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Chapter 10

Mitigation Potential and Costs

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Length

Chapter 10 has been allocated a total of 68 pages in the SRREN. The actual chapter length (excluding references & cover page) is 90 pages: a total of 22 pages over target.

The Executive Summary exceeds its allocation by 2 pages as it shall not exceed 1.5 pages.

Expert reviewers are kindly asked to indicate where the Chapter and Executive Summary could be shortened in terms of text and/or figures and tables.

Structure

In light of the very successful IPCC WG III Expert Meeting 'Modelling Renewable Energies; Coherence Between Model Assumptions and Latest Technological Knowledge', new data and new literature the structure of Chapter 10 has been improved to follow a more logical order. This new structure is subject to IPCC plenary approval. Please note that all content from the chapter outline has been retained. Expert Reviewers are kindly invited to comment on these amendments.

The content of the original 10.2 (Methodological Issues) is now integrated in each relevant sub-section, where appropriate. Similarly, the content of the original 10.7 (Gaps in knowledge and uncertainties) now appears at the end of the relevant sub-sections, where appropriate. The original 10.3 (Assessment and synthesis of scenarios for different renewable energy strategies (top-down and bottom-up)) is shifted to section 10.2 and deals as before with an overview of medium to long-term global, aggregated models. The original section 10.4 (cost curves for mitigation with renewable energy) is split apart into the new sections 10.3 and 10.4. The new 10.3 (Assessment of representative mitigation scenarios for different renewable energy strategies) investigates those models further that have greater technological detail. The new 10.4 (regional cost curves for mitigation with renewable energy) extends on the old 10.4 and goes into further technical detail dealing with regional resource cost curves and mitigation cot curves.

References

References highlighted in yellow are either missing or unclear.

Tables & Figures

The Numbering of tables & figures is not continuous and its structure differs between the numbers attached to the table & figure and the one in the text. That is, numbering of tables & figures starts new with every subsection 10.x and is structured 10.x.1, 10.x.2, … Numbering in the text starts with 1 in every subsection 10.x. Therefore, each reference can be clearly identified by the last digit. For example, in section 10.2, Figure 10.2.5 is referred to as Figure 5 in the text.

Currencies

All monetary values provided will need to be adjusted for inflation/deflation and then converted to US$ for the base year 2005.

Abbreviations

RE, RES	Renewable Energy Sources
OMC	Operation and Maintenance Costs
CHP	Combined Heat and Power

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EXECUTIVE SUMMARY

The evolution of future greenhouse gas emissions is highly depending on the availability of mitigation technologies and their implementation, triggered, amongst others, by cost effects or specific policy incentives. The uncertain future is reflected in the wide, and growing, range of emissions pathways across emission scenarios in the literature, as was well reflected in the most recent IPCC assessment report (IPCC, 2007). One of the main questions in that context is the role renewable energy sources (RE) are likely to play in the future and how they can particularly contribute to GHG-mitigation pathways.

RE, together with energy efficiency, is expected to play an important, and increasing, role in achieving ambitious climate mitigation targets. Although many RE technologies are becoming increasingly market competitive, many innovative technologies in the field of RE still have a long way to go before becoming mature alternatives to non-renewable technologies. Assessing the future role of technologies requires an integrative perspective, interactions with other technologies and the overall energy system have to be considered.

As such, it is most important to appraise the mitigation potentials and costs of RE technologies based on the assessment of the most recent scenario and deployment pathways literature available on the subject, as well on potentials and costs of specific technical analyses of different RE technologies.

Following the comprehensive scenario analysis (investigation of 137 scenarios) performed in this chapter, increasing demand for energy, and for low-carbon energy in particular, if the world chose to reduce greenhouse gas emissions, could lead to RE deployments many times, or even orders-of-magnitude larger than those of today. Indeed, even without climate mitigation, many scenarios include RE deployments by the end of the century larger than the total global energy system today simply by virtue of growing energy demand. However, there are several challenges RE are facing in the context of climate mitigation. In the near-term, the challenge is achieving deployment increases at a rate that is consistent with meeting very ambitious longer-term levels. There are many objectives in energy policy other than climate change mitigation, such as increasing energy security, reducing energy import dependence, pollution levels or creating job opportunities, that RE contribute to and that served as reasons for establishing incentive schemes to support RE deployment in the recent past. Although the potential is quite large and other reasons are relevant to push market penetration of RE, tremendous uncertainty surrounds the role of RE in climate mitigation. This uncertainty is manifest in the wide range of RE deployments in the scenarios reviewed in this section. The range is a reflection of uncertainty in: energy demand growth; the degree to which the development and deployment of high-efficiency energy end-use technologies mitigates this growth; the degree of climate mitigation; the ability of RE technologies to overcome their costs, performance, and other barriers; and the ability of competing supply technologies, most notably nuclear energy and fossil energy with CCS, to overcome cost and performance, social acceptance, environmental, and other barriers.

However, given the still high unexploited technical opportunities of RE, although without having reached their full technological development limits so far, it can be concluded that technical potentials are not the limiting factor to the expansion of the renewable energy generation.

If the renewable industry could maintain the growth rates between 2000 and 2009 for the next decades, all combined power technologies could achieve an electricity share of 39% by 2020, 58% by 2030; and before 2050 the entire electricity could come from renewable power sources, if in the same time period global power demand showed only a moderate growth rate (69% increased by 2050 compared to 2005 level).

Similar to the more aggregated scenario overview presented in this chapter, the more in depth look on selected scenarios and in particular on the possible contribution of RE in different sectors or for different applications show a substantial range of different results. The total share of renewable heating systems in all scenarios by 2050 varies significantly between 21%, if combining a high power demand and a low RE market development case, and 69%, anticipating the advanced market development and low demand case. A medium range market development and medium increase of heat demand would lead to a renewable heat share of 27% by 2020 and up to 47% by 2050.

In the most optimistic case, which is a combination of a high market development for renewable energies and a successfully implemented energy efficiency strategy, renewable energies could provide 61% of the world energy needs by 2050. While there is a potential to supply the entire global power demand with renewable energies and 69% of global heating and cooling demand, the most problematic sector for renewable energy to supply substantial shares is the transport sector. Even the energy scenarios with the most ambitious growth rates for renewable energy did not exceed an exhaustion rate of the technical potential of 3.2% (China, 2020) on a regional level and 0.58 % (2050) on a global level.

Based on the selected scenarios and calculated with the status quo specific emission factors for electricity generation, heat and fuel as an orientation mark, the total annual CO_2 reduction potential varies significantly between the low, medium and high cases. While the low case abatement potential for renewable is only 5.8 Gt CO_2/a by 2050, which represents the business as usual pathway, the medium case achieves a total of 15.4 Gt CO_2/a by 2050. The annual high case CO_2 savings lead to 33.3 Gt CO_2/ a, which is equal to a 70% reduction of energy related CO_2 emissions of the analysed reference scenarios.

To follow the scenario pathways is of course quite challenging. A strategic increase of the production capacity of 50 to 100 GW/a for each technology (in the power sector) within the next decade is required to achieve drastic emission cuts - but also to achieve cost reductions in order to become independent from support programs. However, this does not seem to be impossible, as annual growth rates from RE have been constantly underestimated in the past decades.

This chapter also focuses on the concept of supply curves of RE and therefore adds regional cost aspects to renewable energy potentials. The concept of abatement, energy and conservation supply curves nowadays is a very often used approach for mitigation strategy setting and prioritizing abatement options. One of the most important strengths of this method is, of course, that the results can be understood easily and that the outcomes of those methods give, on a first glance, a clear orientation as they rank available options in order of cost-effectiveness.

While abatement curves are very practical and can provide important strategic overviews, it is pertinent to understand that their use for direct and concrete decision-making has also some limitations. Most of the concerns are, amongst others, related to simplification issues; difficulties with the interpretation of negative costs; the reflecting of real actor’s choice; the uncertainty factors with regard to the discount rate as a crucial assumption for the resulting cost data; the missing dynamic system perspective considering relevant interactions with the overall system behaviour; and the sometimes not very sufficient documentation status

The reviews of the existing regional and national literature on RE as well as mitigation potential literature as a function of cost show a very broad range of results. In general, it is very difficult to compare data and findings from renewable energy supply curves as there have been very few studies using a comprehensive and consistent approach and detailing their methodology; and most studies use different assumptions (technologies reviewed, target year, discount rate, energy prices, deployment dynamics, technology learning, etc.). Concerning the analyzed regional/country studies[1] it is worth to mention that they attribute fairly low abatement potential to renewable energies under USD100/tCO_2 – typically in the single digit range, with their highest contribution of 13% of emissions foreseen in Australia in 2030. The findings translated in terms of the potential role of RE for mitigation pathways from the analysed studies are somehow quite different from answers given through other methods (even such as scenario based RE supply curve analysis conducted in this section).

In this chapter, the renewable power cost curves for 10 world regions have been reviewed for 2030 exemplary for two scenarios - World Energy Outlook (IEA, 2008b) and Energy [R]evolution scenario (Krewitt et al, 2009a) - and one for 2050 (Energy [R]evolution scenario). The calculated cost curves represent dynamic deployment potentials rather than static technical or economic ones. Although the curves are based on different deployment paths as a result of the two selected scenarios, a few general regional and technological trends are shown by these curves. Most typically, on- and offshore wind power prove to be the most cost-effective in many regions, both in the shorter and longer terms. Hydropower is often close to wind in cost-effectiveness in 2030, especially in the WEO scenario, but it looses parts of its competitiveness in many regions by 2050. While these two technologies dominate many of the curves at reasonable costs (e.g. under USD 150/MWh) in 2030, by 2050 a more balanced portfolio of technologies appears in most regions, with many other technologies taking a large share of the available low-cost potential, including CSP, PV, and geothermal. Ocean energy is also projected to compete successfully with other technologies in regions with access to the seas, but its overall contribution to the potential remains limited everywhere. In 2050, geothermal, hydropower and CSP become the least attractive options from the perspective of costs in most regions, although CSP is projected to be among the most cost-competitive options and also supplying very large potentials in Africa and the Middle East in both the shorter and longer term, and is very cost-competitive in North America over both periods.

With regard to temporal dynamics of potential size, the curves underline the importance of a long-term perspective and a consequent market introduction policy. Many regions see a several-fold increase in their low-cost renewable energy potential between 2030 and 2050, including an almost doubling in Latin-America, other Asian countries and other transition economies, over a doubling in China and OECD Pacific, 2.5 times increase in Africa, and over a triplication in India and the Middle East.

Although some of the technologies applied in the field of renewable energy usage are already competitive, at least in niche market applications, a review of energy generation costs reveals that most of them are still not competitive. As most of these technologies are in early stages of their respective innovation chains, which cover research and development, demonstration, deployment and the final step to commercialization, learning by research (triggered by research and development expenditures) and/or by learning by doing (resulting from capacity expansion programs) effects, however, this might result in considerable lower costs in the future.

In the past, the energy generation costs of the most important innovative renewable energy technologies showed a significant decline. In general, the cost decrease is well described by empirical experience curves with learning rates between 8 and 32% (wind onshore), 13 to 26 % (photovoltaic), 2 to 15% (concentrating solar power), and up to 30 % for biomass.

In order to realize the learning effects mentioned above and to approach the break-even point, significant upfront investments are needed (deployment costs). On a global scale, annual investment needs in the order of 100 billion USD are expected in case that ambitious climate protections goals (e.g., the 2°C mean temperature change limit) are pursued. This number allows assessing future market volumes and resulting investment opportunities. Due to avoided fossil fuel costs and

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[1] available in the public domain as of Summer 2009

decreased investment needs for conventional technologies, the additional costs (learning investments) might be considerably lower than the deployment costs.

Learning by research and learning by doing can be facilitated by suitably designed research and development programs (intended to result in a technology push) and capacity expansion promotion programs (intended to establish a market pull). Due to market failures, the internalization of the external costs of carbon (e.g., via emission trading schemes) might not suffice to design emission mitigation strategies that are cost-effective from a long-term perspective. In addition, a technology specific support for selected innovative technologies (e.g., via feed-in tariffs) might be recommended to cover the specific characteristic of RE systems in a suitable manner.

Although social and environmental external costs vary heavily amongst different energy sources and are still connected with an high uncertainty range, they should be considered if the advantages and disadvantages of future paths are being assessed. Typically, the production and use of fossil fuel cause the highest external costs dominated by the costs due to climate change impacts. Most of the time, RE sources have clearly lower external costs assessed on life-cycle basis. However, the uncertainty and variability by energy chains is considerable. Some RE production cases can cause considerable external impacts as well. The increase of RE in the energy system typically reduces the overall external costs of the system which produces external benefits. The increase of RE decreases also society’s dependency on fluctuating prices and depleting resources of fossil fuels and it can improve the access to energy. It can also have a positive impact on trade balance and employment, e.g. in the case of energy biomass production. However, according to the results of some economic model studies, a forced increase of RE can raise the price level of energy and slow slightly the growth of the economy as well, in certain situations.

10.1 Introduction

The evolution of future greenhouse gas emissions is highly depending on the availability of mitigation technologies and their implementation triggered amongst others by cost effects or specific policy incentives. The uncertain future is reflected in the wide, and growing, range of emissions pathways across emission scenarios in the literature, as was well reflected in the most recent IPCC assessment report (IPCC, 2007). One of the main questions in that context is the role renewable energy sources (RE) are likely to play in the future and how they can particularly contribute to GHG-mitigation pathways.

RE, together with energy efficiency, is expected to play an important, and increasing, role in achieving ambitious climate mitigation targets. Although many RE technologies are becoming increasingly market competitive, many innovative technologies in the field of RE still have a long way to go before becoming mature alternatives to non-renewable technologies. Assessing the future role of technologies requires an integrative perspective, interactions with other technologies and the overall energy system have to be considered.

Behind that background this chapter assesses the mitigation potentials and costs of RE technologies taken as a whole based on an assessment of the most recent scenario literature available on the subject, as well at least for some sections on inputs (in particular deployment pathways) coming from previous technology chapters (chapters 2-7) in this report.

This chapter starts (Section 10.2) by providing context for understanding the role of RE in climate mitigation through the review of a total of more than a hundred medium- to long-term scenarios from large-scale, integrated, energy-economic models as well as from more technology detailed models. The underlying goal of this exercise is besides others to gain a better understanding of robust evolutions of RE as a whole and single technologies reflecting different sets of assumptions.

The section that follows (Section 10.3) complements the review with a more detailed and near-term-focused review based on a selected part of the global scenarios. This sections provides a next level of detail for exploring the role of RE in climate change mitigation. As such, while section 10.2 coming from a more statistical perspective gives a comprehensive overview about the full range of mitigation scenarios and tries to identify the major relevant driving forces and system interactions (e.g. competing technologies) for the resulting RE deployment in the market and the specific role of these technologies in mitigation paths, section 10.3 provides a more detailed view in particular of the required generation capacity, annual growth rates and the potential costs of RE deployment into the future. Within that context the section distinguishes between different applications (electricity generation, heating and cooling, transport) and regions.

Then the purpose of the section that follows (Section 10.4) is to go to a next level of detail with regard to regional potentials as a function of costs. The section first of all assesses the strengths and shortcomings of supply curves for RE and GHG abatement, and then reviews the existing literature on regional RES [TSU: Renewable Energy Sources] supply curves as well as abatement cost curves as they pertain to mitigation using RE. The section comes out with a consistent set of regional cost curves for RE. For the calculation data are used from a subgroup of scenarios which have already been discussed in the previous sections and covering different future pathways.

The next section (Section 10.5) deals with the costs of RE commercialization and deployment. The idea is to review the present RE technology costs, as well as the expectations on how these costs might evolve into the future. Learning by research (triggered by R&D expenditures) and learning by doing (fostered by capacity expansion programs) might result in a considerable long-term decline of RE technology costs. The section therefore will present historic data on R&D funding as well as on observed learning rates. In order to allow an assessment of future market volumes, the investment in RE will be discussed which is required if ambitious climate protections goals are to be achieved.

The following section (Section 10.6) synthesizes and discusses social, environmental costs and benefits of increased deployment of RE in relation to climate change mitigation and sustainable development. The analysis is performed by RE technology and, to a minor extent also by geographical area, as regional information is still mostly very sparse, in the context of sustainable development.

Gaps in knowledge and uncertainties associated with RE potentials and costs are discussed in each of the sections of the chapter.

10.2 Synthesis of mitigation scenarios for different renewable energy strategies [TSU: deviation from structure agreed by plenary: "Methodological issues"]

This section provides context for understanding the role of RES in climate mitigation through the review of medium- to long-term scenarios from large-scale, integrated, energy-economic models. In particular, the section is motivated by four strategic questions at the heart of RES mitigation cost and potential. First, what sorts of RES deployment levels are consistent with different climate change mitigation targets? Second, over what time frames and where will RES deployments occur? Third, how are the costs of mitigation tied to RES deployments? Finally, what factors influence the answers to all of the above?

The scenarios explored in this were developed using large-scale energy-economic and integrated assessment models. The benefit of large-scale, integrated models is that they capture the interactions with other technologies, other parts of the energy system, other relevant human systems (e.g., agriculture), and important physical processes associated with climate change (e.g., the carbon cycle), that serve as the environment in which RES technologies will be deployed. In addition, they explore these interactions over at least several decades to a full century and often at a global scale. This degree of coverage is critical for establishing the strategic context for RES. However, this degree of coverage puts limits on the degree of detail that these scenarios can represent. The section that follows, Section 10.3, complements the review here with a more detailed and near-term-focused review of a smaller set of scenarios; it provides a next level of detail for exploring the role of RES in climate change mitigation.

Several important themes emerge from the review in this section. First, increasing demand for energy, and for low-carbon energy in particular if the world chooses to reduce greenhouse gas emissions, could lead to RES deployments many times, or even orders-of-magnitude, larger than those of today. Indeed, even without climate mitigation, many scenarios include RES deployments by the end of the century larger than the total global energy system today simply by virtue of growing energy demand. Second, there are both a near-term and long-term contexts for considering the challenges facing RES in climate mitigation. The longer-term challenge will increasingly be one of scale, as the total deployment of low-carbon energy, including RES, nuclear power, and fossil energy with CCS, could reach several times the total global energy system today. In the near-term, the challenge is achieving deployment increases at a rate that is consistent with meeting these longer-term levels. However, there are objectives in energy policy other than climate change mitigation, such as reducing energy import dependence, pollution levels or creating job opportunities, that RES contribute to and that served as reasons for establishing incentive schemes to support RES deployment in the recent past. Finally, although the potential is quite large, tremendous uncertainty surrounds the role of RES in climate mitigation. This uncertainty is manifest in the wide range of RES deployments in the scenarios reviewed in this section. The range is a reflection of uncertainty in: energy demand growth; the degree to which the development and deployment of high-efficiency energy end-use technologies mitigates this growth; the degree of climate mitigation; the ability of RES technologies to overcome their cost, performance, and other barriers; and the ability of competing supply technologies, most notably nuclear energy and fossil energy with CCS, to overcome cost and performance, social acceptance, environmental, and other barriers.

10.2.1 State of scenario analysis

Scenarios are a tool for understanding, but not predicting, the future. Scenarios provide *a plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships* (IPCC, 2007). They are thus a means to explore the potential contribution of RES to future energy supplies and to identify the drivers of their deployment. In a climate stabilization regime, RES must compete with other options, such as nuclear energy, carbon capture and storage (CCS), energy efficiency and behavioural changes, to reduce GHG emissions the future energy system. Therefore, it is important to put renewable energy sources into the larger context of the energy system and the economy as a whole, in particular when thinking about the longer-term perspective to 2030, 2050 or even beyond.

The climate change mitigation scenario literature largely consists of two distinct approaches: quantitative modelling on the one hand and qualitative narratives on the other hand (see (Morita et al., 2001; Fisher et al., 2007) for a more extensive review). There have also been several attempts to integrate narratives and quantitative modelling approaches (Nakicenovic and Swart, 2000; Morita et al., 2001; Carpenter et al., 2005). The analysis in this section relies exclusively on scenarios that provide a quantitative description of the future. These scenarios are valuable because of they provide quantitative estimates of renewable deployments and other important parameters and because they explicitly and formally represent the interactions between technologies and other factors. It is important to note, however, that there is enormous variation in the models used to construct the quantitative scenarios. Many authors have attempted to categorize these models as either bottom-up and top-down. For several reasons (see Box 1) [TSU: Box 10.1], this review will not rely on the top-down/bottom-up taxonomy. Instead, the characteristics of “technology detail” and “level of integration” will be used to help define modelling approaches.

Box 10.1: Moving Beyond Top-Down vs. Bottom-Up?

In previous IPCC reports (e.g. (Herzog *et al.*, 2005; Barker *et al.*, 2007)) quantitative scenario modelling approaches were broadly separated into two groups: top-down and bottom-up models. While this classification may have made sense in the past, recent developments make it decreasingly appropriate. Most importantly, (i) the transition between the two categories is continuous, and (ii) many models, while being rooted in one of the two traditions (e.g. macro-economic or energy-engineering models), incorporate aspects from the other approach and thus belong to the class of so-called hybrid models (Hourcade *et al.*, 2006; van Vuuren *et al.*, 2009a).

In addition, the terms top-down and bottom-up can be misleading, because they are strongly context dependent: they are used differently in different scientific communities. For example, in previous IPCC assessments (RS: Provide precise references), all integrated modelling approaches were classified as top-down models regardless of whether they included significant technology information (van Vuuren *et al.*, 2009a). On the other hand, the interpretation of both terms depends on the aggregation level that is typically addressed by the respective scientific community. In the energy-economic modelling community, macro-economic approaches are traditionally classified as top-down models and energy-engineering models as bottom-up. However, in engineering sciences, even the more detailed energy-engineering models that represent individual technologies such as power plants, but essentially treat them as “black boxes”, are characterized as top-down models as opposed to a component-based view which is considered to be bottom-up.

To avoid the confusion borne by the top-down/bottom-up taxonomy, this section will organize modelling approaches along two axes: “technology detail” and “level of integration”. By “technology detail” on the one hand the number of individual technologies and corresponding resource grades (e.g. wind on-/offshore) included in the models and on the other hand the adequate representation of their technical characteristics (e.g. fluctuating electricity generation from RES) is captured. While the former might lead to an over- or underestimation of the (technical and economic) potential, the latter can have significant impacts on the competitiveness of technologies. The “level of integration” in energy studies varies significantly from single technology and sectoral assessments to energy-economic and integrated assessment modelling where the latter also includes interactions of the energy sectors with the biosphere, the climate system, etc.

A total of 150 scenarios from the recent literature are reviewed in this section. Although this set of scenarios is by no means exhaustive of the recent work on mitigation scenarios, it is large enough and extensive enough to provide robust insights into the role of RES in climate change mitigation. In addition, although the level of integration and technology detail varies considerably across the underlying modelling frameworks, they all share an energy systems view; that is, no scenarios/studies that only look at single sectors or technologies are included. In addition, at least basic coverage of socio-economic variables (population, GDP) and climate indicators (atmospheric CO_2 concentration) was required. Included in this set are a number of scenarios from three co-ordinated studies: the Energy Modeling Forum (EMF) 22 international scenarios (Clarke et al., 2009), the ADAM project (Edenhofer et al., 2009b) and the RECIPE comparison (Edenhofer et al., 2009a; Luderer et al., 2009) that harmonize some scenario dimensions, such as baseline assumptions or climate policies across the participating models. The whole set of scenarios covers a large range of climate stabilization levels (350-1050 ppm atmospheric CO2 concentration by 2100) and time horizons (2050, 2100). The majority of the scenarios are global in scope.

This set of scenarios has several distinguishing characteristics that make is most appropriate for the consideration of RES. First, the scenarios represent the most recent work of the quantitative modelling community, and therefore reflect the most recent understanding of key underlying parameters. Second, the scenario set includes a relatively large number of selected 2nd-best scenarios which cover less optimistic views on international action to deal with climate change (delayed participation) or address consequences of limited mitigation portfolios (technology failure). While traditionally 1st-best scenarios used to dominate the mitigation scenario literature, more recently 2nd-best scenarios have received growing attention (Clarke et al., 2009; Edenhofer et al., 2009a). As shown in Table 1, the share of 2nd-best scenarios is decreasing towards lower CO2 concentration levels, indicating that attainability of the lower targets gets increasingly difficult under 2nd-best assumptions. Finally, in developing the database for this section, RES information was collected at a level of detail beyond that found in most published papers or existing scenario databases, e.g. those compiled for previous IPCC reports (Morita et al., 2001; Hanaoka et al., 2006; Nakicenovic et al., 2006). For example, many scenario databases represent renewable energy technologies as either bioenergy or non-biomass renewables (e.g., Clarke et al., 2009).

Table 10.2.1: Number of long-term scenarios categorized by CO2 concentration levels in 2100 (categories as defined in the IPCC AR4, WGIII, see (Fisher et al., 2007)), assumptions on participation in a global climate regime and technology availability. The assumptions regarding delayed participation vary considerably, but are mostly taken from two harmonized studies (see (Clarke et al., 2009; Luderer et al., 2009)). Similarly, technology availability is not defined homogenously across all scenarios in the analyzed set. Scenarios from (Kurosawa, 2006; van Vuuren et al., 2007; Akimoto et al., 2008; IEA, 2008; Shukla et al., 2008; Alban Kitous et al., 2009; Bosetti et al., 2009a; Bosetti et al., 2009b; Calvin et al., 2009; Gurney et al., 2009; Krewitt et al., 2009; Krey and Riahi, 2009; Leimbach et al., 2009; Loulou et al., 2009; Luderer et al., 2009; Magne et al., 2009; van Vliet et al., 2009). [TSU: No reference in text]

	CO2 concentration by 2100 [ppm]	all scenarios	mitigation scenarios		
			1st-best	2nd-best (del. participation)	2nd-best (limited tech. portfolio)
Cat I+II (350-440ppm CO2)	350 - 440	39	24	3	12
Cat III+IV (440-570ppm CO2)	440 - 570	81	36	17	28
references (>600ppm CO2)	> 600ppm	30	-	-	-
Total	-	150	60	20	40

Figure 1 [TSU: Figure 10.2.1] shows the development of global fossil and industrial CO2 emissions in the medium- to long-term scenarios over the century, grouped by different categories of atmospheric CO2 concentration in 2100. Similar to previous assessments (e.g. (Fisher et al., 2007)) and as illustrated by the broad range of emissions in the baseline scenarios (without climate policies) as well as the different emission trajectories in the intervention cases, there is considerable uncertainty about the future evolution of the energy system. This uncertainty is reflected in the different assumptions used to develop scenarios and, as a result, in the aggregate characteristics of the energy system. For instance, fossil and industrial CO2 emissions by 2050 in the baseline scenarios cover a range of 43 to 84 GtCO2, leading to CO2 concentration levels of 490-570 ppm by 2050 and further to concentrations of 610-1050 ppm by 2100.

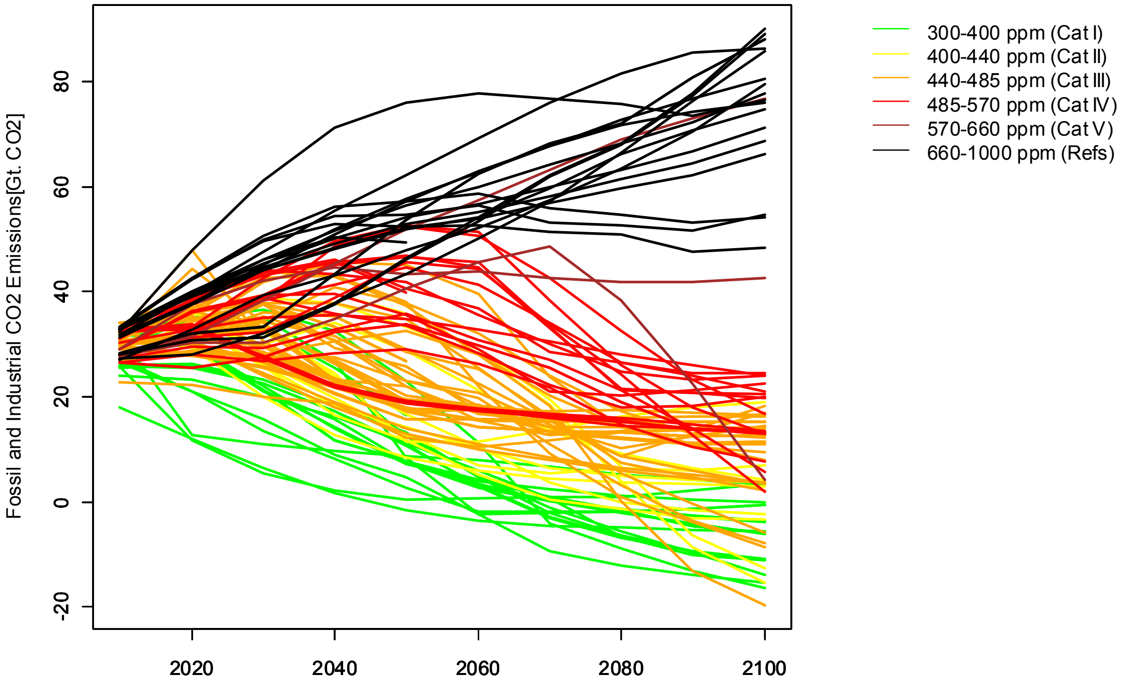

Figure 10.2.1: Global fossil and industrial CO2 emissions of long-term scenarios between 2010 and 2100(colour coding is based on categories of atmospheric CO2 concentration level in 2100). Scenarios from (Kurosawa, 2006; van Vuuren et al., 2007; Akimoto et al., 2008; IEA, 2008; Shukla et al., 2008; Bosetti et al., 2009a; Bosetti et al., 2009b; Calvin et al., 2009; Gurney et al., 2009; Kitous, 2009; Krewitt et al., 2009; Krey and Riahi, 2009; Leimbach et al., 2009; Loulou et al., 2009; Luderer et al., 2009; Magne et al., 2009; van Vliet et al., 2009; van Vuuren et al., 2009b). AUTHOR COMMENT: [include historical CO2 emissions since approx. 1950, add SRES, post SRES, AR4, etc. ranges as bars on right-hand-side for continuity with previous IPCC work]

10.2.2 The role of RES in scenarios

The potential deployment of renewable energy depends on a number of factors. One set of factors sets the scale for the deployment of low-carbon energy generally. This includes both the mitigation goal and the fundamental drivers of energy demand, such as population growth, economic growth, the evolution and emergence of end-use technologies that convert energy into useful services such as lighting, cooling, transportation, and industrial processes, along with energy policy choices. The factors that set the scale of the energy system are discussed in Section 10.2.2.1. Within this broader context, RES deployments depend on factors such as the competition between technologies that provide low-carbon energy (e.g., RES, nuclear energy, and fossil energy with CCS), and energy and mitigation policy approaches. In addition, the distribution of deployments over time and space depends on the relative level of mitigation among countries and the particular manner in which countries take action on climate mitigation and other energy-related issues (e.g., energy security). These issues are discussed in Section 10.2.2.2. Finally, the role of RES in moderating the costs of mitigation is discussed in Section 10.2.2.3.

