly 8760 hours. The drivers behind the levelized annual fuel cost are in addition the price of the fuel input and the thermal efficiency of the plant. O&M cost on the other hand is often expressed as a fraction of *I*. Levelized annual external cost add to the generation cost in case that a CO_2 price is charged for the plant emissions.

For this project, the comparison of technology assumptions was undertaken with respect to their importance for the competitiveness of a technology. Ideally, the impact of all technology-specific parameters on the levelized cost of electricity (LCOE), which serves here as a proxy for the competitiveness, would be analysed for different plant types across the scenarios. Due to the limited access to modeling data, only the most relevant cost drivers were compared for each technology, as far as they were available.

The relevance of certain technology-specific parameters differs across the technologies. The varying significance of parameters such as fuel price, plant lifetime or investment cost for the LCOE can be derived from IEA (2005) or Rafaj and Kypreos (2007), and allows for the following qualitative conclusions (see Table 2, where L_INV stands for the levelized investment cost, L_O&M for the levelized O&M cost, and L_FUEL for the levelized fuel cost):

- Levelized O&M cost is generally a minor component of the total LCOE, except for nuclear power generation, where the share may rise to around 30%. Nuclear technologies are characterized by a high share of levelized investment cost, particularly in case of a high discount rate or a short plant lifetime.

- The LCOE of gas-fired technologies is very sensitive to the gas price and the thermal efficiency, since levelized fuel cost accounts for 70–80% of the total cost. The comparatively low investment cost results in valuable flexibility towards uncertainties in future demand.

- Renewable technologies, by contrast, are characterized by very high levelized investment cost shares, which are driven by expensive initial investments and low capacity factors. Therefore learning rates are crucial for the reduction of investment cost, together with long plant lifetimes and a low discount rate. Obviously, fuel cost is not relevant for renewables, as long as back-up technologies to cover the intermittency are not considered.

- For coal-fired technologies, levelized investment and fuel cost are of similar relevance, depending on the choice of the discount rate.

Table 2 Components of LCOE

Components of Levelized Cost of Electricity				L_INV = Lev. investment cost L_O&M = Lev. O&M cost L_FUEL = Lev. fuel cost
IEA: dr =5%; global; existing plants or under construction in 2003				
	Coal	Gas	Nuclear	Renewables
L_INV	35%	14%	**50%**	**High**
L_O&M	20%	8%	30%	Low
L_FUEL	**45%**	**78%**	20%	-
IEA: dr = 10%; global; existing plants or under construction in 2003				
	Coal	Gas	Nuclear	Renewables
L_INV	**50%**	20%	**70%**	**High**
L_O&M	15%	7%	20%	Low
L_FUEL	35%	**73%**	10%	-
Rafaj/Kypreos: dr = 5%; Region Asia; plants in 2050				
	Coal	Gas	Nuclear	Renewables
L_INV	30%	20%	35%	90%
L_O&M	30%	10%	30%	10%
L_FUEL	**40%**	**70%**	35%	-

3. Energy models

The results of the selected scenario publications are computed with bottom-up energy models, which are technology-rich quantifications of the energy system. A scenario approach, which usually includes narrative storylines and numerical assumptions, is followed in all models in order to explore different futures. However, only those elements of a storyline that are translated into model assumptions have an impact on the solutions and can be investigated here. In the paper at hand, the term *scenario* therefore refers to the quantifiable and modeled elements[17].

The energy models used in the selected studies are described in this chapter. The description is based on publicly available information, and therefore only captures the origin and the main structure of these models, and the processes that drive technology deployment, including the choice of technologies. The objective is to identify the important features of the different approaches applied to scenario development which may affect technology deployment across the scenarios.

3.1. World Energy Model

The following description is mainly based on *IEA (2008c).* The World Energy Model (WEM), used for the WEO, has been developed since 1993 by the IEA to provide medium to long-term energy projections. It was mainly designed to analyse:

- Global energy prospects
- Environmental impacts of energy use
- Effects of policy actions and technological changes
- Investments in the energy sector

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[17] For an introduction into the scenario modeling approach, see for example IPCC (2000), Chapter 1.2. *What are scenarios?*

The WEM is a technology-rich partial equilibrium model. As a simulation model it optimizes the objective function in a yearly, recursive approach. This facilitates the interaction with the many experts of the IEA through multiple run iterations, and the use of the rich IEA databases[18]. The majority of the historical data comes from IEA's own databases, in addition to referenced external sources. An extensive policies and measures database, with over 3000 policies in OECD and non-OECD countries, is compiled to support the Alternative Policy Scenario in the WEO.

The WEM is made up of six main modules:

- Final energy demand
- Power generation
- Refinery and other transformations
- Fossil-fuel supply
- CO_2 emissions
- Investments

The power generation module first calculates the new generation capacity requirements, accounting for growth in total capacity requirements and plant retirements. Different technology options then compete to fill the new generation capacity requirements on the basis of levelized electricity cost (see Section 2.3 for an explanation of this approach).

The projections for renewable technologies are calculated in a separate sub-module, which is driven by the WorldRES model[19]. This model was developed in the Energy Economics Group at the Technical University Vienna and incorporates dynamic cost-resource curves and technological learning. Thereby static cost-resource curves are developed for each technology, followed by a dynamic assessment of cost and restrictions based on potentials, learning rates, financial incentives and technical and social constraints.

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[18] *IEA (2008b).*

[19] For a detailed discussion of the WorldRES model see Resch et al. (2008).

To explore the energy-market impact of higher GDP growth rates within the High Growth Scenario, the hybrid WEM-ECO was developed[20]. WEM-ECO couples WEM to the top-down general equilibrium economic model IMACLIM-R.

3.2. ETP MARKAL [21]

The ETP MARKAL model, used for the Energy Technology Perspectives scenarios, belongs to the family of **Mark**et **Al**location models that was initially developed in the late 1970's within the IEA's Energy Technology Systems Analysis Programme (ETSAP). The ETP MARKAL was originally designed to study global energy efficiency and CO_2 emission reduction potentials, particularly in the industrial sector, but has been expanded to cover all sectors. Energy technology scenarios based on ETP MARKAL were published for the first time in 2006, to respond the request made by G8 leaders to *"advise on alternative energy scenarios and strategies aimed at a clean, clever and competitive energy future*" (Gielen and Taylor, 2007).

ETP MARKAL is a bottom-up, partial equilibrium systems engineering model. Unlike simulation models (such as the World Energy Model), ETP MARKAL is a cost optimization model. It minimizes the discounted total system cost in a perfect foresight[22] approach, which means that all periods are optimized at once. The solution consists of technology deployment, production, emissions and prices. Macroeconomic feedback links are not explicitly represented.

ETP MARKAL divides the world into 15 regions and covers the time period from 2000 – 2050, with the base year calibrated to the IEA energy statistics. The energy system is represented as a network of processes that are linked by flows of energy carriers and materials, with around 1500 technology options described in terms of physical and economical parameters. GDP growth and energy demand are calibrated to the IEA World Energy Outlook 2004. Importantly, a fixed energy demand must be met by the model, which leads to a competition between energy saving and supply options, i.e. the model can reduce energy demand or invest in more supply, depending on the cost-effectiveness of both strategies.

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[20] Jointly with the Centre International de Recherche sur l'Environnement et le Développement, Paris.

[21] Most of the information of this section is drawn from Gielen and Taylor (2007).

[22] Exact knowledge of the future, i.e. the model chooses energy production and consumption options that maximise the net total welfare of the energy users and producers, given exogenous bounds on total emissions (CO2 and/or other pollutants).

Technologies are chosen in order to minimize the energy systems total cost over the whole period. The solution accounts for certain constraints, e.g. the availability of technologies, the rate of penetration or the starting capacity. Environmental policies are usually represented by a price for emissions, which increases the competitiveness of cleaner technologies.

Endogenous technology learning is not represented in ETP MARKAL, according to the authors, because of computational constraints and methodological issues. Instead a minimum quantity of renewable technology deployment is forced in via a lower bound; and investment costs are assumed to decline exogenously based on fixed learning rates and the level of deployment specified by the lower bound.

3.3. MESAP PlaNet

Schlenzig (1998) provides a detailed description of the **M**odular **E**nergy **S**ystem **A**nalysis and **P**lanning tool, which was used for the Greenpeace Energy Revolution scenarios. MESAP has been developed since 1984 at the *Institut für Energiewirtschaft und Rationelle Energieanwendung* (IER) at the University of Stuttgart, and was designed to analyse strengths and weaknesses of energy systems and to support decision making on local and international levels. PlaNet is a MESAP calculation module for the simulation and analysis of energy supply. Different predefined strategies can be explored in a recursive approach.

The Reference Energy System (RES) is the structuring principle of PlaNet. It reproduces the real topology of the energy system including the network design and all flows of goods and transformations from resources to services. Based on the RES, the mathematical simulation of future energy supply is calculated within the PlaNet-Flow and PlaNet-Cost modules.

PlaNet-Flow simulates the physical flows defined in the RES and calculates quantities of all commodities, input and output flows and energy, emission and cost balances. The PlaNet-Cost module uses the PlaNet-Flow balances to derive a detailed cost calculation: investment cost, fuel cost, O&M cost, generation cost, external cost and taxes are calculated to obtain the discounted total cost of the energy system. In addition, PlaNet-Cost calculates the capacities via the full load hours and process flows, unless the market shares of technologies are predefined exogenously.

The PlaNet-Case Manager enables to test different hypotheses on manipulable parameters, e.g. environmental policies or market shares of technologies. Thereby, the impact on dependent variables can be analysed. The PlaNet-Analyst assists in the comparison of assumptions and results from different cases and enables the creation of standardized reports.

In line with the simulative nature of MESAP PlaNet, the user is enabled to choose the market shares of competing technologies and analyse the impacts on the energy system. In the GR study, the choice of technologies is defined exogenously, although some effort to minimize the total cost of the energy system was made (Krewitt, 2008). According to the authors, likely deployment rates and potentials are taken into account, but not in a formal modeling sense.

3.4. POLES

The development of the **P**rospective **O**utlook on **L**ong-term **E**nergy **S**ystems model was funded under the EU research programme JOULE, with the main contribution of CNRS-IEPE[23], JRC-IPTS[24], Enerdata and others. The POLES model is used in the WETO and WEC scenario studies analysed here. The model has been fully operational since 1997 and is used to develop:

- Long term world energy outlooks
- Costing studies for CO_2 abatement policies, through the introduction of a shadow carbon tax
- Technology improvement scenarios with exogenous or endogenous technological change[25]

POLES is a partial equilibrium, simulation model. It simulates the evolution of the energy system in dynamic, recursive steps from 2000-2050, with lagged adjustments to prices and a feedback loop through international energy prices. The model represents 46 regions, 22 energy demand sectors and around 40 energy technologies. POLES consists of a hierarchical system of five sub modules for each region, representing:

- Final energy demand
- New and renewable energy technologies
- Hydrogen and carbon capture and sequestration technologies
- Conventional energy technologies

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[23] *Centre National de la Recherche Scientifique*, *Institute for Energy Economics and Politics*, University of Grenoble

[24] *Joint Research Centre*, Institute for Prospective Technological Studies, Sevilla

[25] Criqui (2001)

- Fossil fuel supply

The expected cost and performance data for each key technology come from the Techpol database, whereas the historical consumption, production and price data is derived from the Enerdata databases.

Technology choice is driven by a permanent inter-technology competition, with dynamically changing attributes for each technology. Investment cost is a function of cumulative capacities, and accounts for endogenous technological learning processes leading to cost reductions. POLES takes into account capacity constraints by calculating the evolution of anticipated demand, load curves and cost.

As shown in Figure 2, the electricity generation required from large scale plants (i.e. conventional fossil, nuclear and hydro generation) is calculated as the difference between total electricity consumption and the contribution of new and renewable technologies (and imports, losses and own consumption).

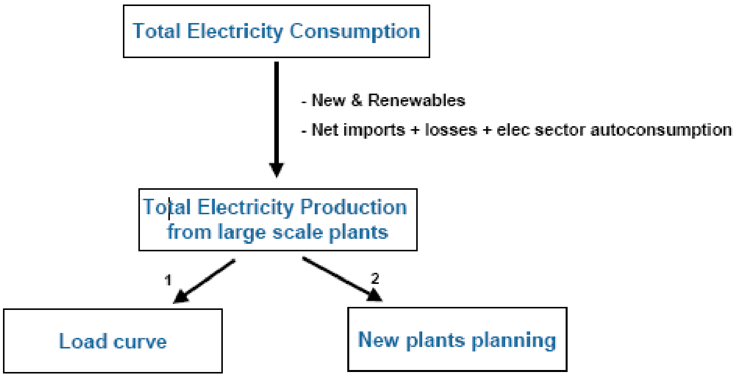

Figure 2 POLES production from large scale plants, Kitous (2006)

The new and renewables module in POLES distinguishes between technical and economical potentials, and accounts for time constants to characterize the diffusion process. An increase in cost competitiveness of a technology leads to a higher market potential and diffusion speed.[26]

Effects that are not captured with price competition can be considered through calibration variables. Thereby, technology trends and structural market share coefficients of final consumption or electricity generation capacities can be used to account for regional and sectoral differences.

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[26] Kitous (2006)

3.4.1. WEC methodology

The WEC Energy Policy Scenarios were calculated with the POLES model, but the specification of the scenario storylines followed a distinct approach. Regional groups of experts each developed four storylines[27] in terms of the *3 A's*:

- Accessibility: affordable and sustainable prices for energy services
- Availability: continuity and quality of energy services
- Acceptability: public attitudes towards the environment

Each region group thereupon produced qualitative trends for the following key indicators: growth in gross domestic product, demographic growth, energy intensity, primary energy mix, total primary energy required, greenhouse gas emissions, and supply–demand tensions for oil, gas, coal, nuclear power, renewable energy, non-commercial or traditional energy

The POLES model was applied to check the consistency of these parameters, with the WEC scenarios compared to the WETO reference case in order to check the quantification of the assumptions. The projections were finally established through an iterative process with the regional groups until global consistency was achieved. The WEC authors characterize this type of process as a modified Delphi study.

3.5. Summary

As this brief description and analysis shows, a wide range of modeling approaches are applied for the different technology deployment scenarios. One crucial distinction can be drawn in the method applied to compute the solutions. For instance, ETP MARKAL is an optimization model that seeks to determine the least cost combination of technologies and fuels over the entire modeling time horizon. In contrast, the outcomes in MESAP PlaNet are strongly determined by the user and can be based on expert judgement. The POLES and the World Energy Model are also simulation-type models with optimization of the energy technology mix in each time period, whereas in addition, in the WEO and WEC studies the models are coupled with expert judgement. These different approaches should be borne in mind to understand some of the differences in technology deployment in the scenarios, which we discuss in more detail in Chapter 5.

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[27] Combinations of low or high Cooperation & Integration and Government Engagement (cf. Ch. 2.1)

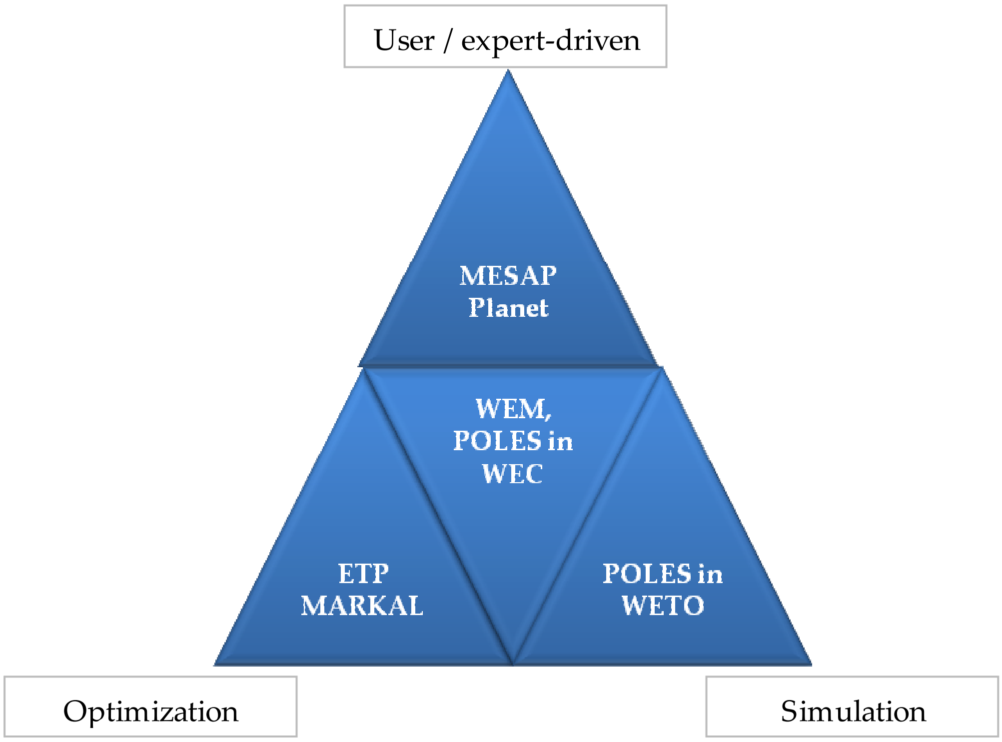

Figure 3 Modeling approaches

4. Scenario inputs affecting technology choice

The comparison of energy scenarios is structured along the modeling process. This chapter compares the modeling inputs, which include macroeconomic and technology-specific assumptions, while the results of the modeling (including technology deployment) are discussed in Chapter 5.

4.1. Key scenario drivers

The deployment of electricity generation technologies is, first and foremost, driven by demand for electricity. Accordingly, the factors driving energy and electricity demand are among the key drivers affecting technology deployment. One way to understand this quantitatively is to modify the Kaya identity[28] and to decompose electricity demand into the following key driving forces:

$Elc = P * (G/P) * (E/G) * (Elc/E)$

The total electricity demand (Elc) can be expressed as the product of four inputs: population (P), GDP per capita (G/P), final energy use per unit of GDP (E/G), i.e. energy intensity, and electricity per unit of final energy consumed (Elc/E), i.e. electrification. These main drivers are compared in this chapter. In addition, electricity intensity, as the product of energy intensity (E/G) and electrification (Elc/E), is compared across the scenarios in Section 4.1.5.

4.1.1. Population

Population growth assumptions across all studies are based on the UN *World Population Prospects*. Nevertheless, WETO assumes a considerable lower population growth, and the WEC scenarios diverge slightly after 2035 (Figure 4).

The lower expectations in WETO are not explained, but we speculate that they are based on an older UN report, since the publication of WETO dates back to 2006. WEO, ETP and GR refer to the

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[28] The Kaya identity relates the factors that determine the level of greenhouse gas emissions, and was developed by the japanese energy economists Kaya and Yokobori (1997).

UN *World Population Prospects: the 2006 Revision*, and are consistent with the medium UN version in future fertility paths. Both storylines behind WEC2ELE and WEC1LEO include low international cooperation, which leads to moderate aid for less developed areas and to higher population estimates after 2035.

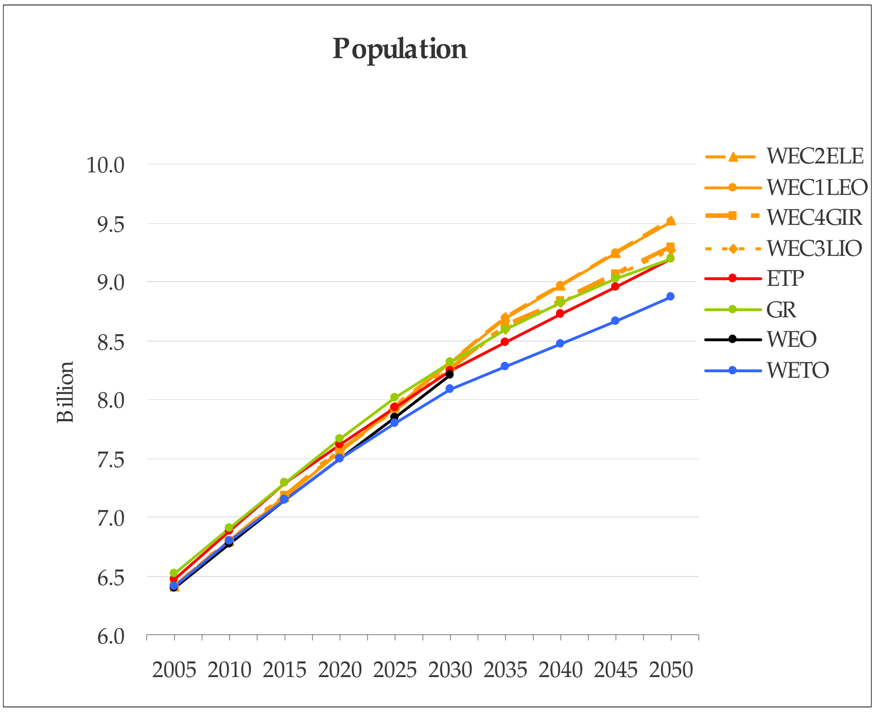

Figure 4 Population growth assumptions

4.1.2. Gross domestic product

The developments of global GDP and GDP per capita differ substantially across the scenarios, with WETO and the WEC *Low Cooperation* scenarios at the lower end of the expectations (Figures 5 and 6).

In WETO's neoclassical growth model, GDP evolves directly as an endogenous function of the population size. Therefore, the modest GDP estimates are possibly caused by the comparatively low population growth assumptions. WEO refers to the International Monetary Fund *World Economic Outlook 2007* for past rates, but relies on own assumptions for the future. Growth rates are assumed to be in average at 3.6% per year between 2005 and 2030, and decline in all regions over the projection period. Both GR and ETP calibrate their GDP assumptions explicitly to WEO. The extrapolation up to 2050 reveals in average a 0.4% higher yearly growth rate for GR, compared to ETP. The WEC storylines with low cooperation and integration, WEC2ELE and WEC1LEO, lead to the lowest GDP estimates. In comparison, in the WEC3LIO and WEC4GIR scenario, minor government engagement is assumed to lead to a free and prospering market, and therefore accelerates GDP growth.

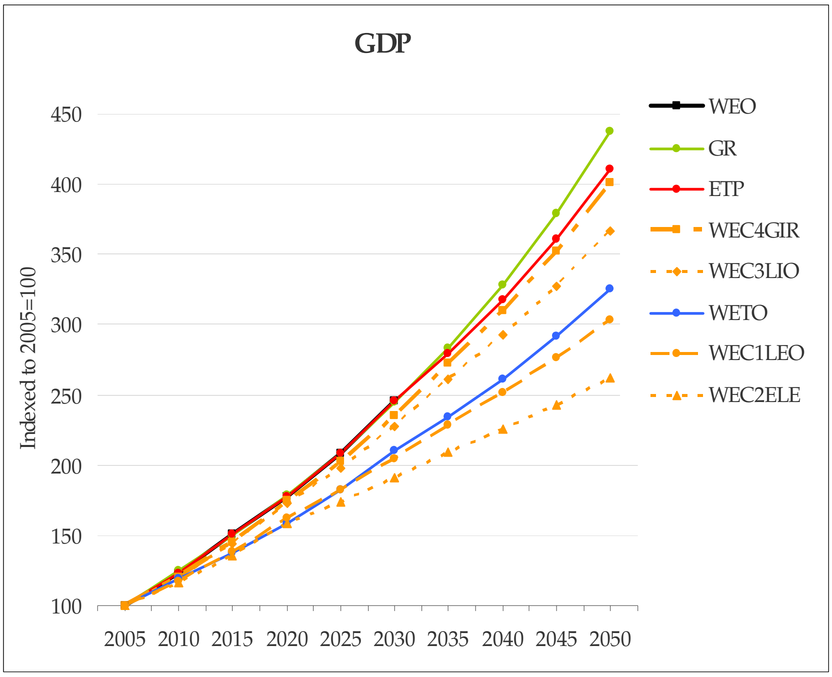

Figure 5 GDP growth assumptions

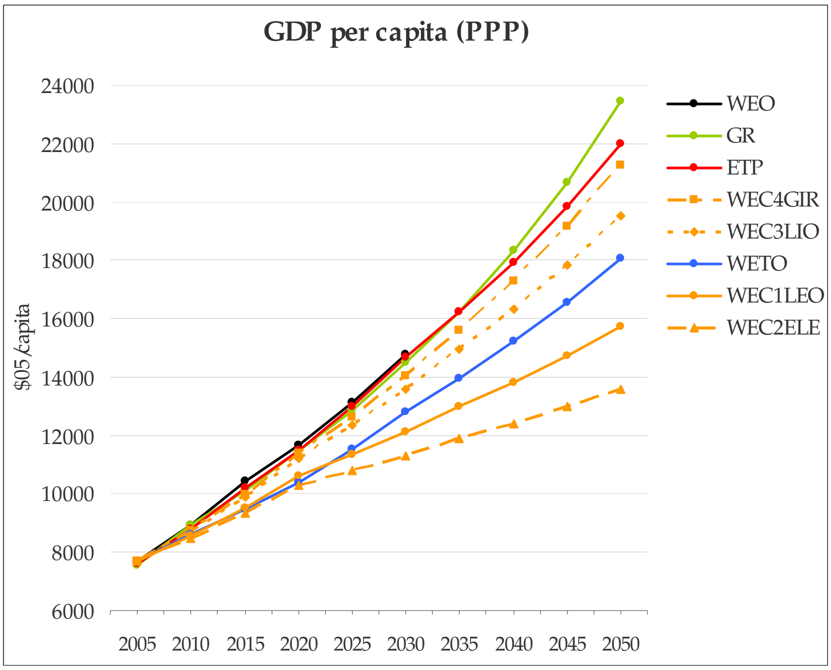

Figure 6 Global GDP per capita

4.1.3. Final energy intensity

Energy intensity represents the rate at which energy is converted to economic output, and is an inverse way of looking at the efficiency of energy use. The economic structure (particularly the role of heavy industry in the economy) and the energy efficiency of appliances, buildings or transportation all affect the energy intensity.