10.2.2.1 Setting the Scale of Renewable Energy Deployment: Energy System Growth and Long-Term Climate Goals

It is useful to begin the discussion of RES deployments by first considering the broad forces that drive the need for low-carbon energy, which includes RES, nuclear energy, and fossil energy with CCS. Two forces are of particular importance: the scale of the energy system, here represented by primary energy demands, and the long-term climate goal.

Although there is some degree of correlation between primary energy demands and long-term mitigation goals in the scenarios, there is also a great deal of variation (Figure 2) [TSU: Figure 10.2.2]. One reason for this variation is simply our lack of knowledge about how key drivers of energy demand, such as economic growth, might evolve over the coming century. To some degree, the variation increases with the stringency of the long-term climate goal. The baseline scenarios are less varied because few scenarios envision primary energy demands decreasing over the coming century without emissions constraints. The constrained scenarios are more varied because these scenarios may assume abundant low-carbon options (leading to high primary energy demands) or approaches to mitigation based on reducing the demand for energy (leading to low primary energy demands).

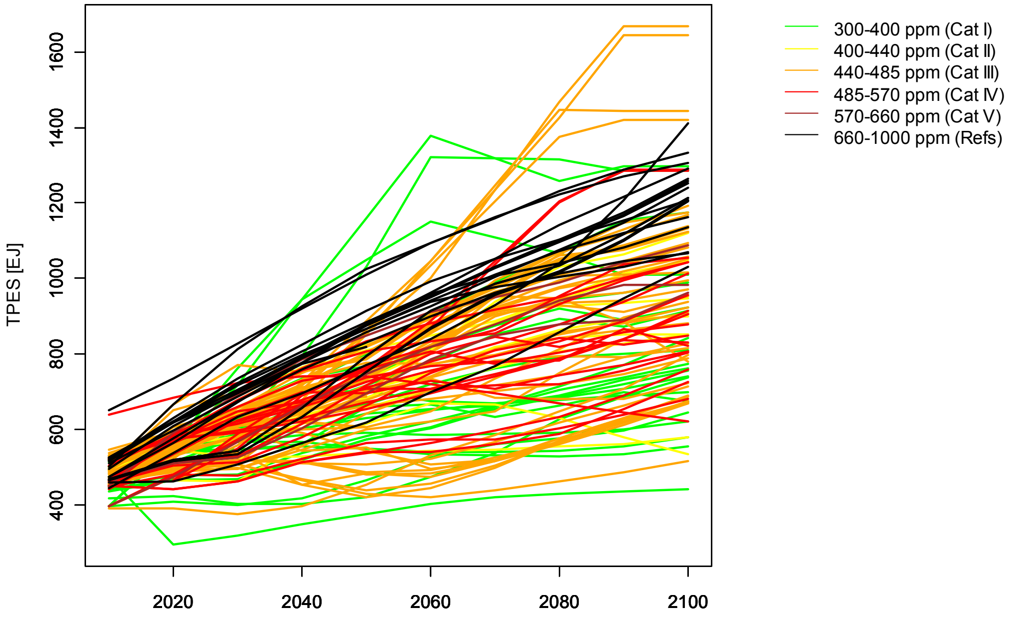

Figure 10.2.2: Primary energy consumption (direct equivalent) across both baseline and mitigation scenarios (colour coding is based on categories of atmospheric CO2 concentration level in 2100). Note the large range of primary energy consumption. Scenarios from (Kurosawa, 2006; van Vuuren et al., 2007; Akimoto et al., 2008; IEA, 2008; Shukla et al., 2008; Bosetti et al., 2009a; Bosetti et al., 2009b; Calvin et al., 2009; Gurney et al., 2009; Kitous, 2009; Krewitt et al., 2009; Krey and Riahi, 2009; Leimbach et al., 2009; Loulou et al., 2009; Luderer et al., 2009; Magne et al., 2009; van Vliet et al., 2009; van Vuuren et al., 2009b).

In contrast to the variation in total primary energy, the production of freely-emitting fossil energy is tightly constrained by the long-term climate goal (Figure 3) [TSU: Figure 10.2.3]. Meeting long-term climate goals requires a reduction in the CO2 emissions from energy and other anthropogenic sources. Physical systems, such as the global carbon cycle, put bounds on the levels of CO2 emissions that are associated with meeting any particular long-term goal. This puts limits on the amount of energy that can be produced from freely-emitting fossil energy sources. The tighter the climate constraint, the tighter are the near- and mid-term constraints on both CO2 emissions and freely-emitting fossil energy. Looser constraints imply greater flexibility over the coming decades, although CO2 emissions must necessarily be reduced toward zero, or beyond in some scenarios, in the longer term. Note that there is some degree of flexibility in the limits on freely-emitting fossil energy, as reflected by the ranges shown in Figure 3. Factors that lead to this flexibility include: the ability to switch between fossil sources with different carbon contents (e.g., natural gas has a lower carbon content than coal); the potential to achieve negative emissions by utilising e.g. biochar, bioenergy with CCS or forest sink enhancement, which allows for greater emissions of freely-emitting fossil energy; and differences in the time path of emissions reductions over time as a result of differing underlying model structures, assumptions about technology and emissions drivers, and representations of physical systems such as the carbon cycle.

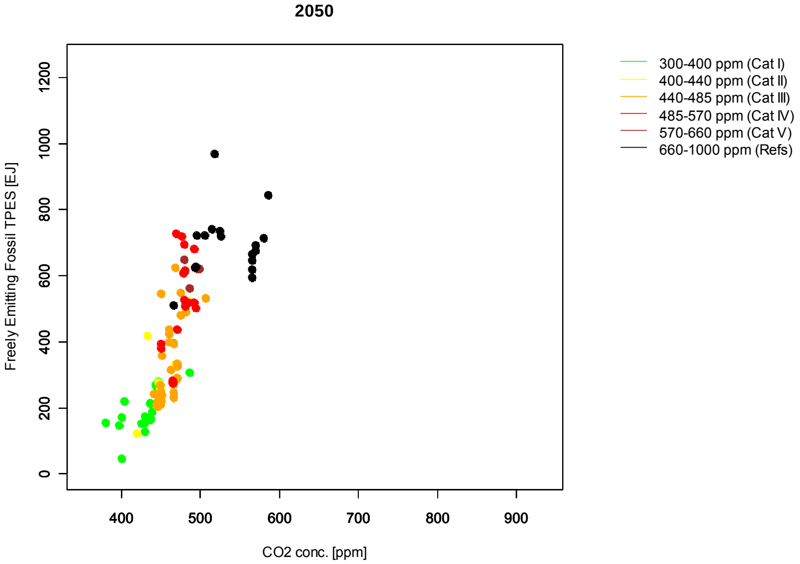

Figure 10.2.3: Freely emitting fossil primary energy consumption in the long-term scenarios by 2050 as a function of atmospheric CO2 concentrations in 2050 (colour coding is based on categories of atmospheric CO2 concentration level in 2100). Scenarios from (Kurosawa, 2006; van Vuuren et al., 2007; Akimoto et al., 2008; IEA, 2008; Shukla et al., 2008; Bosetti et al., 2009a; Bosetti et al., 2009b; Calvin et al., 2009; Gurney et al., 2009; Kitous, 2009; Krewitt et al., 2009; Krey and Riahi, 2009; Leimbach et al., 2009; Loulou et al., 2009; Luderer et al., 2009; Magne et al., 2009; van Vliet et al., 2009; van Vuuren et al., 2009b).

The demand for low-carbon energy, including not just RES, but also nuclear power and fossil energy with CCS, is the difference between total primary energy demand, reductions from end-use efficiency improvements notwithstanding, and the production of freely-emitting fossil energy that meets the long-term climate goal (the left panel in Figure 4) [TSU: Figure 10.2.4]. It follows that the low-carbon energy production is correlated to the long-term climate goal: as the stringency increases, CO2 emissions must decrease, and low-carbon energy increases (O’Neill et al., 2009). At the same time, because of the wide uncertainty in the magnitude of the energy system, the variation in low-carbon energy among scenarios to meet any long-term goal is large. Given the variability in low-carbon energy deployments more generally, it is not surprising that there is also great variation in the deployment of renewable energy deployments among scenarios, even for specific long-term climate goals (the right panel in Figure 4) [TSU: Figure 10.2.4].

Despite the variation in RES deployments, the actual levels of RES deployment are dramatically higher than those of today in the vast majority of the scenarios. In 2007, total global RES deployment stood at 62.4 EJ/yr (IEA, 2009).[2] In contrast, by 2050, deployments in many of the scenarios reach 200 EJ/yr or up through 400 EJ/yr. This is an extraordinary expansion in RES energy. The ranges for 2100 are substantially larger than these, reflecting continued growth throughout the century.

It is also important to note that although deployments of RES technologies in the baseline scenarios are not in general as large as those in the more aggressive mitigation scenarios, these baseline deployments are also quite large in many instances. These large deployments are simply a matter of energy system scale and assumptions about the relative competitiveness and resource base for RES technologies. As discussed earlier, there is a large increase in primary energy consumption over the coming century in most of the scenarios. This demand will need to be met by both CO2-emitting and non-CO2-emitting sources. Those scenarios that assume relatively strong competitiveness from RES technologies exhibit RES deployments that can be dramatically larger than those of today.

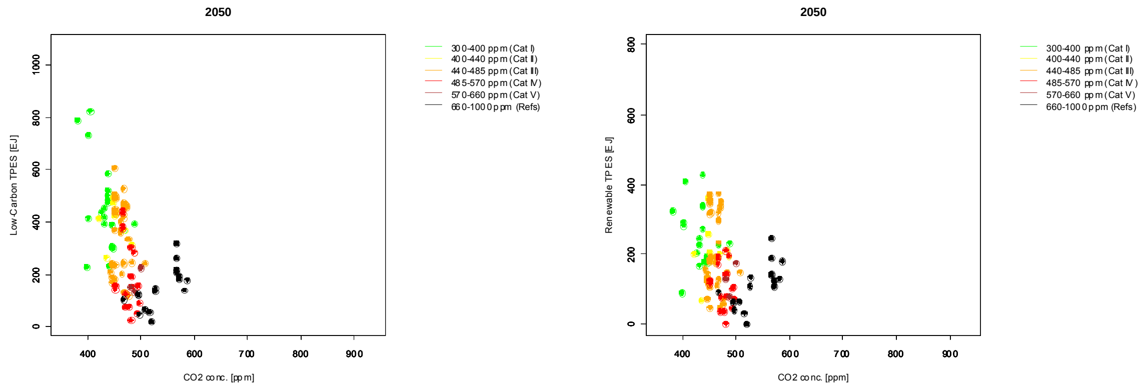

Figure 10.2.4: Global low-carbon primary energy consumption (left panel) and renewable primary energy consumption (right panel) in the long-term scenarios by 2050 as a function of atmospheric CO2 concentrations in 2050 (colour coding is based on categories of atmospheric CO2 concentration level in 2100). Scenarios from (Kurosawa, 2006; van Vuuren et al., 2007; Akimoto et al., 2008; IEA, 2008; Shukla et al., 2008; Bosetti et al., 2009a; Bosetti et al., 2009b; Calvin et al., 2009; Gurney et al., 2009; Kitous, 2009; Krewitt et al., 2009; Krey and Riahi, 2009; Leimbach et al., 2009; Loulou et al., 2009; Luderer et al., 2009; Magne et al., 2009; van Vliet et al., 2009; van Vuuren et al., 2009b).

Another additional uncertainty affecting RES deployments is the competition with other options for reducing carbon emissions. RES are only one option for meeting the energy demands while reducing carbon emissions. The others are nuclear energy, fossil energy with CCS, and reductions in total energy demand through more efficient end use technologies or reductions in end use demand. All other things being equal, RES deployments will be lower if these other options are more competitive.

It follows that the presence or absence of competing low carbon supply technologies, nuclear power and fossil energy with CCS, has an important influence on the deployment of RES. Scenarios such as these are often referred to as 2nd best scenarios because they reflect a less than full set of technology options. All other things being equal, when these competing options are not available, RES deployments will be higher because RES technologies must carry more of the load associated

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[2] IEA 2009 Energy Balances report this value for 2007, but note that geothermal and solar thermal is accounted for differently by IEA (factors 10 and 2 respectively for electricity and heat generation) which is not so easily converted to direct equivalent because of CHP (at most 2 EJ deviation).

with mitigation. In addition, because the costs of mitigation are higher in these cases, total primary energy consumption is also lower as end use options – increased efficiency or reduced demand – become increasing economically attractive with higher CO_2 prices. In the scenarios reviewed here, it is clear that for individual models the absence of competing low-carbon supply technologies such as nuclear power and CCS leads to higher RES deployments (Figure 5) [TSU: Figure 10.2.5]. Although the extent to which the RES contribution to primary energy greatly varies across the models, in almost all available examples the unavailability of CCS has a stronger impact on the RES share than the unavailability of nuclear power. One possible explanation for this is that CCS affords, in many scenarios, for the production of energy that couples bioenergy and CCS, leading to negative emissions. There is no such possibility for nuclear power. An additional explanation may be that models have assumed greater environmental, security/proliferation, and safety limits on the possible deployment of nuclear power. These dynamics are not explored here. Instead, it simply noted that these 2nd best scenarios clearly demonstrate the influence of competition between low-carbon options.

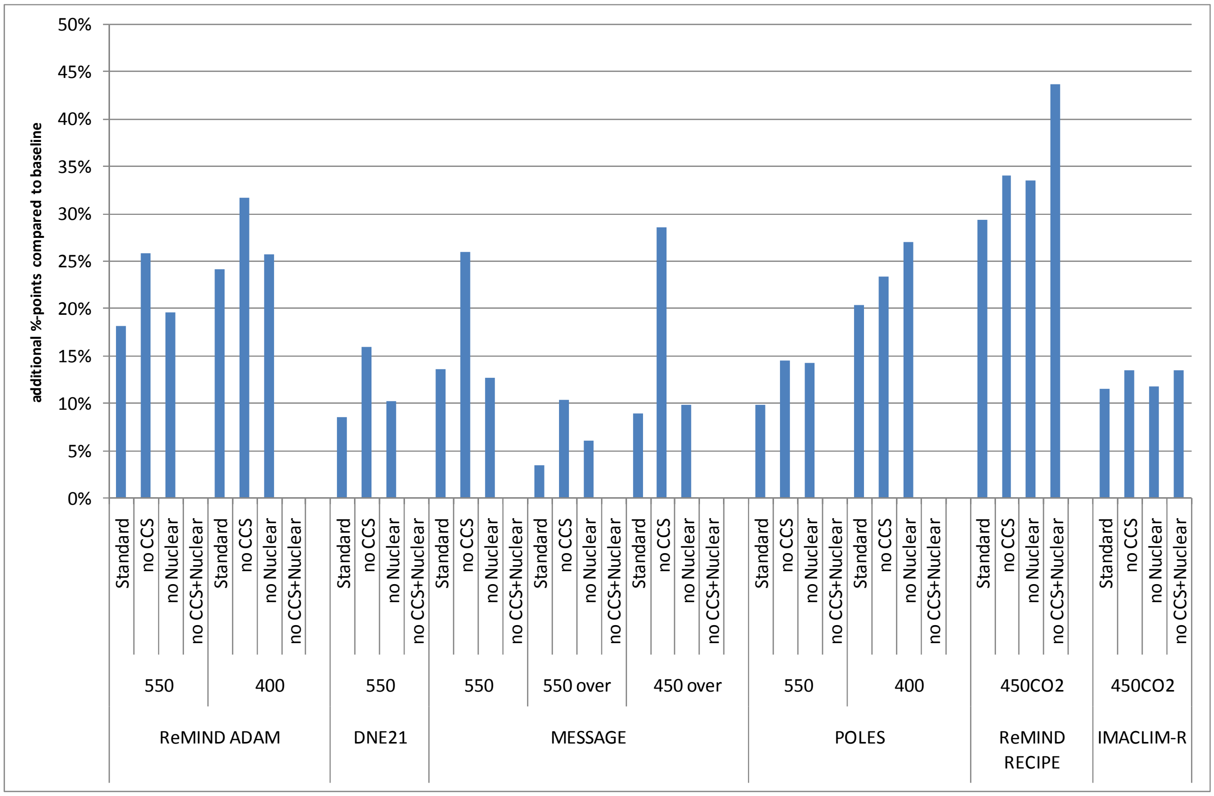

Figure 10.2.5: Increase in renewable primary energy share by 2050 in 1st- and 2nd-best mitigation scenarios in percentage points compared to the respective baseline scenarios. Note that the exact definition of the "no CCS", "no Nuclear" and "no CCS+Nuclear" cases varies across models. Moreover, the magnitude of the increase shows a large spread, mostly because the deployment in the respective baselines differs significantly between the models.Scenarios from (Akimoto et al., 2008; Edenhofer et al., 2009a; Kitous, 2009; Krey and Riahi, 2009; Leimbach et al., 2009).

At the same time, although it is tempting to attribute the variation in RES deployments across scenarios to the character of the competing options, the discussion to this point should make clear that the fundamental drivers of energy system scale – economic growth, population growth, energy intensity of economic growth, and energy end use improvements – along with the technology characteristics of RES technologies themselves are equally critical drivers of RES deployments (Figure 6) [TSU: Figure 10.2.6]. There appears to be little solid correlation between the availability of CCS and the degree of renewable energy deployment considering all the scenarios reviewed here. In other words, the presence or absence of large-scale deployments of CCS or nuclear are not the only or perhaps even the most critical determinants of future RES deployments to address climate change.

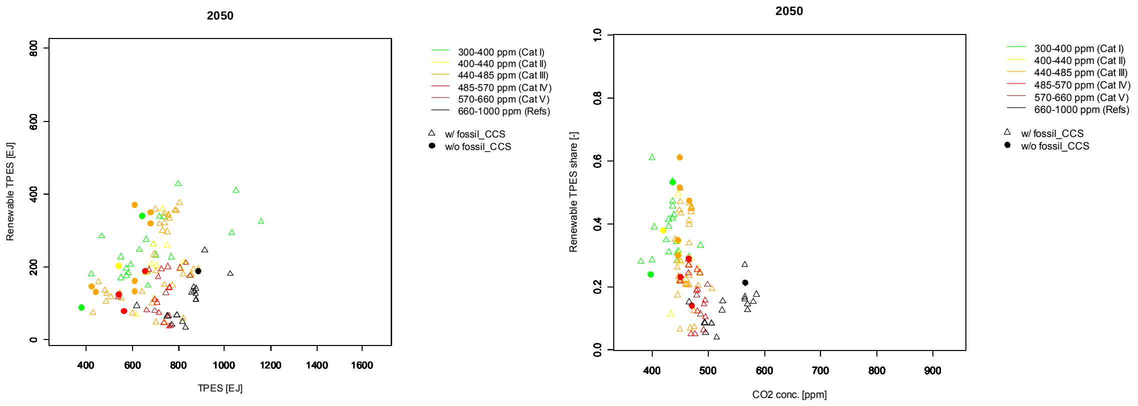

Figure 10.2.6: Global renewable primary energy consumption in the long-term scenarios by 2050 as a function of total primary energy consumption, grouped by different categories of atmospheric CO_2 concentration level in 2100 (left panel) and renewable primary energy share as a function of atmospheric CO_2 concentrations in 2050 (colour coding is based on categories of atmospheric CO_2 concentration level in 2100) (right panel). The availability of CCS in scenarios is indicated by triangles while unavailability by filled circles. Scenarios from (Kurosawa, 2006; van Vuuren et al., 2007; Akimoto et al., 2008; IEA, 2008; Shukla et al., 2008; Bosetti et al., 2009a; Bosetti et al., 2009b; Calvin et al., 2009; Gurney et al., 2009; Kitous, 2009; Krewitt et al., 2009; Krey and Riahi, 2009; Leimbach et al., 2009; Loulou et al., 2009; Luderer et al., 2009; Magne et al., 2009; van Vliet et al., 2009; van Vuuren et al., 2009b).

In summary, the scenarios literature to date indicates several broad elements of future RES deployments. First, the scale of these deployments could be quite large, if climate change is to be addressed. They may, in fact, be quite large even without addressing climate change simply due to the increasing demand for energy and other challenging environmental, public health, or security issues associated with competing technologies such as coal, nuclear energy, natural gas, and petroleum. Second, besides the general expectation of a significant increase there is little consensus on just how large these deployments should be to meet any particular climate goal, given uncertainties about the demand for primary energy in the future, the cost and performance of RES technologies, and the cost of competing technologies such as nuclear and fossil energy with CCS, and the long-term mitigation goal.

10.2.2.2 RES Deployments by Technology and Region

Within the context of total RES deployment, there is great variation in the deployment characteristics of individual technologies (Figure 7) [TSU: Figure 10.2.7]. Several dimensions of this variation bear mention. First, the absolute scales of deployments vary considerably among technologies, representing differing assumptions about long-term potential. Bioenergy deployment is of a dramatically higher scale over the coming 40 years than any of the other renewable energy technologies. By 2050, wind and solar constitute a second tier of deployment levels. Hydroelectric power and geothermal power deployments fall into a lower tier. The variation in these deployment levels represents assumptions by the scenario developers regarding the cost, performance, and potential of these different sources. They indicate, for example, that the consensus among scenario developers is that solar power, bioenergy, and wind power are the most likely large-scale contributors in the 2050 time frame and beyond; there is room for growth in hydroelectric power and geothermal power, but the potential for this growth is limited.

Second, the time-scale of deployment varies across different RESs (Figure 7 and Figure 8) [TSU: Figure 10.2.7 and Figure 10.2.8], in large part representing differing assumptions about technological maturity. Hydro, wind and biomass show a significant deployment over the coming one or two decades in absolute terms. These are the most mature of the technologies. (Note that the bioenergy assumed here may include cellulosic approaches, which are an emerging technology.). Solar energy is deployed to a large extent beyond 2030, but at a scale that is surpassing that of the other renewable energy sources apart from biomass, capturing the notion that there is substantial room for technological improvements over the next several decades that will make solar largely competitive and increase the capability to integrate solar power in the electricity system. Indeed, solar energy deployment by 2100 is on the same scale at bioenergy production. Direct biomass use in the end-use sectors is largely stable or even slightly declining across the scenarios. It should be noted that direct use is dominated by traditional, non-commercial fuel use in developing countries (Figure 7) [TSU: Figure 10.2.7] which is typically assumed to decline as economic development progresses. This decrease cannot be compensated by an increase in commercial direct biomass use in the majority of scenarios. In contrast, biomass that is used as a feedstock for liquids production or an input to electricity production – commercial biomass -- is increasing over time, reflecting assumptions about growth in the ability to produce bioenergy from advanced feedstocks, such as cellulosic feedstocks.

Third, the deployment of some renewables in the scenarios is driven mostly by climate policy (e.g. solar, geothermal, commercial biomass) whereas others are considerably deployed irrespective of climate action (e.g. wind, hydro, direct use of bioenergy) (Figure 8) [TSU: Figure 10.2.8]. This is also to a large degree a reflection of assumptions regarding technology maturity. Wind and hydro are already considered largely mature technologies, so the imposition of climate policy would not provide the same increase in competitiveness as it would for emerging technologies such as solar, geothermal, and advanced bioenergy.

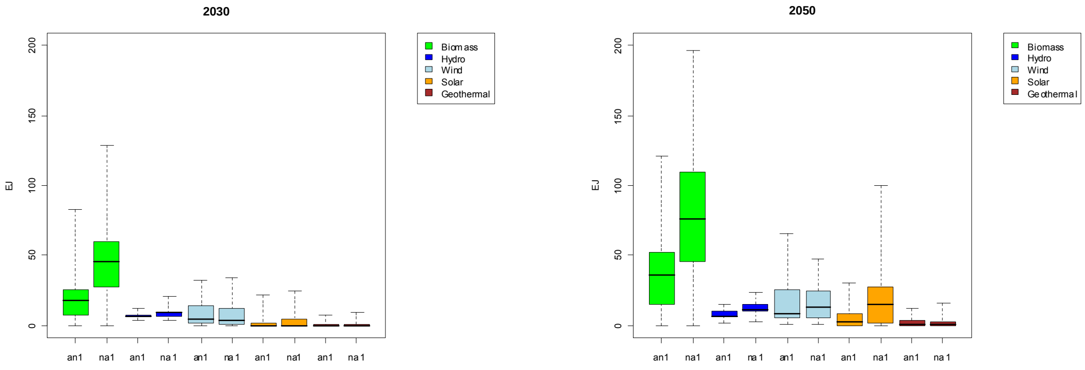

Figure 10.2.7: Renewable primary energy consumption by source in Annex I and Non-Annex I countries in the long-term scenarios by 2030 and 2050.[3] Scenarios from (Kurosawa, 2006; van Vuuren et al., 2007; Akimoto et al., 2008; IEA, 2008; Shukla et al., 2008; Bosetti et al., 2009a; Bosetti et al., 2009b; Calvin et al., 2009; Gurney et al., 2009; Kitous, 2009; Krewitt et al., 2009; Krey and Riahi, 2009; Leimbach et al., 2009; Loulou et al., 2009; Luderer et al., 2009; Magne et al., 2009; van Vliet et al., 2009; van Vuuren et al., 2009b).

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[3] In these and all following box-plots the thick black line corresponds to the median, the coloured box corresponds to the interquartile range (25th-75th percentile) and the whiskers correspond to the total range across all reviewed scenarios.

Finally, the distribution of RES deployments across countries is highly dependent on the nature of the policy structure. In scenarios that assume a globally efficient regime in which emissions reductions are undertaken where and when they will be most cost-effective, non-Annex 1 countries begin to take on a larger share of RES deployment toward mid-century. This is a direct result of the assumption that these regions will continue to represent an increasingly large share of total global energy demand, along with the assumption that RES supplies are large enough to support this growth. All other things being equal, higher energy demands will require greater deployment of renewable energy sources. This is important in the sense that it highlights that RES in climate mitigation is both an Annex 1 and a non-Annex 1 issue.

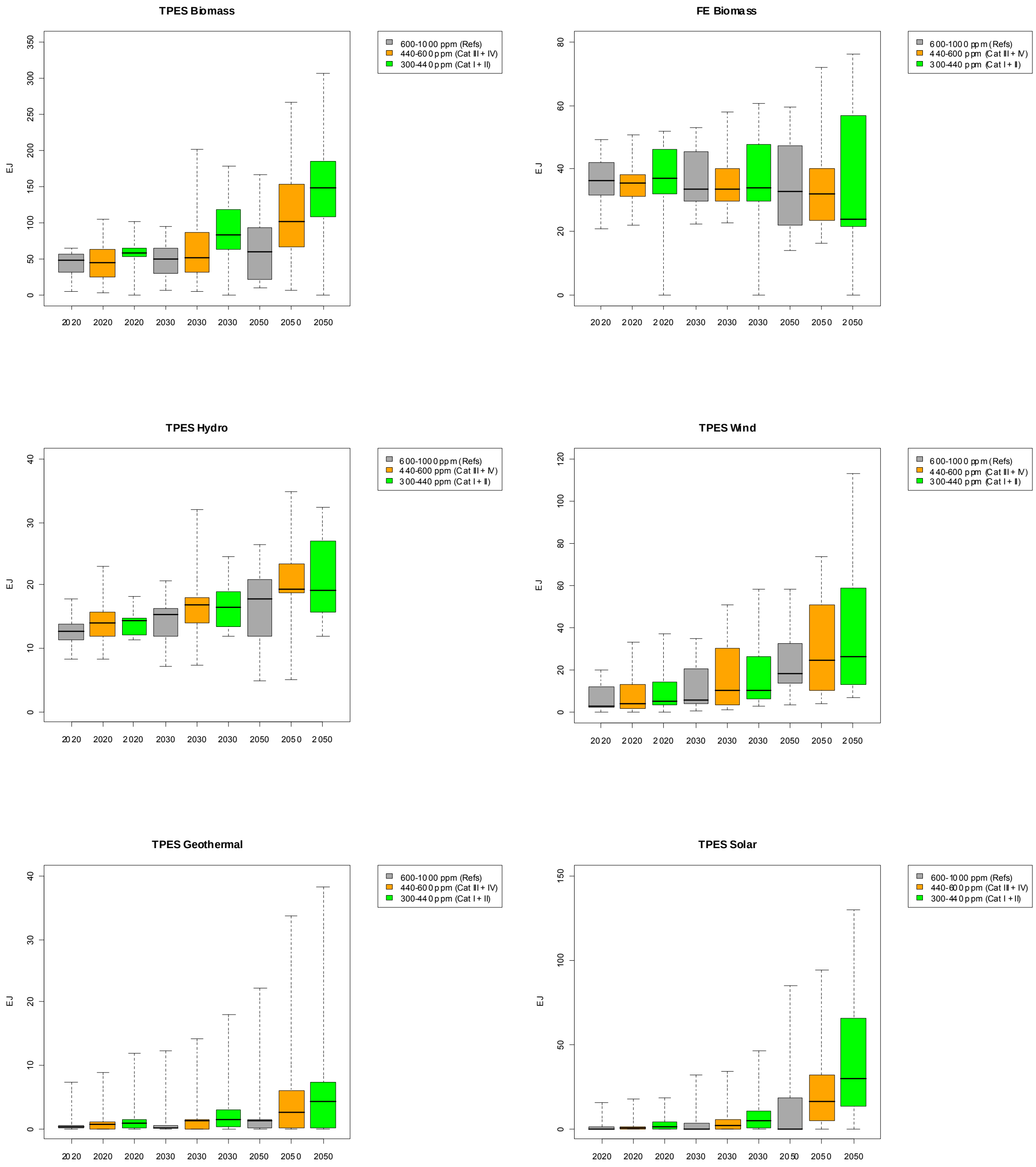

Figure 10.2.8: Global energy consumption of biomass, hydro, wind, solar and geothermal in the long-term scenarios by 2020, 2030 and 2050, grouped by different categories of atmospheric CO_2

concentration level in 2100. Scenarios from (Kurosawa, 2006; van Vuuren et al., 2007; Akimoto et al., 2008; IEA, 2008; Shukla et al., 2008; Bosetti et al., 2009a; Bosetti et al., 2009b; Calvin et al., 2009; Gurney et al., 2009; Kitous, 2009; Krewitt et al., 2009; Krey and Riahi, 2009; Leimbach et al., 2009; Loulou et al., 2009; Luderer et al., 2009; Magne et al., 2009; van Vliet et al., 2009; van Vuuren et al., 2009b).

The notion that deployment in the non-Annex 1 will become increasingly important is robust across scenarios; in the long run, meeting the stricter goals will require fully comprehensive global mitigation. At the same time, near- to mid-term mitigation efforts may differ substantially across regions, with some regions taking on larger commitments than others. In this real-world context, the distribution of renewable energy deployments in the near-term would be skewed toward those countries taking the most aggressive action. As an example, Figure 9 [TSU: Figure 10.2.9] shows the change in RES deployment in China in 2020 and 2040 from the Energy Modeling Forum 22 study (Clarke et al., 2009). This study explored the implications of delayed participation by non-Annex 1 regions on meeting long-term climate goals. In the delayed accession scenarios, China takes no action on climate prior to 2030. After 2030, China begins mitigation. The figures show that RES deployments are influenced by the variation in mitigation among regions. When China delays mitigation, the relative deployments of RES are lower. The impact is generally more severe for tighter constraints, because the degree of mitigation is higher in these cases. Delay clearly decreases deployment during the period when China is taking on no mitigation (2020). The effect of delay on RES deployments is ambiguous in the period after China has begun mitigation (the right panel in Figure 9) [TSU: Figure 10.2.9]. In some cases, deployments are larger in 2050 and in some cases they are lower. This ambiguity is in part because China may need to quickly ramp up mitigation efforts by 2050 if action has been delayed but the same long-term climate target is to be met as the case with immediate action. It is also important to note that there is some degree of RES deployment in every region even in the absence of mitigation. This is the reason that there is little effect on RES deployment in some scenarios in 2020.

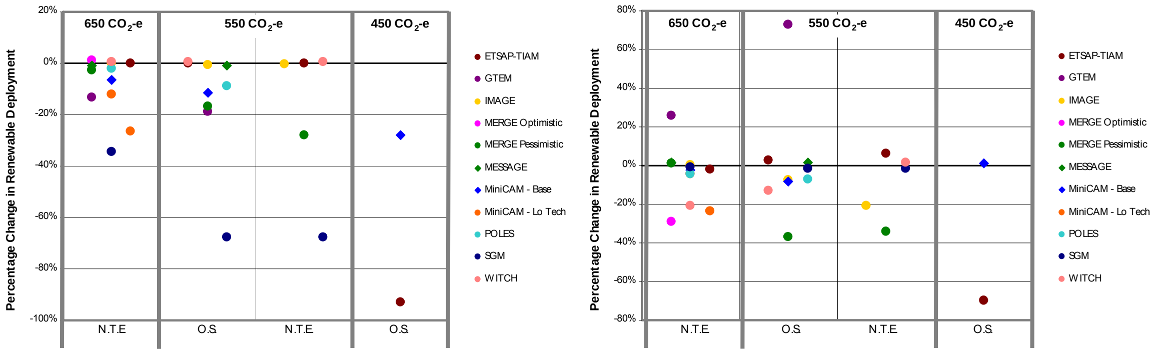

Figure 10.2.9: Change in RES deployment in China across EMF 22 scenarios as a result of delayed accession in 2020 (left panel) and 2040 (right panel) (Clarke et al., 2009).

10.2.2.3 Renewable energy and the costs of mitigation

One way that researchers characterize the challenge of mitigation is to quantify the economic consequences of mitigation. Technological improvements that reduce costs or improve performance will make it easier to address climate change. It is therefore useful to explore the relationship between RES deployments that the economic indicators of mitigation cost.

A first point to note is that the scenarios literature generally demonstrates that although mitigation reduced GDP, the other forces that drive GDP exert a larger influence. This means that RES deployments in response to climate mitigation will not be largely linked to total global GDP. Figure 10 [TSU: Figure 10.2.10] shows global GDP across the scenarios analyzed in this study (left panel) and the correlation between carbon prices and RES deployments (right panel). There is little correlation between GDP and stabilization level. Although mitigation following most of the scenarios will reduce economic output, the uncertainty in underlying drivers of economic growth swamps this effect. Moreover, a minor part of the literature finds that climate mitigation could lead to increased economic output (cf. e.g. (Barker et al., 2006)).

Nonetheless, mitigation should have a real cost. The CO_2 price is one of several metrics that has been used to characterize the economic implications of mitigation. The right panel in Figure 10 [TSU: Figure 10.2.10] demonstrates that higher RES deployments are generally associated with higher CO_2 prices, but that there is a great deal of variation in this correlation. There are several interacting, and some degree counteracting forces at work here. First, more aggressive mitigation generally calls greater deployment of low-emissions energy sources. CO_2 prices are higher with higher RES deployments because these low-emissions sources are generally more costly then their emitting counterparts. Larger energy demands will also require greater deployments of low-emissions sources (see the discussion above), and this may further increase the CO_2 price. The second dynamic is that, to the extent that RES technologies have higher performance, larger supplies, or lower cost, they will both have higher deployments and make mitigation cheaper. This effect would tend to correlate larger RES deployments with lower CO_2 prices. These two effects are not disentangled in this section. It is only noted here that the scenarios reviewed here generally do not indicate a clear correlation between RES deployments and carbon prices.

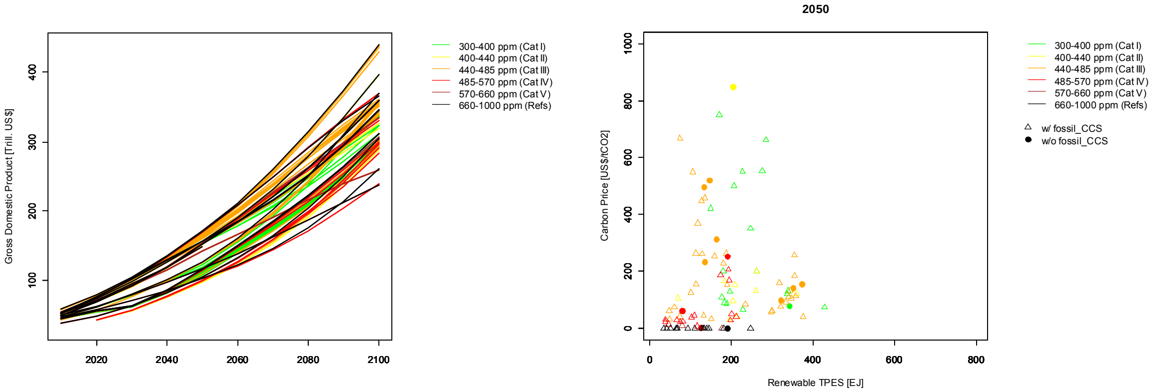

Figure 10.2.10: Gross World Product development and carbon price by 2050 as a function of renewable primary energy consumption grouped by different categories of atmospheric CO_2 concentration level in 2100. Scenarios from (Kurosawa, 2006; van Vuuren et al., 2007; Akimoto et al., 2008; IEA, 2008; Shukla et al., 2008; Bosetti et al., 2009a; Bosetti et al., 2009b; Calvin et al., 2009; Gurney et al., 2009; Kitous, 2009; Krewitt et al., 2009; Krey and Riahi, 2009; Leimbach et al., 2009; Loulou et al., 2009; Luderer et al., 2009; Magne et al., 2009; van Vliet et al., 2009; van Vuuren et al., 2009b).

10.2.3 The deployment of RES in scenarios from the technology perspective

This section summarizes the results of the deployment sections from the individual technology chapters and puts the deployment levels from the reviewed scenarios into context. AUTHOR COMMENT: [Information from several chapters has been summarized, but additional iterations will be needed to make this section really coherent with the deployment sections of [TSU: the technology] Chapters 2-7 and the systems integration chapter 8. It will be completed for the Second-Order Draft of this report.]

All scenarios report global primary energy biomass consumption levels by 2050 that are compatible with corresponding biomass resource potentials which take into account key sustainability criteria and amount to more than 400 EJ, also by 2050. However, due to the complexity of bioenergy production and the variety of fuel chains involved, much more than a simple comparison of total bioenergy potentials is needed to provide a coherent and integrated picture. This includes potential conflicts with food production (e.g. first generation biofuels), land-use change and environmental and socio-economic impacts of bioenergy deployment (see Chapter 2.8).

The contribution of solar PV in 2020 and 2030, being lower than 7 EJ in the majority of scenarios (75th percentile) is considered to be relatively low. On the other hand, the PV growth rates after 2030 which lead to sizeable deployment levels by 2050 are judged to be on the high side (see Chapter 3.9).

Global and regional availability of geothermal resources do not pose a constraint on the deployment of geothermal energy in the scenarios. Even under the most optimistic assumptions which foresee a contribution of geothermal energy at the primary energy level of up to 38 EJ globally by 2050 market penetration seems to be reasonable. However, in particular the median deployment levels which are much lower than that (up to 4.5 EJ by 2050) are considered to be on the conservative side and considerably lag behind the deployment levels as projected by technology experts (see Chapter 4.8.3).

For hydropower, currently only about a third of the economically feasible potential is developed, corresponding to about 3000 TWh electricity generation or 11 EJ in primary energy units. In the most optimistic scenarios this - under current conditions – economically feasible potential is exploited by 2050 (about 35 EJ) while in the median case only a doubling a current electricity generation is projected. Compatible with the assessment of the technology experts is the finding that most of the hydropower expansion will most likely happen in the non-Annex I countries, because in many Annex I countries the largest part of the potential has been developed in the past. However, both the scenarios and the technology experts still project significant hydropower capacity expansion also in Annex I countries (see Chapter 5.9.1).

Compared to previous IPCC estimates in the AR4 (based on literature available until 2005), which assumed a contribution of wind power in the order of 8 EJ by 2030 (7% of global electricity supply) the role of wind has increased in the recent scenario literature where the median by 2030 ranges between about 6 EJ under baseline conditions and more than 10 EJ under modest to more stringent climate mitigation scenarios. The large diversity of results reflects on the one hand the underlying uncertainties (see Section 10.2.2) and on the other hand the diversity of modelling approaches used to generate these scenarios. In particular, more modelling tools with less technological detail do not adequately reflect "technical and economic viability" of high wind penetrations which are relevant at geographical and temporal scales way smaller than most existing modelling tools are capable of addressing. As for the other RES, the technical potential is unlikely to pose a constraint on the wind deployment levels as reported by the scenarios and also upscaling of wind industry production capacities is not considered to be a problem even under the most aggressive wind penetration levels of up to 100 EJ globally by 2050, provided that adequate policy frameworks will be in place. To realize these higher global wind deployment levels, however, a greater geographic distribution of deployment will be necessary. In any case, to ensure sufficient investments over the long term, incentive policies (carbon price or other, see Chapter 11) that provide adequate economic attractiveness as well as stability are likely to be required (see Chapter 7.9).

From a systems integration perspective, dealing with fluctuating RES in electricity generation (wind, solar, wave, tidal and run-of-river hydropower) is most challenging, but a broad portfolio of technologies including quickly dispatchable plants is available that can help address these challenges. In addition, a wider geographical distribution and improved forecasting of variability can lead to a smoothing of total electricity output over time. More generally speaking, the ability to integrate larger shares of fluctuating RES into the electricity generation system depends on the architecture and flexibility of the overall power supply system. At higher deployment levels of fluctuating RES, backup generation may be needed to maintain reliable grid operation. Moreover, load management and more flexible market instruments can help dealing with higher RES shares while reducing the need for investments into power plants, storage systems and other infrastructure (see Chapter 8).

10.2.4 Strengths and weaknesses of scenario analysis

Scenario analysis is used to explore alternatives of how the future might unfold. The focus here is on the contribution of RES to the energy supply against the background of avoiding dangerous anthropogenic interference with the climate system. The scenarios reviewed in this section are not meant to be predictive. Their greatest value lies in setting up thought experiments that generate robust insights into the issues of interest rather than creating large sets of numbers. The analysis presented here emphasizes this view by showing a very rich future for RES that spans - depending on a number of determining factors - a spectrum from essentially negligible up to the dominant energy sources in the medium-term.

The strength of global scenarios is to provide an integrated view on the role of RES, but they might not accurately cover all details that govern decision making at the national or even company scale, in particular in the short-term. Integrated global and regional scenarios are therefore most useful for the medium- to long-term outlook, i.e. starting from 2020 onwards. For shorter time horizons, other tools, such as market outlooks or shorter-term national analysis that explicitly address all existing policies and regulations might be more suitable sources of information. Section 10.3 provides a shorter-term view of RES deployments using scenarios, and is therefore complementary to this section.

Important features of the scenarios included in this review are plausibility, internal consistency and a certain level of integration that covers the interaction of RES with the energy system, the economy and the climate system. The emphasis of different aspects greatly differs across the scenarios covered in this assessment with some having a much more detailed representation of individual renewable and other energy technologies and aspects of systems integration of RES while others focus on the implications of renewable deployment for the economy as a whole. Whereas for certain questions one or the other approach might be preferable, including different methods and modelling approaches in the assessment provides us with a representation of the deep uncertainties associated with future dynamics of the energy system, the role of RES therein and the resulting GHG emission trends.

10.3 Assessment of representative mitigation scenarios for different renewable energy strategies [TSU: deviation from structure agreed by plenary: “Assessment and synthesis of scenarios for different renewable energy strategies]

While chapter 10.2 coming from a more statistical perspective gave a comprehensive overview about the full range of mitigation scenarios and tried to identify the major relevant driving forces for the resulting market share of renewable energies and the specific role of these technologies in mitigation paths, in this chapter a more detailed view should be given on the specific renewable energy technologies. Behind that background several scenarios from the given general overview have been selected to build the basis for a more in-depth analysis. The primary data for this analysis has been provided by the scenario authors and/or institutions.[4] Besides that, additional data has been taken from chapter 2 till 7.

All analysed scenarios used a 10-region global energy system model environment and represent with the exemption of the reference scenario of the IEA World Energy Outlook which is a typical forecasting approach target oriented scenarios based on a back-casting process. The 10 regions correspond to the world regions as specified by the IEA's World Energy Outlook 2007 (Africa, China, India, Latin America, Middle East, OECD Europe, OECD North America, OECD Pacific, Rest of Developing Asia, Transition Economies). The Energy [R]evolution (ER2008) as well as IEA World Energy Outlook and ETP are based on IEA energy statistics (DLR 2008, IEA 2007, IEA 2008).

10.3.1 Technical Potentials from renewable energy sources

Before looking on the role renewable energies is given by different scenarios, it is worth to know about the upper application limit. The overall technical potential for renewable energy – i.e. the total amount of energy that can be produced taking into account the primary resources, the socio-geographical constraints and the technical losses in the conversion process – seems to be huge and several times higher as the current total energy demand. The assessment about the total (global) technical potential for all renewable energies sources varies significantly from 2.477 EJ/a (Nitsch 2004) up to 15,857 EJ/a (UBA 2009)[5]. Based on the global primary energy demand in 2007 (IEA 2009) of 503 EJ/a the total technical potential of renewable energy sources at the upper limit would exceed the demand by a factor of 32. However barriers to the growth of renewable energy technologies may rather be posed by economical, political, and infrastructural constraints. That's why the technical potential will never be realised in total.

Assessing long term technical potentials is subject to various uncertainties. The distribution of the theoretical resources is not always well analysed, e.g. the global wind speed or the productivity of energy crops. The geographical availability is subject to issues as land use change, future planning decision on where technologies are allowed to be installed and accessibility of resources, e.g. for geothermal energy. The technical performance will develop on the long term and the rate of development can vary significantly over time. Next to these inherent uncertainties, one is confronted with uncertainties regarding the definition and the transparency of literature sources. The data provided even in the cited studies is not always consistent, and underlying assumptions are often not explained in detail. Similarly, not all studies use well-established potential definitions, or the definitions are not stated explicitly, which results in uncertainties when comparing potentials between different literature sources (UBA 2009).

The meta study from DLR, Wuppertal Institute and Ecofys which has been commissioned by the German Federal Environment Agency provides a comprehensive overview about the technical renewable energy potential by technologies and region (DLR 2009). The survey analysed 10 of the major studies which estimate global or regional RE potentials. Different types of studies were used, e.g. studies that focused on all or many RE sources like the World Energy Assessment (UNDP/WEC, 2000) and (Hoogwijk, 2004), and studies that only focus on one source, for instance

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[4] All data from the World Energy Outlook 2008 & 2009, Energy Technology Perspectives 2008 has been provided by the IEA, the energy [r]evolution scenario data from Deutsche Luft- und Raumfahrt (DLR) and data for technology based road maps e.g. `Global Wind Energy Outlook, Sawyer 2008` from industry associations such as Global Wind Energy Council.

[5] DLR, Wuppertal Institute, Ecofys; Role and Potential of Renewable Energy and Energy Efficiency for Global Energy Supply; Commissioned by the German Federal Environment Agency FKZ 3707 41 108, March 2009.

(Hofman et al, 2002) and (Fellows, 2001)[6]. The study compared for each renewable energy source, assumptions and regional scope of the relevant studies and special attention has been paid to environmental constraints and their influence on the overall potential. The study came out with an own assessment of potential based on a literature research but also on new calculation from the authors. The assessment provides data for the years 2020, 2030 and 2050 – no ranges given. The technical potential given in table 10.3.1 can be seen as additive in terms of the needed geographical areas for each renewable energy source.

Table 10.3.1: Technical Potential by technology for different times and applications.

		Technical potential EJ/yr electric power							Technical potential - heat - EJ/a		Technical potential – primary energy – EJ/a		Total
		solar PV	solar CSP	hydro-power	wind onshore	wind offshore	ocean energy	geothermal electric	geothermal direct uses	solar water heating	biomass residues	biomass energy crops	
World	2020	1125,9	5156,1	47,5	368,6	25,6	66,2	4,5	495,5	113,1	58,6	43,4	7.505
	2030	1351,0	6187,3	48,5	361,7	35,9	165,6	13,4	1486,6	117,3	68,3	61,1	9.897
	2050	1688,8	8043,5	50,0	378,9	57,4	331,2	44,8	4955,2	123,4	87,6	96,5	15.857
World Energy Demand 2007: IEA 2009 [EJ/a]	502,9												
Technical Potenial in 2050 versus World primary energy demand 2007		3,4	16,0	0,1	0,8	0,1	0,7	0,1	9,9	0,2	0,2	0,2	32

Source. DLR, Wuppertal Institute, Ecofys; Role and Potential of Renewable Energy and Energy Efficiency for Global Energy Supply; Commissioned by the German Federal Environment Agency FKZ 3707 41 108, March 2009; Potential versus World energy demand: S. Teske

The complexity to calculate renewable energy potentials is in particular high as these technologies are comparable young connected with a permanent change of performance parameter. While the calculation of the theoretical and geographical potential has only a few dynamic parameters, the technical potential is already dependent on a number of uncertainties. A technology breakthrough or significant technology improvements for example could have a serious impact on the potential. This could change the technical potential assessment already within a short time frame. Considering the huge dynamic of technology development, many existing potential studies are based on data which cover from a nowadays perspective quite old technology characteristics. The results and estimates of this study have to be converted using more recent numbers (e.g. significantly increased average wind turbine size, suitability factor) which would increase technical potentials even further[7]. Given the high unexploited potentials already although without having reached the full technological development limits so far it can be concluded that technical potential is not the limiting factor to expansion of renewable energy generation.

10.3.2 Regional and sectoral breakdown of renewable energy sources

To exploit the entire technical potential is neither needed nor unproblematic. Implementation of renewable energies has to respect sustainability criteria in order to achieve a sound future energy supply. Public acceptance is crucial to the expansion of renewable energies. Due to the decentralized character of many renewable energy technologies, energy production will move closer to consumers. Without a public acceptance, a market expansion will be difficult or sometimes even impossible. Especially the use of biomass has been controversial in the past years as competition with other land use, food production, nature conservation needs etc. accrued. Sustainability criteria

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[6] Overview of main literature sources analyzed: Aringhoff et al. 2004 World regions Solar CSP 2040/2050, Bartle A. 2002 World regions Hydropower 2010/2020, Bjoernsson et al. 1998 World Geothermal 2020,De Vries et al. 2006, DLR 2005, Doornbosch and Steenblik 2007, Elliot D. 2002, Fellows 2000, Fridleifsson 2001Gawell et al. 1999.

[7] The wind speed is converted to output in terms of full-load hours using a linear relation. A suitability factor was applied in order to quantify maximum area for wind electricity production. At these suitable areas, a power density of 4 MW/km2 was assumed. The output of a wind turbine was calculated assuming an average wind turbine size of 1 MW for 2005 and 3 MW for 2050, with a linear increase from 2020 to 2050. While there were no 5 MW or even 6 MW turbines on the market, in 2009 those turbines are already available. Turbines with higher capacities do have a higher hub height (above 100 m). This results in higher wind speeds and therefore an increased output when assuming a roughness length of 0.1 m of 10%.

have a huge influence on the overall market potential and whether bio energy can play a crucial role in future energy supply.

Much more important especially for policy purposes as the technical potential is the market potential. This term is defined in chapter 1 [TSU: in the Glossary to the report], but often used in different manner. Often the general understanding is that market potential is the total amount of renewable energy that can be implemented in the market taking into account the demand for energy, the competing technologies, and subsidies for any form of energy supply as well as the current and future costs of renewable energy sources, and the barriers. As also opportunities are included, the market potential may in theory be larger than the economic potential, but usually the market potential is lower because of all kind of barriers. Market potential analyses have to take into account the behaviour of private economic agents under their specific frame conditions which are of course partly shaped by public authorities. The energy policy frame work has a profound impact on the expansion of renewable energy sources. An approximation of what can be expected for the future markets can be achieved via using the results of in particular bottom up energy scenarios delivering an in depth view on renewable energy technologies from an overall system perspective taking relevant interaction into consideration.

Behind that background the goal of the chapter is to come out with a range of possible futures, described here as high, medium and low market penetration of renewable energy technologies. Therefore, in this section an analysis of selected “bottom up” global energy scenarios have been conducted which have substantial information on a number of technical details. The selected eight global scenarios represent a wide range of emission categories; from up to 1000ppm – as a reference case - , via category IV + III (>440 – 660ppm) down to category I + II (<440ppm). While there are a relative huge number of category III and IV scenarios, global energy scenario from category I and II with greater technical details were not available for this analysis and might be added if published. This indicates that more research is needed in category I and II scenarios.

Table 10.3.2: Overview: Different demand projections of the analysed scenarios. (ETP Data to come). [TSU: no reference in text]

Categories	Scenario name	Energy demand [EJ/a]		Renewable energy share	
		2030	2050	2030	2050
References (>600ppm)	World Energy Outlook 2008 World Energy Outlook 2009 ETP Base 2008	721 712	868 (1) No data	14% 14%	13% (1) No data
Categories III + IV (> 440 – 660 ppm)	ETP ACT ETP BLUE IEA 550ppm (2008) IEA 450ppm (2008 /2009)	648 601 / 602	No data No data	24% / - 18% / 22%	no data no data
Categories I + II (< 440 ppm)	Energy Revolution [DLR / EREC GPI]	526	481	31%	56%
(1) DLR 2008					

Besides the discussion of mitigation scenarios the subchapter considers the findings of the technical chapters 2 – 7 as well and summarizes the different technology parameters and energy potentials and their deployment over time from their perspective. Also “Technology Roadmaps” and “Market Development Reports” have been analysed if suitable. The possible market penetration for each sector, region and time horizon depends on a number of assumptions. Especially the assumptions of current and future costs for different renewable energy technologies are crucial for the scenario results. Feedback loops have to be considered as the achievement of cost reduction potentials (= learning curves) correlates with possible annual market growth. While there is information available for the cost development within the power sector, there is very little data available for the heating and cooling sector. In fact the level of detail for the cost development in the heating and cooling is so poor, that a cost analysis was not possible. This is particularly problematic as renewable heat shows not only a huge technical potential, but is in many cases already cost effective (ISES 2003).

10.3.2.1 Renewable Power sector

Global energy scenarios provide the greatest detail for the renewable power sector and the available statistical information about the current renewable market is – compared to the renewable heating sector – very good. The outcomes of the energy scenarios depend on many assumptions which can vary significantly between the considered studies. Most important are of course assumptions for market developments, costs and other scenario relevant technical details.

10.3.2.1.1 Factors for market development in the renewable power sector

The biggest variations in the cost development assumptions can be found for younger technologies such as solar photovoltaic, concentrated solar power plants and ocean energy (cf. table 4). Among these technologies, in particular the cost projections for solar photovoltaic vary significantly, which leads in the scenarios to very different market development pathways. For 2020, the highest costs projection was US$ 5960 /kW and the lowest projection at US$ 2400/kW[8]. The upper limit was so far even higher than the current market price. That demonstrates a typical problem of scenario analysis covering a young technology market where technology framework conditions and cost degression effects can heavily be underestimated. However cost projections for photovoltaic in 2050 had a significant lower range from US$ 830/kW for the low case and US$ 1240/kW for the high case.

Among all renewable energy technologies for power generation, for the already very well established onshore wind energy the least variation in cost projection from around +/- 10% over the entire timeframe could be found. Offshore-Wind costs projections vary slightly more, due the different regional circumstance of the water depth and distance to the shore.

Besides the investment cost estimates another crucial variable is the capacity factor which has – in combination with the assumed installation cost – a tremendous impact on the specific generation costs. The scenario analysis showed that the ranges are rather small and all scenarios assumed roughly the same capacity factors.

10.3.2.1.2 Annual market potential for renewable power

Annual market growth rates in the analysed scenarios are very different, in some cases a drastic reduction of the current average market growth rates have been outlined. The photovoltaic industry had an average annual growth rate of 35% between 1998 and 2008 (EPIA 2009). The wind industry experienced 30% annual growth rate over the same time period (GWEO 2009). While the advanced technology roadmaps from the photovoltaic, concentrated solar power plants and wind industry indicate these annual growth rates can be maintained over the next decade and decline to between 20% and 10% between 2020 and 2030 and below 10% after 2030. In contrast, all analysed integrated energy scenarios assume much lower annual growth rates for all renewable power technologies in the range of about 20% till 2020 further declining to 10% or lower afterwards. Only concentrated solar power had higher annual growth rate projections.

Based on the energy parameters of the analysed scenarios, the required annual production capacity has been either calculated (IEA scenarios) or has been provided by the scenario authors. Table 4 [TSU: Table 10.3.3] provides an overview about the required annual manufacturing capacities

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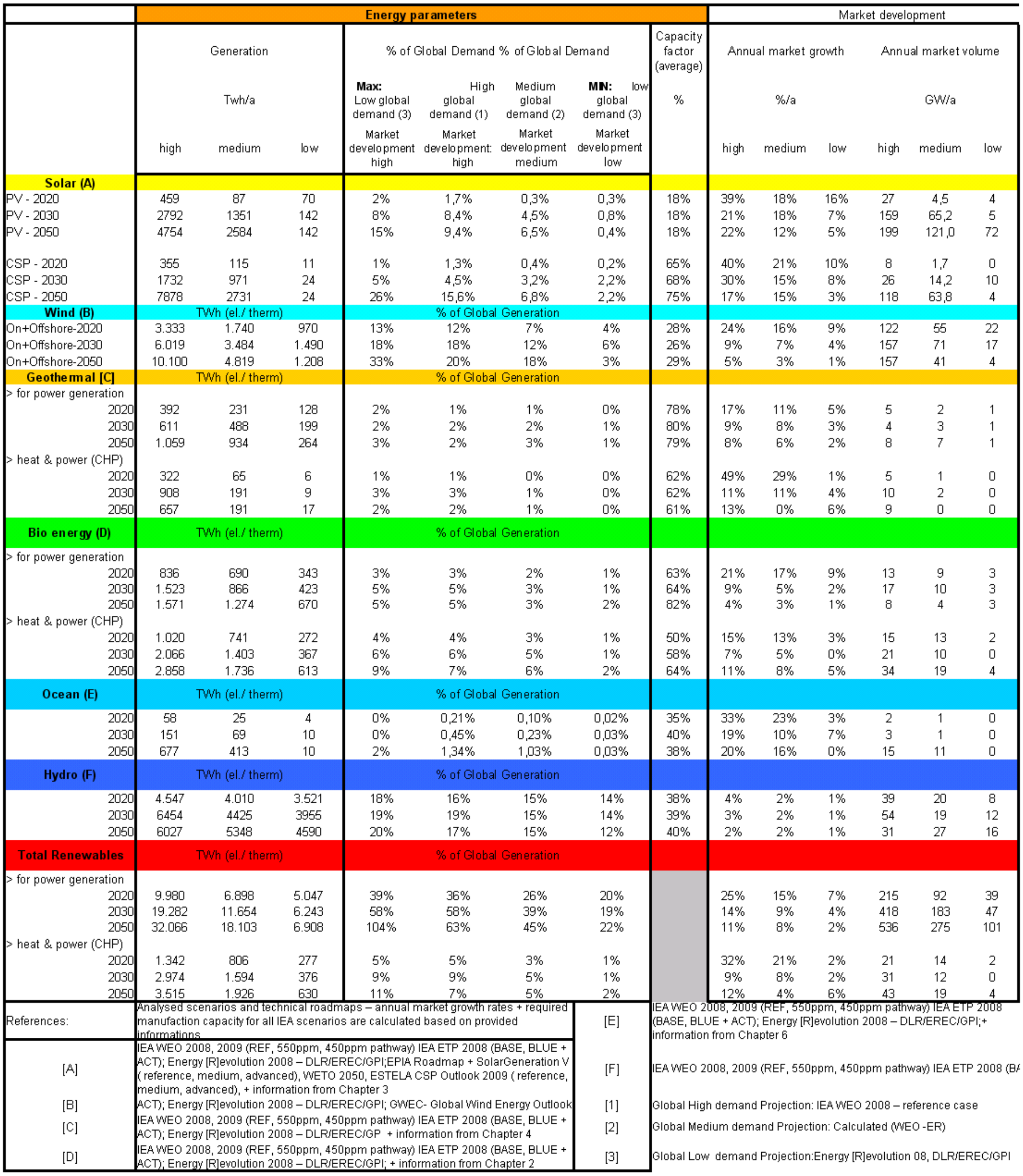
[8] While the average market price in 2009 for solar photovoltaic generators (including installation) in Germany was already at around 3,800 Euro/kW (US$ 5,700/kW)[8] for households, larger photovoltaic parks in the MW-range achieved significant lower prices.