Final energy intensity (shown in Figure 7) is calculated as the ratio of total final energy consumption (TFC, lower chart in Figure 7) and GDP changes (Figure 5). Final energy intensity decreases across all scenarios over the time horizon, but there is a substantial divergence across the scenarios, which range from a decrease of slightly under 40% (in some of the WEC scenarios) to almost 75% (in the GRREVO scenario) by 2050. The average intensity reduction is around 55% until 2050.

Looking more closely at the scenarios, GR assumes exogenous final energy intensity reductions of 1.25% per year for GRREF, and an accelerated decrease for GRREVO[29]. This decrease is based on a study on energy efficiency potentials[30]. The most important energy saving options assumed to take place for determining the input energy demands in GRREVO are efficient passenger and freight transport, improved heat insulation and building design.

WEOREF and ETPBASE exhibit a similar moderate trend in energy intensity to GRREF until 2030 (noting that ETPBASE and GRREF are intended to follow WEOREF) – this improvement is quite close to the average of around 1% per year observed for the past century (IPCC 2000, Section 4.4.5.7). In comparison, a more rapid decrease is observed in WEOAPS which explicitly assumes efficiency improvements for energy-consuming appliances and equipment. The authors of WEO also state that energy intensity decreases more rapidly in developing and transition countries than in developed countries. A strong decrease in intensity is also seen in both ETPACT and ETPBLUE, in which energy efficiency options contribute substantially to reducing demand and CO_2 emissions. While ETPACT is characterized by large reductions in energy use in the building sector, which encompass space heating, cooling needs, lighting and electric appliances, ETPBLUE in

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[29] Greenpeace/EREC (2008), p. 54

[30] derived from a study conducted by the Dutch institute Ecofys (Harmelink et. al., 2005)

addition features significant energy savings in the transportation sector, including improved engine technologies and vehicle design[31].

Turning to those scenarios with a relatively smaller decrease in energy intensity, we see that the relatively slower GDP growth in WETO leads to more modest energy intensity reductions, with further reductions in WETOCC arising from more efficiency and behavioural changes[32], resulting in the third lowest TFC. Finally, the WEC scenarios seek to represent regulatory, economic and investment-related energy efficiency measures[33], but on a modest scale. WEC1LEO and WEC2ELE in addition assume the lowest GDP growth rates overall, consistent with less innovation and deployment of efficient technologies, thus leading to less improvement in energy intensity.

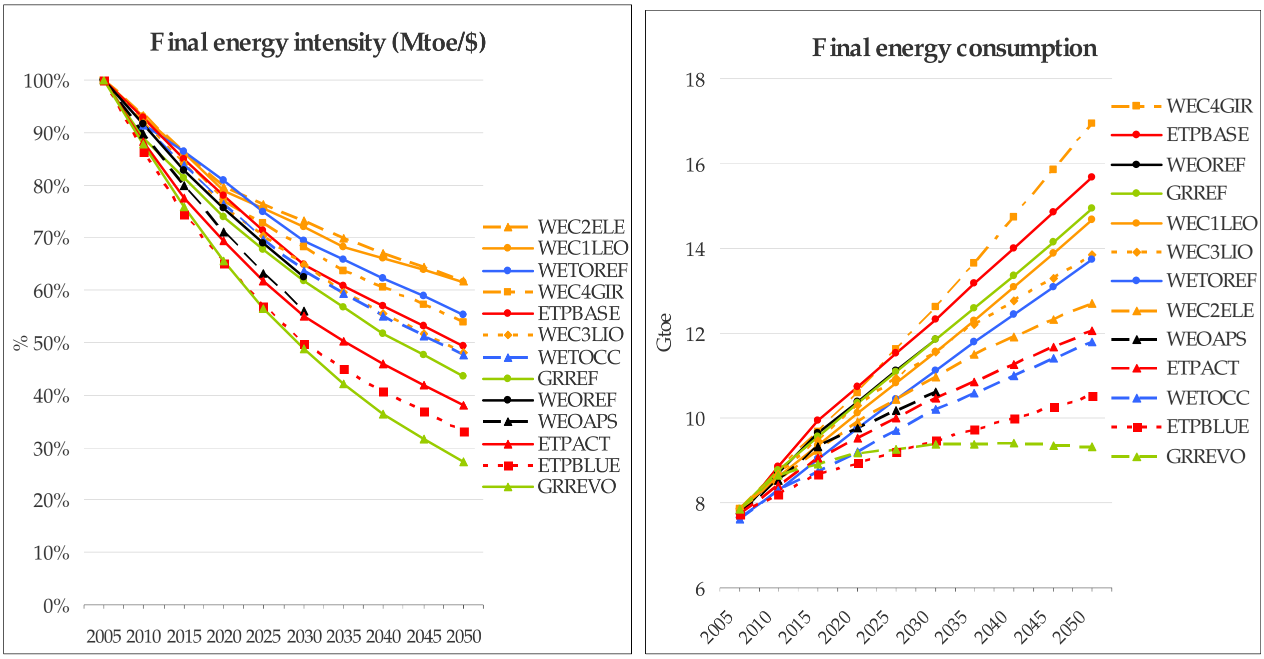

Figure 7 Final energy intensity

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[31] IEA (2008a), p. 79

[32] EC (2007), p.57

[33] WEC (2007b), p.8

4.1.4. Electrification

The deployment of technologies for the generation of electricity is determined to some extent by the relative contribution of electricity to the fuel mix. Across the scenarios, we can see some important distinctions in terms of the share of electricity in final energy consumption (Figure 8, cf. Figure 7 for the FEC).

Particularly WETO, WEC and ETPBLUE reveal a rapid increase in electrification. The increase in ETPBLUE is clearly driven by the widespread use of heat pumps, plug-in hybrids and other electric vehicles. The authors of WETO and WEC on the other hand do not refer to the triggers of this high electrification, but it is again likely to be related to assumptions about fuel-switching and potentially further electrification of transportation. No explanation is provided in the WEO report of the comparatively lower electrification in WEOAPS compared to WEOREF.

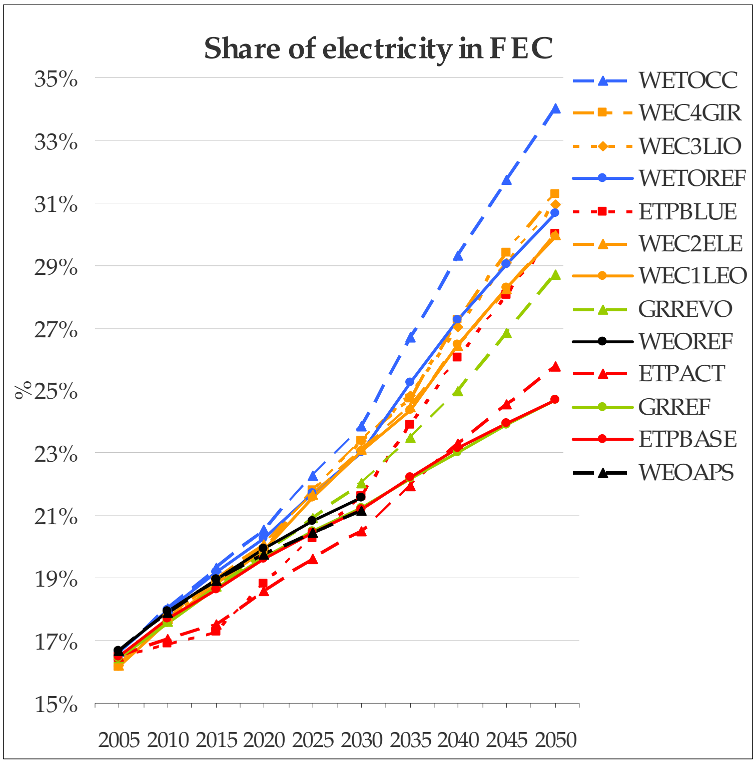

Figure 8 Electrification of final energy consumption

4.1.5. Electricity intensity

With regards to electricity intensity, which is calculated as the product of energy intensity (E/G) and electrification (Elc/E), two distinct groups of scenarios can be observed. WETO and WEC not only feature comparatively high energy intensity (see Section 4.1.3), but also higher electricity intensity (shown in Figure 9). These scenarios require more electricity, in terms of TWh, to produce one unit of GDP. The ratio does not decrease significantly at any time between 2005 and 2050, thus implying a combination of fewer measures to improve electricity efficiency and/or increasing electrification.

Conversely, ETP, WEO and GR reveal a substantial decrease in electricity intensity. In ETPBLUE and ETPACT, motor systems, appliances, lighting and cooling are reported to be given top priority. Electricity intensity stabilizes in ETPBLUE from around 2030 due to higher level of electrification (cf. Section 5.1.3). Still, end-use electricity efficiency makes a smaller contribution than end-use fuel efficiency in terms of CO_2 emission reductions.[34] The electricity savings in WEOAPS are primarily due to more efficient appliances in the residential and services sectors, whereas more efficient motors in industry contribute only marginally.

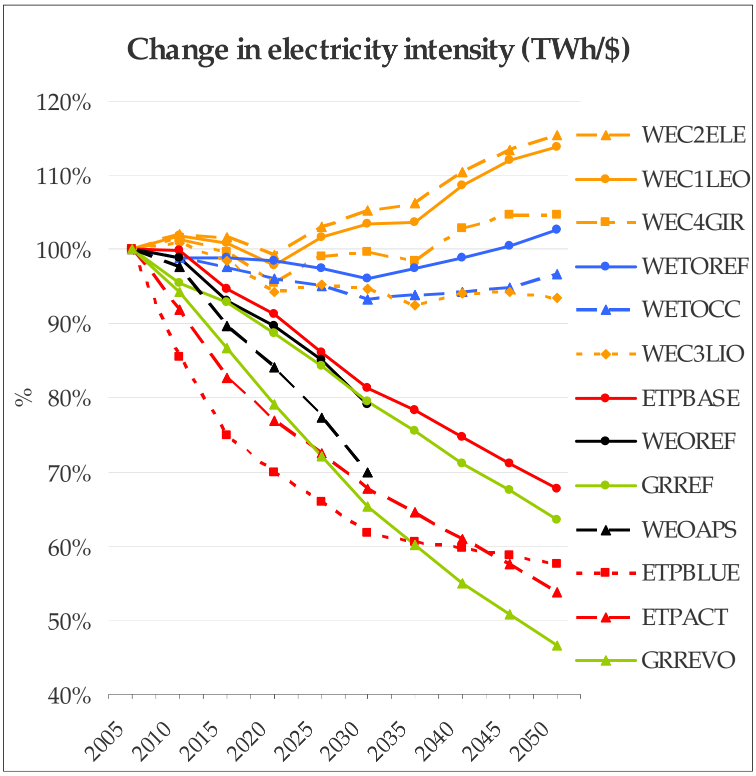

Figure 9 Changes in electricity intensity

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[34] ETPBLUE emission reductions by 2050, compared to ETPBASE: 5.76 Gt from electricity efficiency vs. 11.52 Gt from fuel efficiency.

4.2. Price assumptions

The most relevant prices that affect the energy system are compared in the following sections. While CO_2 prices are exogenously defined in all models, the fossil fuel prices depend on demand in the POLES studies (WETO and WEC), but are otherwise exogenous.

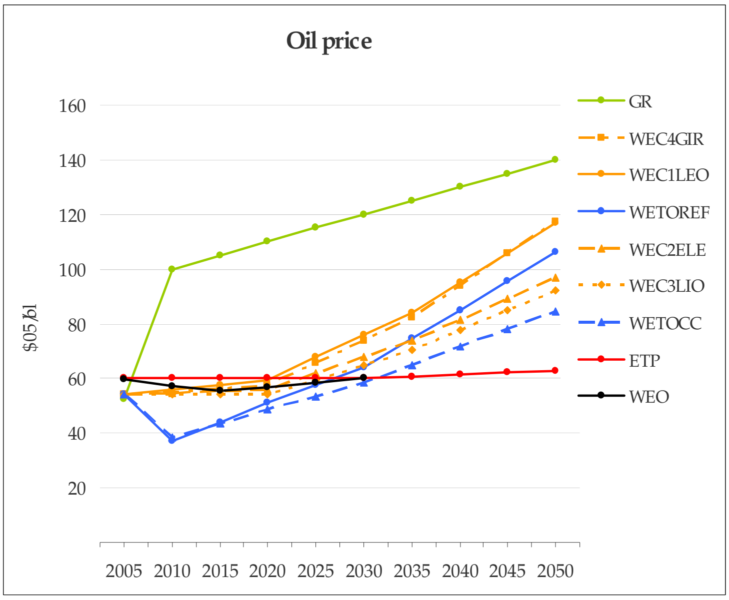
4.2.1. Oil and gas prices

In most of the scenarios the gas price is coupled to the oil price, so these fuels exhibit similar behaviour. Real prices of oil and gas increase drastically in POLES and GR, whereas WEO and ETP assume very stable prices. As a result, a wide range of perspectives on future prices is represented in the set of scenarios selected for this study (Figure 10). No evidence was found to explain the slight deviations in 2005 prices across the scenarios.

The stability in WEO, and the one in ETP, which is derived one-to-one from WEO, is hypothesized by the authors on the basis of rapid increases in oil production capacities. Moreover, the authors of WEO state that oil remains the main driver of energy prices through inter-fuel competition and price indexations. We infer that fossil fuel prices are of marginal importance in the ETP CO_2 mitigation scenarios, since their response to the lower demand in ETPACTMap and ETPBLUEMap is not reported.

Resource constraints cause a steady rise in fuel prices in WETOREF. In detail, oil production is said to peak in the short-term in non-OPEC countries and in the long-term in OPEC and Gulf countries, and results in a production plateau between 2030 and 2050. Within WETOCC, the higher carbon prices lead to lower demand for fossil fuels and to a price erosion. The lower initial values of WETO indicate that the analysis was likely committed before the prices increased sharply in 2005. Based on the same endogenous price modeling as WETO, the prices in the WEC scenarios respond to changes in demand. Therefore, the *low government engagement* scenarios WEC1LEO and WEC4GIR, with their higher GDP and final energy demands result in higher prices.

The authors of GR justify the substantial increase in oil and gas prices with the same argument of growing global demand. This study was prepared during 2008, when the oil prices peaked at close to $150/bbl. They do not explain, however, the basis for these high prices in GRREVO, in which demand for fossil fuels contracts sharply.



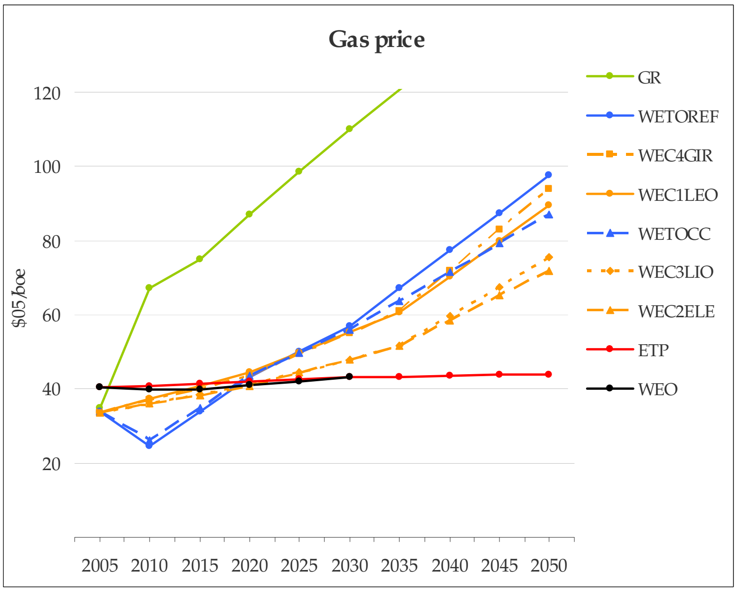


Figure 10 Oil and gas price assumptions

4.2.2. Coal prices

Similar to oil and gas prices, coal prices increase remarkably in most of the scenarios, but still, coal remains comparatively cheap compared to the other fuels (Figure 11). GR assumes again an extraordinary increase for both scenarios, while WEO and ETP presume a stable coal price over the whole projection period.

The POLES scenarios indicate roughly a doubling of the coal price, taking into account the vast coal resources and policy interventions through CO_2 prices. The coal prices for WETOCC are somewhat lower, since coal trade is reduced four-fold compared to WETOREF after 2030.

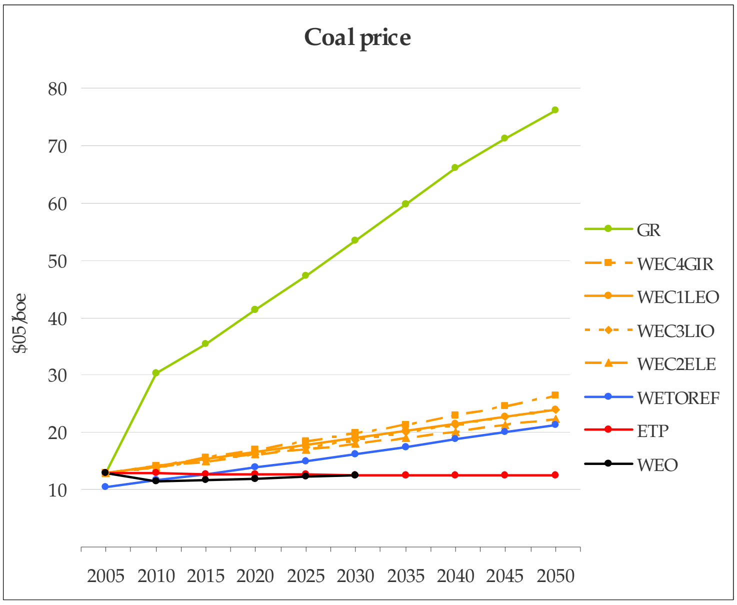


Figure 11 Coal price assumptions

4.2.3. CO_2 prices

As discussed earlier, the scenarios examined in this study include some that do not consider any additional climate change mitigation policy beyond the one adopted until mid-2007 (e.g. WEOREF or ETPBASE), and others that assume moderate to strong emission targets, which are achieved with CO_2 prices. Among those studies that consider a CO_2 price, a wide agreement prevails that prices rise towards \$50/t CO_2 in 2050 (Figure 12)[35]. Substantially higher prices are assumed in ETPBLUE and WETOCC, which require high exogenous carbon prices in order to achieve the emission reductions.

The WETO assumptions vary by region to represent different levels of obligation, and imply early action by Annex-B countries[36]. Also ETP considers a time lag for the implementation of CO_2 prices in developing countries (Gielen, 2008).[37] GR on the other hand achieves the emission reduction

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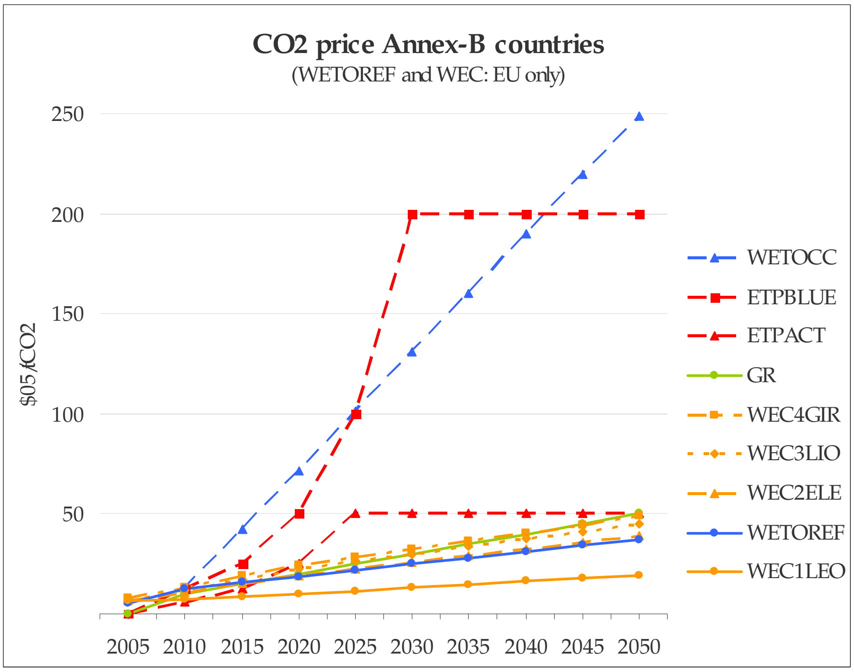
[35] Which is a significant increase compared to the current price level of European emission allowances, which are traded at around \$15/t CO_2 in the first quarter of 2009.

[36] Defined as the 39 emissions-capped industrialised countries and economies in transition, listed in Annex B of the Kyoto Protocol.

[37] In addition, ETP considers the case that carbon-capture-and-storage is not available, which leads to CO2 prices of up to \$394 to achieve the emissions targets in ETPBLUE.

from GRREF to GRREVO through mechanisms other than price, since the CO_2 prices are assumed to be identical for both scenarios. The WEC scenarios imply moderate CO_2 prices, while the WEO scenarios do not consider any incentive levels at all.



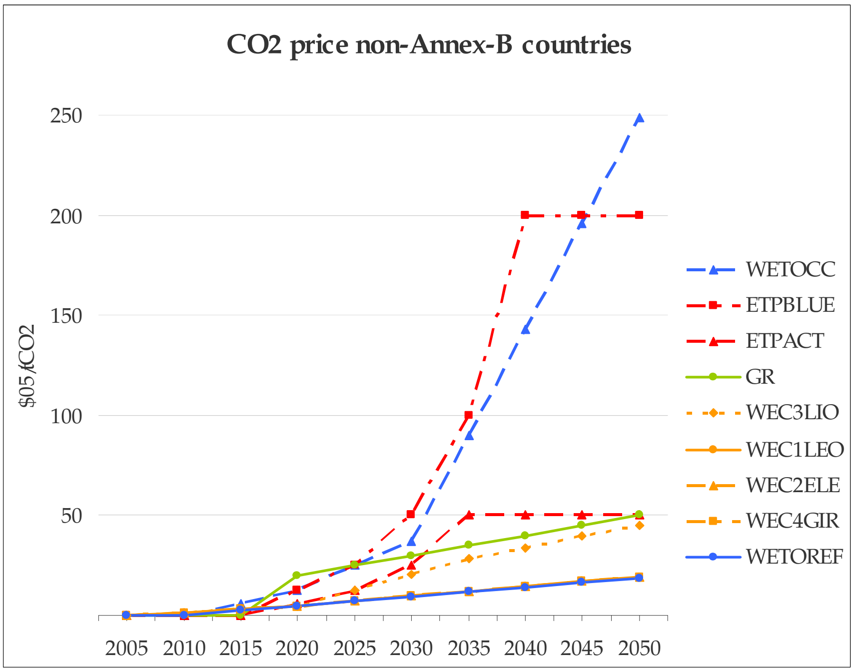


Figure 12 CO_2 price assumptions

4.3. Technology assumptions

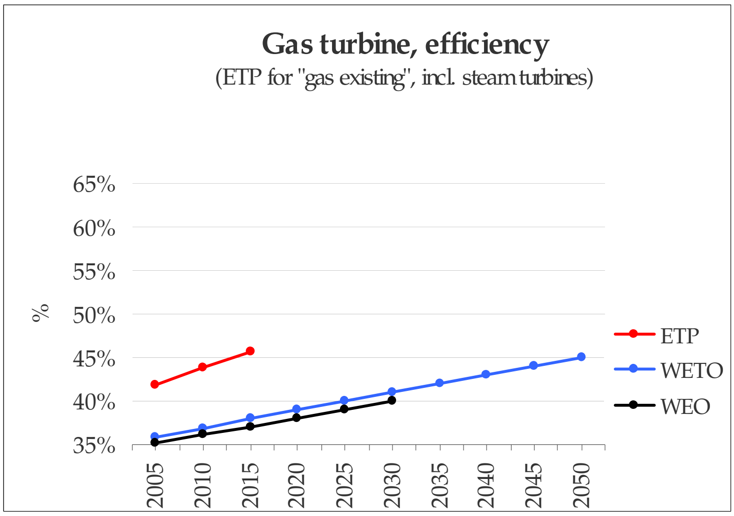
To obtain qualitative indications on the competitiveness of certain technologies within a scenario (summarized in Section 4.3.6), the available technology assumptions are analysed with respect to their impact on the levelized cost of electricity (LCOE). As described in Section 2.3, only the most relevant parameters affecting the LCOE are compared for each technology, since the available data does not allow for a proper calculation and comparison of the actual LCOE.

4.3.1. Gas-fired technologies

The main factors affecting the levelized annual fuel cost are compared in Figures 10 and 13. Gas price assumptions appear to be decisive for the deployment, since thermal efficiencies are relatively similar in all models. Thus, the levelized fuel cost is lowest in WEO and ETP, and highest in GR, ceteris paribus.

The strongly increasing gas prices in WETO, WEC and GR, as shown in Figure 9, reduce the competitiveness of gas-fired plants. The deployment in GR however is led by user-defined market shares of certain technologies, and therefore not necessarily dependent on cost assumptions. See Section 4.2.1 for a further discussion of gas prices.

Thermal efficiencies for gas turbines and combined cycles powerplants increase similarly across all studies. The extraordinary high gas turbine efficiency in ETP is likely due to the fact that these values represent all existing gas plants, including more efficient steam turbines. In addition we see some initial divergence in gas combined cycle efficiency, particularly in the WEO and GR scenarios. Some similar results are observed below for other technologies, and we can speculate that these differences as early as 2005 are related to the choice of statistics used to calibrate the models, differences in calibration years, limited data availability for many countries, and potentially different technology definitions.