(annual market volume) in order to implement the given renewable energy generation within the analysed scenarios. These calculated manufacturing capacities do not include the additional needs for repowering.

Table 10.3.3: Overview: renewable power generation, possible market shares, capacity factors, annual market growth rates and required annual manufacturing capacity. All factors interact with each other and influence the specific generation costs in cent/kWh over time significantly. Source: DLR/GPI/EREC: Energy [R]evolution 2008 / IEA WEO 2008, ETP 2008, information from chapter 2-7, Sven Teske (scenario analysis).



	Energy parameters								Market development					
	Generation			% of Global Demand % of Global Demand				Capacity factor (average)	Annual market growth			Annual market volume		
	Twh/a			**Max:** Low global demand (3)	High global demand (1)	Medium global demand (2)	**MIN:** low global demand (3)	%	%/a			GW/a		
	high	medium	low	Market development high	Market development: high	Market development medium	Market development low		high	medium	low	high	medium	low
Solar (A)														
PV - 2020	459	87	70	2%	1,7%	0,3%	0,3%	18%	39%	18%	16%	27	4,5	4
PV - 2030	2792	1351	142	8%	8,4%	4,5%	0,8%	18%	21%	18%	7%	159	65,2	5
PV - 2050	4754	2584	142	15%	9,4%	6,5%	0,4%	18%	22%	12%	5%	199	121,0	72
CSP - 2020	355	115	11	1%	1,3%	0,4%	0,2%	65%	40%	21%	10%	8	1,7	0
CSP - 2030	1732	971	24	5%	4,5%	3,2%	2,2%	68%	30%	15%	8%	26	14,2	10
CSP - 2050	7878	2731	24	26%	15,6%	6,8%	2,2%	75%	17%	15%	3%	118	63,8	4
Wind (B)	TWh (el./ therm)			% of Global Generation										
On+Offshore-2020	3.333	1.740	970	13%	12%	7%	4%	28%	24%	16%	9%	122	55	22
On+Offshore-2030	6.019	3.484	1.490	18%	18%	12%	6%	26%	9%	7%	4%	157	71	17
On+Offshore-2050	10.100	4.819	1.208	33%	20%	18%	3%	29%	5%	3%	1%	157	41	4
Geothermal [C]	TWh (el./ therm)			% of Global Generation										
> for power generation														
2020	392	231	128	2%	1%	1%	0%	78%	17%	11%	5%	5	2	1
2030	611	488	199	2%	2%	2%	1%	80%	9%	8%	3%	4	3	1
2050	1.059	934	264	3%	2%	3%	1%	79%	8%	6%	2%	8	7	1
> heat & power (CHP)														
2020	322	65	6	1%	1%	0%	0%	62%	49%	29%	1%	5	1	0
2030	908	191	9	3%	3%	1%	0%	62%	11%	11%	4%	10	2	0
2050	657	191	17	2%	2%	1%	0%	61%	13%	0%	6%	9	0	0
Bio energy (D)	TWh (el./ therm)			% of Global Generation										
> for power generation														
2020	836	690	343	3%	3%	2%	1%	63%	21%	17%	9%	13	9	3
2030	1.523	866	423	5%	5%	3%	1%	64%	9%	5%	2%	17	10	3
2050	1.571	1.274	670	5%	5%	3%	2%	82%	4%	3%	1%	8	4	3
> heat & power (CHP)														
2020	1.020	741	272	4%	4%	3%	1%	50%	15%	13%	3%	15	13	2
2030	2.066	1.403	367	6%	6%	5%	1%	58%	7%	5%	0%	21	10	0
2050	2.858	1.736	613	9%	7%	6%	2%	64%	11%	8%	5%	34	19	4
Ocean (E)	TWh (el./ therm)			% of Global Generation										
2020	58	25	4	0%	0,21%	0,10%	0,02%	35%	33%	23%	3%	2	1	0
2030	151	69	10	0%	0,45%	0,23%	0,03%	40%	19%	10%	7%	3	1	0
2050	677	413	10	2%	1,34%	1,03%	0,03%	38%	20%	16%	0%	15	11	0
Hydro (F)	TWh (el./ therm)			% of Global Generation										
2020	4.547	4.010	3.521	18%	16%	15%	14%	38%	4%	2%	1%	39	20	8
2030	6454	4425	3955	19%	19%	15%	14%	39%	3%	2%	1%	54	19	12
2050	6027	5348	4590	20%	17%	15%	12%	40%	2%	2%	1%	31	27	16
Total Renewables	TWh (el./ therm)			% of Global Generation										
> for power generation														
2020	9.980	6.898	5.047	39%	36%	26%	20%		25%	15%	7%	215	92	39
2030	19.282	11.654	6.243	58%	58%	39%	19%		14%	9%	4%	418	183	47
2050	32.066	18.103	6.908	104%	63%	45%	22%		11%	8%	2%	536	275	101
> heat & power (CHP)														
2020	1.342	806	277	5%	5%	3%	1%		32%	21%	2%	21	14	2
2030	2.974	1.594	376	9%	9%	5%	1%		9%	8%	2%	31	12	0
2050	3.515	1.926	630	11%	7%	5%	2%		12%	4%	6%	43	19	4

References:	Analysed scenarios and technical roadmaps – annual market growth rates + required manufaction capacity for all IEA scenarios are calculated based on provided informations	[E]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI;+ information from Chapter 6
[A]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI;EPIA Roadmap + SolarGeneration V (reference, medium, advanced), WETO 2050, ESTELA CSP Outlook 2009 (reference, medium, advanced), + information from Chapter 3	[F]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (B
[B]	ACT); Energy [R]evolution 2008 – DLR/EREC/GPI; GWEC- Global Wind Energy Outlook	[1]	Global High demand Projection: IEA WEO 2008 – reference case
[C]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GP + information from Chapter 4	[2]	Global Medium demand Projection: Calculated (WEO -ER)
[D]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI; + information from Chapter 2	[3]	Global Low demand Projection:Energy [R]evolution 08, DLR/EREC/GPI

Besides the expectations for renewable energies the specific numbers for the overall electricity demand are decisive for specifying the resulting role of renewable energies. High power demand and high market development projections are not necessarily from the same scenario. The IEA World Energy Outlook assumes a rather high demand development while the projections from renewable energy markets are among the lowest of all analysed scenarios and vice versa. The Energy [R]evolution scenario has the lowest demand projection of all analysed scenario, but the renewable market projections (in absolute numbers) are under the medium or even in low case (hydro, biomass). Therefore table 10.3.4 provides for each market projection (low, medium, high) three possible market shares – under low, medium and high demand projections. As the data combination are not a strong result of the scenarios, these calculations should be seen more as a theoretical exercise, but nevertheless as a important orientation about the possible range renewable energies could cover.

The lower case projections for solar photovoltaic, wind power and concentrated solar power represent the reference case and assume a lower global manufacturing capacity in 2020, than there is currently available. This indicates once more the problem to deal with a very dynamic and in this case policy driven sector within scenario analysis. The World Energy Outlook 2008 for example representing the lower range assumed a shrinking manufacturing capacity for wind from about 25 GW/a in 2008 (GWEC 2009) down to 22 GW/a in 2020 only 4 GW/a in 2050.

This has been somehow revised in the World Energy Outlook 2009 which assumes a annual manufacturing of around 50 GW/a in 2015 and 80 GW/a in 2030 and is therefore in line with the moderate development pathway over that timeframe expected by the respective industry (GWEC 2009).

The high case projections for wind require an annual production capacity of 157 GW by 2020 – which would represent a 6-fold increase of production capacity on a global level. This would lead to a global wind power share of 33 % under the low demand projection. A combination of the low market development and high demand projection would mean that the global wind share would be only 3% by 2050.

The medium case assumes a doubling of production capacity by 2020 (55GW/a) and tripling by 2030 (71 GW/a) – for 2050 the annual additional capacity would drop to 41 GW/a, but significant manufacturing capacity would be needed for repowering at the time.

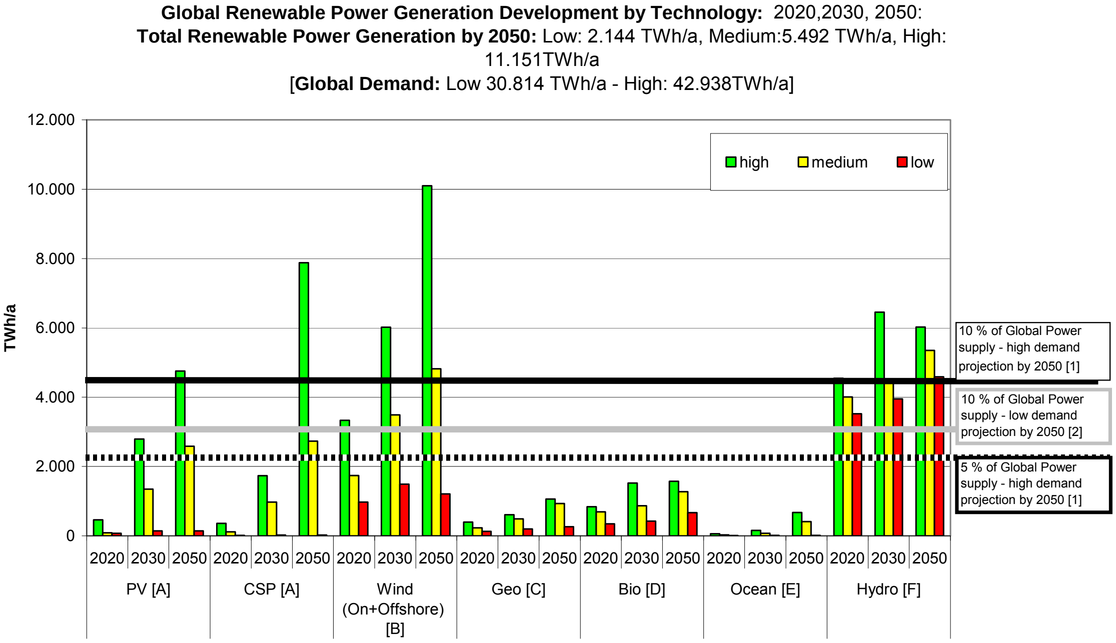
The expected role of CSP as another example is very different within all scenarios and has a wide range from 2.2% of the world’s electricity production by 2050 under the high demand and low or now market development case and up to 25.6% under the advanced market development and low demand case. The advanced case assumes that annual manufacturing capacity will go up to 118 GW/a which is still well under the advanced case of the wind industry (157 GW/a).

Both geothermal and bio energy power plants – including combined-heat and power technologies – have very diverse technologies in the market and under development as well. However their annual market volume and therefore the required production capacity are low compared to the projections for solar and wind power technologies. The highest projection for the global geothermal power market by 2050 is with 17 GW/a on the level of the global wind power market in the year 2000 (17.4 GW/a). This represents only 0.7% of the global technical potential for geothermal power generation, which indicates that further research in the development of a larger market potential is required. The highest geothermal electricity share (incl. CHP) will be achieved with a combination of the low demand and advanced market development case with 5.6%.

The bio energy share in all analyses is – relative to other technologies – low as well. The advanced case estimates an annual market volume and a required manufacturing capacity of 38 GW/a. Similar to geothermal power generation; bio energy plays in most scenarios a rather low role and achieves an electricity share of maximum 9.3%.

Figure 10.3.1 summarizes the resulting range electricity generation of renewable energies reflecting the selected scenarios distinguishing between the different technologies and compares it with different demand projections. Solar photovoltaic, concentrated solar power (CSP) and wind power have the largest expected market potential beyond 2020. Hydro power remains on the same high level in almost all scenarios and the range of the high (1905 GW) and low case (1055 GW) indicates a high correlation of projections. The total renewable power market potential in the low case is 7% above the 2008 level with 22% by 2050.

This will happen if the low market projection correlates with the highest growth in electricity demand. A medium range renewable market growth and a medium demand development, would lead to a renewable electricity share of 26% in 2020, 39% in 2030 and 45% by 2050. More than half of the worlds electricity demand could be supplied under the assumption that the market volumes for all renewable power generation technologies will continue to grow according to the renewable industry’s moderate market projections. If the renewable industry can maintain the growth rates between 2000 and 2009 for 5 more years, while the global power demand will not grow more than 67% by 2050 (base year 2005), all combined power technologies could achieve an electricity share of 39% by 2020, 58% by 2030 and before 2050 the entire electricity could come from renewable power sources.



[A]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI;EPIA Roadmap + SolarGeneration V (reference, medium, advanced), WETO 2050, ESTELA CSP Outlook 2009 (reference, medium, advanced), + information from Chapter 3	[F]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI; + information from Chapter 5
[B]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI; GWEC- Global Wind Energy Outlook 2008,Lemming *et al.* 2008 (Riso high wind), + information from Chapter 7	[1]	Global High demand Projection: IEA WEO 2008- reference case
[C]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GP + information from Chapter 4	[2]	Global Medium demand Projection: IEA WEO 2009-550ppm scenario
[D]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI; + information from Chapter 2	[3]	Global Low demand Projection: Energy [R]evolution 08; DLR/EREC/GPI

Figure 10.3.1: Global Renewable Power Development Projections by Technology.

10.3.2.2 Market potential for the renewable heating and cooling sector

Renewable heating technologies can be used for cooling as well, which offers a huge new market opportunity for countries with Mediterranean, subtropical or tropical climate. None of the analysed scenarios provide detailed information about renewable heating or cooling technologies. Renewable cooling could be used for air-conditioning and would therefore reduce electricity demand for electric air-conditioning significantly. While the cost reduction potential for geothermal and bio energy share is relatively low as it is already a established technology, the cost reduction potential for solar heating is still significant (ESTIF 2009). The influence of oil and gas prices as well as building construction regulations is huge for market development of renewable heating and cooling technologies. Solar heating as well as some forms of bio energy heating (e.g. wood pellets) and geothermal (ground heat pumps) have been already competitive in North Europe when oil and gas prices have been high in the first half of 2008. Therefore oil- and gas price projections in scenarios will have a profound impact on the market potential.

10.3.2.2.1Factors for market development in the renewable heating and cooling sector

The renewable heating sector shows much lower growth rate projections than outlined for the power sector. The highest growth rates are assumed for solar heating – especially solar collectors for water heating and space heating followed by geothermal heating. Geothermal heating includes heat-pumps, while geothermal co-generation plants are presented in chapter 10.3.2.1 under renewable power generation.

Even in the most advanced scenario, solar heating systems will need until 2030 till toady’s bio energy production level will be reached. However the market growth rates for solar collectors in all scenarios between 2010 and 2020 are 21% in the low case and 54% in the high case.

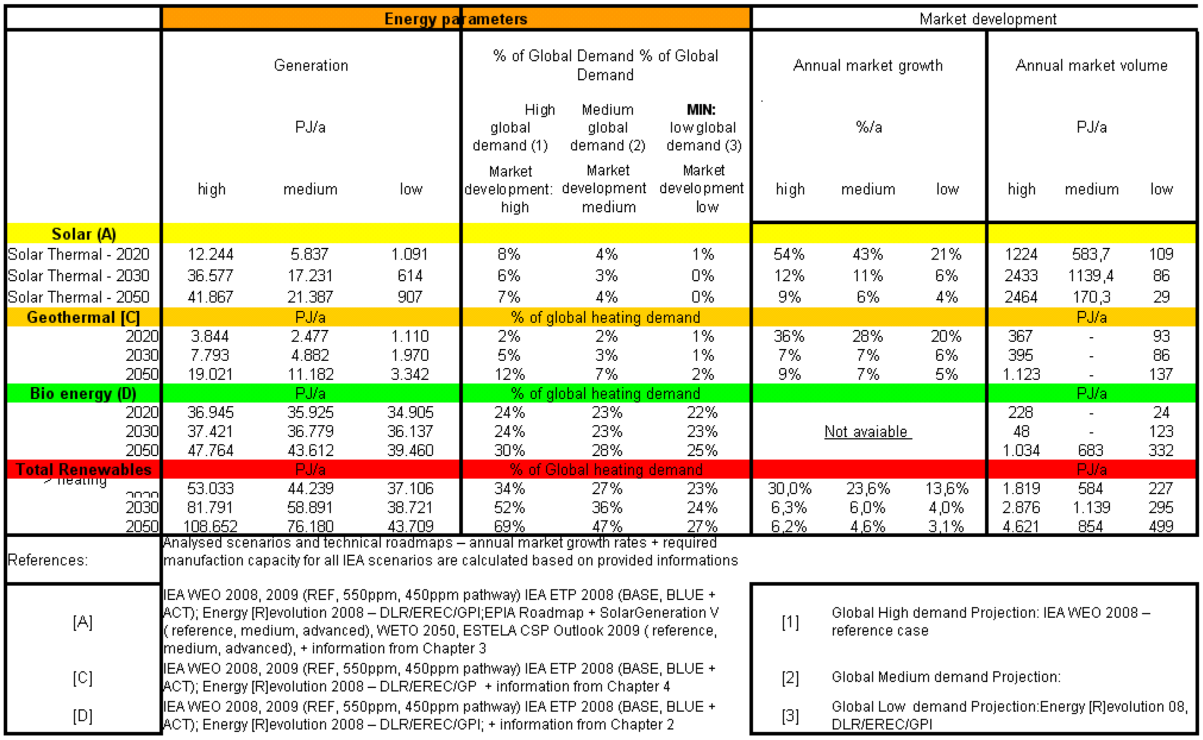
A shift from unsustainable traditional use of bio energy for heating towards modern and more sustainable use of bio energy heating such as wood pellet ovens are assumed in all scenarios. The more efficient use of biomass would increase the share of biomass heating without the necessity to increase of fuel volume. However none of the analysed scenarios provide information about the specific breakdown of traditional versus modern bio energy use. Therefore it is not possible to estimate the real annual market development of the different bio energy heating systems. Geothermal heating and cooling systems are expected to grow fast in the coming decade (until 2020) as well and remain on a high level towards 2050.

10.3.2.2.2Annual market potential for the renewable heating and cooling

The market potential for renewable heating technologies such as solar collectors, geothermal heat pumps or pellet heating systems overlaps with the market potential analysis of the renewable power sector. While the solar collector market is independent from the power sector, biomass cogeneration could be listed under the power sector or the heating/cooling sector. Geothermal heat pumps use power for there operation and therefore increase the demand for electricity. Renewable heating and cooling is even more dispersed and decentralized than renewable power generation, what explains to a certain extend that the statistical data is still quite poor and needs further research.

Based on the energy parameters of the analysed scenarios, the required annual market volume has been calculated in order to identify the needed manufacturing capacities and how they relate to current capacities. Table 10.3.5 [TSU: Table 10.3.4] provides an overview about the annual market volumes in order to implement the given renewable heating capacities within the analysed scenarios. These calculated annual market volumes do not include the additional needs for repowering. Even with relatively low growth rates manufacturing capacities for all renewable heating and cooling technologies must be expanded significantly in order to implement the projected renewable heat production in all analysed scenarios. The annual market volume for solar collectors until 2020 must be expanded from less about 35 PJ/a in 2008 to 109 PJ/a in 2020 in the low case and up to 1224 PJ/a in the high case. Due to the diverse technology options for bio- and geothermal energy heating systems and the low level of information in all analysed scenarios, it is not possible to provide specific market size data by technology.

Table 10.3.4: Projected renewable heat production, possible market shares, annual growth rates and annual market volumes.



	Energy parameters						Market development					
	Generation			% of Global Demand % of Global Demand			Annual market growth			Annual market volume		
	PJ/a			High global demand (1)	Medium global demand (2)	**MIN:** low global demand (3)	%/a			PJ/a		
	high	medium	low	Market development: high	Market development medium	Market development low	high	medium	low	high	medium	low
Solar (A)												
Solar Thermal - 2020	12.244	5.837	1.091	8%	4%	1%	54%	43%	21%	1224	583,7	109
Solar Thermal - 2030	36.577	17.231	614	6%	3%	0%	12%	11%	6%	2433	1139,4	86
Solar Thermal - 2050	41.867	21.387	907	7%	4%	0%	9%	6%	4%	2464	170,3	29
Geothermal [C]	PJ/a			% of global heating demand						PJ/a		
2020	3.844	2.477	1.110	2%	2%	1%	36%	28%	20%	367	-	93
2030	7.793	4.882	1.970	5%	3%	1%	7%	7%	6%	395	-	86
2050	19.021	11.182	3.342	12%	7%	2%	9%	7%	5%	1.123	-	137
Bio energy (D)	PJ/a			% of global heating demand						PJ/a		
2020	36.945	35.925	34.905	24%	23%	22%				228	-	24
2030	37.421	36.779	36.137	24%	23%	23%		Not avaiable		48	-	123
2050	47.764	43.612	39.460	30%	28%	25%				1.034	683	332
Total Renewables	PJ/a			% of Global heating demand						PJ/a		
> heating 2020	53.033	44.239	37.106	34%	27%	23%	30,0%	23,6%	13,6%	1.819	584	227
2030	81.791	58.891	38.721	52%	36%	24%	6,3%	6,0%	4,0%	2.876	1.139	295
2050	108.652	76.180	43.709	69%	47%	27%	6,2%	4,6%	3,1%	4.621	854	499

References:	Analysed scenarios and technical roadmaps – annual market growth rates + required manufaction capacity for all IEA scenarios are calculated based on provided informations		
[A]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI;EPIA Roadmap + SolarGeneration V (reference, medium, advanced), WETO 2050, ESTELA CSP Outlook 2009 (reference, medium, advanced), + information from Chapter 3	[1]	Global High demand Projection: IEA WEO 2008 – reference case
[C]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GP + information from Chapter 4	[2]	Global Medium demand Projection:
[D]	IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI; + information from Chapter 2	[3]	Global Low demand Projection:Energy [R]evolution 08, DLR/EREC/GPI

Within the heating sector, solar energy has the highest growth projections of all technologies followed by bio energy and geothermal heating. Bio energy has currently the highest share in global heat production, which is mainly due to the traditional use of biomass and in many cases not sustainable[9]. The total share on renewable heating system in all scenarios by 2050 varies significantly between 21% if combining the high demand und low market development case to 69% anticipating the advanced market development and low demand case. A medium range market development and medium increase of heat demand would lead a renewable heat share of 27% by 2020 and up to 47% by 2050.

10.3.2.3 Market potential for renewable energies in the transport sector

[AUTHOR COMMENT: The quality and quantity of data submitted at the deadline for the 1st order draft was not comprehensive enough to provide an overview about the estimated market potential. However the data collection will continue and an analysis will be part of the second order draft.]

There are two categories of RE used in scenarios.

Direct renewable energy drives:

- Biodiesel
- Ethanol

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[9] See also Chapter 2.1.1.

- Marine Wind energy use:
    - Sails
    - Other marine wind energy systems such as second generation sails

Indirect renewable energy drives: (in competition with stationary use)

- Electricity from RE
- Hydrogen production from RE

10.3.2.4 Global renewable energy primary energy contribution [TSU: unclear]

The total contribution of renewable energy sources to the world global primary energy demand is the summary of the scenario outcomes for all sectors: power generation, heating/cooling and transport. Figure 10.3.3 provides an overview of the projected primary energy production by source and in the selected categories low, medium, high for 2020, 2030 and 2050 and compares the numbers as a numerical exercise with different global primary energy demands. Bio energy has the highest market share both in the medium and the low case, followed by geothermal. This is due to the fact, that bio energy can be used across all sectors (power, heating & cooling as well as transport) while geothermal can be used for power generation and heating / cooling. As the residual material potential and available land for bio energy is limited and competition with nature conservation issues as well as food production must be avoided, the sectoral use for the available bio energy depends on where it is used most efficiently. Cogeneration power plants use bio energy most efficiently to a level of up to 90%.

However solar energy can be used for heating/cooling and power generation as well, but solar technology starts from a relatively low level. In the medium case, solar energy ranks third by 2050 followed by hydro- and wind energy. The relatively low primary energy share for wind and hydro is due to its exclusive use in the power sector. None of the analysed scenarios looks in to the use of wind in the transport sector, such as advanced wind drives for shipping.[10]

The high case ranks bioenergy first, with a possible primary energy share of 19.7% by 2050, solar energy with 18.2% second and geothermal and wind with 10.4% and 7.6 % third and fourth. About 59% of the needed global primary energy could come from only three renewable energy sources.

The total renewable energy share by 2050 has a huge variation across all scenarios. With only 17.1% by 2050 – about 5% more than in 2007 – the combination of a low renewable energy development and high demand will mean only a very moderate increase of the global renewable energy share. The medium case – a combination of a rather moderate market development for RE and a moderate increase of the global energy demand, renewable energy provides 21% of the energy needs in 2050. This shows once more the meaning of combining both strategies extension of renewable energies on the one hand and substantial increase of energy efficiency on the other hand to contribute effectively to mitigation targets.

In the most optimistic case, which is a combination of a high market development for RE and a successfully implemented energy efficiency strategy, RE could provide 61% of the world energy needs. While there is a potential to supply the entire global power demand with REs and 69% of global heating and cooling demand, the most problematic sector for renewable energy to supply substantial shares is the transport sector.

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[10] The International Maritime Organization (IMO) published a study in April 2009 which estimated the emissions from shipping are at 1.046 million tonnes of $CO2$ in 2007, which corresponds to 3.3% of the global emissions during 2007. Modern wind drives such as sails for containerships are estimated to save up to 35% of the annual needed fuels. More research is needed to identify the future technical and market potential for wind power use in modern vessels.