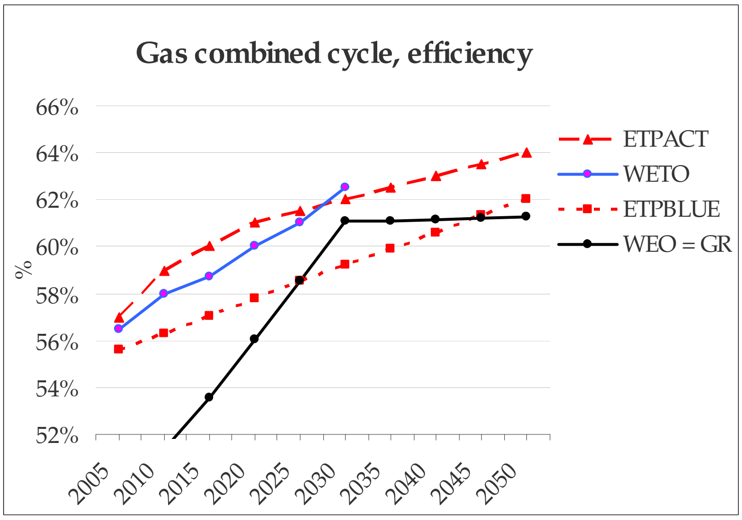


Figure 13 Gas-fired technologies, efficiencies

4.3.2. Coal-fired technologies

As discussed above, levelized investment cost appears to be a relevant factor for the deployment of coal-fired generation technologies. Figure 14 compares the investment cost for a range of coal-fired technology options represented in the various scenarios. Based on this data, levelized investment cost is expected to be lowest in WEO, ceteris paribus, although differences in discount rates and plant lifetimes (for which data were not available) could alter this evaluation.

The POLES studies, WEC and WETO, have among the highest capital cost for coal-fired generation, at least in the long-term. Interestingly, the starting value for IGCC differs between them, even though both studies refer to the TECHPOL database. Investment cost assumptions for advanced coal technologies reveal an accelerated decline in ETP, which is more optimistic about technology development and learning. Conversely to the other studies, WEO assumes a decline only after 2015.

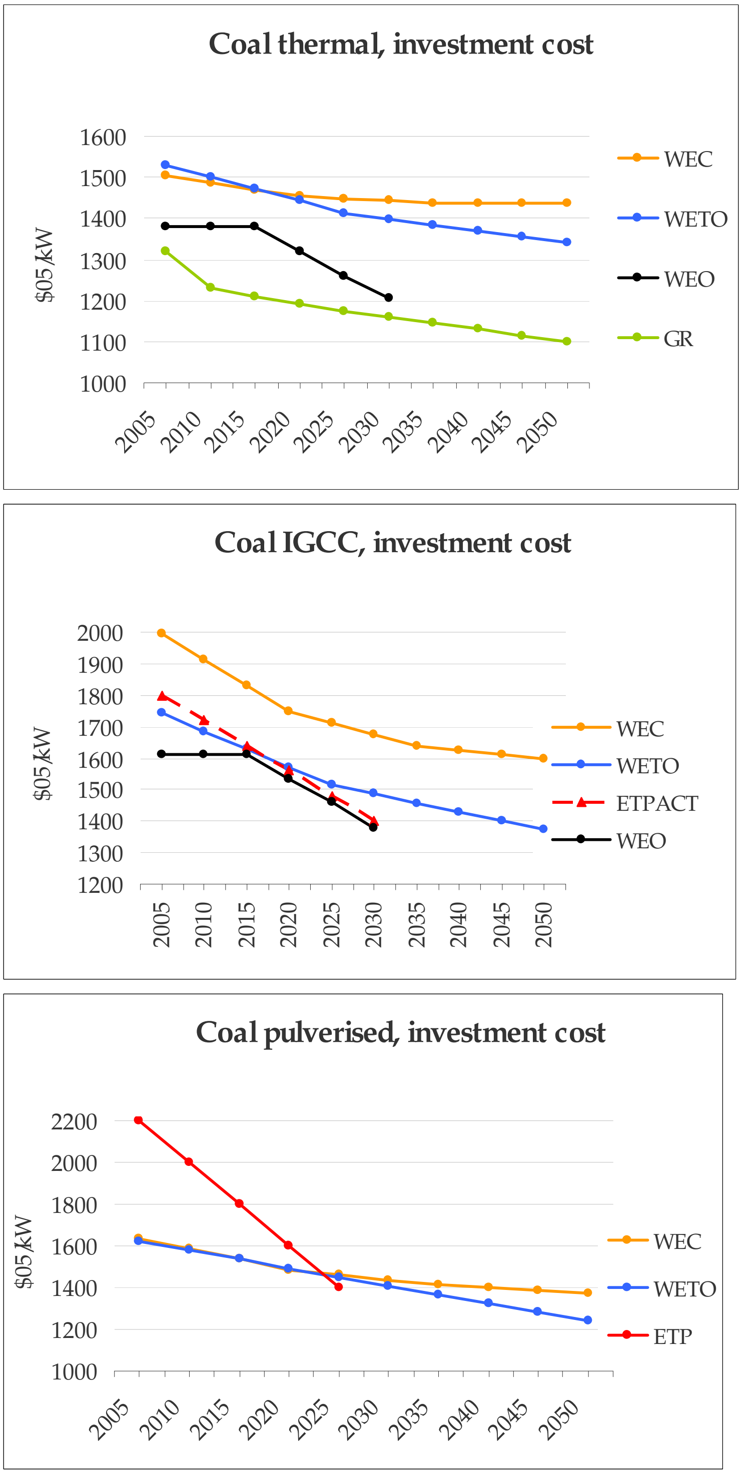


Figure 14 Coal-fired technologies, investment cost

The other important factor for overall LCOE of coal technologies is the levelised fuel cost. For each of the scenarios, this is determined by the fuel price and efficiency assumptions. Based on the available data, the levelized fuel cost is lowest in WEO, which combines stable coal prices (see

Section 4.2.2) and increasing efficiencies (Figure 15). At the other end of the range, Figure 11 shows that coal prices are much higher in GR, WETO and WEC scenarios. The direct comparability of these studies, however, is limited by the missing data on efficiencies of WEC and the simulative character of GR. Nonetheless, even with extremely optimistic assumptions on efficiency, WEO and ETP still have the lower levelized fuel cost.

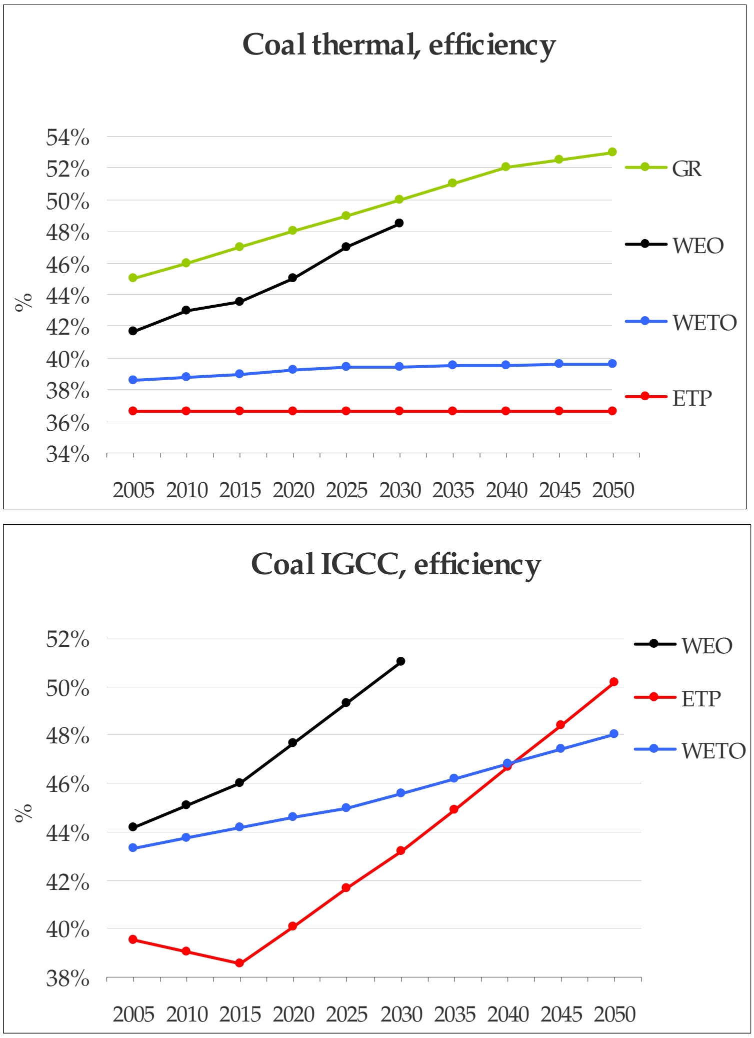


Figure 15 Coal-fired technologies, efficiencies

4.3.3. Nuclear technologies

The competitiveness of nuclear technologies is strongly dependent on the levelized annual investment cost. This cost component is expected to be lowest in WEO, based on the low investment cost and the high capacity factors[38] (shown in Figures 16 and 17). Levelized investment cost is comparatively higher in WETO, WEC and ETP, where both higher investment cost and lower capacity factors are assumed. Cost discussions are not relevant in GR, due to the simulated phasing out of nuclear energy.

The comparison of capacity factors in Figure 16 reveals that the scenarios use assumptions falling within a range between 80 and 90 percent. The highest capacity factors are seen in WEO and WETO, whereas the capacity factors are lower for all WEC scenarios. No evidence can be found to explain the slight decline in WEC, nor why all WEC scenarios experience a similar decline. The increases, particularly the step in ETPBASE, coincide with the deployment of advanced nuclear technologies after 2030, which operate with higher full load hours. The fact that capacity factors differ across the scenarios for 2005 is an interesting finding itself. Obviously the studies are not based on the same statistical data.

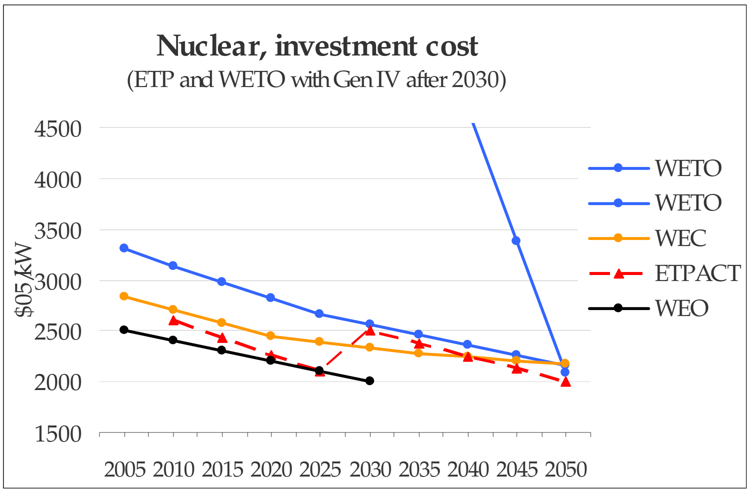


Figure 16 Nuclear plant, investment cost

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[38] Capacity factors represent the ratio between actual power plant output and the output if the plant were assumed to have operated at full capacity.

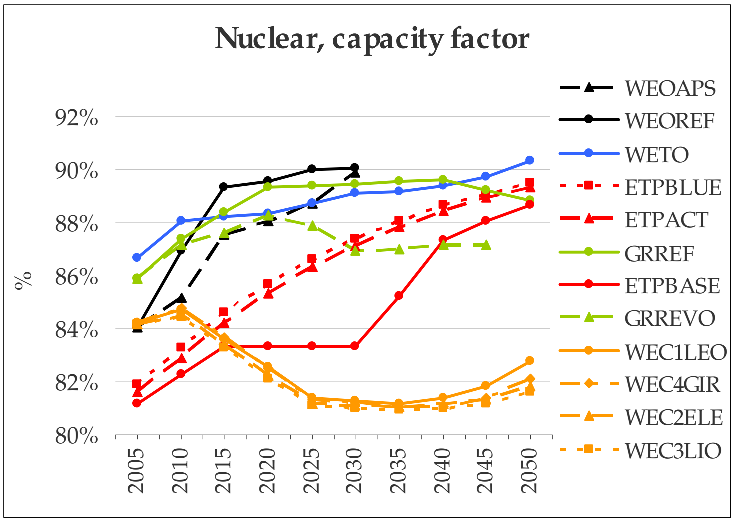

Figure 17 Nuclear plant, capacity factors

4.3.4. Renewable technologies

Levelized annual investment cost clearly accounts for the largest share in LCOE of renewable technologies. The subsequent discussion focuses on specific investment cost and capacity factors, due to the availability of only limited information on discount rates and plant lifetime assumptions. It can be highlighted that GR features the highest initial investment cost assumptions across all technologies except for Solar PV, and WEO uses comparatively low levelized investment cost for most of the renewables.

Wind

Figure 18 reports investment cost across the scenarios for onshore wind plants. From this information, levelized investment cost is estimated to be relatively low in WEO, based on low investment cost and stable capacity factors, and seems to be highest in WETO and WEC, due to lowest capacity factors and the second highest investment cost. The low investment cost in ETP, combined with the higher capacity factors, is likely to result in an average levelized investment cost.

Apparently, the investment cost assumptions move towards a similar floor cost, except for GR, but start at different initial values. The deviation in starting costs may appear surprising, but must reflect variations in sites, country, material costs or technology specifications - however, no explanation is provided in the scenario studies.

The comparison of capacity factors in Figure 19 displays a high agreement in the long term, but deviations in the time path. WEO assumes stable capacity factors, whereas they increase in WEC and WETO and decrease in ETP. The published reports themselves provide no explicit explanation of this variation. We can speculate that the capacity factor decreases in ETP because the authors have assumed that the best sites with high wind speeds are used first, while the increasing capacity factors in the WEC and WETO scenario studies are possibly due to assumptions about technological improvements.

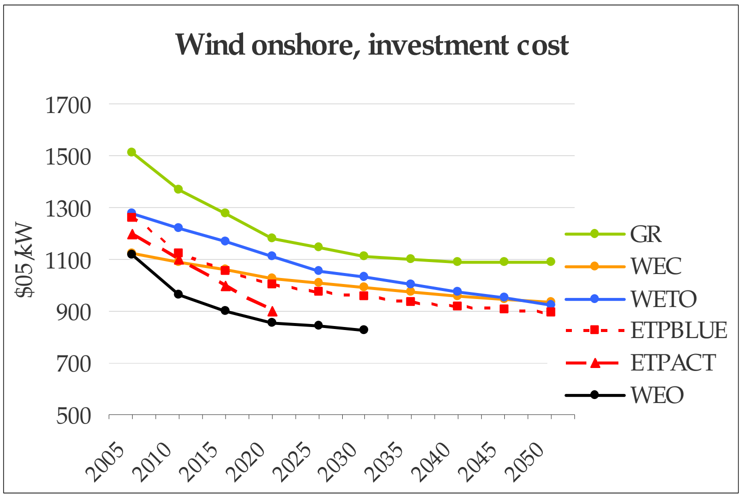

Figure 18 Wind onshore plant, investment cost

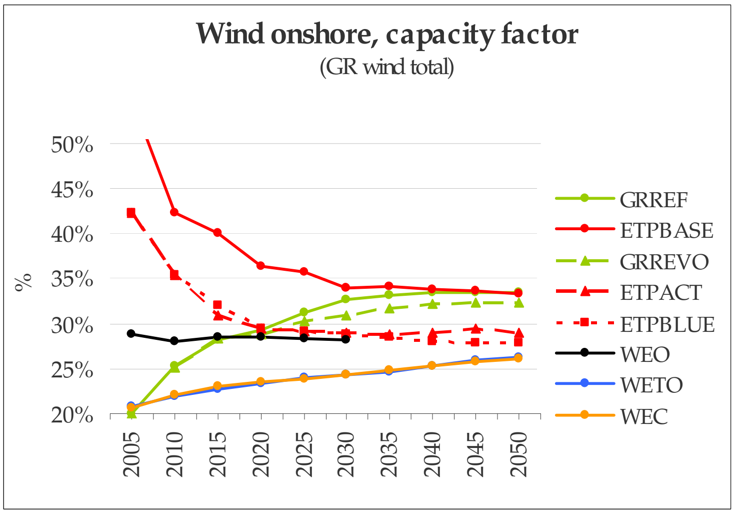

Figure 19 Wind onshore plant, capacity factors

Similar conclusions can be drawn for offshore wind plants: levelized investment cost is likely to be lowest in WEO again, and possibly on a similarly medium level in the other studies, which all assume both initial investment cost and capacity factors to be either high, in case of ETP, or low, in case of WETO and WEC (Figures 20 and 21).

The development of capacity factors in Figure 21 resembles the one for wind onshore, except for the substantially higher assumptions in WEO. Conversely, the comparison of investment cost assumptions indicates larger uncertainties than for onshore wind plants.

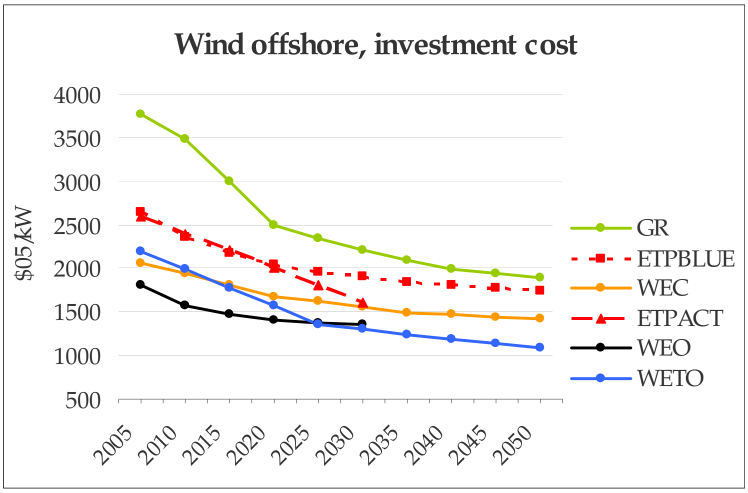

Figure 20 Wind offshore plant, investment cost

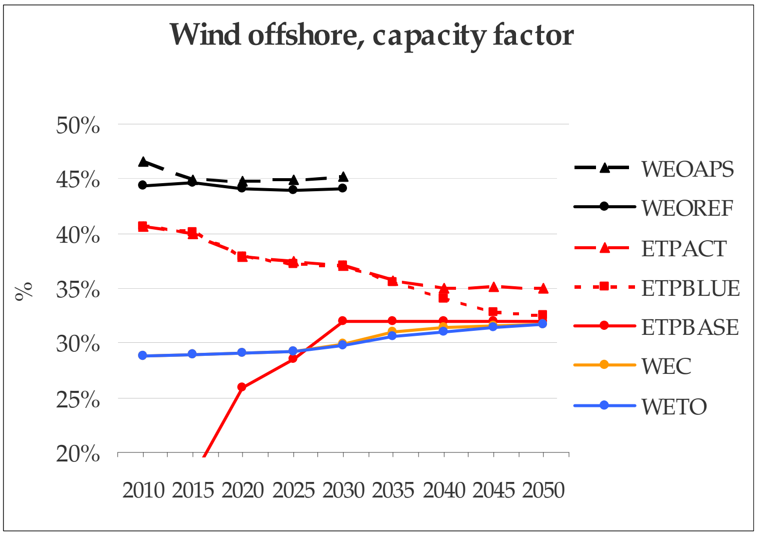

Figure 21 Wind offshore plant, capacity factors

Solar

Investment costs and capacity factors for solar PV generation are presented in Figures 22 and 23. Levelized investment cost for solar PV is likely to be lowest in ETP, which incorporates very optimistic capacity factors, and GR, which assumes a low specific investment cost. WETO and WEC by contrast have a rather high levelized investment cost, since the specific investment cost is high and the capacity factors are the lowest among all the scenarios.

Specific investment costs decrease to similar values across all studies by 2050, with the exception of WETO and WEO (see Figure 22). The differing initial values among the ETP scenarios are not explained by their authors, but definitely increase the competitiveness of solar PV in ETPBLUE.

The capacity factors in Figure 23 show a surprising variation for the current values today - again, no explanation is provided for this in the scenario studies. This variation is maintained through the projection period, , and thus the studies appear to apply the same trends with an increase of around 3 to 4 percentage points by 2050.

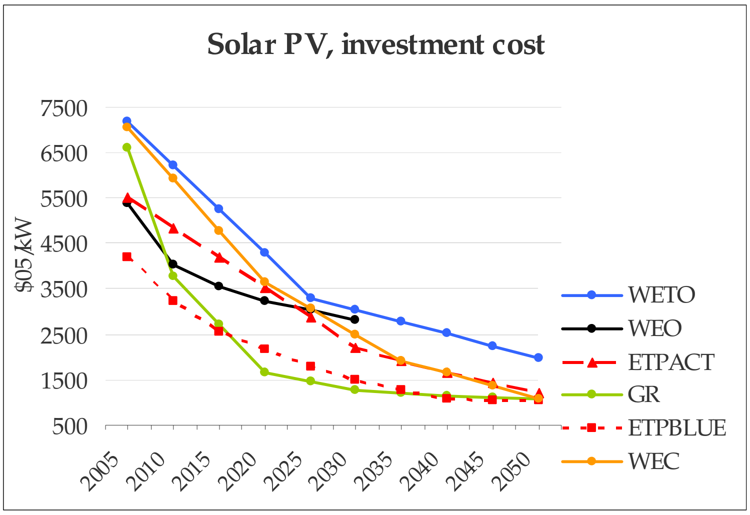

Figure 22 Solar PV, investment cost

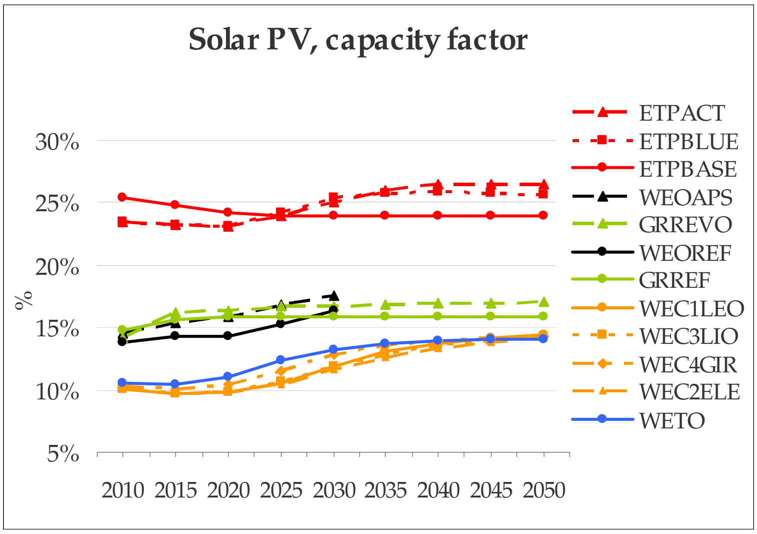

Figure 23 Solar PV, capacity factors

Solar thermal power plant investment costs and capacity factors are presented in Figures 24 and 25. Based on the data in the figures, the levelized investment cost of solar thermal power plants seems to be lowest in ETPBLUE, which is characterized by the lowest initial investment cost and a relatively high capacity factor. Also WEO appears to assume modest levelized investment cost, whereas GR assumes medium levelized investment cost, due to the high estimates for both parameters.

Different starting values in the initial investment can be observed again for the ETP scenarios[39]. GR reveals surprisingly high assumptions for both investment cost and capacity factor. The capacity factors are absolutely identical for WEC and WETO, and in the same range for all the other studies except for ETPBLUEMap.

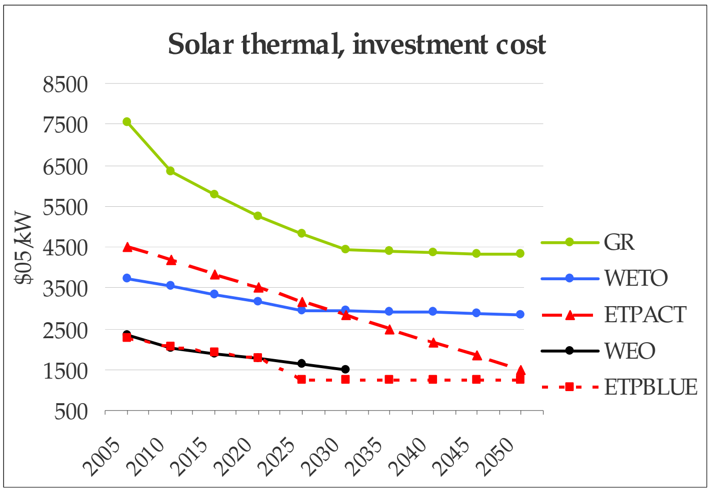

Figure 24 Solar thermal plant, investment cost

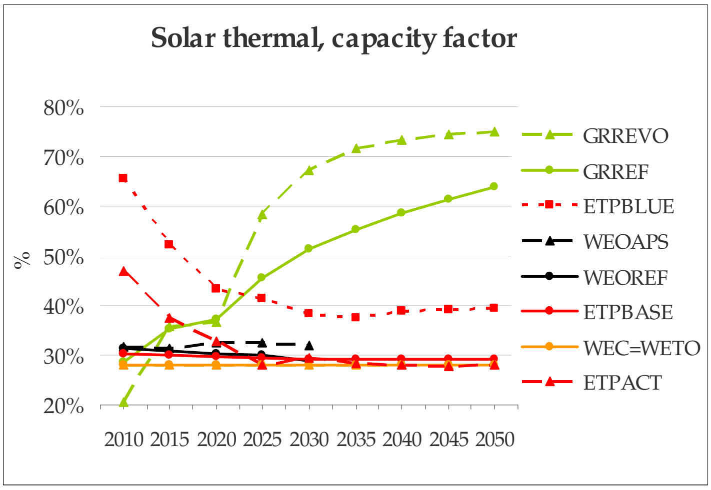

Figure 25 Solar thermal plant, capacity factors

Hydroelectric generation

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[39] The linear decrease in ETPACTMap is due to the rough interpolation over the whole projection period.

A wide range of hydroelectric investment cost is reported in the various studies, as shown in Figure 26. For large scale hydro plants, the levelized investment cost appears to be lowest in ETP, although the available cost and capacity parameters come from different ETP scenarios. By contrast, WETO and in GR likely feature the highest levelized investment cost share.

The authors of GR explain their assumption of an increasing cost on the basis of limited economical potential; in other words, the better sites are exploited first, leaving only more expensive options later in the century. In contrast to the GR assumptions, WETO reports decreasing specific investment cost without further explanation (although one could assume this is related to assumptions about technological progress).

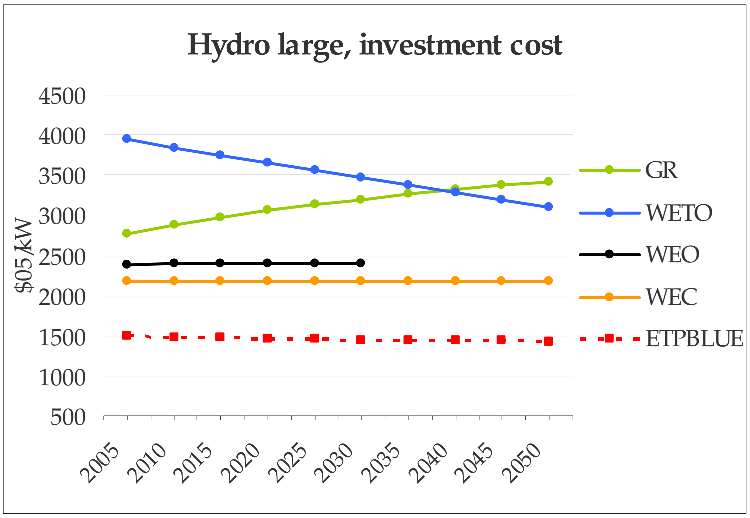

Figure 26 Hydro large scale plant, investment cost

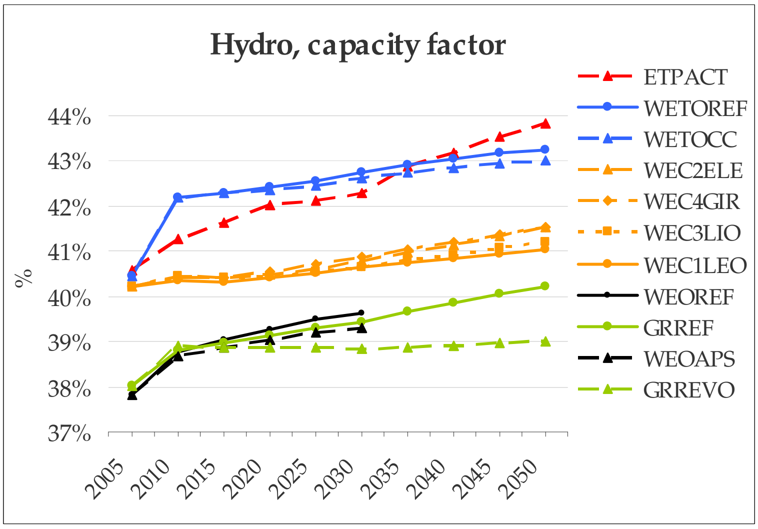

Figure 27 Hydro plant, capacity factors

4.3.5. Carbon capture and storage (CCS)

The scenario studies only report very limited information about their assumptions for carbon capture and storage (CCS) technologies. For instance, in the GR scenarios CCS is not deployed at all in GR, based on the authors view that this technology is unattractive due to risks of leakage at the storage site, late commercial deployment, residual CO_2 emissions at the plant, and high costs, with the GR report estimating a doubling of the generation cost[40]. CCS is also not used in the WEOREF and WEOAPS scenarios, most likely due to missing CO_2 price incentives[41].

The additional cost of installing CCS equipment is shown for selected coal and gas-fired power plants in Figure 28. In WETO, the levelized cost of CCS appears to be cheaper for gas-fired plants if we assume high capacity factors: investment and O&M cost, as well as the efficiency losses (see Figure 29) are lower than for coal-fired plants This further increases the spread between efficiencies of gas- and coal-fired plants (cf. Figures 13 and 15). The few data points for ETP perhaps indicate more optimistic investment cost for CCS in coal-fired plants and a higher efficiency loss in gas-fired plants in 2050.

It remains unclear to what extent cost drivers such as transport and storage cost, or additional fuel cost are incorporated into this data. The *IPCC Special Report on CCS* (Metz et. al., 2005*)* claims that the CCS process requires a considerable amount of energy and would therefore increase the fuel cost of a plant by about 25% for coal-fired and about 15% for gas-fired plants. These and other system cost are estimated to increase the cost of energy from a new power plant with CCS by 21-91%.[42]

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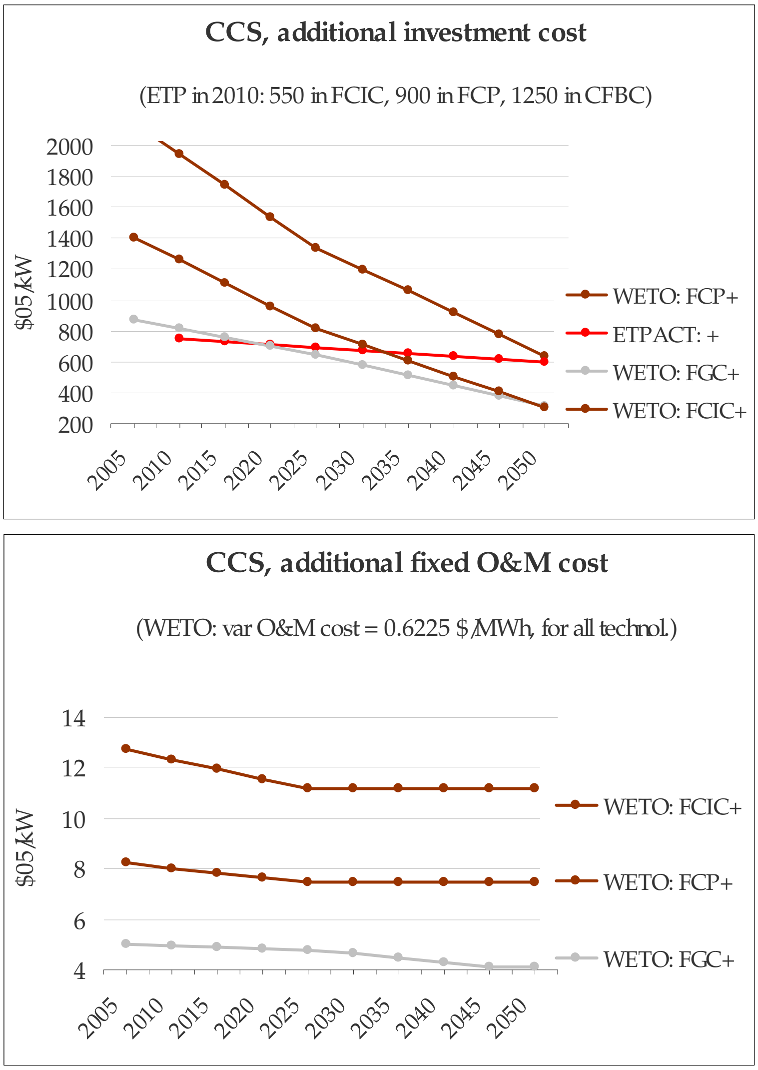
[40] Greenpeace, EREC (2008)

[41] However, CCS is deployed in the WEO *450 Stabilisation Case*, which is not assessed in this paper due to the non-disclosure of data.

[42] For useful information see also www.zero-emissionplatform.eu


CCS, additional investment cost

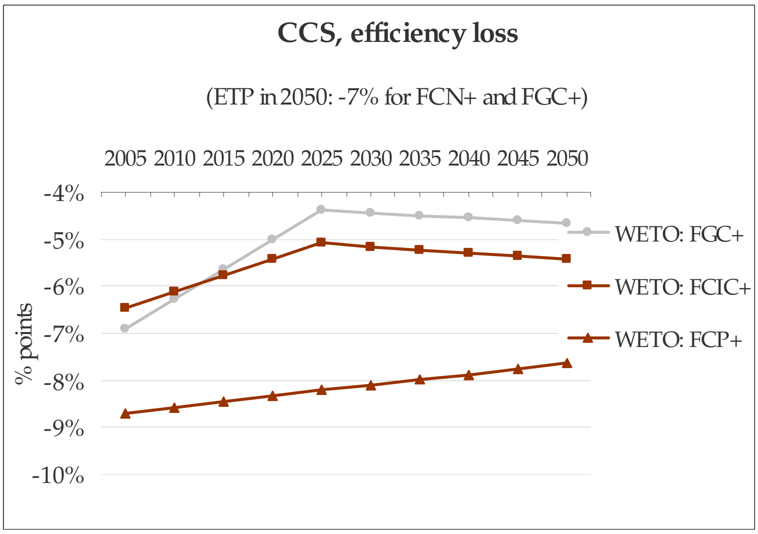
(ETP in 2010: 550 in FCIC, 900 in FCP, 1250 in CFBC)

CCS, additional fixed O&M cost

(WETO: var O&M cost = 0.6225 $/MWh, for all technol.)

Abbr.	**Technology**
+	CCS
FCIC+	Coal Integrated Gasif. Comb. Cycle with CCS
FCN+	Coal New with CCS
FCP+	Coal supercritical pulverised with CCS
FGC+	Gas turbine combined cycle with CCS

Figure 28 CCS, additional cost


CCS, efficiency loss

(ETP in 2050: -7% for FCN+ and FGC+)

Figure 29 CCS, efficiency losses

4.3.6. Cost competitiveness of technologies across the scenarios

Table 3 summarizes the preceding discussion of the relevant levelized cost components.For each group of technologies, the available data was used to estimate the most important cost components, implicitely assuming identical values for the unknown data (ceteris paribus). This qualitative comparison provides insights into the variability of cost assumptions across the studies, and does not necessarily explain the deployment of each technology within one study, since this depends on the interplay of parameters.

Nevertheless, we are able to use the cost data of the studies as the reference of what constitutes a high, low or medium cost for different technologies in 2030. For example, looking at nuclear power generation in WEO, low investment cost and high capacity factors lead to a comparatively low levelized investment cost, assuming that other parameters are identical across the studies. In addition, conclusions within each study of whether particular technologies may be favoured by more optimistic assumptions can be drawn: WEO appears to use comparatively low cost assumptions for renewables, while WETO operates with high cost estimates. GR finally is characterized by uncommonly high cost assumptions for fossil-fired technologies.

Table 3 Relative magnitude of LCOE components

		ETP	**GR**	**WEC**	**WEO**	**WETO**
Gas	Lev. ann. fuel cost	low	high	medium	low	medium
Coal	Lev. ann. fuel cost	medium	high	medium	low	medium
Nuclear	Lev. ann. investment cost	medium		medium	low	medium
Wind onshore	Lev. ann. investment cost	medium	medium	high	low	high
Wind offshore	Lev. ann. investment cost	medium	high	medium	low	medium
Solar PV	Lev. ann. investment cost	low	medium	high	medium	high
Solar thermal	Lev. ann. investment cost	medium	medium	high	low	high
Hydro	Lev. ann. investment cost	low	high	medium	medium	high

This provides an interesting view on the different perspectives on the future economic characteristics of different technology options. Clearly, there is uncertainty regarding future cost and performance of different technologies, given uncertainties about the pace and direction of technological development and change, and future fuel availability and price. Scenario studies provide a means to explore such uncertainties, and the range of perspectives identified here shows, to a certain extent, that the scenario literature goes some way towards surveying possible future technology landscapes.

5. Technology deployment

The scenario outcomes are discussed in this chapter, focusing on technology deployment. At first, aggregate indicators on energy and electricity use are compared in Section 5.1. The disaggregated deployment of the most relevant power generation technologies follows in Section 5.2, and is discussed in relation to the scenario inputs identified in the previous chapters. In this way, the chapter identifies key differences in technology deployment and the factors affecting the deployment in the different scenarios.

5.1. Aggregate indicators

Aggregate modeling outputs are compared in the following sections. Primary energy supply (discussed in Section 5.1.1) is understood as a result of the assumed final energy consumption and the available conversion technologies to produce final energy. CO2 emissions (Section 5.1.2) are then caused by the primary energy mix. Sections 5.1.3 and 5.1.4 finally present the total electricity generation, which is one type of final energy, and its shares of fossil, nuclear and renewable sources across the scenarios.

5.1.1. Total primary energy supply

A wide range can be observed for the total primary energy supply (see Figure 30). GRREVO, which assumes a full exploitation of efficiency potentials, results in an unchanged TPES in 2050 compared to 2005, while the TPES in WEC4GIR more than doubles. Some of this divergence can be understood by considering the differences in economic growth across the scenarios (see Section 4.1.2); however other factors are also important.

For example, the decline in TPES in GRREVO after 2020 occurs to a large part because of assumptions on energy intensity (see Section 4.1.3) leading to final energy demand increasing only 28 percent from 2005 to 2050. However, the resulting change in TPES in GRREVO even exceeds this potential. The modest increases in TPES in ETPACT and ETPBLUE are driven by energy efficiency and fuel-switching; total demand for fossil fuels in ETPBLUE in 2050 is 13% below the level of 2005.

Conversely, the higher economic growth in WEC4GIR drives the large increase of TPES in this scenario, with only moderate improvements in energy intensity (see Section 4.1.3). Similarly, the lower economic growth in WEC2ELE, coupled with high policy concerns on energy efficiency, leads to considerably lower TPES. The other WEC scenarios are within the common range of the reference scenarios, but include a dampening of TPES in WEC3LIO, which reflects policy concerns on efficiency and emissions.

WEOREF is used to calibrate ETPBASE and GRREF until 2030, according to the authors of the studies. The extrapolation beyond 2030 out to 2050 yields a lower TPES for GRREF compared to ETPBASE, which may be due to the assumed constant reduction of final energy intensity of 1.25% on average per year in GRREF. The gap between WEOREF and WEOAPS grows remarkably over the projection period, as capital equipment can be replaced by more efficient technologies. WETOREF is comparable to the other reference scenarios with respect to the trend, but starts on a slightly lower level. This discrepancy might be due to the fact that final energy consumption is explicitly depending on income. Hence, the lower population growth assumption possibly contributes to this shift towards a lower TPES. WETOCC on the other hand appears to respond immediately to the higher CO2 prices. This leads to a modification of demand towards more efficient energy use.

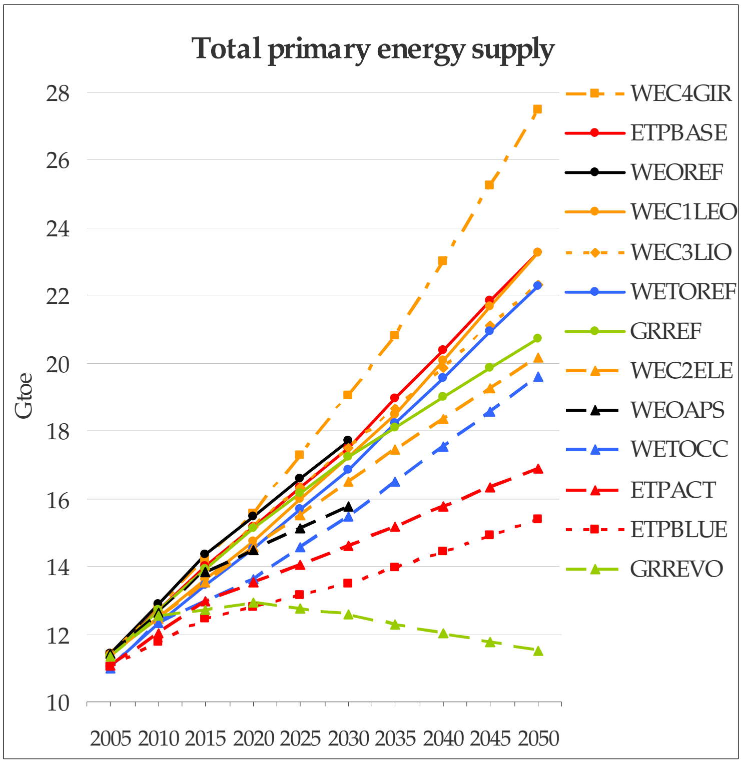


Figure 30 Total primary energy supply

5.1.2. CO_2 emissions

An immense spread characterizes the comparison of the resulting total CO_2 emissions of the entire energy sector in Figure 31. While GR, ETP and WETO investigate emission constraints, WEO and WEC follow no explicit emission targets.

GRREVO considers the most ambitious emission target, with a 50% reduction of the 1990 emissions level by 2050. Similarly, ETPBLUE aims at halving the 2005 emissions level by 2050, which is estimated by the ETP authors to stabilize the atmospheric concentration of CO_2 at 450 ppm, compared to today's 385 ppm. A less stringent emission target is assumed for ETPACTMap and WETOCC, which require emissions in 2050 to return to the 2005 level. Still, this implies a 50% reduction for annex-B countries in WETOCC.

All baseline scenarios lead to unsustainable paths with regards to climate change, since emissions grow by a factor two to three until 2050. The stabilization of emissions in WEC3LIO and WEC2ELE reflect the comparatively low TPES and the increasing share of non-fossil energy. WETOREF incorporates stable emissions for industrialized countries, but the three-fold increase of emissions from developing countries leads to increasing global emissions.

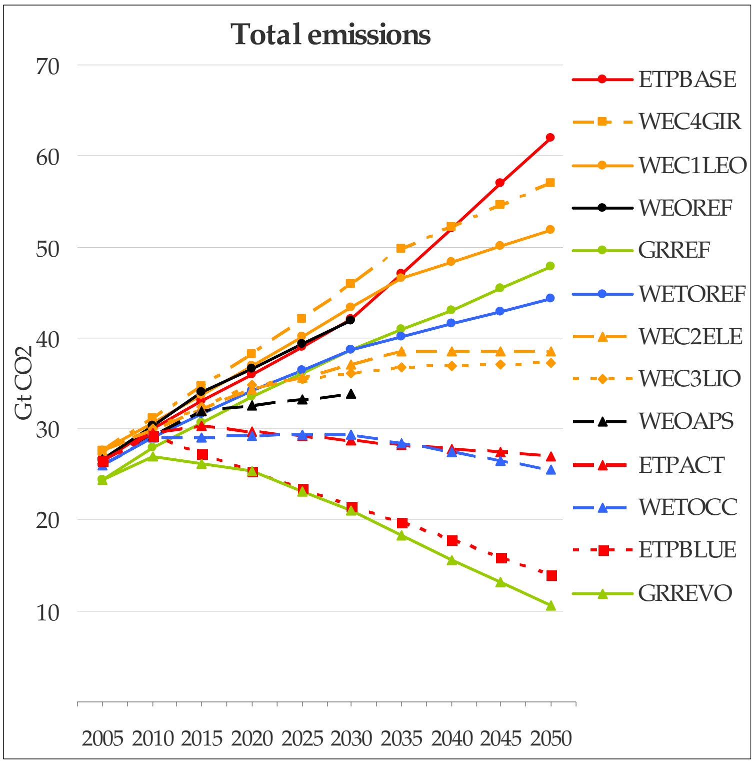


Figure 31 Total CO_2 emissions

Turning to CO_2 emissions from the electricity sector (Figure 32, upper chart), a decrease of about 50% between 2005 and 2050 is achieved in ETPACT, GRREVO and WETOCC, whilst ETPBLUE achieves a 71% reduction.GRREVO achieves this halving without the use of CCS or nuclear generation. Still, the power sector remains the largest source of emissions in GRREVO, which implies that emission reductions also take place in other sectors. Conversely, the electricity sector leads the decarbonization of the energy system in other scenarios with emission targets. The ratio of power sector to total energy emissions (shown in Figure 32, lower chart) decreases rapidly in ETPACT, WETOCC and WEC3LIO, which all feature large deployment of nuclear power and CCS. ETPBLUE on the other hand features an increasing level of electrification in transportation and buildings, but still manages to substantially reduce the contribution of electricity generation to total emissions.

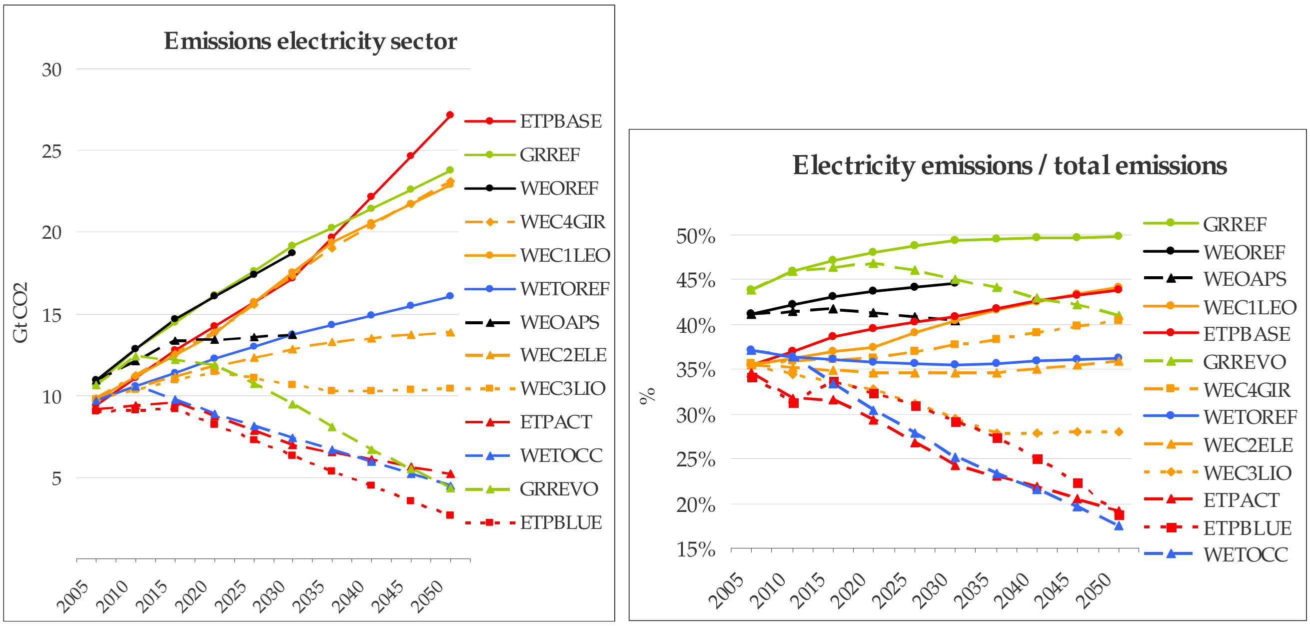


Figure 32 CO_2 emissions from the electricity sector

5.1.3. Total installed capacity and generated electricity

The total deployment of electricity generation technologies in terms of installed capacity and generated electricity is shown in Figures 33 and 34. The comparison reveals a major dependency on GDP growth rates and emission targets.

Electricity use is highest in the WEC and WETO scenarios, primarily due to high electricity intensity. The remaining difference among the WEC scenarios can be largely explained by differences in GDP. Total electricity generation in 2050 is lowest in GRREVO and ETPACT. The more ambitious emission target in ETPBLUE requires a higher electrification in the buildings and transport sectors, and therefore results in additional 3 PWh electricity generation compared to ETPACT[43]. Substantially lower electricity generation in GRREVO, but hardly unchanged capacities compared to GRREF indicate a massive deployment of renewables in GRREVO. The relatively high amount of installed capacity in WEC3LIO also indicates a larger deployment of renewable technologies. Similarly, the emission target in WETOCC requires a decarbonization and more installed capacity compared to WETOREF.

An interesting aside is the fact that the studies use different values for the totally installed capacity in 2005, ranging from 3913 GW (5,6 % below average) to 4235 GW (2.6 % above average). The 2005 values for total electricity generation on the other hand are more evenly distributed (+/- 0.9% compared to the average).

We can see that the four main factors discussed in Chapter 4 are important for determining total electricity demand and hence generated electricity. These key drivers affecting the scale of electricity output include: population, GDP per capita, efficiency (energy intensity), and electrification.