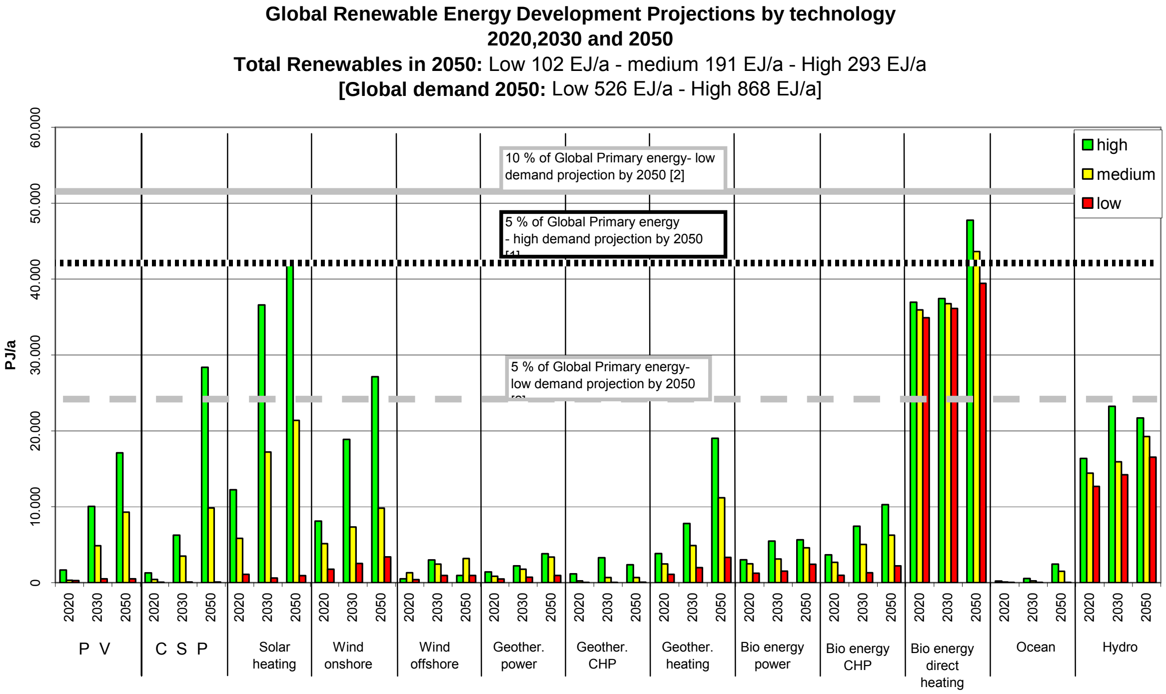
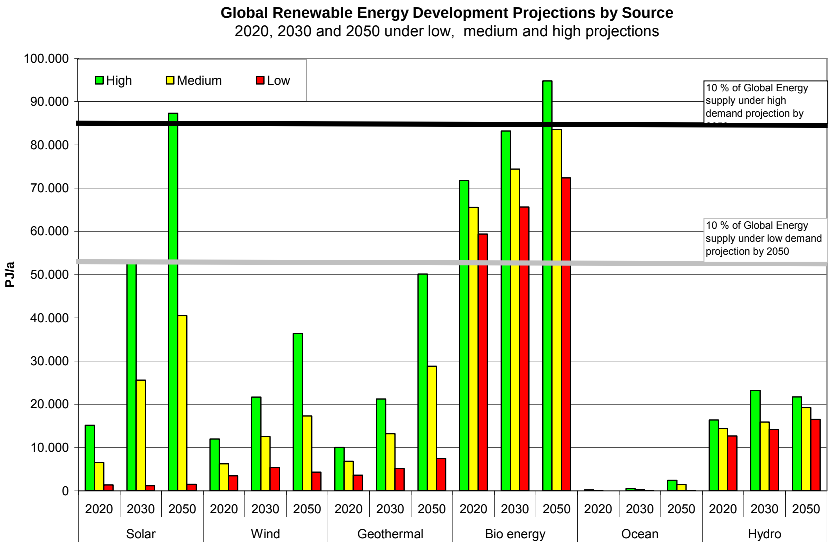
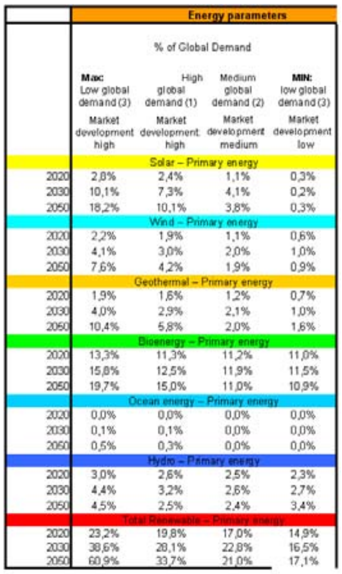


Figure 10.3.2: Summary: Global Renewable Energy Development Projections by Technology. [TSU: No reference in Text; No Source]





	Energy parameters			
	% of Global Demand			
	Max: Low global demand (3) Market development high	High global demand (1) Market development high	Medium global demand (2) Market development medium	**MIN:** low global demand (3) Market development low
	Solar – Primary energy			
2020	2,8%	2,4%	1,1%	0,3%
2030	10,1%	7,3%	4,1%	0,2%
2050	18,2%	10,1%	3,8%	0,3%
	Wind – Primary energy			
2020	2,2%	1,9%	1,1%	0,6%
2030	4,1%	3,0%	2,0%	1,0%
2050	7,6%	4,2%	1,9%	0,9%
	Geothermal – Primary energy			
2020	1,9%	1,6%	1,2%	0,7%
2030	4,0%	2,9%	2,1%	1,0%
2050	10,4%	5,8%	2,0%	1,6%
	Bioenergy – Primary energy			
2020	13,3%	11,3%	11,2%	11,0%
2030	15,8%	12,5%	11,9%	11,5%
2050	19,7%	15,0%	11,0%	10,9%
	Ocean energy – Primary energy			
2020	0,0%	0,0%	0,0%	0,0%
2030	0,1%	0,1%	0,0%	0,0%
2050	0,5%	0,3%	0,0%	0,0%
	Hydro – Primary energy			
2020	3,0%	2,6%	2,5%	2,3%
2030	4,4%	3,2%	2,6%	2,7%
2050	4,5%	2,5%	2,4%	3,4%
	Total Renewable – Primary energy			
2020	23,2%	19,8%	17,0%	14,9%
2030	38,6%	28,1%	22,8%	16,5%
2050	60,9%	33,7%	21,0%	17,1%

Figure 10.3.3: Global Renewable Energy Development Projections by Source and Global renewable primary energy shares by source. [TSU: No Source]

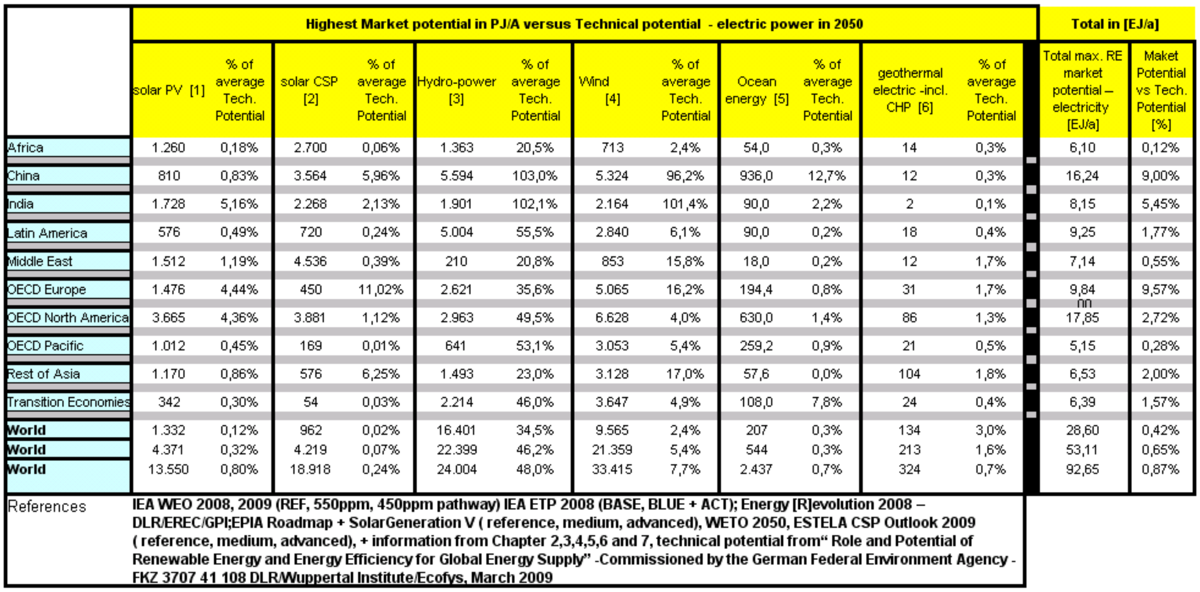
10.3.3 Regional Breakdown – technical potential versus market potential

This section provides an overview about the market penetration paths given in the analysed scenarios versus the technical potential per region as well as an overview about the regional scenario data. The table [TSU: 10.3.5] compares the maximum value (high case- of this scenario analysis) with the technical potential in order to calculate the maximum deployment rate of the technical potential. Within this survey, the bio energy potential was devided by energy crops and residuals, but not by technology and/or sector.

10.3.3.1 Renewable Power sector by Region

The quality of the regional data is not as comprehensive as global scenario data. This is partly due to the fact, that the number of available regional scenarios and/or regional technology roadmaps is very limited, especially for developing regions. In some cases there are only specific country scenarios available (e.g. USA) but no further regional scenarios are given. In general there are many specific energy scenarios available for Annex I countries, but very little data can be used for developing countries. Besides that, another major obstacle for a precise discussion of national energy scenarios for developing countries e.g. in Central Africa, is the lack of exact energy statistics and the lack of data for regional specific renewable energy potentials.

Table 10.3.5: Overview of achieved potential shares (high case scenario based market growth versus technical potential – power sector, by technology).



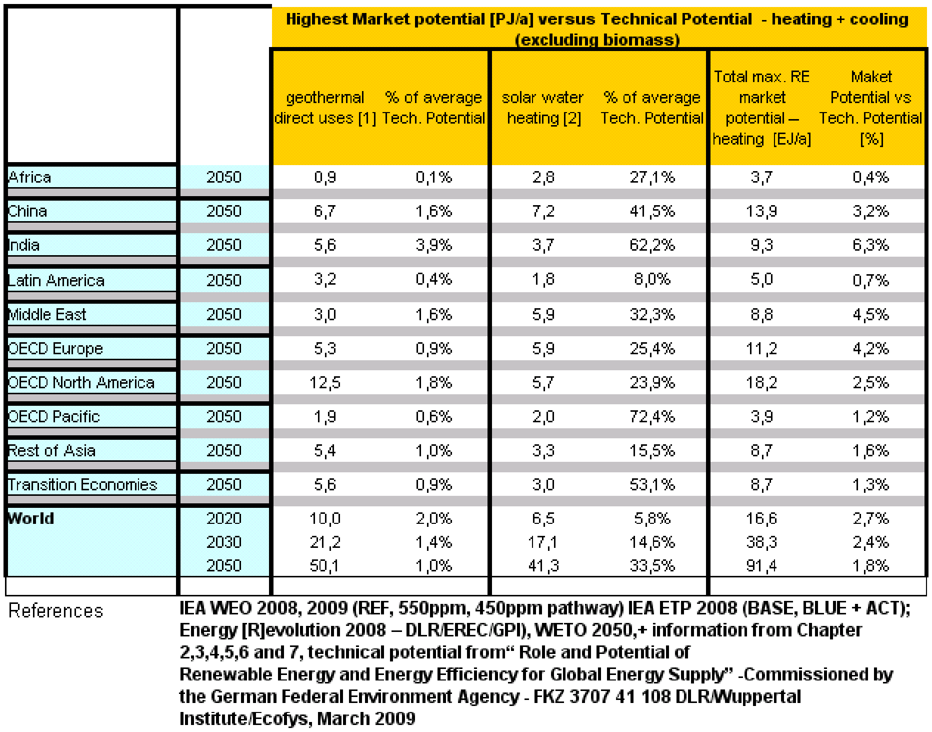
	Highest Market potential in PJ/A versus Technical potential - electric power in 2050												Total in [EJ/a]	
	solar PV [1]	% of average Tech. Potential	solar CSP [2]	% of average Tech. Potential	Hydro-power [3]	% of average Tech. Potential	Wind [4]	% of average Tech. Potential	Ocean energy [5]	% of average Tech. Potential	geothermal electric -incl. CHP [6]	% of average Tech. Potential	Total max. RE market potential – electricity [EJ/a]	Maket Potential vs Tech. Potential [%]
Africa	1.260	0,18%	2.700	0,06%	1.363	20,5%	713	2,4%	54,0	0,3%	14	0,3%	6,10	0,12%
China	810	0,83%	3.564	5,96%	5.594	103,0%	5.324	96,2%	936,0	12,7%	12	0,3%	16,24	9,00%
India	1.728	5,16%	2.268	2,13%	1.901	102,1%	2.164	101,4%	90,0	2,2%	2	0,1%	8,15	5,45%
Latin America	576	0,49%	720	0,24%	5.004	55,5%	2.840	6,1%	90,0	0,2%	18	0,4%	9,25	1,77%
Middle East	1.512	1,19%	4.536	0,39%	210	20,8%	853	15,8%	18,0	0,2%	12	1,7%	7,14	0,55%
OECD Europe	1.476	4,44%	450	11,02%	2.621	35,6%	5.065	16,2%	194,4	0,8%	31	1,7%	9,84	9,57%
OECD North America	3.665	4,36%	3.881	1,12%	2.963	49,5%	6.628	4,0%	630,0	1,4%	86	1,3%	17,85	2,72%
OECD Pacific	1.012	0,45%	169	0,01%	641	53,1%	3.053	5,4%	259,2	0,9%	21	0,5%	5,15	0,28%
Rest of Asia	1.170	0,86%	576	6,25%	1.493	23,0%	3.128	17,0%	57,6	0,0%	104	1,8%	6,53	2,00%
Transition Economies	342	0,30%	54	0,03%	2.214	46,0%	3.647	4,9%	108,0	7,8%	24	0,4%	6,39	1,57%
World	1.332	0,12%	962	0,02%	16.401	34,5%	9.565	2,4%	207	0,3%	134	3,0%	28,60	0,42%
World	4.371	0,32%	4.219	0,07%	22.399	46,2%	21.359	5,4%	544	0,3%	213	1,6%	53,11	0,65%
World	13.550	0,80%	18.918	0,24%	24.004	48,0%	33.415	7,7%	2.437	0,7%	324	0,7%	92,65	0,87%
References	**IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI;EPIA Roadmap + SolarGeneration V (reference, medium, advanced), WETO 2050, ESTELA CSP Outlook 2009 (reference, medium, advanced), + information from Chapter 2,3,4,5,6 and 7, technical potential from“ Role and Potential of Renewable Energy and Energy Efficiency for Global Energy Supply” -Commissioned by the German Federal Environment Agency - FKZ 3707 41 108 DLR/Wuppertal Institute/Ecofys, March 2009**													

The overall estimated market share for renewable power generation did not exceed 10% of global technical potential. For 2050, the highest deployment rate of the technical renewable power potential per region has been found in OECD Europe (9.6%), followed by China (9%), India (5.9%), OECD North America (2.7%) and Developing Asia (2%). The other remaining regions have rates below 2%. On a global level none of the analysed scenario exceeds a deployment rate of 1% of the total technical potential for renewable power generation.

10.3.3.2 Renewable Heating and cooling by sector and region

The quality of the regional data for heating and cooling is even less comprehensive than the regional data for power generation. Especially the statistical data for the current situation for heating and cooling is weak. While there is some data available for industrial (process) heat for developing countries there is very little data available for those regions for the residential heating and cooling sector. All statistical data for the heating sector is based on IEA Statics. This analysis can only provide a first overview about future potential exhaustion. In the following table [TSU: 10.3.6] numbers are given for geothermal energy and solar water technologies.

Table 10.3.6: Highest market potential versus technical demand by region and technology.



		Highest Market potential [PJ/a] versus Technical Potential - heating + cooling (excluding biomass)					
		geothermal direct uses [1]	% of average Tech. Potential	solar water heating [2]	% of average Tech. Potential	Total max. RE market potential – heating [EJ/a]	Maket Potential vs Tech. Potential [%]
Africa	2050	0,9	0,1%	2,8	27,1%	3,7	0,4%
China	2050	6,7	1,6%	7,2	41,5%	13,9	3,2%
India	2050	5,6	3,9%	3,7	62,2%	9,3	6,3%
Latin America	2050	3,2	0,4%	1,8	8,0%	5,0	0,7%
Middle East	2050	3,0	1,6%	5,9	32,3%	8,8	4,5%
OECD Europe	2050	5,3	0,9%	5,9	25,4%	11,2	4,2%
OECD North America	2050	12,5	1,8%	5,7	23,9%	18,2	2,5%
OECD Pacific	2050	1,9	0,6%	2,0	72,4%	3,9	1,2%
Rest of Asia	2050	5,4	1,0%	3,3	15,5%	8,7	1,6%
Transition Economies	2050	5,6	0,9%	3,0	53,1%	8,7	1,3%
World	2020	10,0	2,0%	6,5	5,8%	16,6	2,7%
	2030	21,2	1,4%	17,1	14,6%	38,3	2,4%
	2050	50,1	1,0%	41,3	33,5%	91,4	1,8%
References	**IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI), WETO 2050,+ information from Chapter 2,3,4,5,6 and 7, technical potential from" Role and Potential of Renewable Energy and Energy Efficiency for Global Energy Supply" -Commissioned by the German Federal Environment Agency - FKZ 3707 41 108 DLR/Wuppertal Institute/Ecofys, March 2009**						

By 2030, the highest market potential projection for direct geothermal heating uses only 1.4% of the available technical potential based on (UBA 2009) and 2.4% in the case of solar hot water heating. The joined technical potential for solar water heating and geothermal heating has be exploited to 2.4% in the analysed market potential projections.

The total technical potential for renewable heating and cooling systems has been exploited in the scenarios by any time to less than 3% until 2050. From the technical point of view, there is still a large potential for market potential improvement.

10.3.3.3 Primary energy by region, technology and sector

The maximum deployment share out of the overall technical potential for solar energy in 2050 were found in energy scenarios for OECD Europe with a total of 3.2%. The second and third biggest deployment rates were found in scenarios for India and China. All other analysed scenarios use less than 2% of the available technical potential for solar energy.

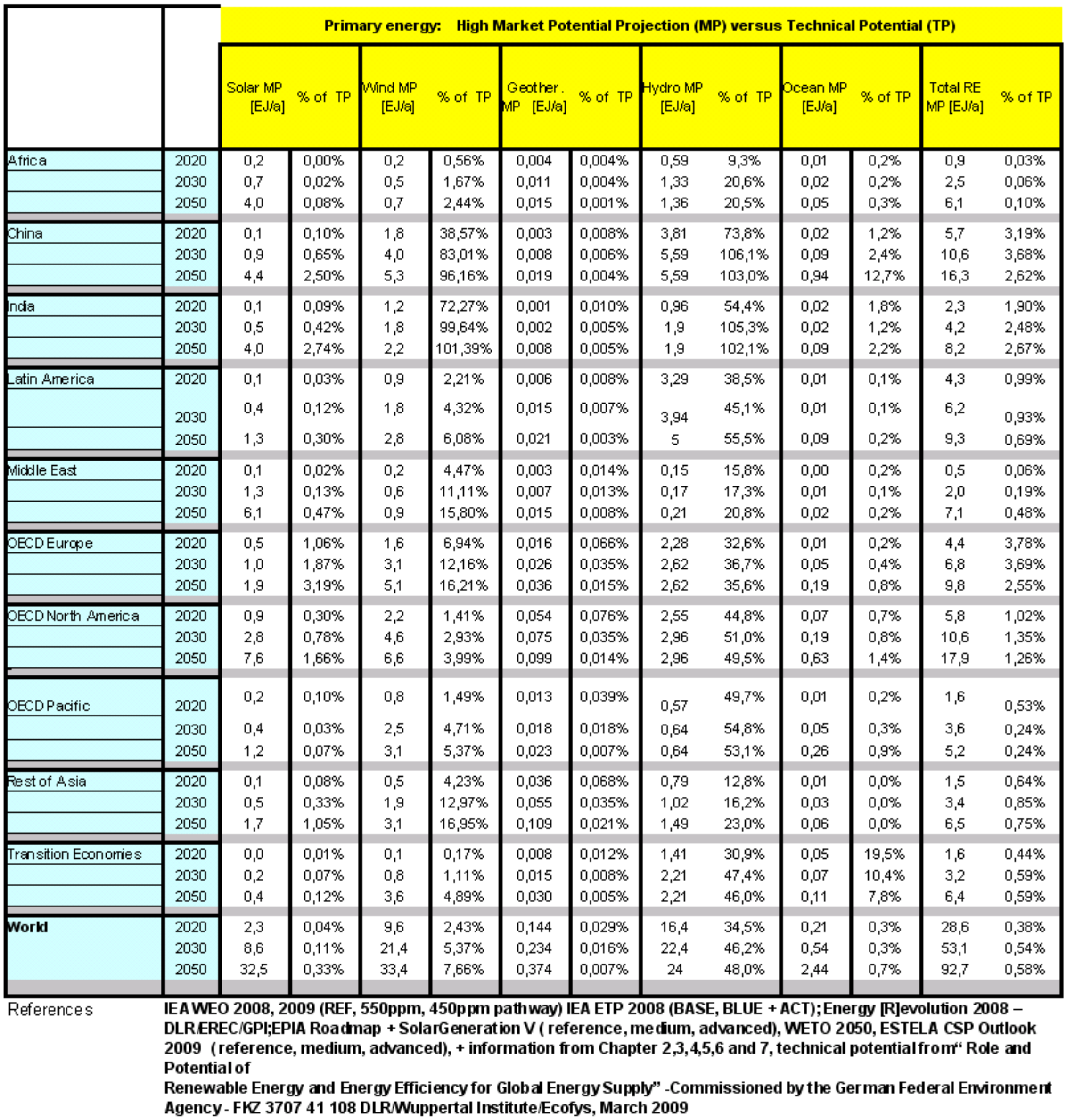
Wind energy has been exploited to a much larger extend in all regional scenarios than solar energy. As indicated in table 10.3.8 [TSU: Table 10.3.7], the wind potential has been fully exploited in scenarios for India and China. However the provided technical potential for wind within those regions is very low compared to other regions.

Geothermal energy does not play a mayor role in neither of the analysed scenarios. Both on a global and regional level the deployment rate of the available technical potential is far below 1%.

The established hydro power market on a global and regional level has exploited roughly half of the believed technical potential on a global level. Analysed scenarios for both China and India, exploited the entire technical potential which indicates, that the estimated capacity for 2050 represents the maximum possible capacity for hydro power in these countries.

Table 10.3.8 [TSU: 10.3.7] gives an overview about the overall renewable primary energy share on a global and regional level.

Table 10.3.7: High case market potential projections versus Technical Potential by technology and region.



		Primary energy: High Market Potential Projection (MP) versus Technical Potential (TP)											
		Solar MP [EJ/a]	% of TP	Wind MP [EJ/a]	% of TP	Geother. MP [EJ/a]	% of TP	Hydro MP [EJ/a]	% of TP	Ocean MP [EJ/a]	% of TP	Total RE MP [EJ/a]	% of TP
Africa	2020	0,2	0,00%	0,2	0,56%	0,004	0,004%	0,59	9,3%	0,01	0,2%	0,9	0,03%
	2030	0,7	0,02%	0,5	1,67%	0,011	0,004%	1,33	20,6%	0,02	0,2%	2,5	0,06%
	2050	4,0	0,08%	0,7	2,44%	0,015	0,001%	1,36	20,5%	0,05	0,3%	6,1	0,10%
China	2020	0,1	0,10%	1,8	38,57%	0,003	0,008%	3,81	73,8%	0,02	1,2%	5,7	3,19%
	2030	0,9	0,65%	4,0	83,01%	0,008	0,006%	5,59	106,1%	0,09	2,4%	10,6	3,68%
	2050	4,4	2,50%	5,3	96,16%	0,019	0,004%	5,59	103,0%	0,94	12,7%	16,3	2,62%
India	2020	0,1	0,09%	1,2	72,27%	0,001	0,010%	0,96	54,4%	0,02	1,8%	2,3	1,90%
	2030	0,5	0,42%	1,8	99,64%	0,002	0,005%	1,9	105,3%	0,02	1,2%	4,2	2,48%
	2050	4,0	2,74%	2,2	101,39%	0,008	0,005%	1,9	102,1%	0,09	2,2%	8,2	2,67%
Latin America	2020	0,1	0,03%	0,9	2,21%	0,006	0,008%	3,29	38,5%	0,01	0,1%	4,3	0,99%
	2030	0,4	0,12%	1,8	4,32%	0,015	0,007%	3,94	45,1%	0,01	0,1%	6,2	0,93%
	2050	1,3	0,30%	2,8	6,08%	0,021	0,003%	5	55,5%	0,09	0,2%	9,3	0,69%
Middle East	2020	0,1	0,02%	0,2	4,47%	0,003	0,014%	0,15	15,8%	0,00	0,2%	0,5	0,06%
	2030	1,3	0,13%	0,6	11,11%	0,007	0,013%	0,17	17,3%	0,01	0,1%	2,0	0,19%
	2050	6,1	0,47%	0,9	15,80%	0,015	0,008%	0,21	20,8%	0,02	0,2%	7,1	0,48%
OECD Europe	2020	0,5	1,06%	1,6	6,94%	0,016	0,066%	2,28	32,6%	0,01	0,2%	4,4	3,78%
	2030	1,0	1,87%	3,1	12,16%	0,026	0,035%	2,62	36,7%	0,05	0,4%	6,8	3,69%
	2050	1,9	3,19%	5,1	16,21%	0,036	0,015%	2,62	35,6%	0,19	0,8%	9,8	2,55%
OECD North America	2020	0,9	0,30%	2,2	1,41%	0,054	0,076%	2,55	44,8%	0,07	0,7%	5,8	1,02%
	2030	2,8	0,78%	4,6	2,93%	0,075	0,035%	2,96	51,0%	0,19	0,8%	10,6	1,35%
	2050	7,6	1,66%	6,6	3,99%	0,099	0,014%	2,96	49,5%	0,63	1,4%	17,9	1,26%
OECD Pacific	2020	0,2	0,10%	0,8	1,49%	0,013	0,039%	0,57	49,7%	0,01	0,2%	1,6	0,53%
	2030	0,4	0,03%	2,5	4,71%	0,018	0,018%	0,64	54,8%	0,05	0,3%	3,6	0,24%
	2050	1,2	0,07%	3,1	5,37%	0,023	0,007%	0,64	53,1%	0,26	0,9%	5,2	0,24%
Rest of Asia	2020	0,1	0,08%	0,5	4,23%	0,036	0,068%	0,79	12,8%	0,01	0,0%	1,5	0,64%
	2030	0,5	0,33%	1,9	12,97%	0,055	0,035%	1,02	16,2%	0,03	0,0%	3,4	0,85%
	2050	1,7	1,05%	3,1	16,95%	0,109	0,021%	1,49	23,0%	0,06	0,0%	6,5	0,75%
Transition Economies	2020	0,0	0,01%	0,1	0,17%	0,008	0,012%	1,41	30,9%	0,05	19,5%	1,6	0,44%
	2030	0,2	0,07%	0,8	1,11%	0,015	0,008%	2,21	47,4%	0,07	10,4%	3,2	0,59%
	2050	0,4	0,12%	3,6	4,89%	0,030	0,005%	2,21	46,0%	0,11	7,8%	6,4	0,59%
World	2020	2,3	0,04%	9,6	2,43%	0,144	0,029%	16,4	34,5%	0,21	0,3%	28,6	0,38%
	2030	8,6	0,11%	21,4	5,37%	0,234	0,016%	22,4	46,2%	0,54	0,3%	53,1	0,54%
	2050	32,5	0,33%	33,4	7,66%	0,374	0,007%	24	48,0%	2,44	0,7%	92,7	0,58%

References **IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI;EPIA Roadmap + SolarGeneration V (reference, medium, advanced), WETO 2050, ESTELA CSP Outlook 2009 (reference, medium, advanced), + information from Chapter 2,3,4,5,6 and 7, technical potential from" Role and Potential of**
Renewable Energy and Energy Efficiency for Global Energy Supply" -Commissioned by the German Federal Environment Agency - FKZ 3707 41 108 DLR/Wuppertal Institute/Ecofys, March 2009

Ocean energy is at a very early development stage and it is very difficult to estimate the potential market development for the coming years. Furthermore, the technical potential for some regions seems to be very limited. Especially the Transition Economies, but also China will reach – based on current knowledge – technical limits even with a modest expansion of ocean energy.

The overall technical potential for renewable energy exceeds current global primary energy by factor 32 (see chapter 10.3.2). Even the energy scenarios with the most ambitious growth rates for renewable energy did not exceed 3.2% (China, 2020) on a regional level and 0.58 (2050) on a global level.

The analysed regional and global scenarios show a wide range of the renewable shares in the future. In order to show the different ranges of deployment rates for renewable energy sources by sector and region, Figure 10.3.4 (see below) compares a reference scenario (>600ppm) which was developed from the German Space Agency (DLR) on the basis of the IEA World Energy Outlook 2007 with a category II (<440ppm) scenario (Energy [R]evolution 2008 DLR/EREC/GPI). While the reference scenario more or less represents the pathway of a "frozen" energy policy, the ER2008 assumes a wide range of policy measure in favour of renewable energy sources as well as a significant price setting for carbon.

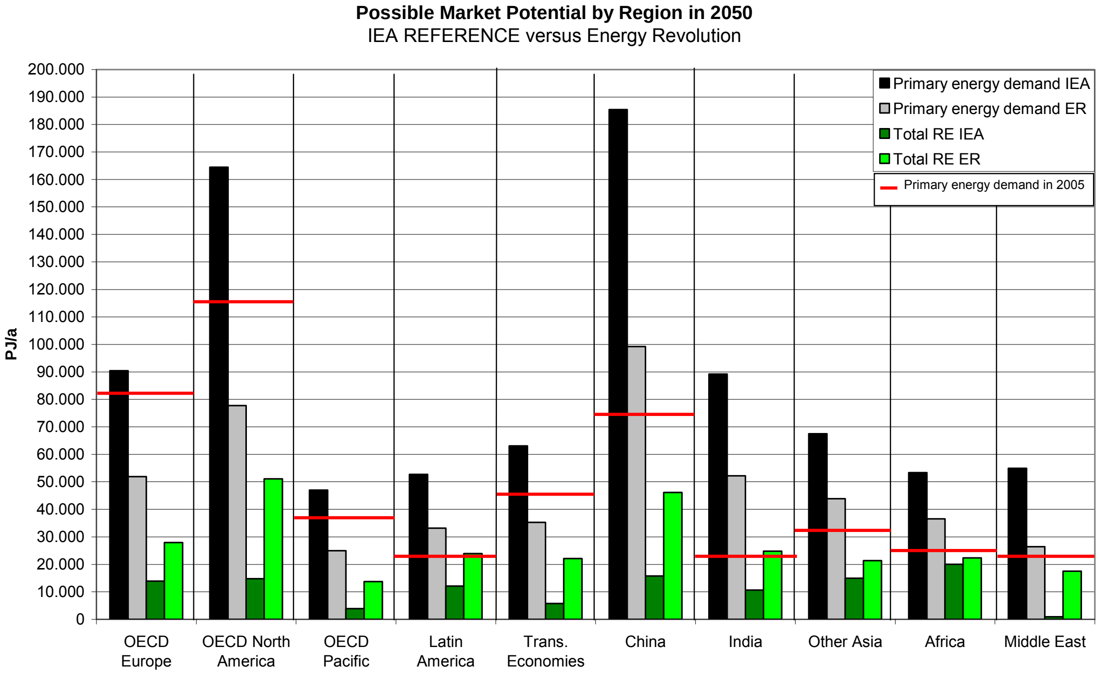


Figure 10.3.4: Regional breakdown from possible renewable energy market potential: Reference (> 600ppm) versus Category II (<440ppm) scenario.

10.3.4 GHG mitigation potential of single options and the effects of Climate Change on potentials

Based on the results of the bottom up scenario analysis and the identified market penetration rates projections for different renewable energy technologies, the GHG mitigation potential has been calculated. For each sector, a factor has been identified based on possible substituted fossil fuel or a mix of different fossil fuels. The calculation is based on simplified assumption and can only be indicative. For the power sector with the current global technology mix, the average specific CO_2 emissions are 0.603 kg CO_2 per kWh (IEA2009). In practice, it might be more sensible to calculate the emission reductions using the specific characteristic of new power plants as reference. The specific number of 0.603 kg CO_2 per kWh in that context represents a specific mix of coal and natural gas fire power plants. For the heating sector, the average specific global CO_2 emission is 71 kt t CO_2/PJ[11].