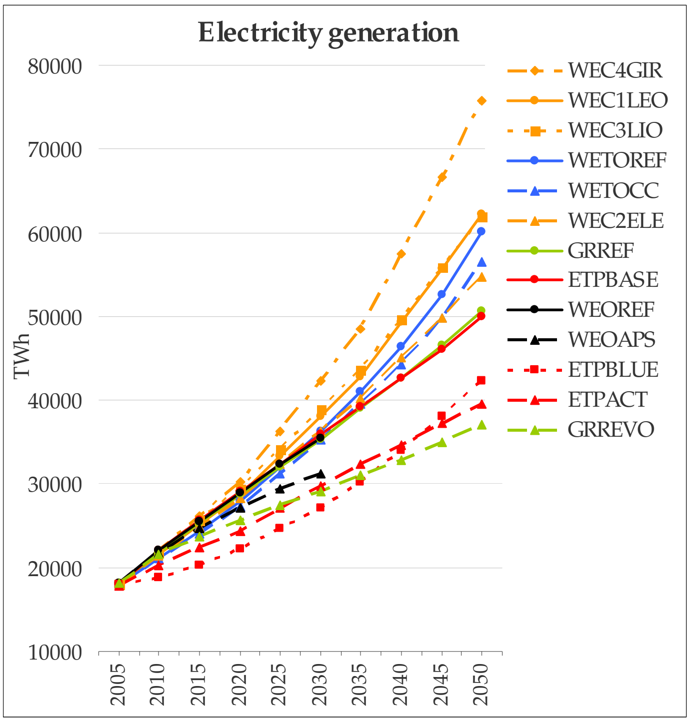


Figure 33 Total electricity generation

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[43] ETPBLUE requires around 4 PWh more CCS, 2.5 PWh more nuclear and 5 PWh more renewable electricity, but 8.5 PWh less fossil (without CCS) electricity than ETPACT.

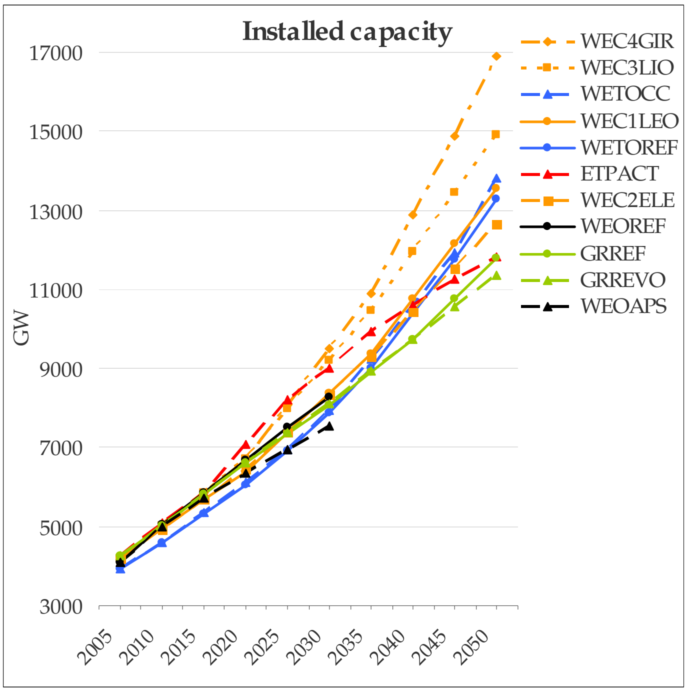


Figure 34 Total installed capacity

The average, economy-wide capacity factors illustrate the ratio between generated electricity and installed capacity (Figure 35). Full load hours decrease over time in the low emission scenarios (e.g. ETPACT, GRREVO, WETOCC), but the most obvious outlier is seen in ETPACT (note that data for ETPBLUE was not available). This U-shape reflects first the strong increase in installation of natural gas-fired generation (with lower capacity factor) displacing coal-based generation, followed after by an increased deployment of advanced coal technologies with CCS, plus some additional nuclear generation.

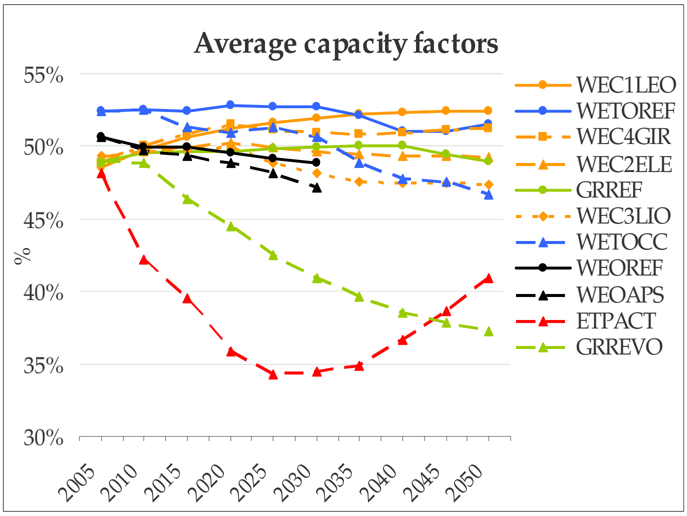


Figure 35 Overall electricity capacity factors

5.1.4. Electricity mix

The comparison of fossil, nuclear and renewable shares in power generation allows for a further characterization of the scenarios (Figures 36 and 37).

Fossil fuels remain the dominant source for electricity generation until 2050, except in ETPBLUE, WETOCC and GRREVO. Also fossil fuels account for less than 50% of generation in ETPACT in 2050 (46%), including the 17% of total generation produced from fossil technologies equipped with CCS. It should be noted that in ETPACT the capacity factor of fossil generation (without CCS) is relatively low due to the high share of and assumptions for natural gas generation. Carbon capture and storage plays an even more important role in WETOCC, WEC3LIO and ETPBLUE, with a share of up to 26% of total generation for the latter scenario.

GRREVO on the other hand is characterized by an 80% share of renewables in installed capacity in 2050. None of the other scenarios comes close to such a vast deployment of renewable technologies. The WEC3LIO and WETOCC scenarios result in renewable capacity shares between 40 and 50%, and WEOAPS is on the same track until 2030. ETPBLUE entails the second highest renewable share in power generation in 2050, followed by ETPACT.

Nuclear technologies produce 35% of electricity in WETOCC in 2050 (the scenario with the highest share), and over 20% in ETPBLUE and WETOREF. Also ETPACT relies heavily on nuclear power, while less use can be made of the deployed capacities in WEC2ELE and WEC3LIO, due to the 8% lower capacity factors (cf. Section 4.3.3).

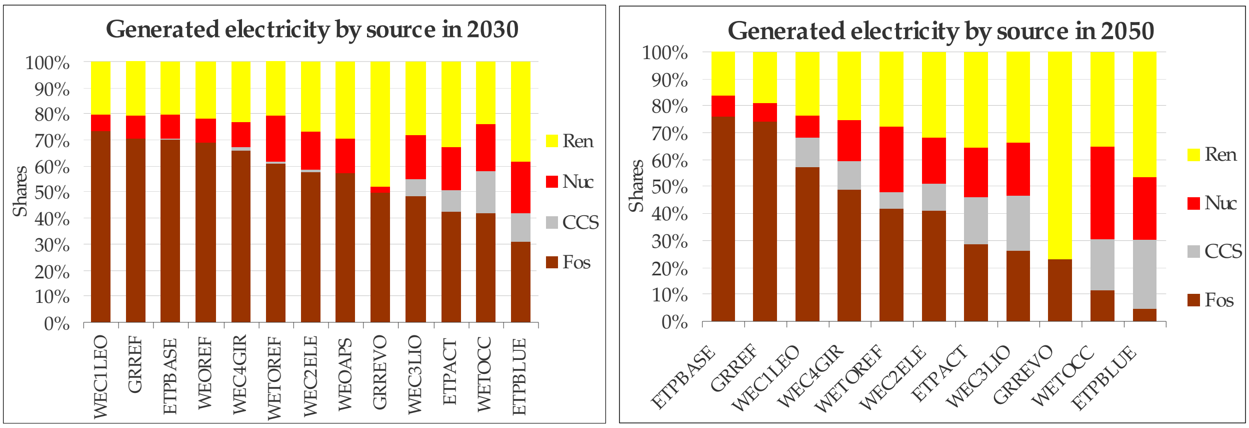


Figure 36 Generated electricity by source

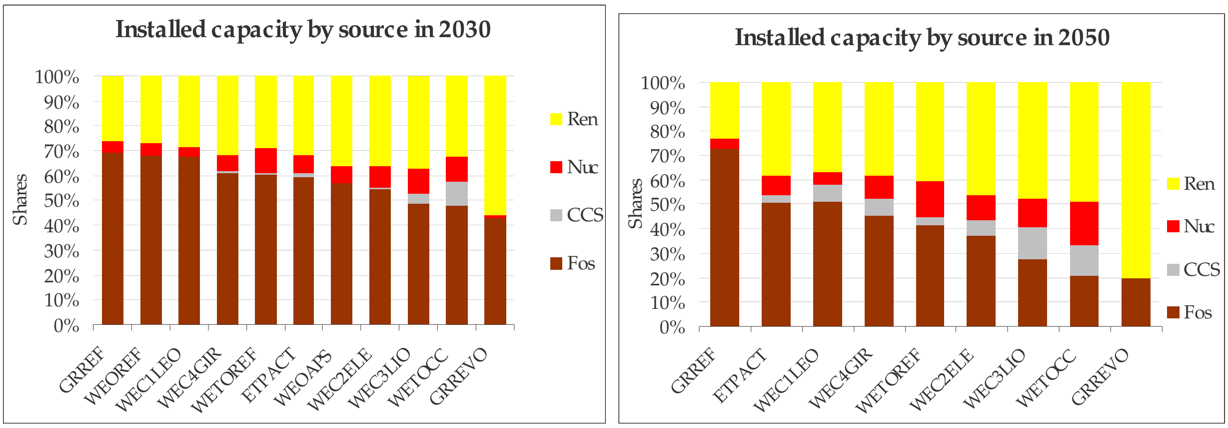


Figure 37 Total installed capacities by source

5.1.5. Characterization of scenarios

Some of the main parameters that characterize the scenario outputs are summarized in Figure 38. The data is presented in relative terms, as percentages of the highest value within each category. All studies consider business-as-usual scenarios with a continuation of CO_2 emission rates, based on high shares of fossil-fueled power generation and only modest energy efficiency improvements. ETPBASE, GRREF, WEC1LEO, WEC4GIR, WEOREF and WETOREF can be assigned to this category.

Furthermore, all studies examine policy-driven scenarios, which slow down the rate of CO_2 emissions. This category includes ETPACT, ETPBLUE, GRREVO, WETOCC, and to a certain extent WEC2ELE, WEC3LIO and WEOAPS. While most of them result in a wide deployment of renewables, only some scenarios incorporate a large contribution of nuclear, as ETPACT, ETPBLUE, WEC3LIO or WETOCC, and the utilization of CCS.

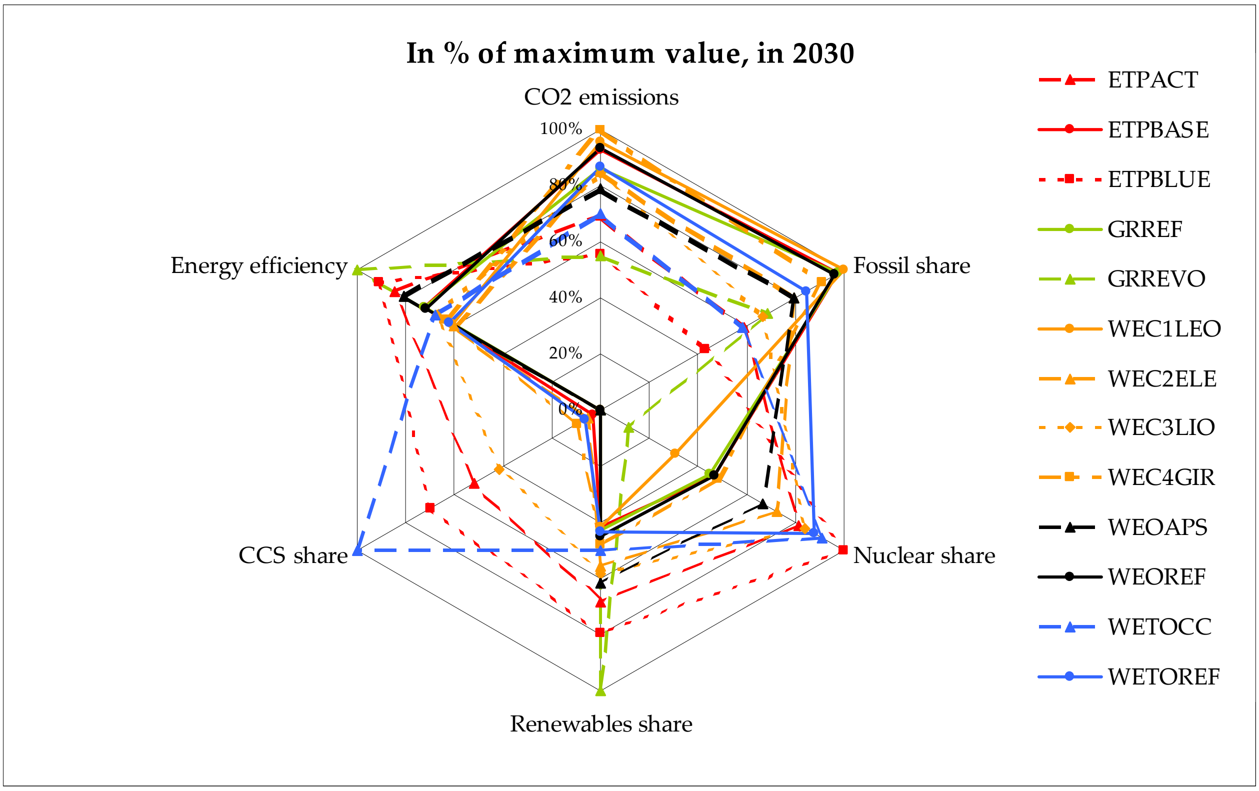
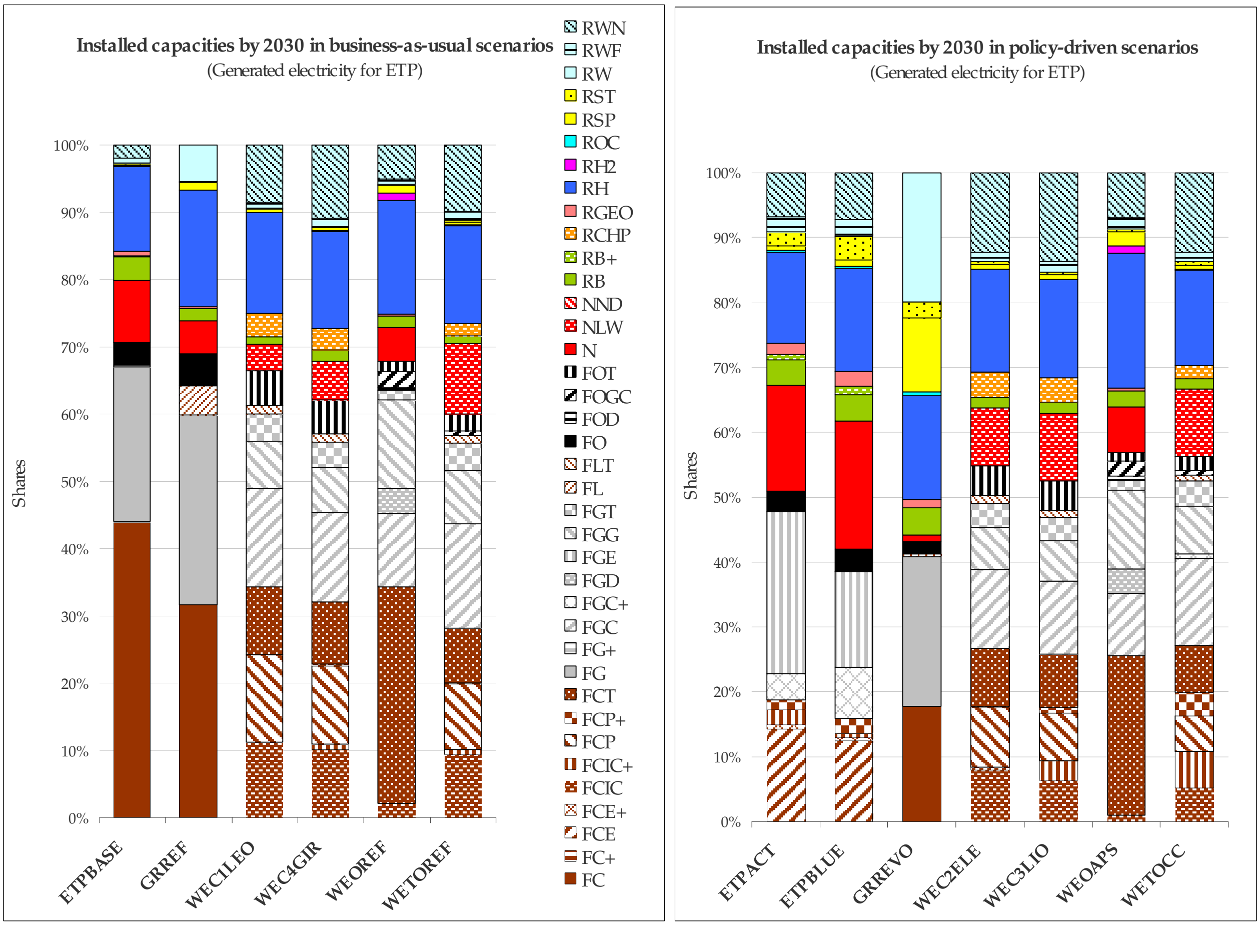


Figure 38 Characterization of the scenarios

5.2. Widely deployed technologies

The electricity mix can be further disaggregated to the level of technologies. Figure 39 presents the technology mix for each scenario in 2030. Many innovative and speculative technologies, such as ocean or geothermal energy, do not contribute significantly to total power generation until 2030 in any of the scenarios. Whether this is because these technologies are deemed to be unviable, or whether they are omitted for other reasons is not entirely clear in many of the scenario studies. For example, WETO does simply not consider geothermal energy. Nonetheless, apart from concluding that the selected scenario literature provides only very limited insights about the deployment of these technologies, they are not discussed further in this study. Furthermore, technologies that use biomass or waste feedstock's, and combined heat and power systems are, besides their marginal contribution in all of the studies, not defined uniformly across the scenarios and are thus difficult to compare. Accordingly, no insights about the deployment of these technologies are derived.



Abbr.	Technology	Abbr.	Technology	Abbr.	Technology	Abbr.	Technology
+	CCS	FCT	Coal Conventional Thermal	FLT	Lignite Conventional Thermal	RCHP	Combined heat and powe
FC	Coal	FG	Gas	FO	Oil/Diesel	RGEO	Geothermal
FC+	Coal CCS total	FG+	Gas CCS	FOD	Oil distributed generation	RH	Hydro
FCE	Coal Existing	FGC	Gas turbine combined cycle	FOGC	Oil used in gas turbine combined cycle	RH2	Fuel Cell
FCE+	Coal CCS Retrofit post-combustion	FGC+	Gas turbine combined cycle with CCS	FOT	Oil Conventional Thermal	ROC	Ocean energy
FCHP	Combined heat and power	FGD	Gas distributed generation	N	Nuclear	RSP	Solar PV
FCIC	Coal Integrated Gasif. Comb. Cycle	FGE	Gas Existing	NLW	Nuclear LWR	RST	Solar Thermal
FCIC+	Coal Integrated Gasif. Comb. Cycle with C	FGG	Gas turbine (gas cycle)	NND	Nuclear new design	RW	Wind
FCP	Coal supercritical pulverised	FGT	Gas Conventional Thermal (steam cycle	RB	Biomass & waste	RWF	Wind Offshore
FCP+	Coal supercritical pulverised with CCS	FL	Lignite	RB+	Bio CCS total	RWN	Wind Onshore

Figure 39 Technology mix at the end of the projection period

The exclusion of some less relevant technologies, as mentioned in the previous section, leads to the comparison of the following technologies in this chapter:

- Coal-fired: thermal, integrated gasification combined cycle, supercritical pulverized
- Gas-fired: steam cycle, gas cycle, combined cycle
- Carbon capture and storage: in coal-fired plants (retrofit post-combustion, IGCC, pulverized), in gas-fired plants (combined cycle)
- Nuclear: light-water reactors, generation IV reactor designs
- Hydropower: large- and small-scale

- Wind power: onshore and offshore plants
- Solar photovoltaics

These remaining technologies cover around 90% of the total installed capacity within each scenario[44] and therefore provide a sufficient basis to analyse technology deployment.

5.2.1. Coal-fired technologies

The total power generation from coal-fired technologies, which includes also plants equipped with CCS, is shown in Figure 40. The deployment of coal-fired technologies appears to be strongly dependent on the CO_2 prices (or abatement target stringency), the availability of CCS and, especially for the POLES studies (WETO and WEC), the deployment of renewables[45].

The WEC scenarios and WETOREF thereby deploy advanced coal technologies, such as integrated gasification combined cycle (IGCC) or supercritical pulverized coal generation, and even the conventional steam cycle remains relevant, with up to 4 PWh generation in WEC4GIR in 2050. The contribution of CCS varies among these scenarios and is described in Section 5.2.3. Conversely, advanced coal technologies play a minor role in WEO, which is dominated by steam technologies during its shorter time horizon to 2030. The modest total production in the innovative ETP scenarios (ETPACT and ETPBLUE) on the other hand comes completely from advanced technologies, with IGCC and retrofitting being relevant in ACT, and mostly supercritical pulverized in BLUE. ETPBASE and GR do not further specify the composition of coal-fired generation.

The deployment of coal-fired technologies in WETOREF, WEC2ELE and WEC3LIO is possibly dampened by the relatively large shares of nuclear and renewable power, and the imposition of modest CO_2 prices. The high CO_2 price in WETOCC, in combination with limited carbon storage capacity, hinders the deployment of advanced coal technologies, which are available from 2015 onwards, enabling only a temporary expansion in coal-fired production. Similarly, the very high coal price is chosen in GRREVO in order to simulate a phase-out of fossil fuels by 2085.

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[44] The coverage ranges from 88.5% in WEC1LEO to 92.8% in ETPBASE.

[45] Cf. Section 3.4 on the POLES model: the deployment of large-scale plants depends on potentials and diffusion of clean technologies.

ETPACT and ETPBLUE are characterized by an almost identical pattern of power generation from coal, but at different total levels, probably due to the different CO_2 price levels in these scenarios. Additionally, the authors of ETP state that early retirement occurs for those coal-fired plants that are not suitable for CCS. The decline in coal-fired generation is interrupted around 2025-2035, which coincides with the increasing availability and deployment of advanced technologies.

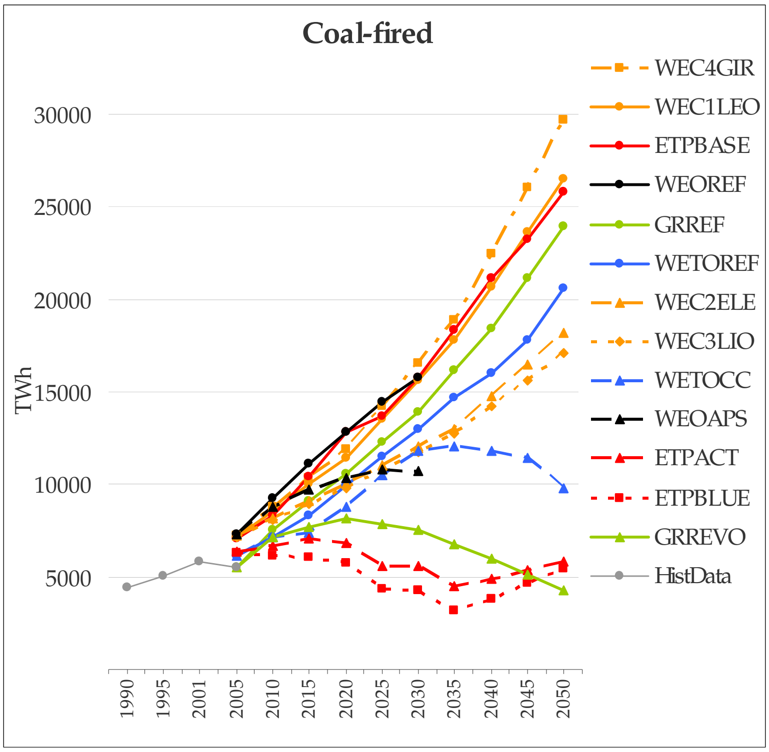

Figure 40 Deployment of coal-fired plants

5.2.2. Gas-fired technologies

In broad terms, the relative level of gas-fired electricity generation follows a similar pattern to that of coal-fired plants across the scenarios[46] (see Figure 41, cf. Figure 40): the WEC and the reference scenarios show a continuous increase, while the deployment in the emission scenarios is restricted by the carbon constraint. Technology-wise, the single cycle gas turbine is more widely deployed than combined cycle turbines in 2050 in WEO, and vice versa in WETO, WEC and ETPACT.

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[46] With the exception of ETPACT where gas use grows substantially compared to coal use.

The diminishing gas-fired generation in WETO and GR around 2030 reflects the high gas price assumptions in these scenarios (see Section 4.2.1). The availability of CCS for natural gas combined cycle generation delays the decrease in WETOCC for a few years, but the limited carbon storage capacity causes an explicit disadvantage for CCS technologies over the longer term. Just as for coal-fired plants, the availability of cleaner technologies also drives the deployment of gas-fired generation in the ETP scenarios: the acceleration after 2020 in the ETPBLUE and ETPACT scenarios is caused by the deployment of CCS for combined cycle generation, making gas an attractive option despite the abatement targets in these scenarios. The slowdown after 2035 (particularly in ETPBLUE) coincides with the increasing carbon price. Still, gas combined cycle plants account for around 40% of the total installed capacity in ETPACT in 2050.

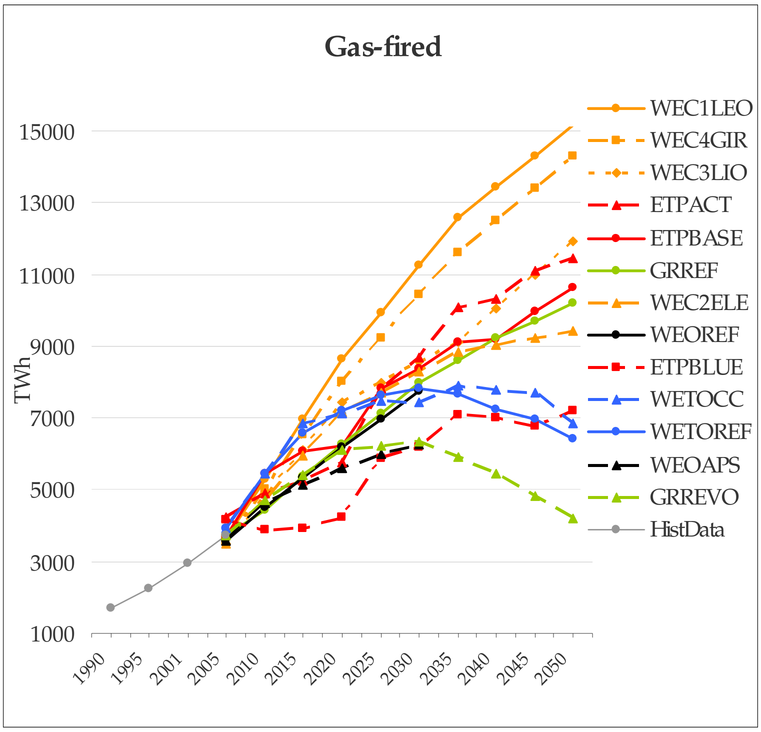

Figure 41 Deployment of gas-fired plants

5.2.3. Carbon capture and storage (CCS)

The comparison of total power generation from plants equipped with CCS in Figure 42 reveals remarkable divergence, which may reflect uncertainties about the future of this technology. CCS is widely deployed in WETO, WEC and ETP, while it is not used at all in GR[47] and WEO.

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[47] See Section 3.3.6 on technology assumptions for the reasons of non-use.

Furthermore, the authors of WETO consider limited carbon storage capacities, which diminish the attractiveness of CCS over the longer term.

CCS is mainly applied to advanced coal-fired technologies in most of the scenarios: coal-fired generation accounts for around 70% of the total electricity from plants equipped with CCS in 2050 in ETPACT, WETOCC and WEC3LIO, and almost 100% in WEC4GIR. By contrast, gas-fired technologies equipped with CCS become available earlier in ETPBLUE and account for about 50% of power generation with CCS in 2050.

In sum, the deployment of CCS in the scenarios appears to be driven primarily by CO2 prices, storage capacity and the timing of the availability of CCS. The factors affecting the choice of coal and gas-fired generation in turn also affect the application of CCS.

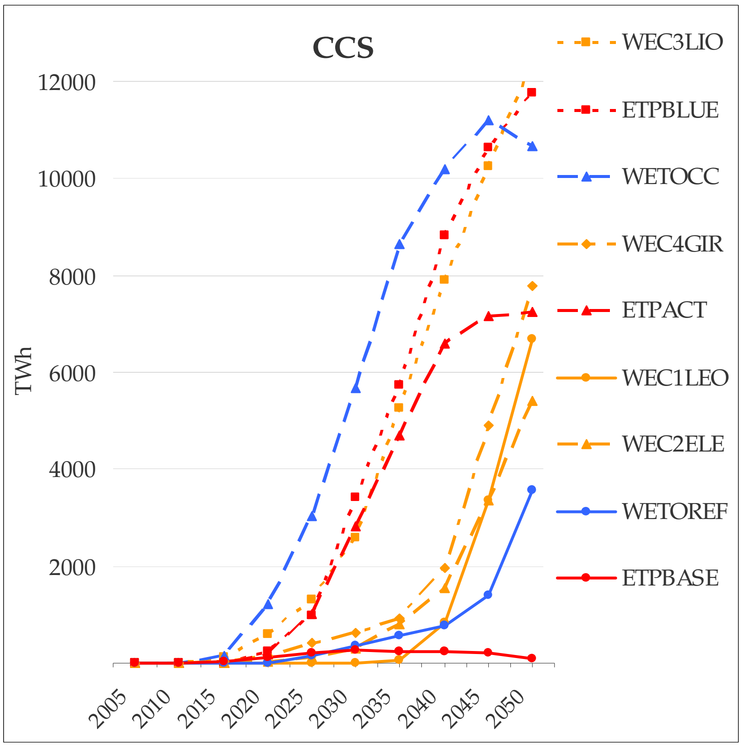

Figure 42 Deployment of carbon capture and storage

5.2.4. Nuclear technologies

An enormous range for the contribution of nuclear electricity can be observed across the scenarios (see Figure 43). Nuclear technologies are commercially competitive in many of the scenarios, but face social constraints that are implemented differently across the studies. Moreover, nuclear deployment is supported in those scenarios with a stringent climate policy since it is a zero- or low-carbon generation option, with the exception of GRREVO as discussed below.

ETPBLUE fully exploits the explicit capacity constraint at 1250 GW by 2050, which is based on past construction rates of about 30 GW/yr (roughly 20 to 30 plants per year worldwide)[48]. In comparison, fewer limits are set to the deployment of nuclear power in WETO, which exceeds the ETP capacity constraint by a factor 2, even though the investment cost assumptions are comparatively high (cf. Section 4.3.3).

Looking at the other scenarios, the production in WEC is defined by exogenous market shares to possibly reflect social concerns, with high levels of government engagement and international cooperation leading to more support for and deployment of nuclear generation. GRREVO by contrast simulates a global phase-out of nuclear energy and assumes that no new plants are constructed after 2008, and only two thirds of the reactors under construction are put in operation. The authors of GRREVO state specifically that the expansion of nuclear energy in ETPBLUE would be *unrealistic, expensive, hazardous and too late to make a difference*.[49].

Similarly, the contribution of plants with advanced reactor designs, often referred to as *Generation IV*[50], differs among the scenarios. New designs become available in WETO and WEC before 2040, and generate between 20 (WEC2ELE, WETO) and 70% (WEC3LIO) of nuclear electricity in 2050. The ETP scenarios on the other hand do not distinguish between generations in the presentation of results , but new plants are implemented constantly.

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[48] The ETP study also explores a variant with a higher maximum nuclear capacity of 2000 GW, which is fully exploited in ETPACT and ETPBLUE.

[49] Greenpeace, EREC (2008), p. 24

[50] For more information on ongoing research and development see also: http://gif.inel.gov

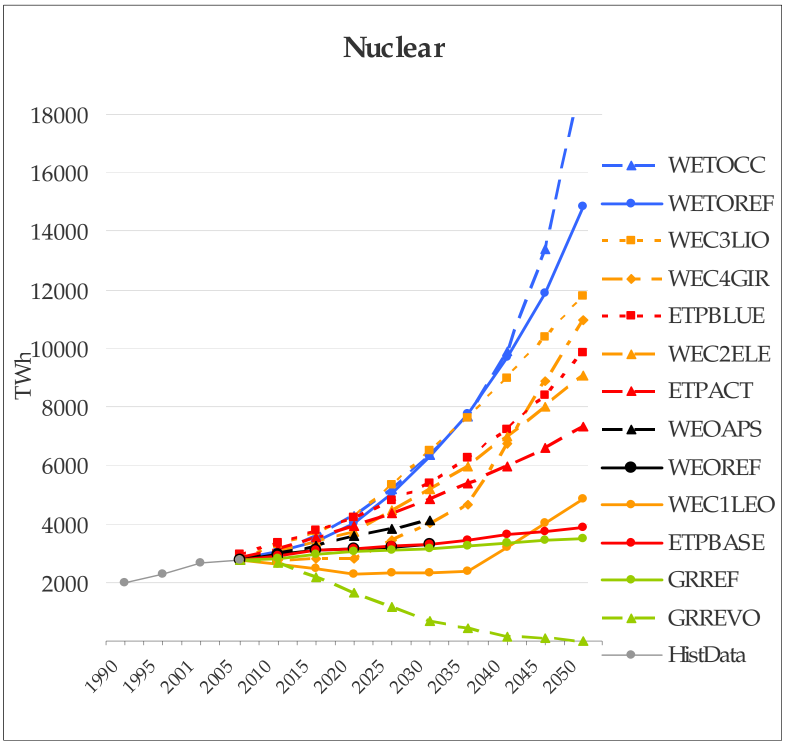

Figure 43 Deployment of nuclear plants

5.2.5. Hydropower

The total hydropower generation exhibits a relatively similar pattern of development across the scenarios (shown in Figure 44). All scenarios report an increase between 2 and 3 PWh by 2050 or, on average a doubling of hydro generation. However, there appears to be a surprisingly wide variation in data for the year 2005, with particular low estimates in ETP.

Overall, hydropower is deployed only modestly in the most policy-driven scenarios, i.e. ETPACT, ETPBLUE, WETOCC and GRREVO. The authors of ETP argue that growth will level off after 2030 due to the limited availability of suitable sites, and appear to apply a constraint on the realisable potential in ETPBASE. The moderate hydropower generation in GRREVO is affected by the lowest capacity factors, which remain on the same level from 2010 onwards (see Section 4.3.4). Hydro generation in WEO on the other hand results in the sharpest increase, despite the second lowest capacity factors and comparatively high investment cost assumptions.

The contribution of small scale hydropower differs substantially among the scenarios. The WEC and WETO scenarios account for 5-7 % small scale hydro in 2005, while ETPACT assigns around 50% of the current production to small scale technologies. This indicates that the distinction between small and large scale is not defined consistently across the different modeling groups.

WEO, on the other hand, reports capacities for conventional hydro power and pumped storage, which makes a comparison of sub-categories impossible.

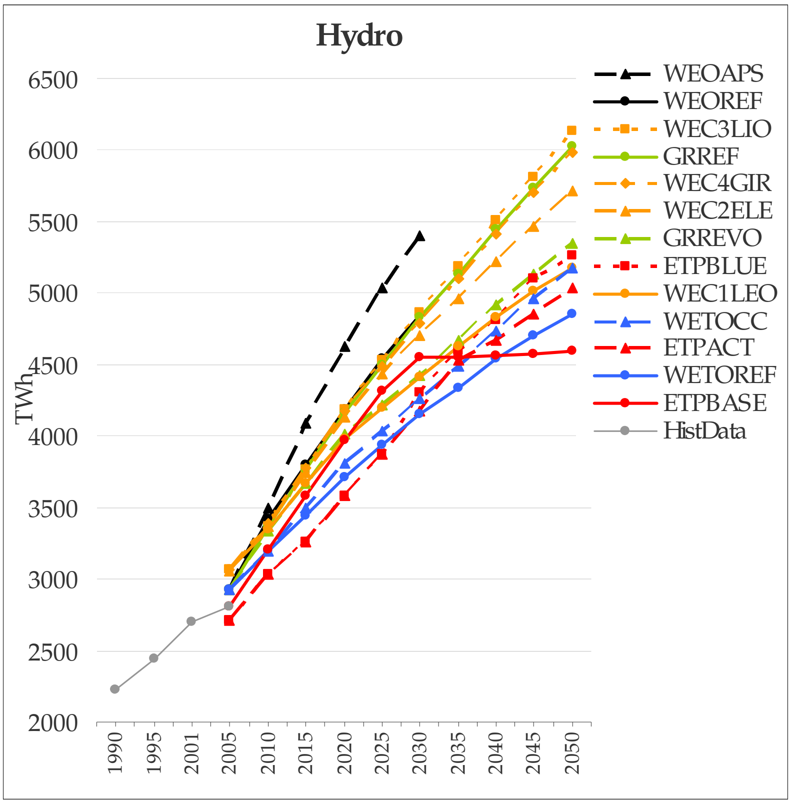

Figure 44 Deployment of hydropower

5.2.6. Wind power

The totally installed capacity[51] of onshore and offshore wind power differs among the scenarios by a factor 8 in 2050. While wind power develops on a modest rate in WEO and in the GRREF and ETPBASE scenarios, which are based on WEOREF, the capacities increase substantially in WEC, WETO and GRREVO. In WEO and ETP, the technical potentials appear to remove the levelized investment cost advantages (cf. Section 4.3.4). Despite the range of estimates, most of the scenarios anticipate a massive increase in the deployment of wind generation - in the order of 30-fold for some of the scenarios - which is likely to be very challenging.

The disaggregation into onshore and offshore capacities in Figure 46 reveals that the divergence between the scenarios comes mainly from different contribution from onshore generation. For

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[51] For once capacity data available for ETPBASE and ETPBLUE as well, and therefore chosen to compare the deployment.

offshore generation, the total potential appears to be smaller and only ETPBASE and ETPACT are outliers in terms of generation - apparently constrained with a lower techno-economic potential. Conversely, the wind onshore capacities develop with quite different rates from the beginning on, but again the ETP scenarios have lower deployment of wind capacity.

In terms of generation (not shown), GRREVO achieves a similar level of wind electricity output to WEC3LIO and WEC4GIR, due to assumed higher capacity factors (see Section 4.3.4). Still, the increase in total capacity, particularly in GRREVO and the WEC and WETO scenarios, seems to be very ambitious.

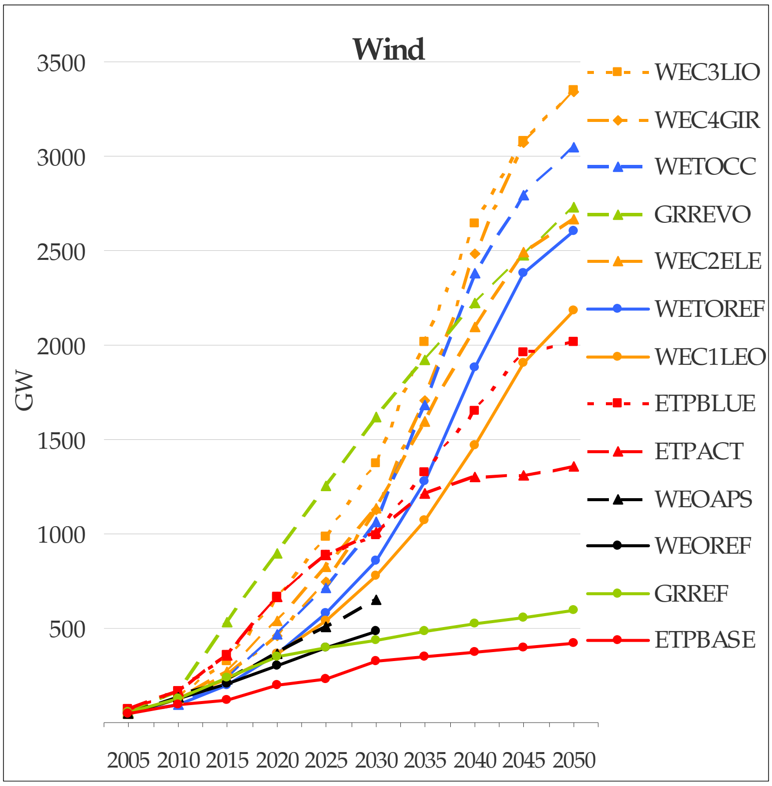

Figure 45 Deployment of wind power

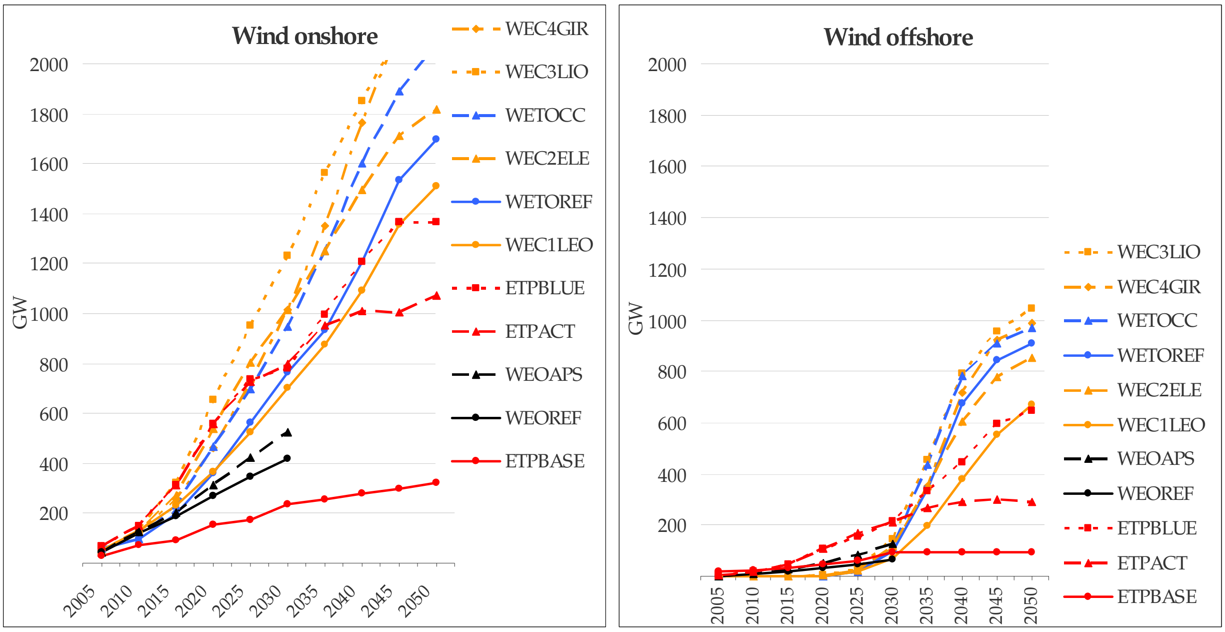

Figure 46 Disaggregated deployment of wind power

5.2.7. Solar photovoltaics

Similar to the deployment of wind power, the use of solar photovoltaics differs substantially across the scenarios (Figure 47). But even in the scenarios with the lowest deployment (ETPBASE and GRREF), there is still a significant increase in deployment compared to today's levels. The production ranges up to levels of a similar order of magnitude to wind generation in GRREVO and ETPBLUE in 2050.

Solar PV power generation increases remarkably in GRREVO around 2015/2020 and in ETP around 2025/2030, while the breakthrough appears to be 10 years later in the WETO and WEC scenarios. The large deployment in GRREVO is likely supported by the low investment cost assumptions, and this is reinforced by the assumptions about other technologies, such as the phase-out of nuclear power and the absence of CCS (thereby provided fewer alternative options for meeting the stringent CO_2 emission targets in this scenario). The deployment in ETP should be considered in the context of the much higher capacity factors assumed (cf. Section 4.3.4). No explanation is provided in the published material for the logistic shape of the curves for both ETP scenarios—but one implication is that there is some saturation of commercial potentials.

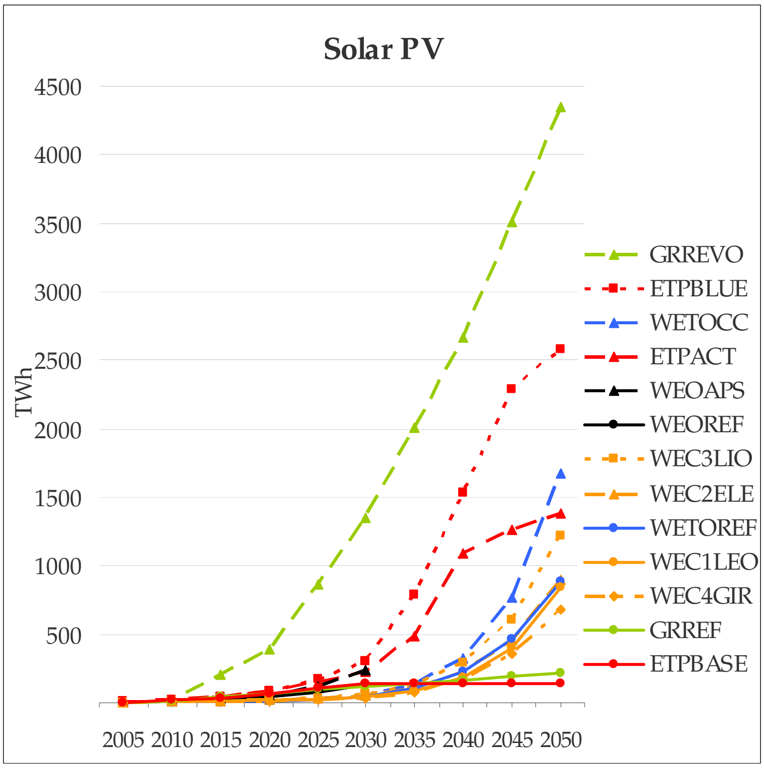

Figure 47 Deployment of solar photovoltaics

5.2.8. Summary

To summarize technology deployment, the market shares of the technologies in terms of electricity generation are shown for 2030 in Table 4 with outliers indicated in colour where the market share is more than one standard deviation above (green) or below (red) the average[52]. Looking at the deployment within a scenario, this also shows which technologies are substituting for lower deployment or are substituted by higher deployment. For example, while coal-fired technologies appear to lose market share to gas-fired technologies in ETPACT, a stronger shift to nuclear and hydro power, and also a larger role for CCS, can be observed in ETPBLUE. Similarly, WEC1LEO relies heavily on gas-fired technologies and less on nuclear, whereas the other WEC scenarios do not reveal any uncommonly high market shares.

One interesting aside related to Table 4, is that when we compare the level of deployment with the relative cost of different technologies in Table 3 (in Section 4.3.6), there is relatively little relationship,which is expected considering that a much larger range of factors affect technology

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[52] The criterion of one standard deviation is chosen to mark outliers, although the data samples are not normally distributed across the scenarios.

deployment (as discussed in Section 6.1), and precisely the reason that detailed integrated energy models representing many of these influences are helpful for understanding technology deployment. This is not to say that cost is not important for technology deployment, but rather that cost alone does not appear to be a significant explanatory factor of the technology deployment differences between the scenarios..

Table 4 Shares in generated electricity

	Share in generated electricity in 2030						
	Coal-fired	**Gas-fired**	***with CCS***	**Nuclear**	**Hydro**	**Wind**	**Solar PV**
ETPACT	18.7%	29.1%	*9.4%*	16.3%	14.0%	9.1%	0.8%
ETPBASE	44.0%	23.3%	*0.7%*	9.2%	12.7%	2.7%	0.4%
ETPBLUE	15.8%	22.8%	*12.6%*	19.9%	15.9%	9.8%	1.1%
GRREF	39.4%	22.5%		9.0%	13.7%	3.6%	0.3%
GRREVO	26.0%	21.8%		2.3%	15.2%	15.1%	4.6%
WEC1LEO	41.1%	29.6%	*0.0%*	6.1%	11.6%	4.4%	0.1%
WEC2ELE	33.1%	22.8%	*0.8%*	14.4%	13.0%	6.8%	0.1%
WEC3LIO	30.3%	22.0%	*6.6%*	16.7%	12.5%	7.7%	0.2%
WEC4GIR	39.1%	24.6%	*1.5%*	9.6%	11.3%	5.8%	0.1%
WEOAPS	34.3%	20.1%		13.3%	17.3%	5.8%	0.8%
WEOREF	44.6%	21.9%		9.3%	13.7%	3.6%	0.4%
WETOCC	33.6%	21.1%	*16.1%*	18.0%	12.1%	6.6%	0.2%
WETOREF	35.8%	21.6%	*1.0%*	17.4%	11.4%	5.2%	0.1%
mean	34%	23%	*5%*	12%	13%	7%	1%
sigma	9%	3%	*6%*	5%	2%	3%	1%
mean+sigma	42%	26%	*11%*	18%	15%	10%	2%
mean-sigma	25%	20%	*-1%*	7%	12%	3%	-1%

6. Discussion and conclusions

We have analysed a range of scenario studies to understand the factors affecting technology deployment across the scenarios. The objective has been to assess the perspectives in the scenario literature and distill insights regarding how specific systems and technologies are deployed, including the role of these technologies in climate change mitigation and energy security. One further objective which we also discuss below concerns the extent to which the scenarios provide an appropriate account of technology deployment, and where there are limitations or areas not covered by this literature which are important for the governance of energy-related risks.

In this chapter we first summarize the key factors affecting technology deployment identified from the surveyed scenario literature (Section 6.1), and identify some of the limitations in the success of the project in extracting the necessary information (6.2). We then discuss how the management of energy security and climate change mitigation is dealt with in the scenario studies, and the areas where the scenario literature provides only limited insights (6.3). In Section 6.4 we discuss the suitability of scenario approaches more generally for supporting policy and decision making. Finally, a number of recommendations on energy scenario development and communication (6.5) and on a potential niche project for IRGC (6.6) are discussed.

6.1. Key factors affecting technology deployment

The detailed analysis of energy technology scenarios in the previous chapters investigates the technology assumptions and levels of deployment across different energy scenarios. It was expected that this comparison of numerical inputs and outputs would allow us to identify differences in assumptions about technology characteristics, and the extent to which these assumptions affect technology deployment; thus identifying potential key factors for deployment. Interestingly, however, across the scenarios the numerical assumptions appear to provide only limited insights into the key drivers of technology deployment. This is because many other factors are affecting technology deployment in the scenario literature, including factors related to the design and methodology applied to develop the scenarios, as well as more explicit assumptions regarding technology or policy. In addition, the interplay of assumptions about technology appears to be crucial. Therefore, scenario outcomes must be analysed in a holistic perspective, which accounts for the entire scenario framework. Some of the main elements are discussed below.

Factors related to scenario design and methodology

Availability of technologies

One of the key factors affecting whether a particular technology is deployed in a scenario is the availability of that technology. This is generally determined by simple assumptions, since the energy systems models used to quantify some aspects of the scenarios analysed in this paper do not themselves model the processes of technology invention and innovation which represent the initial stages in the lifecycle of a technology[53]. Instead, these steps leading up to initial commercialization are qualitative elements of the scenarios, for which much less information is reported in the studies. This appears to indicate that the scenario literature is not the best source of information on factors relevant for the pre-commercialization phase of technology development, but is better suited for providing insights about how the energy system and technology deployment may unfold after technologies have moved through the early phases of development.