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[11] **CO2 intensities heat [kt/PJ]**

District heating plants	95.1
Heat from CHP	187.3
Direct heating	59.1
Total	70.2
Total without CHP	60.8
Total direct only	59.1

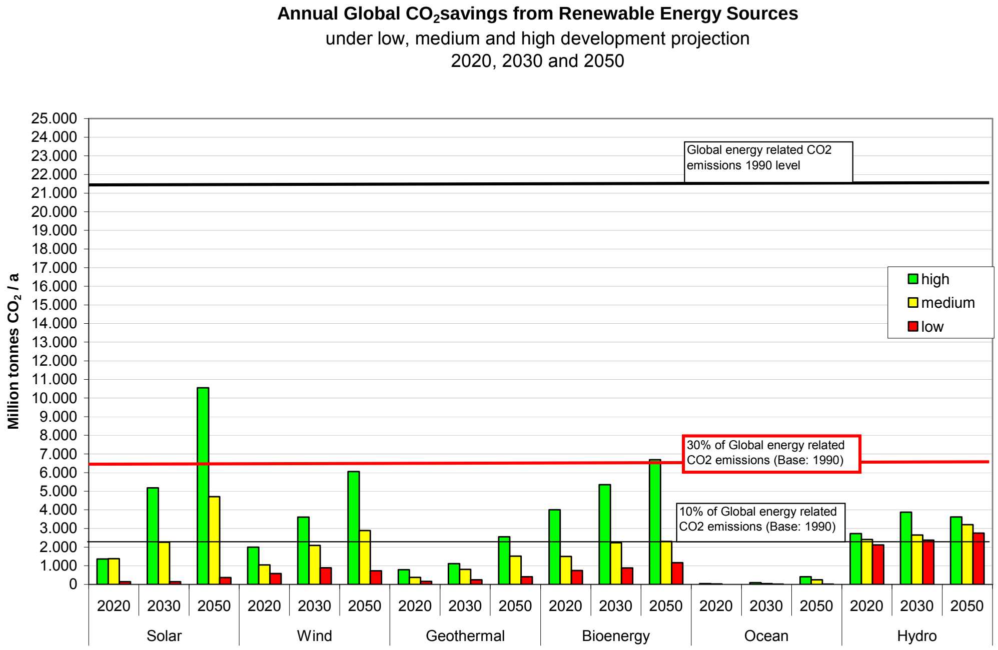
Figure 10.3.5 shows the annual CO_2 reduction potential per source 2020, 2030 and 2050, for the low, medium and high case projections. The red line at 6 Gt CO_2/a identifies 20% of the global energy related CO_2 emissions (Base year 2008), the line below represents 10%.

Solar energy has the highest CO_2 reduction contribution both in the medium and high case. The medium case projections will result 2.2Gt CO_2/a (2030) and 4.7Gt CO_2/a (2050), while the high case will reach 5 Gt CO_2/a 10 years earlier by 2020. By 2050, under a combined high market growth projection for photovoltaic, concentrated solar power and solar heating, results in a total annual reduction potential of 10.5 Gt CO_2/a.

Wind power has the second highest CO_2 reduction contribution from all power technologies. By 2030 both under the high and medium case, wind power could avoid around 10% of 2008 energy related CO_2 emissions. By 2050, this could go up to 20% under the high market growth projections.

As geothermal could play a significant role in the heating sector, the overall CO_2 reduction potential across all sectors is the second largest of all analysed renewable energy technologies under the high case. However, there is a huge range between the medium and high case projections, and the analysis of more scenarios is required.

In this analysis, bio energy contributes between 1169 million tonnes CO_2/a in the low case and 6.695 million tonnes CO_2/a in the high case by 2050. But one has to keep in mind that the uncertainties are significantly higher than at all other technologies. The use of unsustainable bio fuels or solid biomass would reduce this amount significantly and could even result into higher CO_2 emissions compared to fossil fuels.[12] (Sattler, Crutzen, Scharlemann et. al.). In addition all analysed scenario did not identify the share of modern biomass versus modern biomass in the 'direct heating category', therefore the biomass used for direct heating has been excluded from the CO_2 reduction emission calculation.



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[12] Sattler, C., Kachele, H. & Verch, G. 2007. Assessing the intensity of pesticide use in agriculture. Agriculture, Ecosystems and Environment 119: 299-304. and Crutzen, P.J., Mosier, A.R., Smith, K.A. & Winiwarter, W. 2007. N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmospheric Chemistry and Physics Discussions 7: 11191-11205. and Scharlemann, J.P.W. & Laurance, W.F. 2008. How green are biofuels? Science 319: 43-44.

Figure 10.3.5: Annual Global CO_2 savings from RE under low, medium and high development projection for 2020, 2030 and 2050 (NOTE: this is excluding transport). [TSU: No Source]

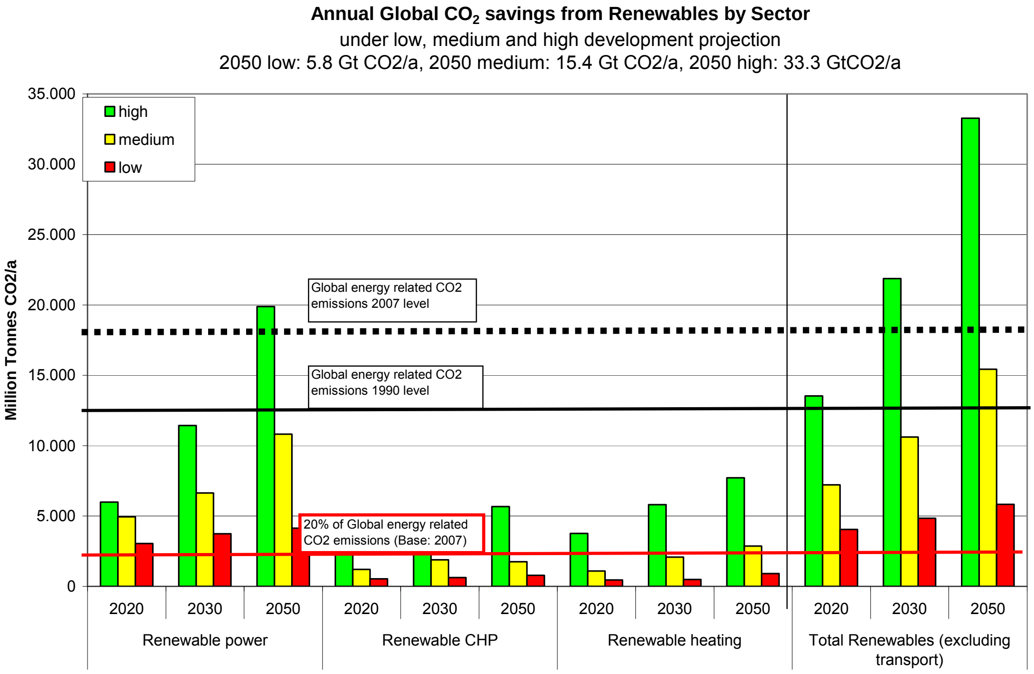

Figure 10.3.6: Annual Global CO_2 savings from RE by Sector and total; under low, medium and high development projection for 2020, 2030 and 2050.

[Analysed scenarios: IEA WEO 2008, 2009 (REF, 550ppm, 450ppm pathway) IEA ETP 2008 (BASE, BLUE + ACT); Energy [R]evolution 2008 – DLR/EREC/GPI;EPIA Roadmap + SolarGeneration V (reference, medium, advanced), WETO 2050, ESTELA CSP Outlook 2009 (reference, medium, advanced), GWEC- Global Wind Energy Outlook 2008,Lemming et al. 2008 (Riso high wind), + information from Chapter 2,3,4,5,6, 7,]

10.3.4.1 Global CO_2 mitigation potential from RE

Based on the analysed scenarios, the total annual CO_2 reduction potential varies significantly between the low, medium and high case. While the low case abatement potential for renewable is only 5.8 Gt CO_2/a by 2050 which represents the business as usual pathway, the medium case achieves a total of 15.4 Gt CO_2/a by 2050. The annual high case CO_2 savings lead to 33.3 Gt CO_2/ a which is equal to a 70% reduction of energy related CO_2-emission of the analysed reference scenarios.

10.3.4.2 Cumulative CO_2 reduction potentials form renewable energies until 2050

Cumulative CO_2 reduction potential from renewable energies between 2020 and 2050 has been calculated on the bases of the annual CO_2 savings shown in figure 10.3.5 and 10.3.6 and under the assumption of 10.3.4.. The analysed scenarios would due to a cumulated reduction of 148 Gt CO_2 under the low case, 333 Gt CO_2 in the medium case and 640 Gt CO_2 in the high case.

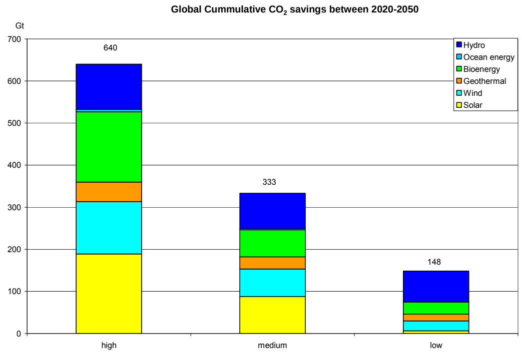

Figure 10.3.7: Global cumulative CO_2 savings between 2020 and 2050. [TSU: No Source]

10.3.5 Comparison of the results with scenario analysis

The deployment pathway of renewable energy sources from the mitigation scenario analysis of chapter 10.2 and the analysis of the "bottom up" scenario in chapter 10.3 differ significantly by source. Table 10.3.9 [TSU: 10.3.8] provides an overview about the different ranges from Low to high in both analyses.

While the figures for hydro are in the same range, the figures for geothermal and solar energy differ significantly. The technical scenarios expect a far higher market potential than the integrated models, especially for new renewable energy technologies. Biomass has significantly higher shares in the high and low case within the integrated models.

Table 10.3.8: Global renewable energy development projections by source – technical detail models ("bottom-up") versus integration model ("top- down") scenarios. [TSU: No Source]

[EJ/a]		High		Medium		Low	
		technical detail modells	integration modells [1]	technical detail modells	integration modells [2]	technical detail modells	integration modells [3]
Solar							
	2020	15	4	7	1	1	0
	2030	53	11	26	2	1	0
	2050	87	63	41	16	2	0
Wind							
	2020	12	14	6	1	3	2
	2030	22	26	13	2	5	4
	2050	36	56	17	16	4	14
Geothermal							
	2020	10	1	7	1	4	0
	2030	21	3	13	1	5	0
	2050	50	7	29	3	8	0
Bio energy							
	2020	72	65	66	46	59	0
	2030	83	117	74	52	66	4
	2050	95	184	84	101	72	22
Hydro							
	2020	16	15	14	14	13	11
	2030	23	19	16	17	14	12
	2050	22	26	19	19	17	12

[1] Categories I+II (<440 ppm), 75% case
[2] Categories III+IV (440-600 ppm), 50% case
[3] References (>600 ppm), 25% case

10.3.6 Knowledge gaps

More research is needed amongst others for the coverage of global potential for CHP. In the scenarios especially the heating/cooling sector have a limited data base. A global reporting system for RE (market volume, production capacity, costs) as well as a better resource assessment (down to 10 x 10 km cluster) required to do more exact scenarios.

10.4 Regional Cost Curves for mitigation with renewable energies [TSU: deviation from structure agreed by plenary: "Cost curves for mitigation with renewable energy"]

10.4.1 Introduction

Governments and decision-makers face limited financial and institutional resources and capacities for mitigation, and therefore tools that assist them in strategising how these limited resources are prioritised have become very popular. Among these tools are abatement cost curves – a tool that relates the mitigation potential of a mitigation option to its marginal cost, as well as ranks these options in order of cost-effectiveness (see, for instance, Fig. 5) [TSU: Figure 10.4.5]. Recent years have seen a major interest among decision- and policy-makers in abatement cost curves, witnessed by the proliferation in the number of such studies and institutions/companies engaged in preparing such reports (e.g. Next Energy 2004, Creyts et al. 2007, Dornburg et al. 2007, McKinsey and Company 2007). Two of the most widely used such efforts include the curves produced by the Energy Technology Perspectives initiative of the International Energy Agency (IEA 2008a), as well as the large number of country/regional and global studies by McKinsey[13] (e.g. McKinsey and Company 2008a, 2009b, 2009c).

While abatement curves are very practical and can provide important strategic overviews, it is pertinent to understand that their use for direct and concrete decision-making has many limitations.

The aims of this section are to: (a) review the concept of abatement cost curves briefly and appraise their strengths and shortcomings; (b) review the existing literature on regional abatement cost curves as they pertain to mitigation using renewable energy; (c) produce a consistent set of regional cost curves for renewable energy supply.

10.4.2 Abatement and energy cost curves: concept, strengths and limitations

10.4.2.1 Concept and Methodological aspects

The concept of supply curves of carbon abatement, energy, or conserved energy all rest on the same foundation. They are curves consisting typically of discreet steps, each step relating the marginal cost of the abatement measure/energy generation technology or measure to conserve energy to its marginal cost; and rank these steps according to their cost. As a result, a curve is obtained that can be interpreted similarly to the concept of supply curves in traditional economics.

Supply curves of conserved energy were first introduced by Arthur Rosenfeld (see Meier et al. 1983) and became a popular concept in the 1980s (Stoft 1995). The methodology has since been revised and upgraded, and the field of its application field extended to energy generation supply curves including renewable cost curves; as well as carbon abatement from the 1990s (Rufo 2003). One of the benefits of the method was that it provided a framework for comparing otherwise different options, such as the cost-effectiveness of different energy supply options to energy conservation options, and therefore was a practical tool for some decision-making approaches, such as integrated resource planning. Although Stoft (1995) explains why the supply curves used in the studies by Meier et al. cannot be regarded as "true" supply curves, including the fact that markets associated with the different types of options depicted in them, such as energy efficiency and energy supply markets, differ in many aspects; he maintains that they are useful for their purpose with certain improvements.

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[13] Colloquial nomenclature sometimes refers to abatement curves as the "McKinsey curves". However, it is important to recognize, as detailed below, that supply curves of energy and mitigation cost curves have been invented and used even decades earlier.

Despite the widespread use of supply curves and their advantages discussed above, there are some inherent limitations to the method that have attracted criticism from various authors that are important to review before we review the literature on them or present the regional cost curves.

10.4.2.2 Limitations of the supply curve method

The concept of abatement, energy and conservation supply curves have common and specific limitations. Much of criticism in the early and some later literature focuses on the notion of options with negative costs. For instance, IEA (2008a) raises an objection based on the perfect market theory from neoclassical economics, arguing that it is not possible to have negative cost options as under perfect market conditions someone must have realized those options complying with rational economic behaviour. The existence of untapped "profitable" (i.e. negative cost) potentials themselves represent a realm of debates ongoing for decades between different schools of thought (e.g. see Carlsmith et al. 1990, Sutherland 1991, Koomey et al. 1998, Gumerman et al. 2001). Those accepting negative cost potentials argue, among others, that certain barriers prevent those investments from taking place on a purely market basis, but policy interventions can remove these barriers and unlock these profitable potentials. Therefore the barriers prevailing in renewable energy markets, detailed in other sections of this report, such as insufficient information, limited access to capital, uncertainty about future fuel prices (for example in the case of fossil fuels or biomass) or misplaced incentives (e.g. fossil fuel subsidies for social or other reasons) hindering a higher rate of investments into renewable energy technologies as well, but even more importantly for untapped energy efficiency measures, potentially resulting in negative cost options (Novikova 2009).

A further concern about supply curves is raised by EEEC (2007), criticizing the methodology simplifies reality. In their view, the curves do not reflect the real choices of actors, who accordingly do not always implement the available options in the order suggested by the curve. Both EEEC (2007) and IEA (2008a) agree that there is the problem of high uncertainty in the use of supply curves for the future. This uncertainty is true both from economic and technological perspectives.

Economic data, such as technological costs or retail rates are derived from past and current economic trends that may obviously not be valid for the future, as sudden technological leaps, policy interventions, or unforeseeable economic changes may occur – as has often been precedented in the field of renewable energy technology proliferation. These uncertainties can be mostly alleviated through the use of scenarios, which may result in multiple curves, such as for example in Van Dam et al. (2007).

One of the key uncertainty factors is the discount rate used in the financial formula for the distribution of investment costs over the lifetime of a project, such as annualization. The uncertainty about discount rates does not only stem from the fact that it is difficult to project them for the future, but because it is difficult to decide what discount rate to use, i.e. social vs. market discount rates. A number of studies (see e.g. Nichols 1994) have discussed that, in the case of investments in energy efficiency or renewable energy, individual companies or consumers often use higher discount rates than would be otherwise expected for other types of e.g. financial investments. On the other hand, as Fleiter et al. (2009) note, society faces a lower risk in the case of such investments, therefore a lower discount rate could be considered appropriate from that perspective. Junginger et al. (2004), in their methodology, set their internal rate of return (IRR)[14] expected by the investors and the support of government towards renewable energy investments according to the preferences of the stakeholders; however social and institutional settings are not taken into consideration, as the authors found it impossible to quantify those aspects.

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[14] While the expected IRR is not equal to the discount rate, it is usually compared to it to evaluate an investment.

For greenhouse gas abatement cost curves, a key input that can largely influence the results is the carbon intensity, or emission factor of the country or geographical area to which it is applied, and the uncertainty in projecting this into the future. Emission factors depend largely on the technologies in place, and thus the abatement potential depends very strongly on the substituted fuel/technology in addition to the introduced abatement measure. This may lead to a situation where the option in one locality is a much more attractive measure than in another one simply as a result of the differences in emission factors (Fleiter et al. 2009). As a result, a carbon abatement curve for a future date may say more about expected policies on fossil fuels than about the actual measures analysed by the curves, and the ranking of the individual measures is also very sensitive to the developments in carbon emission intensity of energy supply. This question can only be addressed using a dynamic approach on one hand and a system perspective on the other hand considering the relevant interdependencies (as also discussed below). Finally, Fleiter et al. (2009) also raise a number of issues about the cost assessment of boundaries that are often mishandled, such as lifetime of investments, external costs and co-benefits.

There are further concerns emerging in relation to abatement cost curves that are not yet fully documented in the peer-reviewed literature. For instance, the costs of a renewable energy technology in a future year largely depend on the deployment pathway of the technology in the years preceding – i.e. the policy environment in the previous decades. The abatement cost of a renewable energy option heavily depends also on the prices of fossil fuels, which are also very uncertain to predict.

Perhaps one of the key shortcomings of the cost curves are that they consider and compare mitigation options apply individually, whereas typically a package of measures are applied together, therefore potentially missing synergistic and integrational opportunities. Optimised, strategic packages of measures may have lower average costs than the average of the individual measures applied using a piecemeal approach. In particular the missing dynamic system perspective considering relevant interactions with the overall system behaviour can be problematic, although cost curves applying advanced methods are dynamic rather than static. In particular this is true for GHG mitigation cost curves where the question of substituted energy options plays a major role for the calculation of the mitigated CO_2-emissions.

While several of these shortcomings can be addressed or mitigated to some extent in a carefully designed study, including those related to cost uncertainty, others cannot, and thus when cost curves are used for decision-making, these limitations need to be kept in mind. In the effort we use in this chapter to construct regional cost curves, we attempt to alleviate as many of these limitations as possible, as described below.

10.4.3 Review of regional energy and abatement cost curves from the literature

10.4.3.1 Introduction

This section reviews the key studies that have produced regional cost curves for renewable energy and its application for mitigation. First, we review work that looks at energy cost curves, followed by a review of the role of renewable in abatement cost curves – since designated cost curves for renewable alone are rare.

10.4.3.2 Regional renewable energy cost curves

In an attempt to review the existing literature on regional cost curves, a number of studies were identified, as summarized in Table 10.1. [TSU: Table 10.4.1] As discussed in the previous section, the assumptions used in these studies have major influence on the shape of the curve, ranking of options and the total potential identified by the curves, the table also reviews the most important characteristics and assumptions of the models/calculations as well as their key findings.

Table 10.4.1: Summary of regional/national literature on renewable energy supply curves, with the potentials grouped into cost categories.

Country/Region	Cost ($/MWh)	Total RES (TWh/yr)	% of baseline	Discount rate (%)	Notes	Source
US (AZ 2025)	<100	0.28	N/A	Biomass and PV: 7.5 Rest: 8	- State of Arizona, United States - RES: wind, biomass, solar, hydro, geothermal - Interest rates vary between energy sources	RES data: Black & Veatch Corporation (2007)
	<200	10.5	N/A			
	<300	20	N/A			
Czech Republic	<100	101	19.93	4	- Only biomass production - Best case scenario where future yields equal the level of the Netherlands	RES data: Lewandowski et al. (2006) Baseline data: IEA (2005)
Germany	<100	160	24.24	N/A	- Only Wind and PV are included - PV only enters above 200 USD	RES data: Scholz (2008) Baseline data: McKinsey and Company (2007)
	<200	177	26.76			
	<300	372	56.20			
Germany	<100	174	N/A	N/A	- Only wind and PV are included - PV available between 100 and 200 USD	Scholz (2008)
	<200	393	N/A			
Netherlands	<100	22	15.17	N/A	- Included: onshore and offshore wind, PV, biomass and hydro; - Interest rate is not available, however, this option is a scenario where sustainable production is calculated. Therefore they use 5% IRR assuming that there are governmental support;	Junginger et al. 2004
	<200	23	15.86			
	<300	24	16.55			
UK	<100	815	22.46	7.9	- Included: "Low-cost technologies" (landfill gas, onshore wind, sewage gas, hydro); - Costs: capital, operating and financing elements; - Baseline is all electricity generated in the UK forecasted for 2015;	RES data: Enviros (2005) Baseline data: UK SSEFRA (2006)
	<200	119	32.95			
United States	<100	3421	14.86	N/A	- Wind energy only	RES data: Milligan (2007) Baseline data: EIA (2009)

Country/Region	Cost ($/MWh)	Total RES (TWh/yr)	% of baseline	Discount rate (%)	Notes	Source
United States (WGA)	<100	177	0.77		- Only the WGA region - CSP, biomass, and geothermal; - Geothermal reaches maximum capacity under 100 $/MWh; - CSP has a large potential, but full range is between 100 and 200 $/MWh	RES data: Mehos and Kearney (2007), Overend and Milbrandt (2007), Vorum and Tester (2007) Baseline data: EIA (2009)
	<200	1959	8.51			
	<300	1971	8.56			
Central and Eastern Europe	<100	3233	74.13	N/A	- Biomass only, best scenario with willow being the selected energy crop (highest yield) - Countries: BG, CZ, EST, HU, LV, LT, PL, RO, SK - Baseline data includes Slovenia, however, its share is rather low, therefore resulting distortion is not so high;	RES data: van Dam et al. (2007) Baseline data: Solinski (2005)
Europe (Wind+PV))	<100	10310			- Only wind and PV included	Scholz (2008)
	<200	14730				
	<300	15904				
Europe (Wind+PV)	<100	13348			- Only wind and PV included - Wind reaches its maximum at around 200 USD - PV reaches its maximum at around 100 USD	Scholz (2008)
	<200	16534				
Global	<100	21000-83000	29-166	10	- Liquid transport fuel from biomass. All land suitable and available for plantations assumed to be used for transport fuel	de Vries et al. (2007) Baseline data for electricity: IEA (2003)
	<100	200000-300000	231-347	10	- Electricity from biomass, onshore wind, PV. Total global power supply potential, without supply-demand balance and other considerations taken into account.	
Global (Biomass)	<100	97200	N/A	10	- Target year is not specified - Study claims biomass production under this price can exceed electricity consumption multiple times	Hoogwijk et al. (2003)

In general, it is very difficult to compare data and findings from renewable energy supply curves, as there have been very few studies using a comprehensive and consistent approach and detail their methodology, and most studies use different assumptions (technologies reviewed, target year, discount rate, energy prices, deployment dynamics, technology learning, etc.). Therefore, country- or regional findings in Table 10.1 [TSU: Table 10.4.1] need to be compared with caution, and for the same reasons findings for the same country can be very different in different studies.

In addition, most renewable energy cost curve studies focused on single, or just a few, renewable energy resources, and few have combined multiple technologies/resources applying a universal methodology (de Vries et al. 2007). Therefore the following discussion focuses on findings from largely single technology curves, but attempts to compare these where possible.

Nonetheless, certain trends can be observed. The most widely analyzed renewable energy sources for the future are wind, biomass and solar PV. Solar PV is typically attributed a large potential, however, with a large uncertainty since costs are very much dependent on the learning curve and the resulting investment and O&M costs. This phenomenon is best demonstrated by de Vries et al. (2007) where according to the scenario chosen, PV may have a bigger potential at around 100 USD/MWh than biomass and wind combined for the highest scenario by 2050, or according to their lowest scenario assumptions, not even starting to produce below 200 USD/MWh (still in the lowest scenario potentials may be large above that cost level).

Another example is the supply curve for Germany for 2030 (Scholz 2008), where PV only becomes available above 200 USD/MWh, whereas wind for example has a large potential even under 100 USD/MWh. Nevertheless, once we reach the cost level where PV starts to supply, available potential becomes large. This study also reinforces the significance of technological development in the case of PV as the supply curve for 2050 shows that at that point of time costs are expected to go down at a scale that its full potential becomes available under around 200 USD/MWh, while in the case of wind, the cost gap between 2030 and 2050 is considerably smaller and starts to widen only when approaching the maximum technical potential.

The same research (Scholz 2008) shows that in Europe as a whole the trend is very similar in terms of the characteristics of supply curves with regard to the gap between 2030 and 2050 cost curves for these technologies.

Projecting biomass energy potentials as a function of cost is a very complex task, depending on many other exogenous projections, including, land availability and competition with other land uses (as discussed in the previous sections), policies related to forestry, agriculture and other land uses; and future yield levels in a changed climate (de Vries et al. 2007). The uncertainty of many of these inputs as well as the significance of government policy choices, lead to the fact that most studies concerning biomass production work with several scenarios even with six or seven, like Lewandowski et al. (2006) and van Dam et al. (2007).

Biomass supply is the most thoroughly analyzed in the Central and Eastern European region from the perspective of cost curves. Although again showing a significant variation, according to the projections of van Dam et al. (2007), biomass may supply a significant share of TPES in that region. Their calculations suggest that around 3233 TWh/yr could be available by 2030, which may comprise over 70% of TPES according to the forecast. At the country level, Lewandowski et al. (2006) find a lower potential of 101 TWh/yr in the Czech Republic under the cost of 100 USD/MWh, but this still represents almost 20% of the TPES foreseen by the IEA (2005) for this year by biomass alone.

With regard to onshore wind, almost all studies agree that energy from this source may be produced in reasonable quantities even under 100 USD/MWh where there is a sufficient technical potential. On a global level de Vries et al. (2007) come to the conclusion that by 2050 at certain places electricity from wind can be generated from around 40 USD/MWh, which is even below the price of electricity produced from woody biomass as found in the study, and it will be possible to generate around 43 PWh/year electricity below the cost of 100 USD/MWh. Data from the United States show that even in the relatively short term, by 2015, almost 15% of TPES may come from wind energy under 100 USD/MWh. However, in this case the input data on the economic potential of wind from Milligan (2007) implies that 40% of the existing grid is available to transport wind energy which is in their case the best scenario. The report produced by Enviros in 2005 for the United Kingdom in 2015 also found that wind is the most promising renewable energy source for the country. It has by far the largest potential almost 75% of which can be realized under 100 USD/MWh while reaching the maximum potential below 200 USD/MWh. Junginger et al. (2004) in the case of the Netherlands finds that most of the technical potential may be reached by 2020, and even at inland locations most of the energy can be produced under a 100 USD/MWh with the best onshore places producing at around half of this cost. As mentioned before, in the case where multiple timeframes are compared for the same regions (Scholz 2008), the finding is that price decrease due to technology learning is not expected to be extremely steep.

The weakness of studies carried out concerning individual regions and/or energy sources is that they usually do not account for the competition for land and other resources such as capital among the various energy sources (except for probably the various plant species in the case of biomass). Only one study was identified among the examined ones that explicitly addressed this issue, de Vries et al. (2007). In their findings potentials seriously decline in case of exclusive land use, with solar PV suffering the worst losses both in technical and economic potential.

10.4.3.3 Regional carbon abatement cost curves

Table 10.2 summarises the findings and characterises the assumptions in the studies reviewed that construct regional carbon abatement cost curves through the deployment of renewable technologies. They typically have a different focus, goal and approach as compared to renewable energy supply curve studies, and are broader in scope. They typically examine renewables within a wider portfolio of mitigation options.

Table 10.4.2: Summary of carbon abatement cost curves literature.