Modeling approach

The methodology used to develop a scenario is also expected to affect the scenario outcome. As discussed in Chapter 3, the market shares of different technologies in the scenarios analysed here are determined either: a) exogenously based predominately on expert judgment in simulation models, like MESAP PlaNet; b) as an outcome of a cost optimization in terms of levelized generation cost, as in the World Energy Model; or c) with a combined approach, e.g. in the POLES-WEC model which includes cost competition and expert judgment. These different approaches could be seen as reflecting different paradigms about how technologies are chosen in reality, including the relative role of economic, technical, social and political factors. It is important to note that although the methodology can directly affect the choice of technology, there are many additional driving factors behind the determination of these market shares that do not depend on the modeling approach.

Storylines

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[53] Grübler et al. (1998)

The underlying storyline or narrative of a scenario, which is not always expressed explicitly in the studies, is a major determinant of the resulting technology mix. Important general distinctions can be drawn between the two groups of scenarios identified in Section 5.1.5: business-as-usual and policy-driven scenarios. Business-as-usual scenarios[54] are characterized by low concern for environmental threats, such as global warming or loss of biodiversity, and security of supply issues. Policies and investments are thus concerned with a limited range of objectives, and technologies are selected based on a narrow economic perspective. As a result, technologies with lower generation cost generally deployed more widely (although there is some diversity, as we discuss further below), and fewer efforts are made in research, development and demonstration of new technologies. In business-as-usual scenarios, no emission targets are pursued and carbon prices remain modest and have little influence. As a result, the electricity mix is not diversified much over time, which leads to a higher exposure towards fossil fuel price disruptions. The deployment of gas- and coal-fired plants is only hindered by high fuel prices in some scenarios. Also the use of other large scale plants, such as nuclear[55] or hydropower, is mostly not restricted by environmental or safety concerns.

Policy-driven scenarios[56] are characterized by international and intergenerational cooperation, fairness and equity. Concerns for the environment and security of supply are taken seriously, and policies and investments also consider long-term effects of human action. In these scenarios, emission targets are based on international cooperation. Extensive RD&D efforts improve the energy efficiency of technologies, reduce the emission activity of fossil-fired plants, and increase the competitiveness of renewable power plants. This supports diversification of the electricity mix. In addition, technology deployment is driven by environmental concerns, with high CO_2 prices reducing the competitiveness of conventional fossil-fueled power plants (and/or supporting the use of CCS where this technology becomes a viable option). The availability of cleaner fossil-fueled technologies, such as combined cycles or supercritical pulverized coal, may also maintain or raise the market shares of coal- and gas-fired plants in some cases. The market share of nuclear power grows rapidly in some scenarios, but is restricted by safety concerns in others. The availability of 4th generation nuclear reactors in the longer term has no obvious impact on the market shares over this time period.

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[54] ETPBASE, GRREF, WEC1LEO, WEC4GIR , WEOREF , WETOREF

[55] Among the studies, only ETP and GR apply capacity constraints for nuclear power.

[56] ETPACT, ETPBLUE, GRREVO, WEC2ELE, WEC3LIO, WEOAPS, WETOCC

Factors related to technology characteristics

The factors above are important for determining some of the boundary conditions for technology deployment in the scenario studies. In addition to these design-related factors, the interpretation and quantification of storylines into specific input assumptions drives technology deployment. As mentioned above, it is also the interaction between the full set of assumptions that is important. Based on the discussion of technology deployment in Section 5.2, some crucial input parameters affecting deployment can be identified for the technologies across the studies. This listing in Table 5 is by no means exhaustive, but represents some drivers that appear to be decisive for the deployment across the selected scenarios.

CO_2 prices (or climate policy stringency more generally), fuel prices and the availability of carbon capture and storage appear to be crucial for the deployment of fossil-fueled power plants. Maximum construction rates and safety concerns (such as proliferation and waste management) determine the market share of nuclear power. The most important parameter for the deployment of hydro and wind power plants appears to be the availability of suitable sites, while technology breakthroughs appear to be necessary to support large-scale deployment of solar photovoltaics.

Table 5 Crucial input parameters

Crucial input parameters

Coal-fired	Gas-fired	with CCS	
CO2 prices Availability of CCS	CO2 prices Availability of CCS Gas price	Availability of CCS Storage capacity	
Nuclear	**Hydro**	**Wind**	**Solar PV**
Construction rate Safety concerns	Suitable sites	Suitable sites	Technology breakthroughs (Investment cost)

Cost assumptions

Cost is an important factor for the deployment of technologies, and a number of the key factors identified in Table 5 work via their impact on cost. However, the anticipated differences in components of LCOE (shown in Table 3) are not reflected in the deployment within and across scenarios (cf. Table 4), although this is expected considering that a much larger range of factors affect technology deployment, and precisely the reason that detailed integrated energy models representing many of these influences are helpful for understanding technology deployment.

Interplay of technology options

As mentioned, technology deployment is strongly affected by the competition between different technology options. To illustrate, high CO_2 prices (or a stringent climate policy) affect not only deployment of technologies with high CO_2 emissions (such as coal-fired generation), but also technologies in competition with coal-fired generation, even if those technologies themselves do not produce CO_2 emissions. An example from the scenario literature is the GRREVO scenario, in which assumptions about safety concerns for nuclear power and the non-availability of CCS provide indirect support for the deployment of other technologies, namely renewables. This may seem obvious, but the interaction of the assumptions about these different factors goes a large way towards explaining the range of outcomes observed in the scenario studies.

Scale of technology deployment

Technology deployment within one scenario can only be understood from a holistic perspective, which considers factors like GDP, energy intensity, the extent of electrification or penetration rates. Together, these factors affect the scale of technology deployment and in some ways are linked to technological progress more generally. This affects potentially also the electricity technology mix, particularly if the rate at which technologies can be deployed is limited or there is a maximum potential for particular technologies (for example, a maximum number of suitable sites for hydroelectric generation).

6.2. Limitations of this review

This review has helped to provide a more in-depth understanding of tendencies and broad drivers of leading scenario studies in a much more detailed, comprehensive and systematic way than has been attempted before. However, the findings in this report must be considered in light of some limitations and challenges faced in this project:

- Technology deployment in energy models arises out of a complex system of interacting parameters, such as cost assumptions, activities or constraints. From an outside perspective, this review has only been able to collect fragmentary data and deduce a limited understanding of the methodological approaches used in the various scenario studies.

- The role of many parameters, which in reality affect technology deployment, could not be assessed due to the limited access to and knowledge about the models. These include factors like construction times, manufacturing capacity, plant lifetimes, discount rates, or material and resources costs and availability (e.g. steel, cement, water, skilled workforce). The impact of the scale (e.g. economic growth, electricity demand) and the constraints (e.g. penetration rates, potentials) of power generation also warrant further detailed analysis.

6.3. Management of energy-related risks in the selected scenario studies

As identified in the proposal (see Terms of reference in Appendix I), public decision makers are often concerned about two major types of energy-related risks: Firstly, the impact of the energy system on the environment, particularly through greenhouse gas emissions, and secondly, the risks related to energy security, i.e. threats to an a*dequate, affordable and reliable supply of energy*[57]. In economic parlance, the atmosphere and energy security are non-exclusive goods, since nobody can be excluded from benefiting either a stable climate or a secure energy system. However, this also means that market forces are unlikely to lead to the optimal production and use of these goods, and a market failure exists. Energy security poses further challenges because arguably some parties benefit from a degree of energy insecurity, where energy can be used as an instrument for pursuing a range of (political) objectives. To ensure the best allocation of society's resources, public decision makers have a role in initiating actions to correct the market failures that are contributing to the risks associated with climate change and energy security. A range of perspectives on how to effectively manage these risks can be found in the selected scenario studies.

With respect to the greenhouse gas emissions, two distinct groups of scenarios can be identified: In business-as-usual scenarios[58], no sufficient measures are taken to reduce CO_2 emissions to the level that is proposed by climate research in order to prevent global warming and serious damages. In policy-driven scenarios[59], energy systems are transformed over time to achieve emission targets. A wide range of policy measures can be found across these scenarios to reduce greenhouse gas emissions:

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[57] As defined in IEA (2007) p. 160.

[58] ETPBASE, GRREF, WEC1LEO, WEC4GIR , WEOREF , WETOREF (cf. Section 6.1)

[59] ETPACT, ETPBLUE, GRREVO, WEC2ELE, WEC3LIO, WEOAPS, WETOCC

- CO_2 prices to reduce the cost-competitiveness of emitting technologies: implemented through cap-and-trade policies or flexible Kyoto-mechanisms (Clean Development Mechanism, Joint Implementation)

- Phasing out of high-emission technologies: CO_2 prices, restrictions on the construction of new plants

- Support for zero- or low-emission technologies: research, development and demonstration projects, feed-in-tariffs or quota systems, subsidies

- Exploitation of energy efficiency options: policies to ensure efficient passenger and freight transport, to improve heat insulation, building design and energy-consuming appliances and equipment (cf. Section 4.1.3)

In contrast to climate change, the selected studies vary considerable in terms of how well management of energy security risks is dealt with. In the WEC study energy security issues are clearly taken into account in the design of the scenarios: the storylines are built according to the accessibility, availability and acceptability of energy services. While the last criteria relates to public attitudes towards the environment, the first two are concerned with the affordability, sustainability, continuity and quality of energy services (cf. Section 3.4.1). Energy security is also dealt with explicitly is in WEO, which uses a policy database of current measures including those dealing with energy security, such as the *IEA emergency response mechanism*[60] to manage the risk of a rapid oil price increase.

In the other studies, energy security is not considered in detail, at least not in a way that provides substantial insights for managing this risk. For example, the GR study indicates that the GRREVO scenario achieves energy security by having a diversified renewable energy mix that is independent of fossil and nuclear power generation, and by principles such as equity and fairness between nations and present and future generations, but does not discuss the practical steps for realizing some of these developments. In the ETP study, energy security is not defined explicitly, but is seen as a result of achievements with regards to climate change and energy efficiency. Similarly, little is published in WETO on aspects of energy security other than the determinants of fossil fuel prices. The POLES model used in this study calculates oil and gas prices based on a

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[60] IEA (2007), p. 162: *Requires IEA countries to hold oil stocks and, in the event of a major oil supply disruption, to release stocks, restrain demand, switch to other fuels or increase domestic production in a co-ordinated manner.*

detailed representation of the reserve and resource constraints, which, in the short-term, particularly depend on the capacities in the Gulf countries.

It is noteworthy, however, that the scenarios which include a more explicit discussion of energy security do not exhibit significantly different patterns of technology deployment for electricity generation compared to the other scenarios. This may be because energy security is assumed to be managed through non-technological means (for example, the WEC scenarios are characterized according to the level of international cooperation), or the scenarios are concerned with security associated with energy resources that play a small role in the electricity sector (e.g. oil). Alternatively, the long time horizon of many of the scenarios (to 2050 or beyond, except for WEO) may mean that energy security challenges associated with global resource depletion become a major factor in all scenarios, even if only a few consider energy security in the conventional geopolitical-economic sense.

6.4. Implications for decision-making

Scenarios can in general be applied to support the governance of energy-related risks. Scenario studies can improve the understanding of current and future energy systems due to the following characteristics:

- Scenarios can explore possible alternative futures
- Different pathways to achieve certain targets can be assessed
- Critical trade-offs can be understood, e.g. between technology or mitigation options
- Crucial factors parameter assumptions can be detected
- Consequences of certain decisions can be anticipated
- Uncertainty can be explored

However, some efforts need to be taken in order to ensure an accurate interpretation and application of scenario studies by public decision makers. Often, scenarios are developed and quantified in ways that are not easy to understand (using sophisticated models of the energy system) without an explanation of the assumptions that are ultimately driving the results. One way to address this is for decision makers to be closely involved in the development of scenario studies which they intend to use to support policy. Some promising approaches to improve the involvement of decision makers are discussed in Section 6.6.

Also, decision makers should bear in mind some limiting properties of energy technology scenarios:

- Scenarios are not predictions, i.e. they rather serve as explorative tools.
- Short-term changes of parameters and shocks are usually not represented in detail, since assumptions are often based on a continuation of trends.
- The range of scenarios is limited to the imagination of scenario developers, i.e. subjective opinions about likely futures determine the choice of scenarios.
- In practice, only a limited range of uncertainty can be taken into account, e.g. scenarios tend to focus on a relatively narrow range of economic futures.
- Scenario studies often have a simplified representation of technology characteristics.
- Historically, energy models used to quantify some of the scenarios have not dealt in detail with spatial and actor heterogeneity. In global scenarios, parameters such as plant location or individual consumer behaviour are usually ignored.
- Scenarios developed with an emphasis on quantification may have a quantification bias: soft factors, such as social interaction or individual behaviour in political decision making or technology invention, are difficult to quantify and may be poorly represented.

6.5. Recommendations on energy scenario development and communication

The cross-comparison of technology deployment and its driving factors reveals some areas where the scenario literature can be improved in areas of communication, understanding and credibility, and also in terms of covering important policy challenges. In order to help political or industrial decision-makers to manage uncertainties and make the most of the considerable effort behind these studies, a few measures could be taken:

1. The *key questions to be investigated* in a study should be emphasized. This would help to reveal the motivations and claims of the stakeholders that are involved in funding, committing, or writing the study.

2. The studies should stress the *nature, purpose and limitations of a scenario analysis*, e.g. by explaining the creation of scenarios in terms of the importance and uncertainty of crucial

assumptions. The choice of certain scenarios should be revealed explicitly, since it implies that the differing drivers are seen as the most important and uncertain ones.

3. Most of the selected scenario studies investigate carbon emission scenarios, while energy security, which is often seen as the other major determinant of the energy system, is not treated sufficiently to support decision making. Apart from the WEC studies, where the storylines are built according to accessibilty, availability and acceptability of energy (cf. Section 6.3), no study explores *scenarios with different levels of energy security*.

4. The design of the reference energy system, i.e. the image of the real world at the base year, is a crucial step. To avoid inconsistencies and to ease comparisons across scenario studies, some *conventions* among scenario developers could be defined on what *current cost and capacity data* should be used.

5. Furthermore, it would be helpful to assess the *likelihood of varying outcomes*, despite the inherent challenges associated with such an exercise. The conditions needed to achieve a certain energy- and technology-mix could be described, as well as the environmental, social and financial risks that are caused by this solution. This could also include an assessment of the technical feasibility of construction rates or energy systems in general.

6. The *assumptions and constraints* applied in a certain energy model should be more *transparent and accessible* for the audience. This would facilitate the comprehension of varying outcomes. However, no complete disclosure can be expected on the part of the modelers, since the collection of data is costly and the models represent high value intellectual property. Nonetheless, better access to data and models and the possibility to rerun scenarios under different assumptions would allow for sensitivity analyses and the recognition of game-changing factors. This deepened understanding of the models would also permit adjustments of the models to simulate additional features of the real energy system (or at least ensuring the most important elements of real energy systems are represented).

7. Another promising area to support the governance of energy-related risks would be to develop a *multi-stakeholder set of scenarios*. This is motivated by the observation that scenario studies, which arise from different stakeholder groups (e.g. green, industry, or government perspectives), apply a wide diversity of assumptions that make comparisons and identification of key technology policy questions challenging. Moreover, this affects negatively the use of scenarios in policy and decision making, since stakeholders do not

start with a common understanding or ownership of scenarios. In comparison, developing a multi-stakeholder set of scenarios would enable all stakeholders to begin from a point of agreement before exploring issues of uncertainty or disagreement. In practical terms, this would involve bringing together representatives from industries, NGO's and governments relatively early in the scenario development process to select a common set of scenario input assumptions. This may also extend to the discussion and formulation of appropriate assumptions for factors such as resources availability, energy efficiency improvements, and so on. Thereupon scenarios could be developed that take account of specific motivations and constraints from each viewpoint.

8. It may be beneficial to consider further *approaches to technology assessment* that can provide a richer set of insights. This may be particularly useful given that some of the anticipated factors of deployment identified in Section 2.2 are not represented in most of the energy models (e.g. various kinds of risks) and some are represented in only a limited manner (e.g. environmental burdens other than greenhouse gas emissions). One promising approach towards a more extensive technology representation in scenario modeling has been demonstrated for example in Eliasson and Lee (2003), who incorporated estimates of external costs for a number of criteria into an electric sector simulation model (see also Kypreos and Krakowski, 2004). This kind of framework provides a way to incorporate a richer range of economic, social and environmental criteria into scenario development; thereby accounting for additional driving forces and factors that affect the deployment of various technology options. An extension of this approach would be to complement or combine directly scenario approaches with multi-criteria technology assessment tools, such as life-cycle assessment (LCA) and multi-criteria decision analysis (MCDA) (see e.g. Hirschberg et al., 2004). Some preliminary work in this direction has been implemented in the European Commission NEEDS project (Hirschberg et al. 2008) and in partnership with Axpo (Roth et al. 2009), establishing with stakeholders a broad set of technology assessment criteria covering economic, environmental and social dimensions. In the future this approach could be implemented in scenario development (addressing also point 7 above).

6.6. Recommendations to IRGC

One objective of this review is to advise IRGC on a niche project in the area of energy technology scenarios. In considering options here, it seems clear that IRGC's objectives are not most effectively served by taking a direct role in scenario development, nor in research on the process of technological change and deployment.

However, IRGC could play a role in two key areas. The first could be in enhancing information flow to policy and other decision makers regarding strategies for the management of energy-related risks. That is, IRGC could act as a clearinghouse for transferring knowledge from different studies and viewpoints on optimizing the energy mix to public decision makers. The comparative advantage of such a project would be that it utilizes the extensive and detailed analysis available in the energy technology scenario literature, but addresses weaknesses related to the dissemination, communication and interpretation of these scenarios. In such a project, IRGC would facilitate a better awareness and understanding among decision makers of the range of perspectives on how best to achieve a transition towards a sustainable, secure and efficient energy economy. IRGC would also be in a position to provide pragmatic and independent guidance with a global perspective to support urgent decisions on technology selection and the timing of deployment. A complementary step would be for IRGC to establish a forum to bring public decision makers, industry, and civil society together with the developers of energy technology scenarios along with other experts (as outlined in Section 6.5, recommendation 7). The objective would be to foster understanding and ensure that developers of scenarios are aware of the important governance challenges and uncertainties most relevant to the audience of the scenario studies. This would help ensure that scenarios—which represent a powerful analytical tool for assessing technology deployment—can be exploited most effectively to support decisions on energy challenges. This may provide a means to address some of the specific areas identified in this review where the scenario literature could better support management of energy-related risks, in areas such as accounting for broader resource issues in energy technology deployment and more explicit analysis of energy security options.

Appendix I: Terms of reference

Proposal: Review of energy technology assessment in the scenario literature

Introduction:

Climate change and increasingly vulnerable energy supplies represent important emerging (and existing) global risks. Developing appropriate strategies for managing the complex and uncertain risks associated with these energy-related challenges requires first an understanding of the systems and technologies of the energy system that can contribute to or alleviate these risks. It is also necessary to understand how these technologies and systems can be deployed (i.e., when, at what rate, and in what circumstances). Moreover, it is important to recognize that responses to these risks, given that they deal with complex systems potentially entail further risks, necessitating a comprehensive systems-based approach.

Given the potential magnitude of energy-related climate change and security risks, and the challenges associated with their management, there exists potentially a critical role for the IRGC to contribute to the development of appropriate risk governance responses. In support of this potential role, it is proposed to conduct a review of the extensive range of work published in the scientific literature exploring future technology trends in the energy sector, and transitions towards sustainable energy systems which exhibit, among other features, reduced greenhouse gas emissions and enhanced energy supply security. The objective is to determine the extent to which the technology landscape has been surveyed in the context of achieving reduced GHG emissions and enhanced energy security, thereby identifying: a) where the literature already provides insights regarding how specific systems and technologies (and the timing of their deployment) can effectively manage the risks described above; and b) the most promising areas that are not covered, and where governance of energy-related risks requires further support.

Proposed research:

Systematic review of work in the field of comprehensive technology assessment and scenario analysis related to transitions toward the provision of low-carbon and secure energy services.

Technologies investigated are: efficiency increase of existing plants switching mainly from coal to gas fired plants, clean, efficient coal fired plants and CCS techniques, renewables (advanced solar, off-shore wind,etc.), nuclear (advanced and next generation plants).

Where covered by the available scenario literature, the systematic review will include a rough assessment of the assumptions related to the following:

- development, commercial deployment, and market penetration times [years], all-in costs [€]
- CO2 abatement potential [Gt CO2 avoided in 2015 and 2030] and abatement costs [€/t CO2]
- scale issues / probability of success / overcoming of barriers [quantitatively]
- negative side effects including environmental and social risks
- implementation issues (e.g. regulatory framework, investment climate, acceptance, "climate rent")

It is recognized, however, that it is likely that the available literature will provide only very limited information on most of the above assumptions.

Methodology:

1. Identify and select most relevant (significant) literature. It will be important to cover a range of leading groups/institutions/documents, which could include:

- OECD IEA (documents provided for G8 summit, Energy Technology Perspectives, World Energy Outlook; ...)
- UN IPCC, including WGIII, SRES (key technology assessment such as CCS; ...)
- USDOE EIA (International Energy Outlook; ...)
- EC activities (FP6/7 research such as the NEEDS and ADAM projects, JRC (background material for EU policy and green paper; PTS (Peter Kind), EI (Giovanni De Santi)))
- EMF (based at Stanford U, John Weyant)
- Morita scenarios database
- Possibly others
    - Prince U (stabilization wedges; Robert Socolow)
    - Stuttgart U (comparison of energy scenarios; Alfred Voss)
    - EPRI (PRISM scenarios ; Richard Richels)
    - PTP stakeholders report (technology availability; …)
    - WBCSD (energy and climate trilogy 2050; ...)
    - Alstom – strategy (using CERA scenarios; Boegli)

2. Carefully check, evaluate and compile information to identify key factors affecting deployment of technologies and the dynamics of technology uptake and diffusion, including technology-specific characteristics (performance, cost) and external influences (broader policy, resource, technology, economic environment; availability of complementary and competing systems and components). This will facilitate comparisons across different assessments to identify robust trends and conclusions.

3. The project will be commonly reviewed on a monthly basis.

4. Write assessment/survey report and send first draft to outstanding persons for comment and advice. The list of persons will be developed in consultation with IRGC.

5. Finalize review report and advise IRGC on a niche project in the respective area.

Timeframe and management:

The whole project should last about 6 months, with a most active part of about 4 months, and will start no later than June 1, 2008. Where possible, IRGC will assist with arranging contacts, the process seeking comment from outstanding persons, and editoral activities.

Appendix II: Detailed power generation mix

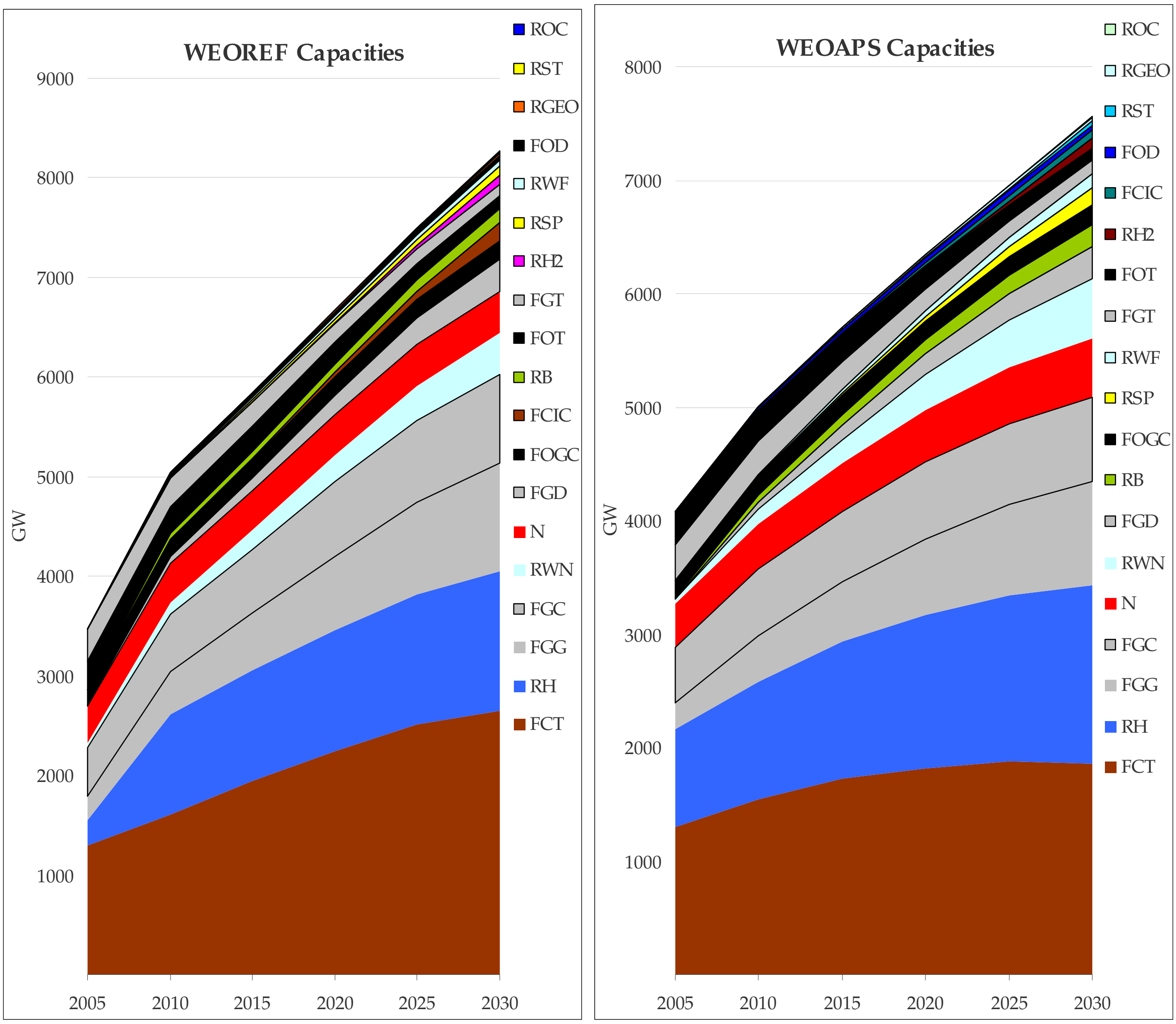

Figure 48 Deployment in WEO

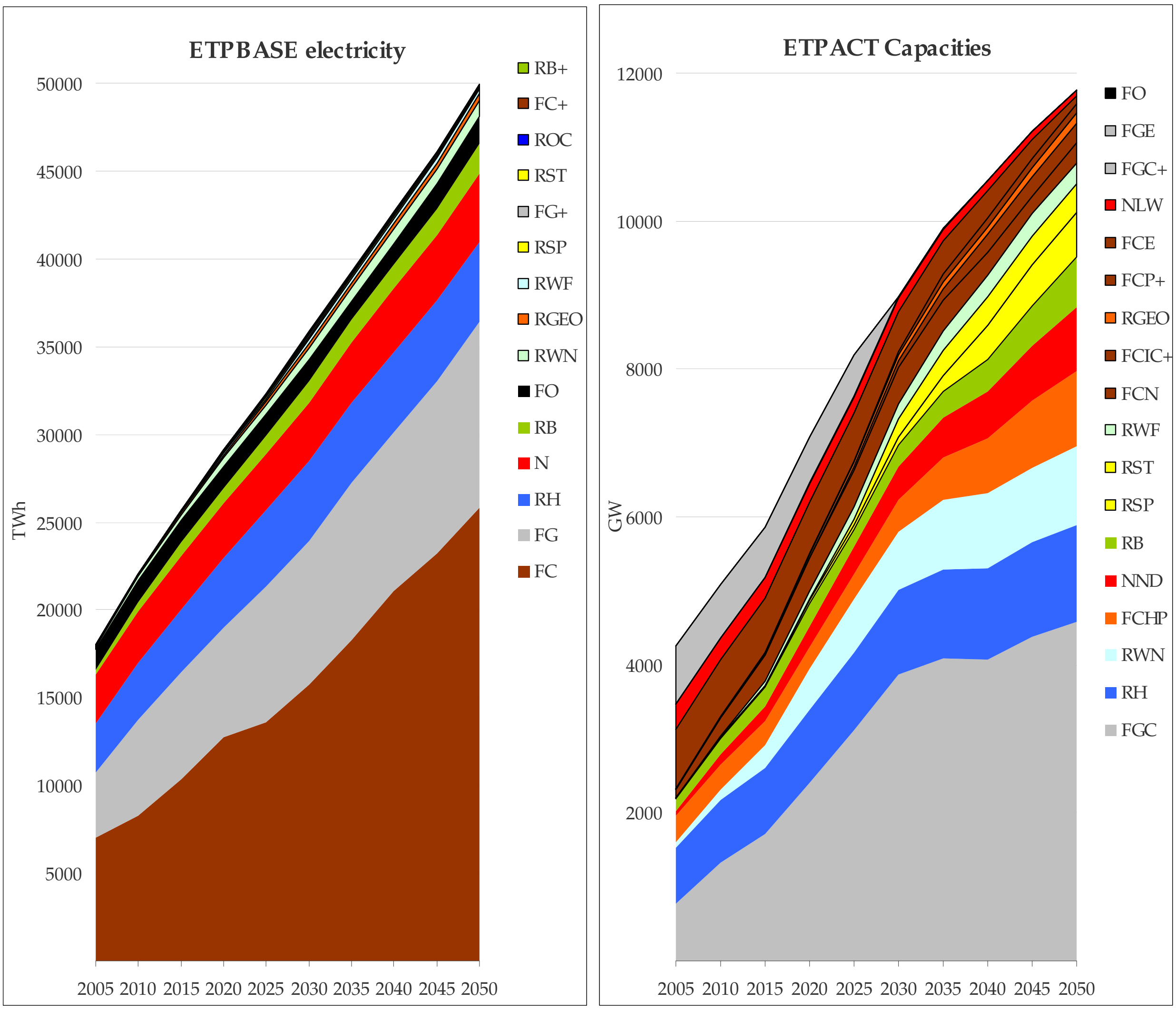

Figure 49 Deployment in ETPBASE and ETPACT

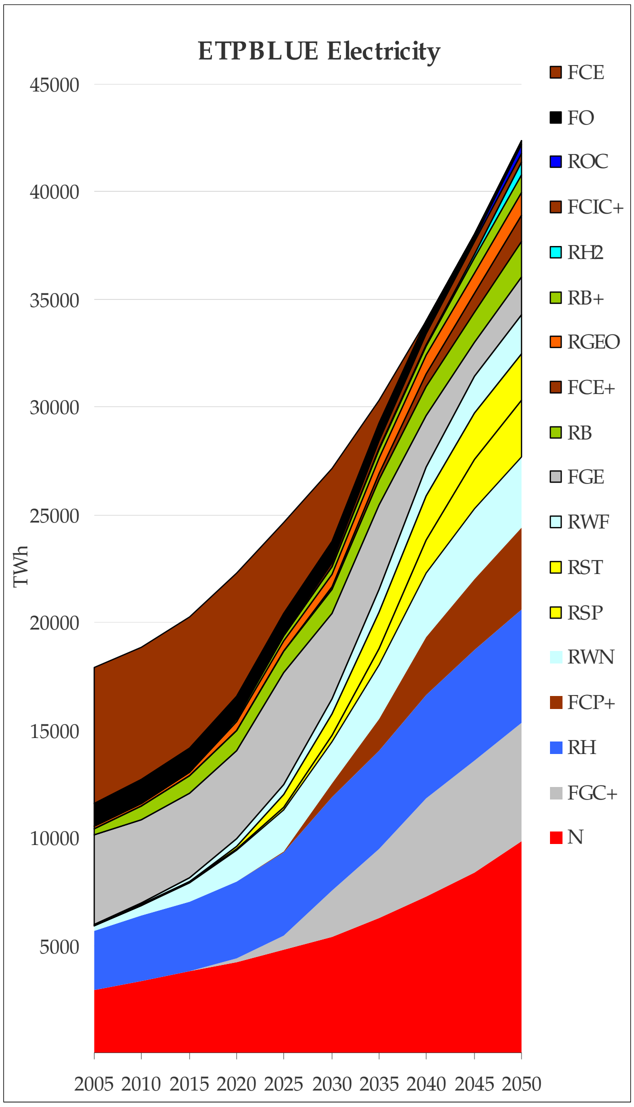

Figure 50 Deployment in ETPBLUE

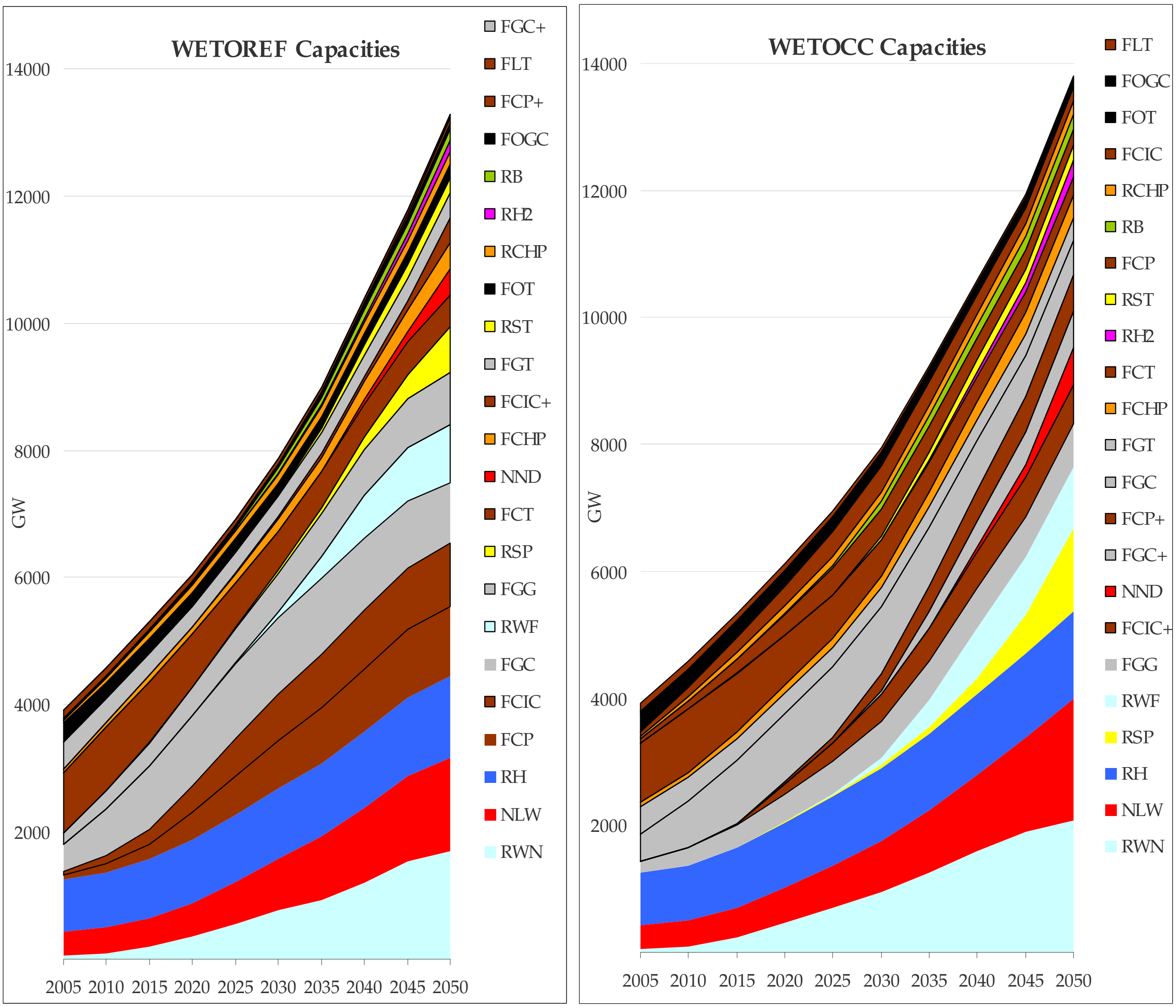

Figure 51 Deployment in WETO

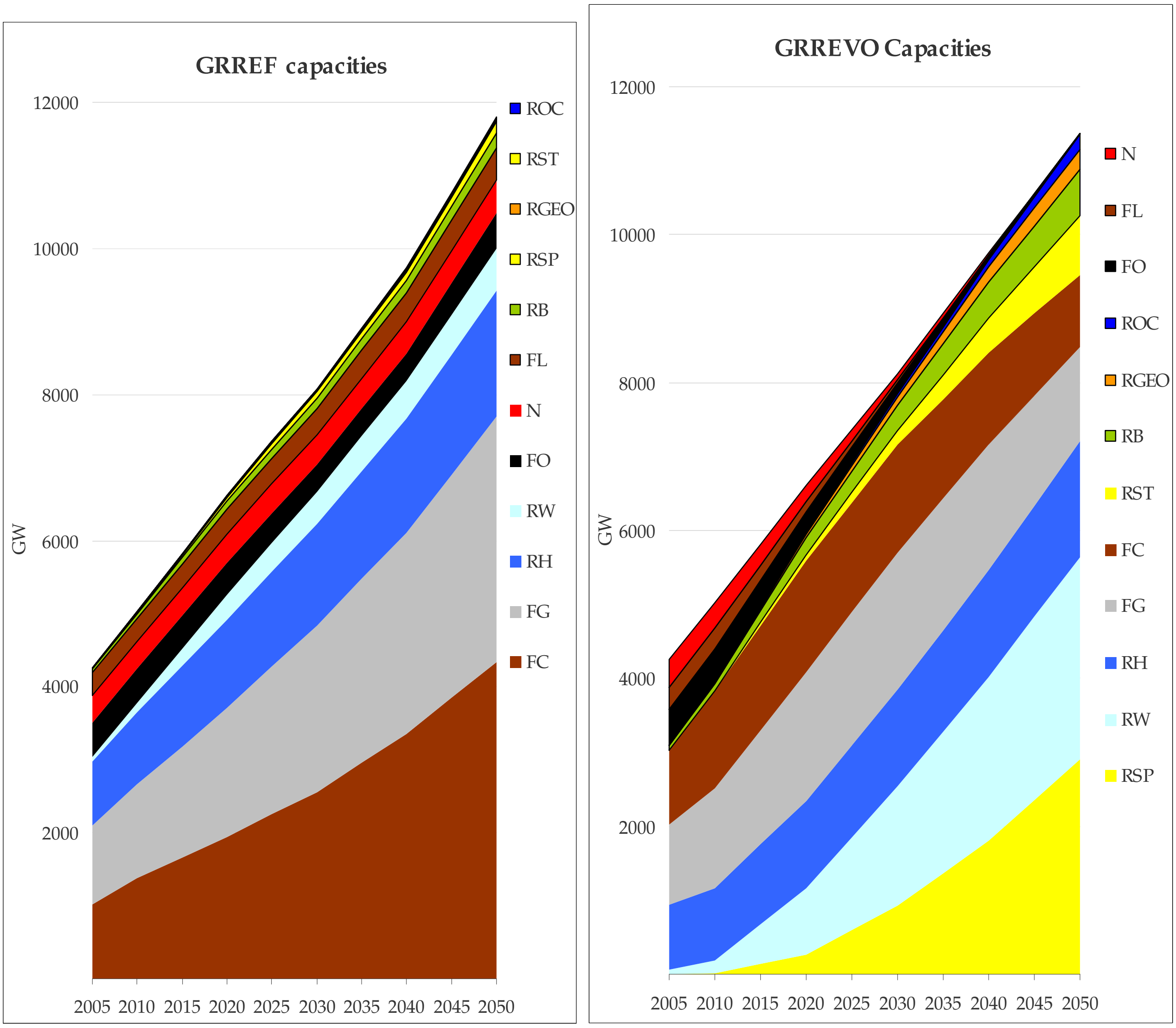

Figure 52 Deployment in GR

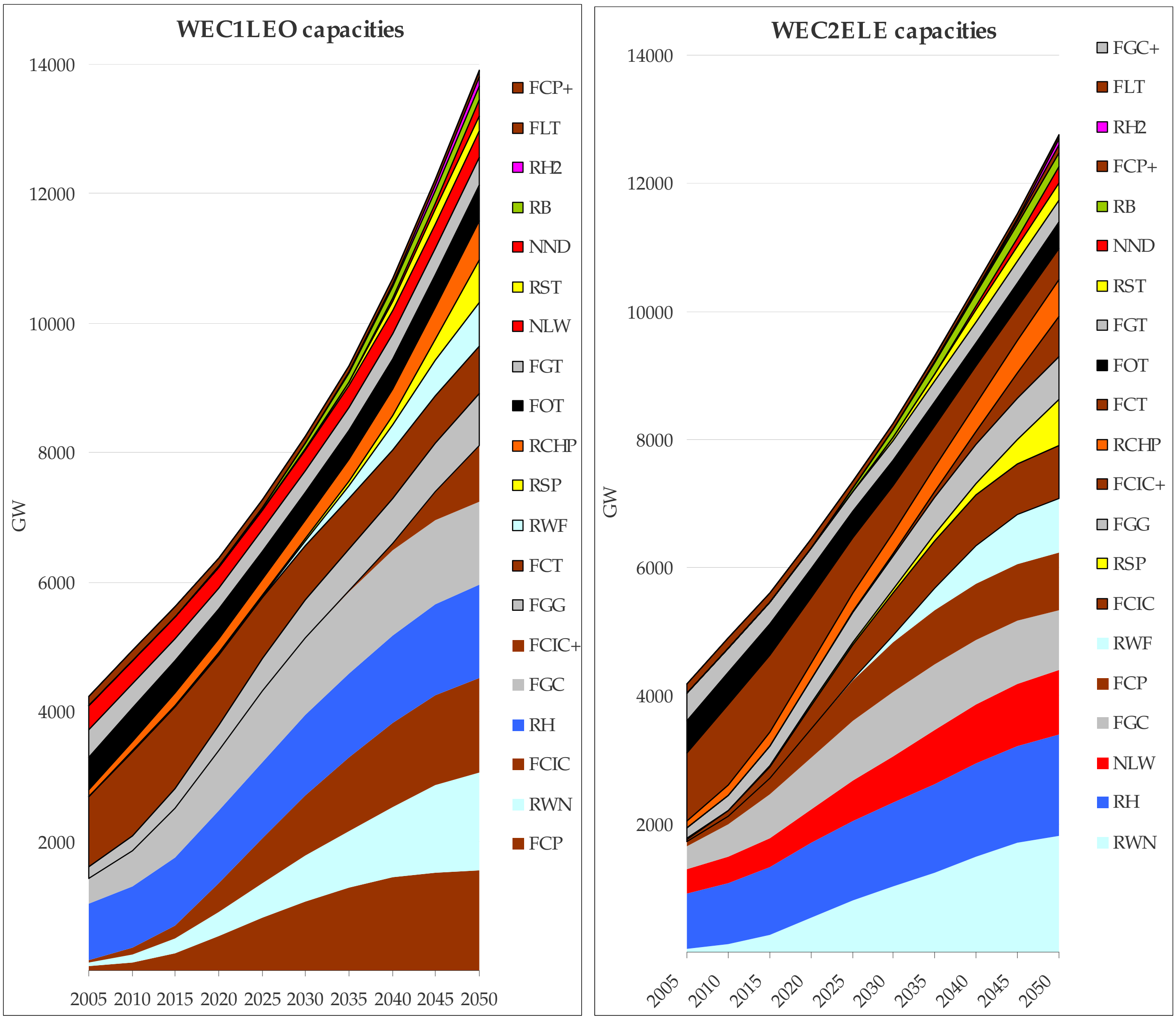

Figure 53 Deployment in WEC1LEO and WEC2ELE

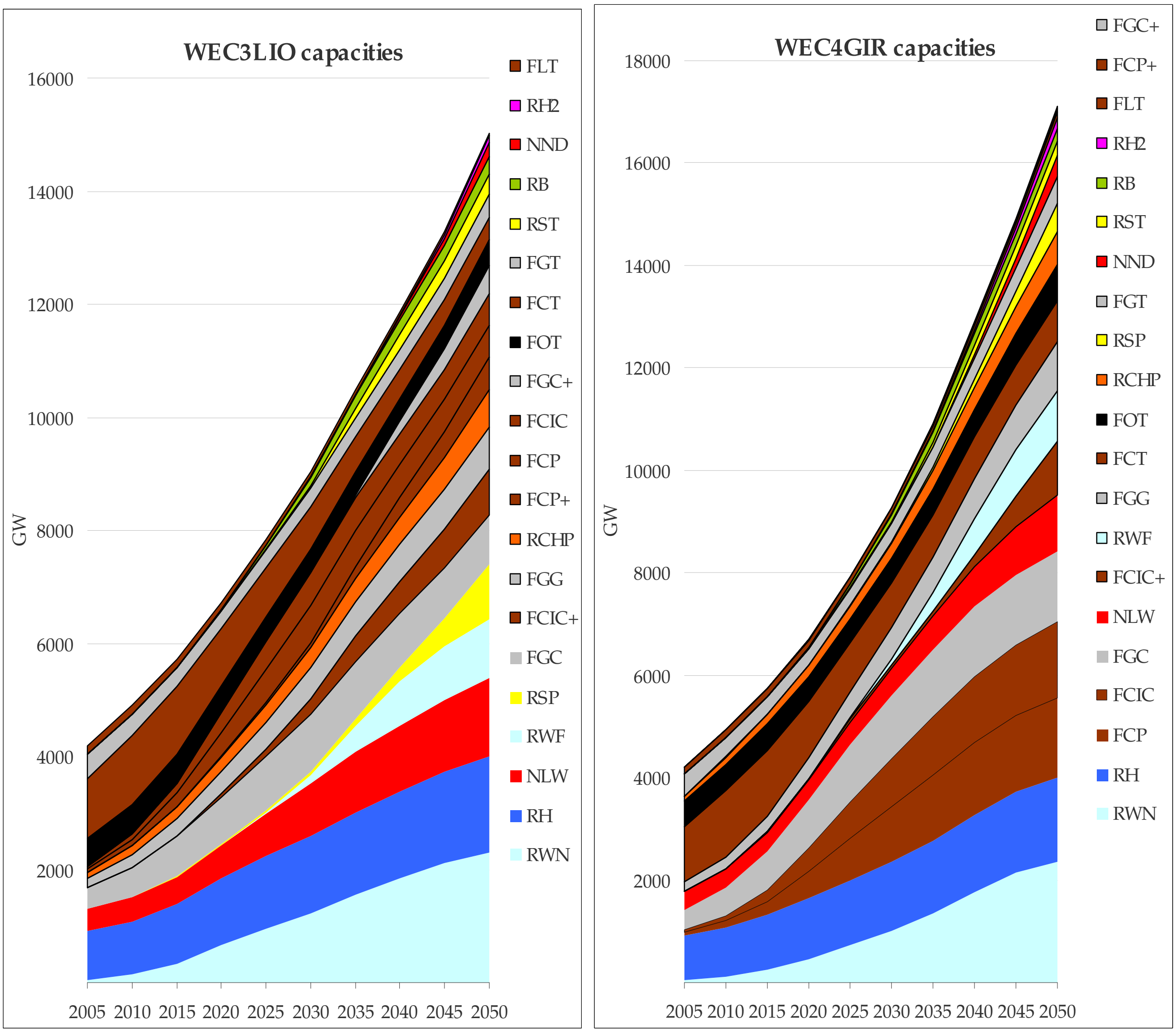

Figure 54 Deployment in WEC3LIO and WEC4GIR

Appendix III: Conversion factors

Table 6 Conversion factors applied for this study

		To: (multiply with)				
		boe	**MBtu**	**GJ**	**toe**	**tce**
From:	**boe**	1	5.8	6.1179	0.146	0.21217
	MBtu	0.1724	1	1.0545	0.02520	0.03658
	GJ	0.1635	0.9483	1	0.02389	0.03468
	toe	6.841	39.6778	41.852302	1	1.573
	tce	4.713	27.3354	28.833489	0.6357	1

(Based on IEA unit converter: www.iea.org/Textbase/stats/unit.asp)

		To: (multiply with)	
		$05	
From:	**$95**	1.253	(Change in US consumer price index)
	$05	1	
	$06	0.967	(Change in US consumer price index)
	€05	1.245	(Annual average exchange rate)

Appendix IV: Publishing institutions

Table 7 Institutions publishing the selected scenarios

Abbr.	Institution	Purpose
OECD	Organisation for Economic Co-Operation and Development	The OECD is a unique forum where the governments of thirty democracies work together to address the economic, social and environmental challenges of globalization. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The OECD member countries are the countries from the EU and EFTA, Australia, Canada, Japan, Korea, Mexico, New Zealand, Turkey and the United States.
IEA	International Energy Agency	The IEA is an autonomous body which was established in November 1974 within the framework of the OECD to implement an international energy programme. The basic aims of the IEA are: To maintain and improve systems for coping with oil supply disruptions; to promote rational energy policies in a global context through co-operative relations with non-member countries, industry and international organizations; to operate a permanent information system on the international oil market; to improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use; to promote international collaboration on energy technology; to assist in the integration of environmental and energy policies.
EC	European Commission	The EC is the executive branch of the European Union. The body is responsible for proposing legislation, implementing decisions, upholding the Union's treaties and the general day-to-day running of the Union.

DG	Directorate-General for Research	The Directorate General's mission is to develop the European Union's policy in the field of research and technological development and thereby contribute to the international cooperation of European industry; to coordinate European research activities with those carried out at the level of the Member States; to support the Union's policies in other fields such as environment, health, energy, regional development, etc; to promote a better understanding of the role of science in modern societies and stimulate a public debate about research-related issues at European level.
WEC	World Energy Council	The WEC is a multi-energy international organization covering all types of energy, including coal, oil, natural gas, nuclear, and renewables. Established in 1923, the WEC has now Member Committees established in 94 countries. Its mission is 'To promote the sustainable supply and use of energy for the greatest benefit of all people'.
GP	Greenpeace	Greenpeace is a global organization that uses non-violent direct action to tackle the most crucial threats to our planet's biodiversity and environment. Greenpeace is a non-profit organization, present in 40 countries across Europe, the Americas, Asia and the Pacific. It speaks for 2.8 million supporters worldwide, and inspires many millions more to take action every day.To maintain its independence, Greenpeace does not accept donations from governments or corporations but relies on contributions from individual supporters and foundation grants.
EREC	European Renewable Energy Council	EREC is an umbrella organization of the leading European renewable energy industry, trade and research associations active in the sectors of photovoltaic, wind energy, small hydropower, biomass, geothermal energy and solar thermal. EREC is committed to the following objectives: To act as a forum for exchange of information and discussion on issues related to renewables as well as to represent the European RES industry & research community; to provide information and consultancy on renewable energies for the political decision makers on local, regional, national and international levels; to launch policy initiatives for the creation of positive frameworks for renewable energy sources; to promote European technologies, products and services on global markets.

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