Country/Region	Year	Cost (\$/tCO$_2$e)	Mitigation potential (million tonnes CO$_2$)	% of baseline	Discount rate (%)	Notes	Source
Australia	2020	<100	74	9.46	N/A	- Costs are converted from Australian dollars[15]	McKinsey and Company (2008a)
Australia	2030	<100	105	13.43			
Australia (NSW region)	2014	<100	8.1	1.04	N/A	- New South Wales region - Includes governmental support for RES	Abatement data: Next Energy (2004) Baseline data: McKinsey (2008a)
		<300	8.5	1.09			
China	2030	<100	1560	10.76	4	- Costs are converted from euros[1] [TSU: reference missing]	McKinsey and Company (2009a)
Czech Republic	2030	<100	9.3	6.24	N/A	- Scenario with maximum use of renewable energy sources - Costs are converted from euros[1] [TSU: reference missing]	McKinsey and Company (2008b)
		<200	11.9	7.99			
		<300	16.6	11.14			
Germany	2020	<100	20	1.91	7	- Societal costs (governmental compensation not included)	McKinsey and Company (2007)
		<200	31	2.96			
		<300	34	3.24			
Poland	2015	<100	50	11.04	6	- Only biomass - Best case scenario - Costs are converted from euros[1] [TSU: reference missing]	Abatement data: Dornburg et al. (2007) Baseline data: EEA (2007)
		<200	55.90	12.35			

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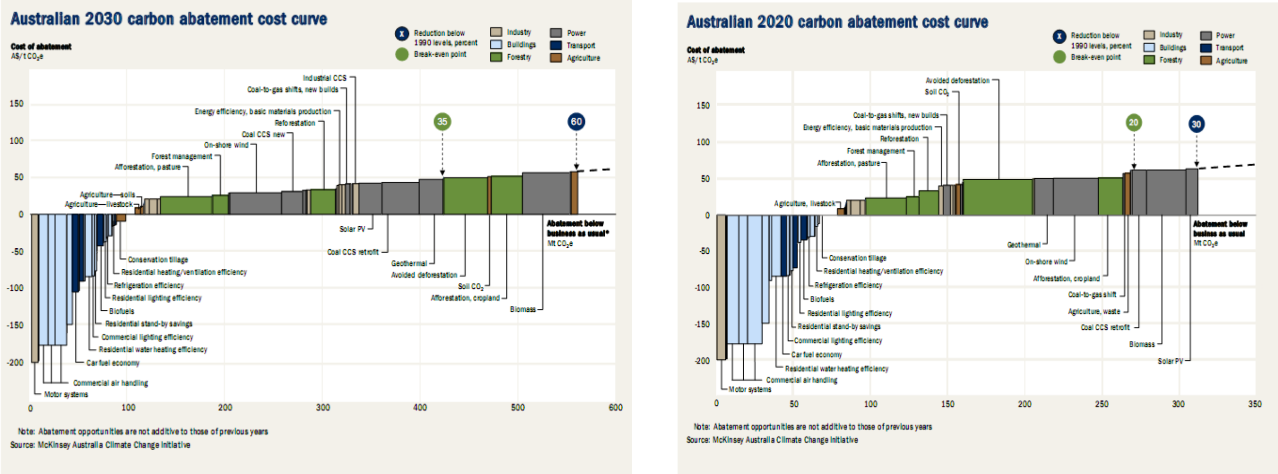
[15] Conversion rate used: 1$ = 1.28 A$

Country/Region	Year	Cost ($/tCO$_2$e)	Mitigation potential (million tonnes CO$_2$)	% of baseline	Discount rate (%)	Notes	Source
Switzerland	2030	<100	0.9	1.61	2.5	- Base case scenario	McKinsey and Company (2009b)
South Africa	2050	<100	83	5.19	10	- Renewable electricity to 50% scenario	Hughes et al. (2007)
Sweden	2020	<100	1.26	1.92	N/A	- Costs are converted from Swedish krones	McKinsey and Company (2008c)
United States	2030	<100	380	3.71	7		Creyts et al. (2007)
United Kingdom	2020	<100	4.38	0.61	N/A	- Costs are converted from euros[2] [TSU: reference missing]	CBI (2007)
		<200	8.76	1.21			
Global	2030	<100	6390	9.13	4	- Scenario A (Maximum growth of renewables and nuclear) - Scenario B (50% growth of renewables and nuclear)	McKinsey and Company (2009c)
		<100	4070	5.81			

One general trend can be observed based on this limited sample of studies. Abatement curve studies tend to find lower potentials for renewable energy than those focusing on energy supply. Even for the same country these two approaches may find very different potentials. For instance, the Enviros (2005) study identified a 33% potential by renewable energy as a% of 2015 TPES in the UK (see Table 10.1 [TSU: Table 10.4.1] and the previous section) under the cost of 200 USD/MWh; while CBI (2007) attributed only an 0.93% carbon mitigation potential for renewables for the UK for 2020 under the cost of 200 USD/t CO_2e. The highest figure in carbon mitigation potential share by the deployment of renewables, as demonstrated by Table 10.3, is for Australia: 13.43% under 200 USD/t CO_2e by 2030 (in contrast with the much higher shares as a % of national TPES reported in the previous section) (data from McKinsey and Company 2008a).

A potential factor contributing to this general trend is that renewable energy supply studies typically examine a broader portfolio of RE technologies, while the carbon mitigation studies reviewed focus on selected resources/technologies to keep models and calculations at reasonable complexity. For instance, remaining with the UK example, the CBI (2007) study does not take into consideration other renewable energy sources presented by Enviros (2005) as low-cost options, such as landfill gas, sewage gas and hydropower.

Countries with the most promising abatement potentials through renewable identified in the sample of studies are Australia, China and Poland. The McKinsey and Company (2008) findings (see Figure 5) [TSU: reference to Figure unclear] in the power sector are in line with the results presented in the previous section in the sense that onshore wind seems to be the option with the largest potential with a reasonably low cost under 50 USD/t CO_2e and biomass has the second largest potential with a slightly higher cost. The steep learning curve for solar PV is also confirmed as costs from 2020 to 2030 are expected to decline to the extent that it becomes cheaper than both biomass and geothermal, although somewhat contradicting the findings of the previous chapter they envision a similarly large drop in the cost of abatement from onshore wind as well.


Australian 2030 carbon abatement cost curve

Note: Abatement opportunities are not additive to those of previous years
Source: McKinsey Australia Climate Change Initiative

Australian 2020 carbon abatement cost curve

Note: Abatement opportunities are not additive to those of previous years
Source: McKinsey Australia Climate Change Initiative

Figure 10.4.1: Carbon abatement cost curves for Australia in 2020 and 2030
Source: McKinsey and Company (2008).

In China it is again wind (both onshore and offshore) and solar PV that take the most important roles in generating renewable energy, although geothermal and small hydro is available at negative costs, but their output is not nearly as significant (McKinsey and Company 2009). According to their assumptions, both wind and solar PV remains slightly more expensive than coal or nuclear, however, the differences will largely decline (Coal: 39 USD/MWh, Nuclear: 42.9 USD/MWh, Wind: 49.4 USD/MWh, Solar PV: 57.2 USD/MWh)[16].

The role of biomass in Central Eastern Europe discussed in the previous section is reinforced by the Dornburg et al. (2007) who estimated carbon abatement potential for Poland at over 11% for biomass alone. Their cost curves are constructed in four steps in which not only do they calculate the amount of biomass and energy produced, but they also account for higher land prices and higher market prices of materials and energy carriers due to an increased production. Similarly to the biomass supply curve studies described in the previous chapter, they also use a relatively high number of scenarios (4) considering the same factors as mentioned above, in two of which they report a mitigation potential below 0 USD/t CO_2e.

10.4.4 Regional renewable energy supply curves

[TSU: No Sources to most of the figure in this section]

This section presents regional renewable electricity supply curves that were constructed based on consistent datasets reported in the literature. Unfortunately such datasets that project renewable energy generation potentials as a function of cost in a regional breakdown in a consistent framework, as well as on as a function of time, are extremely rare. For the present report two such datasources were identified, with one of them already drawing on two different sources of data.

Before detailing the datasets, however, we explain how some of the shortcomings of the cost curve method were alleviated in this exercise. First, recognizing the crucial determining role of carbon emission factors, energy pricing and fossil fuel policies in the ultimate shape of abatement cost curves, the author team of this chapter has jointly decided that it might be more misleading to produce abatement cost curves than informative, thus only renewable energy cost curves are created, avoiding these problems. Second, in order to capture the uncertainties in cost projections stemming from the various reasons detailed above, where possible (2030), two scenarios are reviewed – one that can be considered as more conservative (in this case this is the WEO 2008 (IEA 2008b) due to the typically high costs it projects for RES), and one that describes a scenario in which the world has placed a large emphasis on renewable energy deployment (Energy [R]evolution scenario, Krewitt et al. 2009a).

Another method to strengthen the usefulness of the cost curves produced for this report was to rely on realistic deployment scenarios – i.e. capturing the dynamic nature of potentials and costs in time rather than providing a static cost curve. These cost curves represent snapshot cross-sections of dynamic scenarios in a particular year, providing their details on potentials as a function of costs in that year; but dynamically developing throughout the projection period and making certain assumptions about a deployment path. As a result, the potentials they project for a certain cost category are neither technical nor an economic potentials, but can be considered as deployment potentials, since they already integrates constraints in capacity development, other local constraints such as land availability and competition, opportunities through technology learning, etc.

Unfortunately the Energy [R]evolution scenarios did not include regionally differentiated costs, and thus for their deployment potential figures a separate dataset was used for costs (Krewitt, Nienhaus et al. 2009b). While this is not an ideal solution, the main authors of the two reports have agreed that the costs correspond well to the deployable potentials in the Energy [R]evolution scenario. It is also important to note that the energy potentials are totals for the target year, i.e. include the capacities already in place today.

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[16] Conversion rate used: 1.30 USD/EUR.

A major shortcoming of these curves is that they show only electricity potentials, whereas, in some regions, thermal energy and fuel potentials maybe comparable, or even significantly higher than those for electricity generation. Unfortunately, however, there is a major gap in knowledge for renewable non-electric energy potentials on a regional basis, especially as a function of cost. Finally, the real benefit of the cost curve method, i.e. to identify the really cost-effective opportunities, cannot be utilized for such aggregate datasets. Average costs for a technology for an whole region mask the really cost-effective potentials and sites into an average, compromised by the inclusion of less attractive sites or sub-technologies. Therefore, significant, globally coordinated further research is needed for refining these curves into sub-steps by sites and sub-technologies in order to identify the most attractive opportunities broken out of otherwise less economic technologies (such as more attractive wind sites, higher productivity biomass technologies/plants/sites, etc.).

10.4.4.1 Africa

The differences between the two 2030 scenarios are rather extreme in Africa in the case of both types of solar power sources, PV and CSP. In the Energy [R]evolution scenario, PV and CSP have the second and third largest potentials, respectively, both of them at costs less than 100 USD/MWh. On the other hand, in the WEO 2008 scenario their role is only minor, not to mention that PV comes at the highest cost among all options. In this scenario hydro power alone has more potential than all the other renewable energy sources together with a power generation potential of over 200 TWh annually. Although neither scenario expects a large contribution from geothermal, the differences in the projected cost levels are still remarkable.

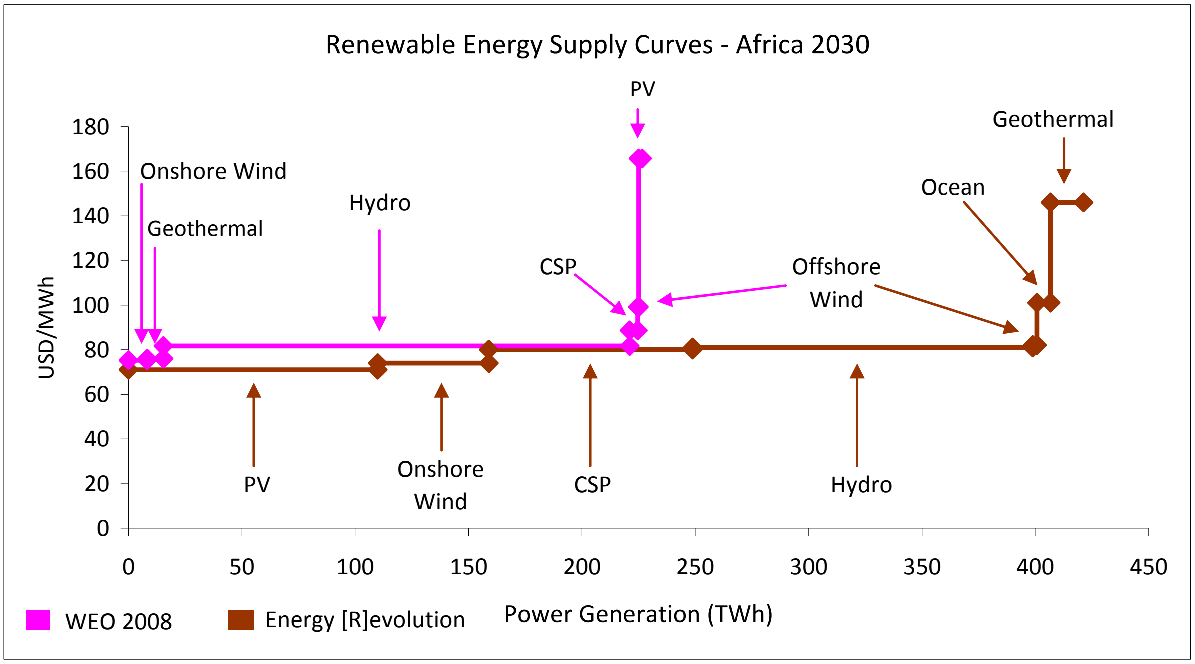

Figure 10.4.2: Renewable energy supply curves for Africa for the year 2030.

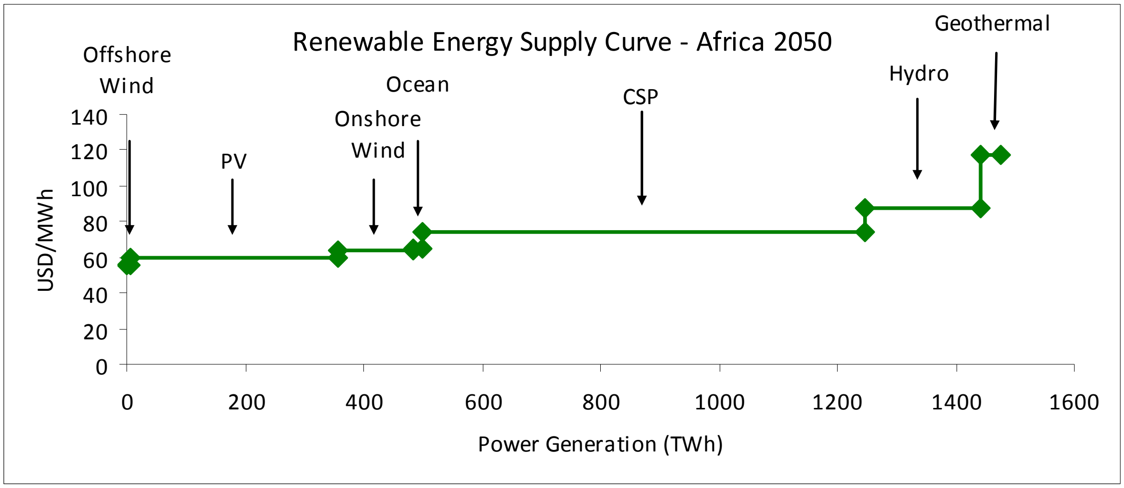

Figure 10.4.3: Renewable energy supply curve for Africa for the year 2050.

Compared to the same scenario (Energy [R]evolution) in 2030, it is evident that potentials will be significantly higher in Africa by 2050 as the total power generation can go up to 1475 TWh from 421 TWh. Shares of the individual renewable energy sources will be similar although CSP will be the one with the largest generation potential and hydro will lose some of its share.

10.4.4.2 China

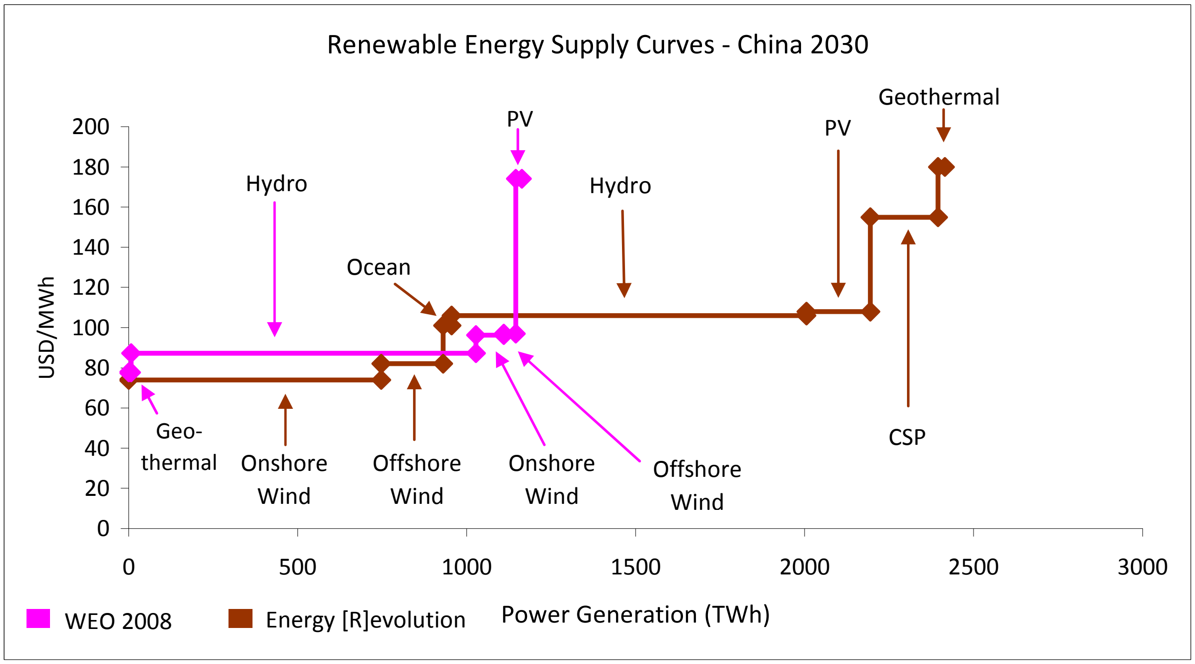

Figure 10.4.4: Renewable energy supply curves for China for the year 2030.

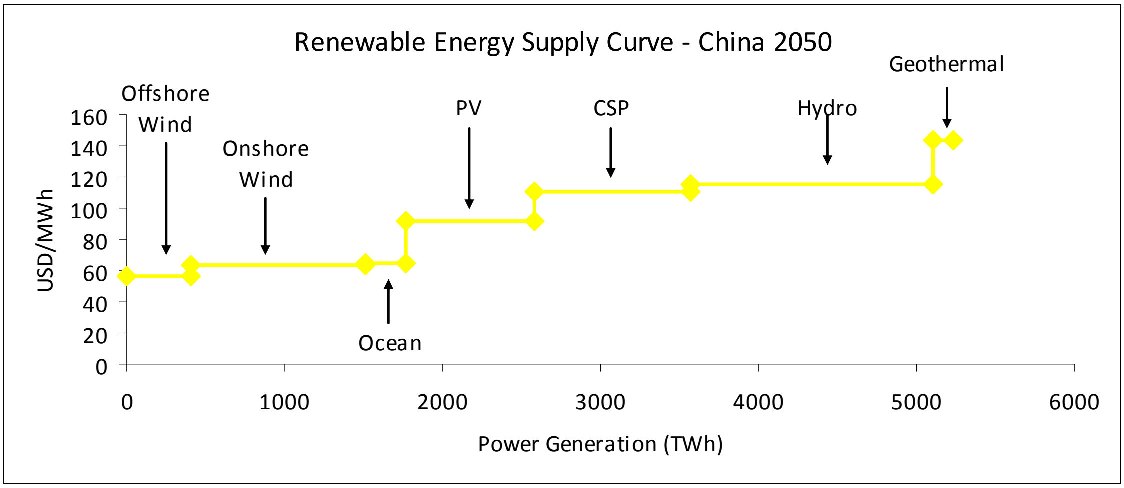

Figure 10.4.5: Renewable energy supply curve for China for the year 2050.

While hydropower in China seems to play an important role in the renewable energy mix in to both scenarios in 2030, the Energy [R]evolution scenario shows a more balanced overall portfolio. As in the case of Africa, the cost of geothermal is again at the two ends of the scale. The WEO 2008 scenario gives no projection on Concentrated Solar Power and on tidal and wave and predicts a much smaller contribution from onshore wind.

If we compare the forecasts for 2030 and 2050 it is evident that all renewable energy sources will have higher potentials. Costs will also be lower as a general trend, although the cost of hydropower is projected to increase slightly.

10.4.4.3 Europe

In the case of Europe wind energy, both onshore and offshore has a significant potential at a relatively low cost not exceeding 102 USD/MWh in either case. Hydro could also play an important role as it has the largest potential in one of the scenarios and the second largest in the other one. Geothermal, wave and tidal and CSP will most likely play a smaller role according to both scenarios, while there is an interesting difference between them in the evaluation of PV. In the Energy [R]evolution scenario it seems to be a feasible option at a cost level of 123 USD/MWh, whereas WEO 2008 predicts 280 USD/MWh making it the most expensive option by far.

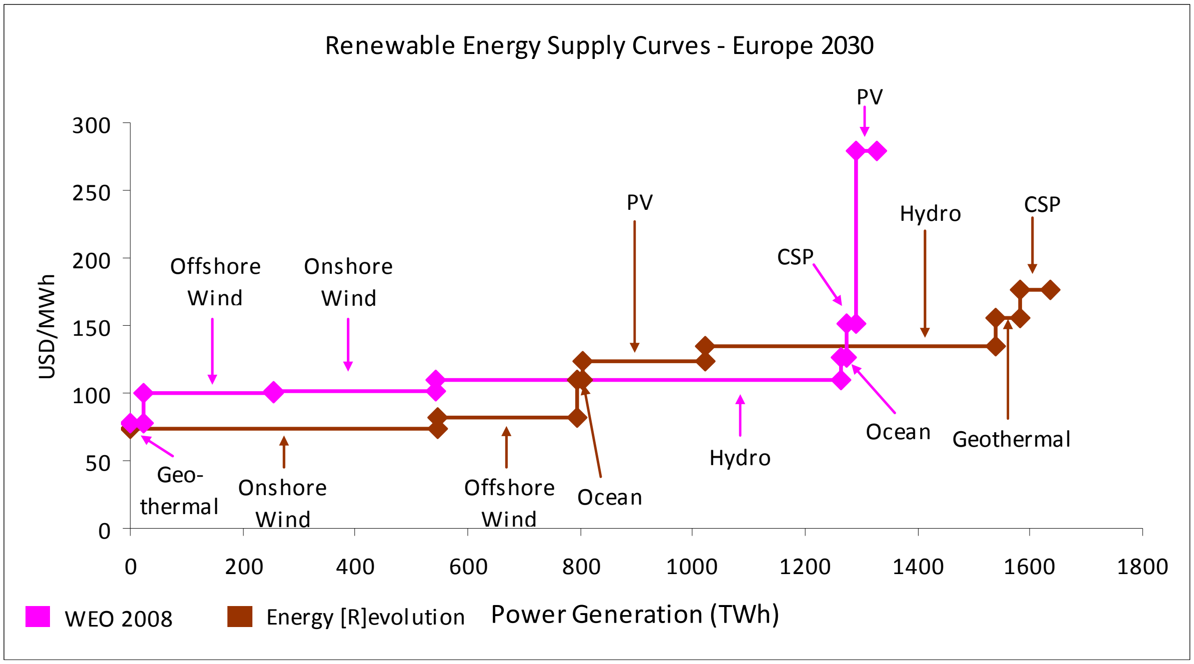

Figure 10.4.6: Renewable energy supply curves for Europe for the year 2030.

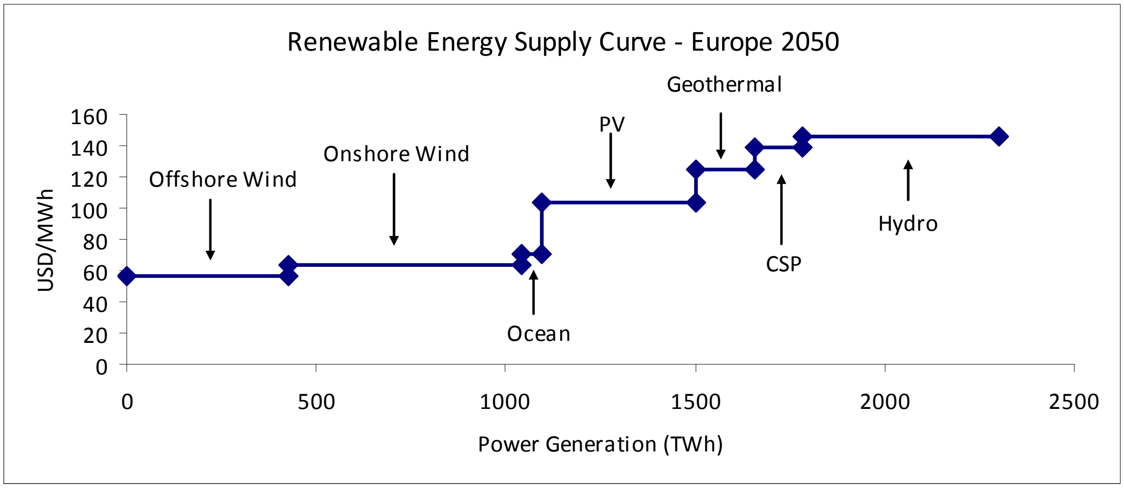

Figure 10.4.7: Renewable energy supply curve for Europe for the year 2050.

The cost level of hydropower is projected to rise also in Europe between 2030 and 2050, making it the option with the highest cost. All the other options will witness similar decreases in costs in this period along with higher power generation potentials.

10.4.4.4 India

Onshore wind is projected to be the most cost-effective option in both scenarios and India is one of the few regions where energy from offshore wind could also be an important energy source even already in 2030. In the WEO 2008 scenario, options are rather limited with only four renewable energy sources and hydro again dominating.

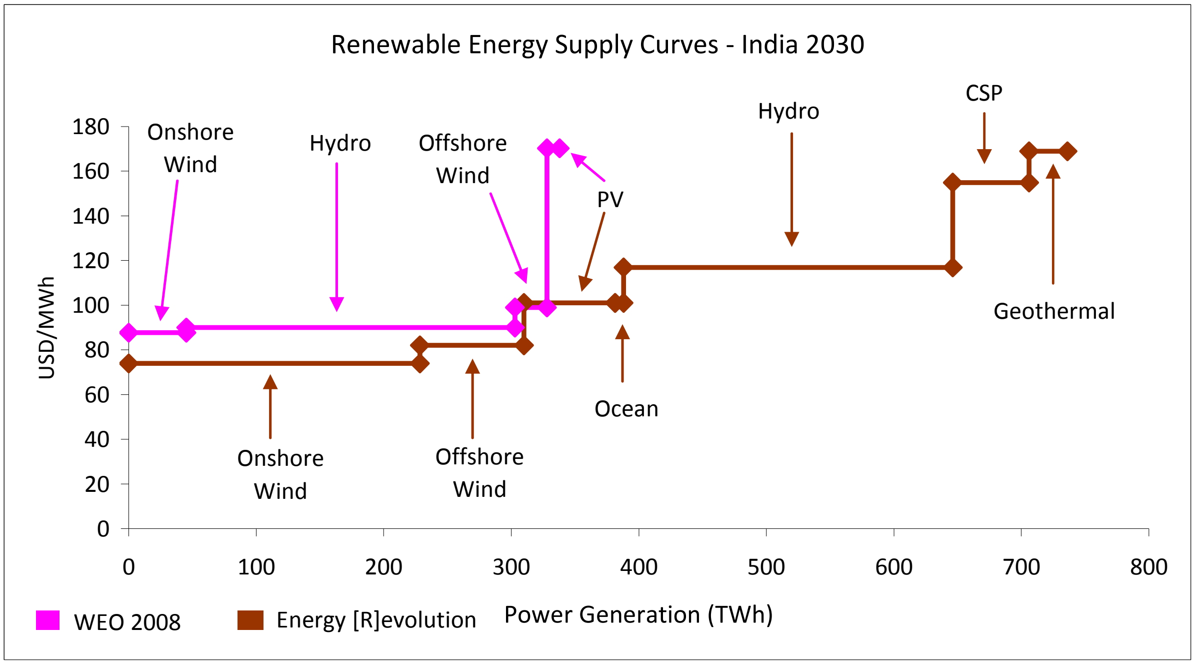

Figure 10.4.8: Renewable energy supply curves for India for the year 2030.

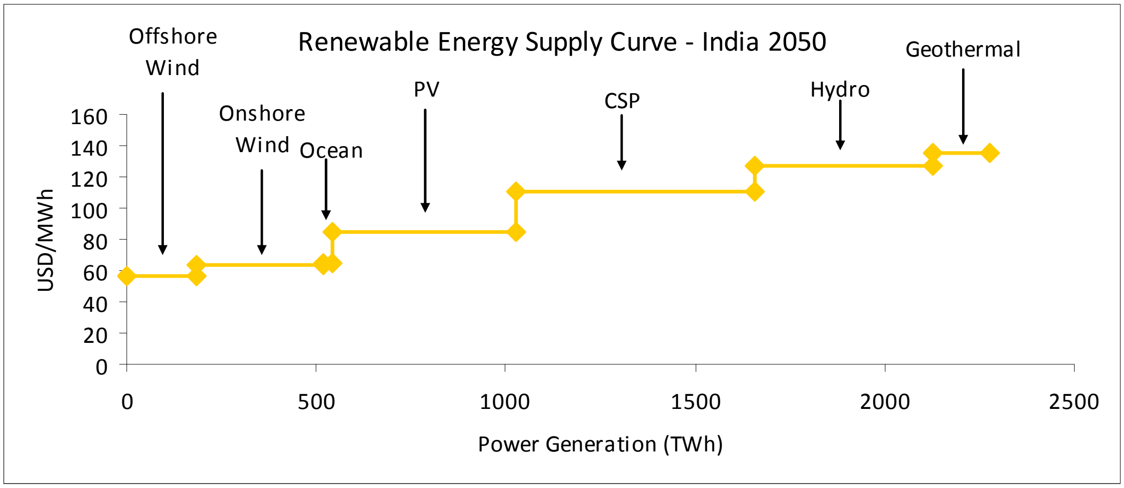

Figure 10.4.9: Renewable energy supply curve for India for the year 2050.

CSP and solar PV will see the highest increase in power generation potentials by 2050 in India and the trend of hydro losing share applies to this region as well. Offshore and onshore wind will still remain the two most cost-effective options, however there might be a different ranking between them.

10.4.4.5 Latin America

Latin America is the only region where the Energy [R]evolution scenario projects a similarly large share of hydro power than WEO 2008 showed for many other regions. The total projected power generation is comparable as well, just as the small contribution of other renewable sources except for onshore wind that is the most cost-effective option in the Energy [R]evolution scenario with a significant share.

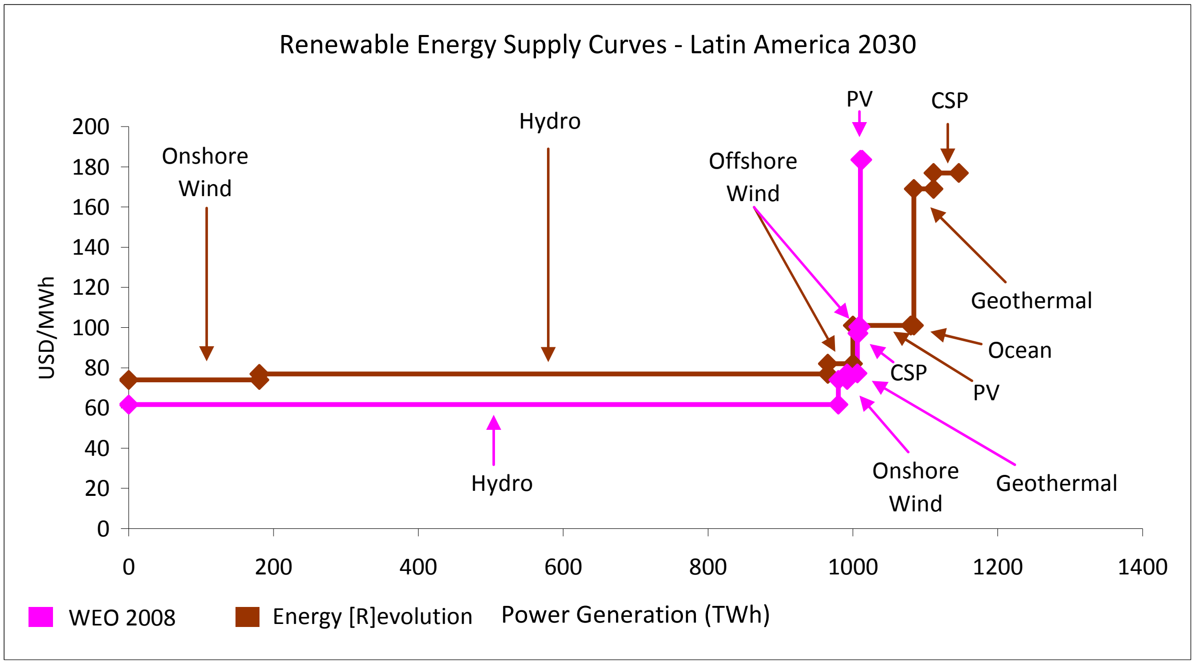

Figure 10.4.10: Renewable energy supply curves for Latin America for the year 2030.

In Latin America hydropower and onshore wind remain the two most important sources of renewable energy potentials in 2050, however all the other options will contribute at a higher level compared to 2030.

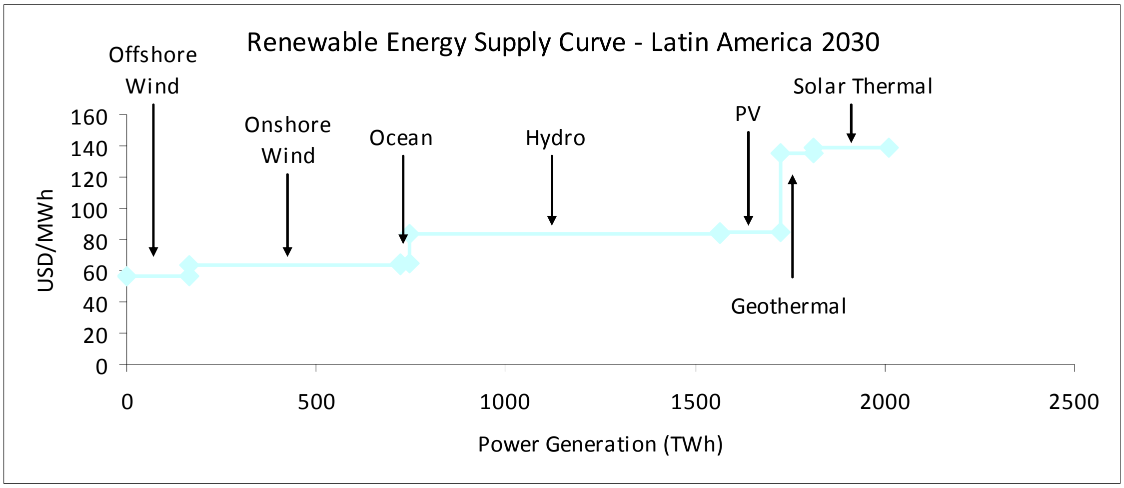

Figure 10.4.11: Renewable energy supply curve for Latin America for the year 2050.

10.4.4.6 Middle East

Whereas in other regions the role of concentrating solar power is usually marginal, it makes the largest contribution to the renewable energy mix in the Middle East according to the Energy [R]evolution scenario. Onshore wind and solar PV are also important contributors, while although offshore wind and ocean energy are in the 100 USD/MWh range as well, they will not yet be used widely in 2030 according to the forecasts. WEO 2008 projections for this region are extremely low.

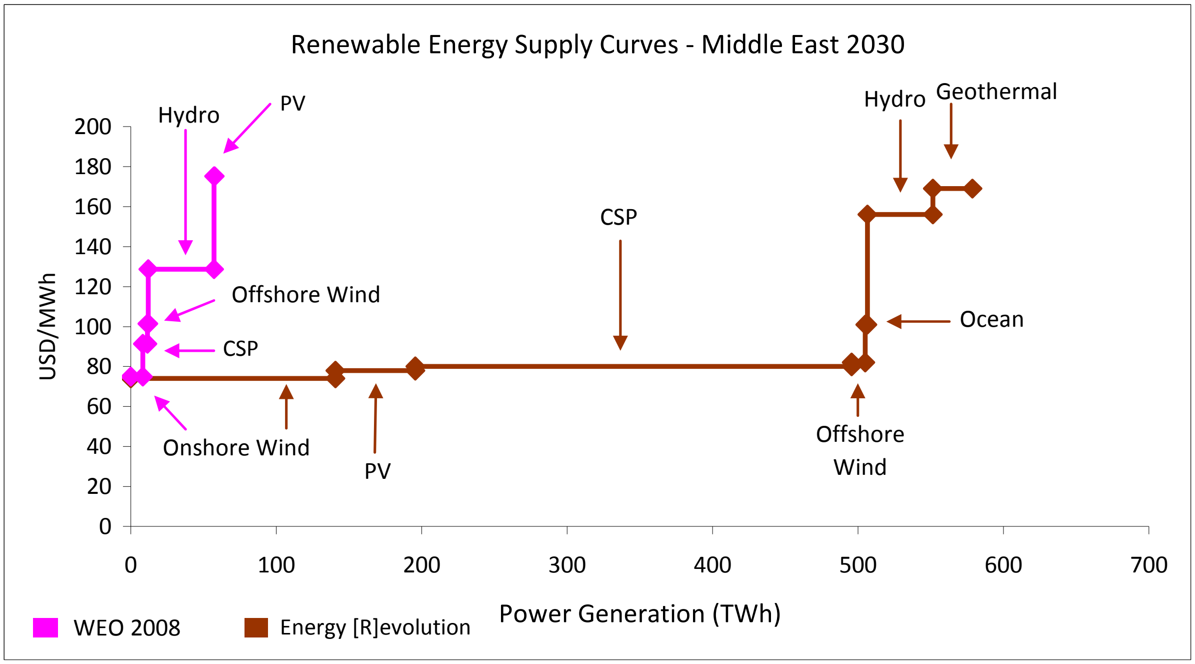

Figure 10.4.12: Renewable energy supply curves for the Middle East for the year 2030.

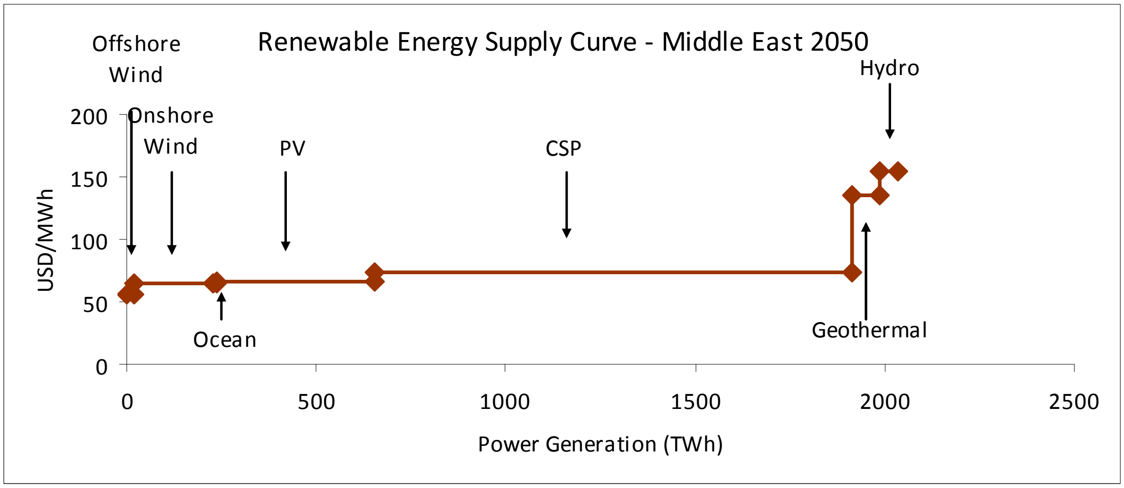

Figure 10.4.13: Renewable energy supply curve for the Middle East for the year 2050.

The graphs for 2030 and 2050 have a similar shape for the Middle East, although power generation from solar PV grows higher than from onshore wind. Hydro and geothermal stay the least attractive options, due to the geographical characteristics of the region.

10.4.4.7 North America

The difference between projected potentials by the two 2030 scenarios is almost threefold in the case of North America which is well demonstrated by the fact that according to the Energy [R]evolution scenario onshore wind alone would produce more energy than the complete renewable energy portfolio in WEO 2008. The cost of Solar PV is again well above 200 USD/MWh if using data from the World Energy Outlook, while it seems rather competitive in the Energy [R]evolution scenario.

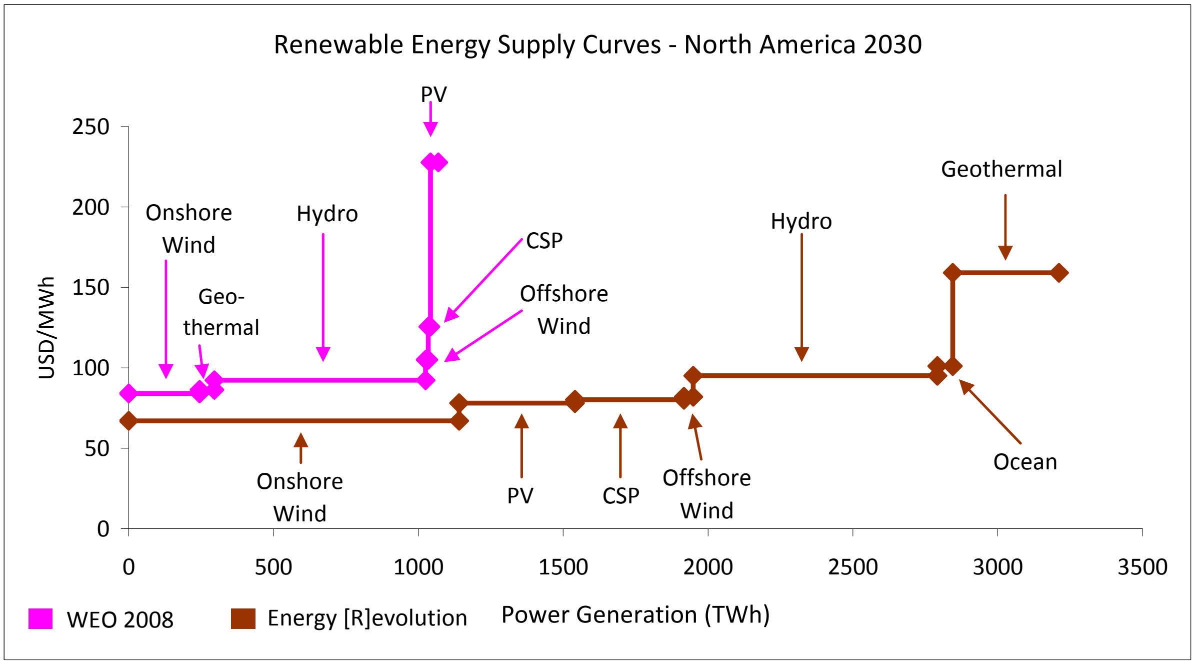

Figure 10.4.14: Renewable energy supply curves for North America for the year 2030.

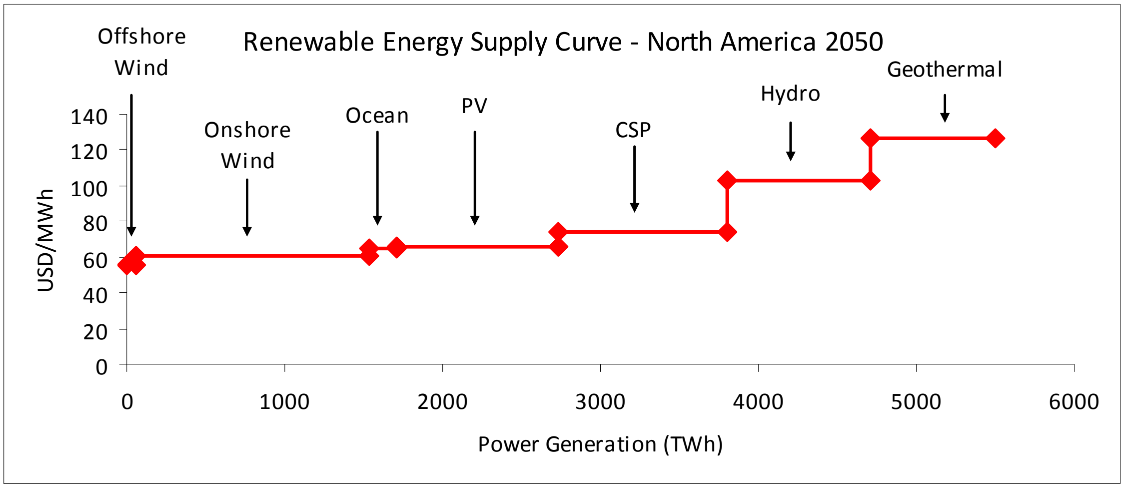

Figure 10.4.15: Renewable energy supply curve for North America for the year 2050.

Trends between 2030 and 2050 follow some of those introduced earlier for other regions: a significant increase in deployable potential but major trends remaining, with the share of hydropower decreasing and at the same time its cost going up by a little while the share of solar PV increasing.

10.4.4.8 OECD Pacific

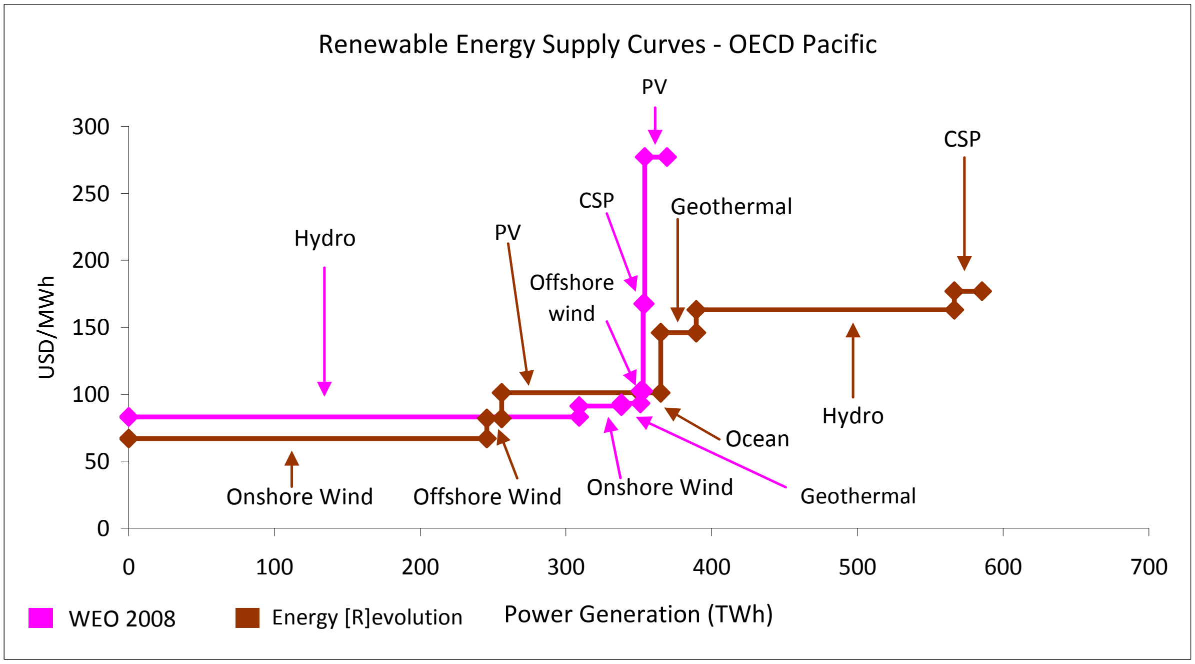

Figure 10.4.16: Renewable energy supply curves for OECD Pacific for the year 2030.

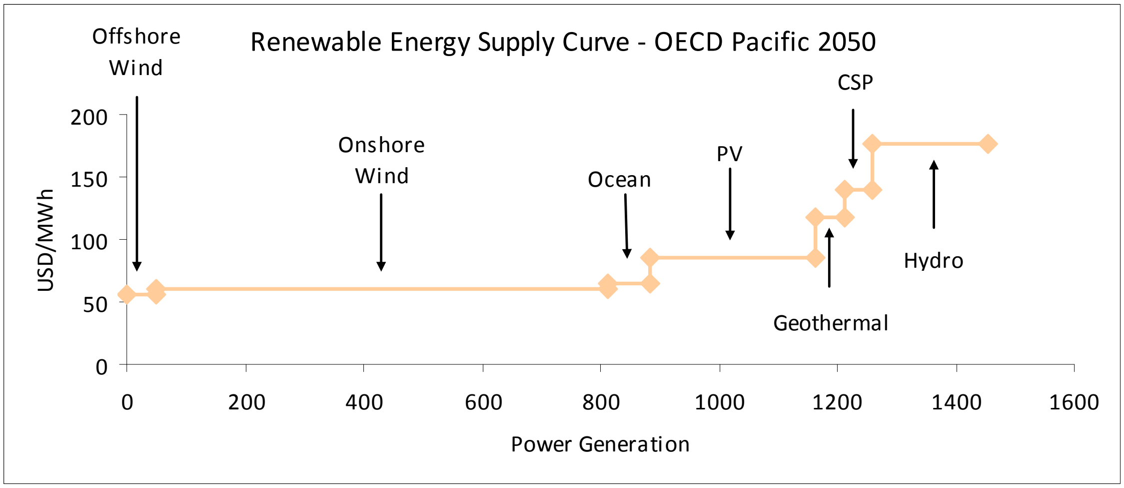

Figure 10.4.17: Renewable energy supply curve for OECD Pacific for the year 2050.

The projections indicate that onshore wind, solar PV and hydro will be the most important renewable energy sources in the OECD Pacific region in 2030. Similarly to the Middle East, offshore wind and ocean energy can be used at relatively low costs. Until 2050, the region follows similar trends as discussed above for North America. The power generation potential from renewable energy sources will more than double during these two decades.

10.4.4.9 Other Asia

The Other Asia region in the Energy [R]evolution scenario shows a well-balanced renewable energy mix with wind and hydro being the largest contributors. All options are under 177 USD/MWh.

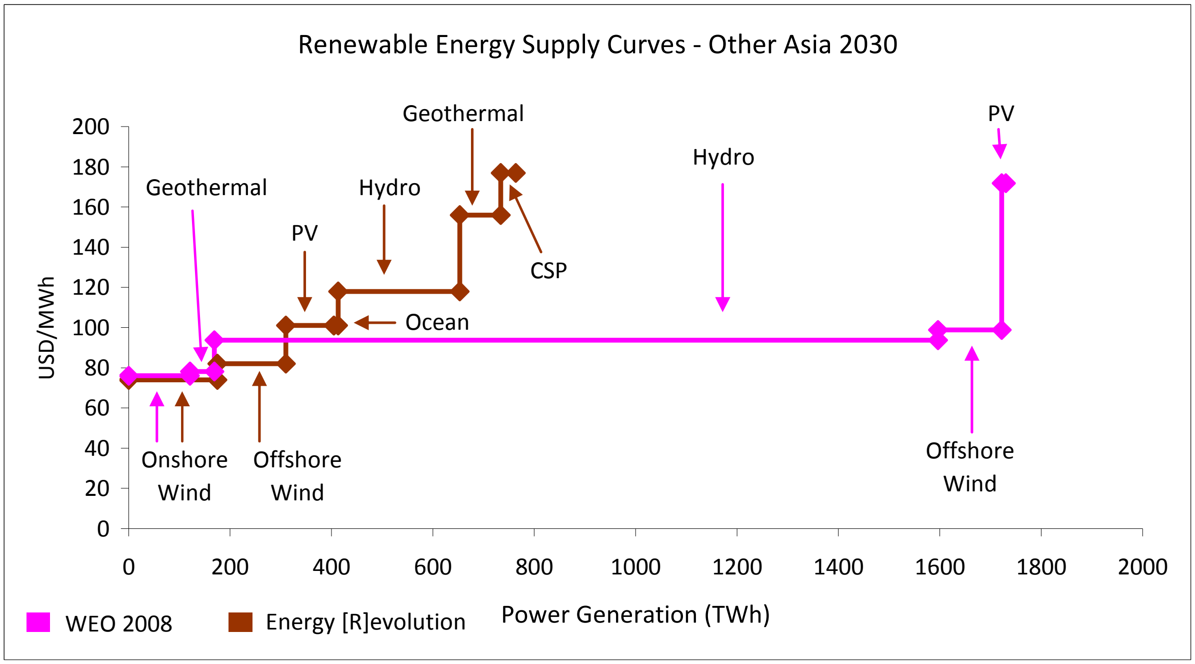

Figure 10.4.18: Renewable energy supply curves for Other Asia for the year 2030.

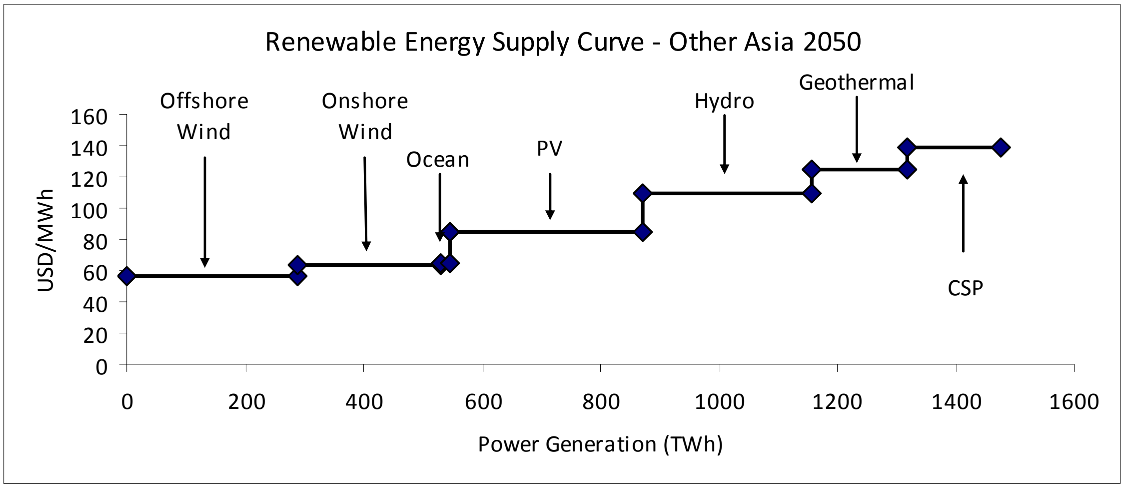

Figure 10.4.19: Renewable energy supply curve for Other Asia for the year 2050.

The Other Asia region will also follow general trends between 2030 and 2050. Offshore wind may become a more cost-effective option than onshore wind.

10.4.4.10 Other Transition Economies

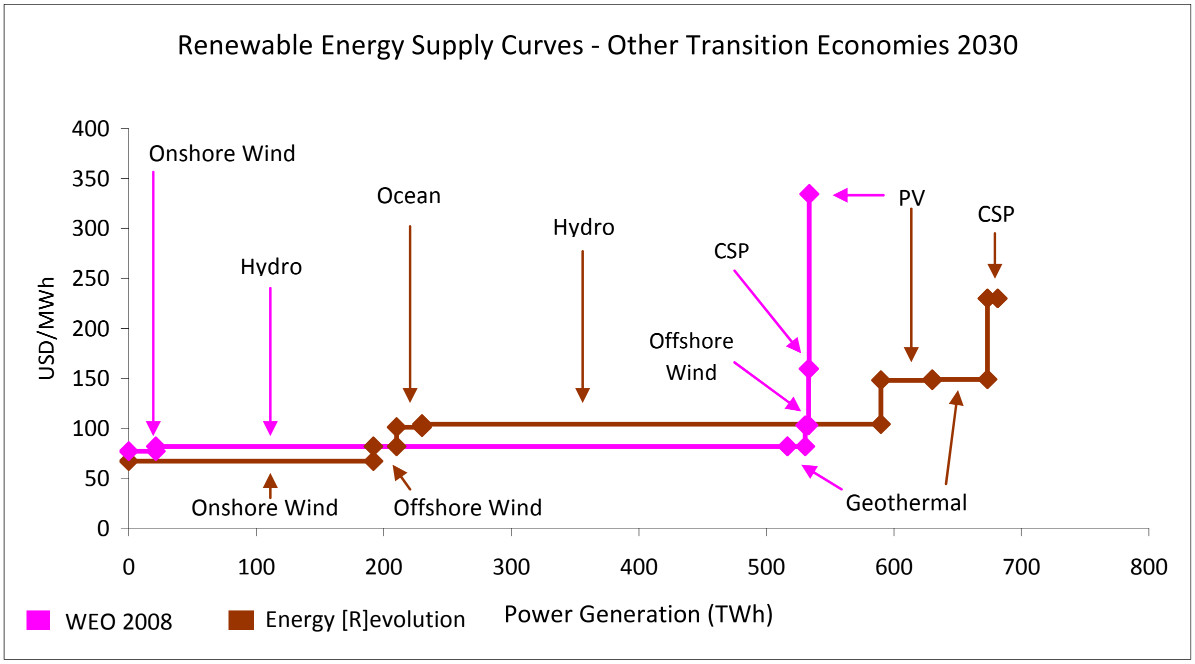

Figure 10.4.20: Renewable energy supply curves for Other Transition Economies for the year 2030.

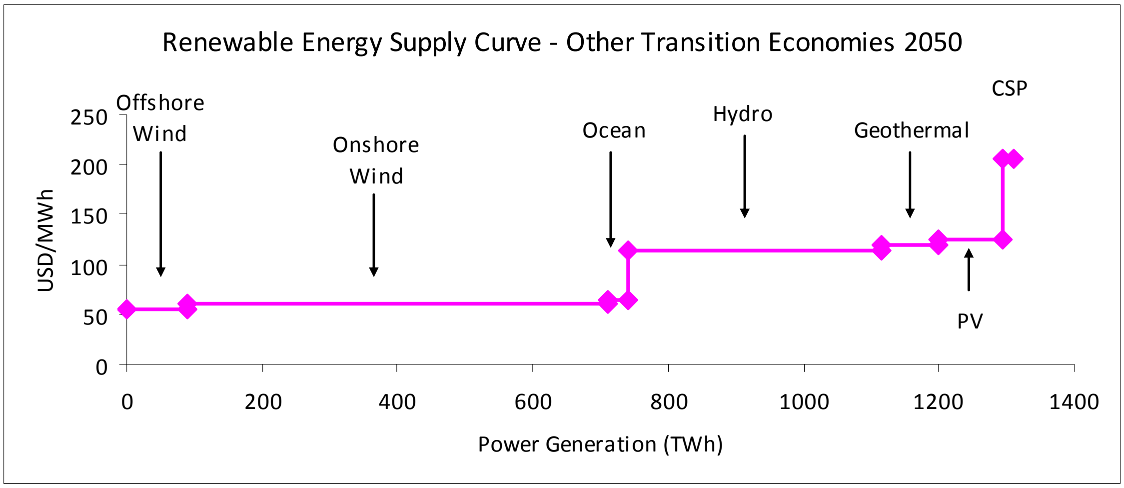

Figure 10.4.21: Renewable energy supply curve for Other Transition Economies for the year 2050.

Onshore wind and hydropower are the major contributors for 2030 in the region. By 2050, offshore wind gains in importance in the Other Transition Economies region as well, while the share of hydropower can decrease here, too.

10.4.4.11 Summary of regional and temporal renewable energy cost-curves

This section has presented the renewable energy supply curves for 10 world regions for 2030 and 2050. For 2030 the existing data are based on two different deployment paths very well documented in existing scenario analysis. The first chosen scenario (World Energy Outlook) makes more conservative cost and potential assumptions than the other (Energy [R]evolution), although in some cases the WEO curve does go below the Energy [R]evolution scenario curve for shorter sections, and even shows a significantly larger potential for Other Asia. Perhaps the largest difference between the two curves is in their projection of PV costs – over a factor of 2. While these curves have mostly regionally specific messages, a few general conclusions can be drawn.

Most typically in the presented cost curves on- and offshore wind power prove to be the most cost-effective option in many regions, both in the shorter and longer term, with the ranking of the two changing region by region. Hydropower is often close to wind in cost-effectiveness in 2030, especially in the WEO scenario, but it looses from its competitiveness by 2050 in many regions, either due to increasing specific costs, or just due to relative cost-effectiveness because the costs of other renewable energies decline. While these two technologies dominate many of the curves at reasonable costs (i.e. under USD 150/MWh) in 2030, by 2050 a more balanced portfolio of technologies appears in most regions, with many other technologies taking a large share of the available low-cost potential, including CSP, PV, and geothermal. Ocean energy is also projected to compete successfully with other technologies in regions with access to the seas, but its overall contribution to the potential remains limited everywhere. In 2050, geothermal, hydropower and CSP become the least attractive options from the perspective of costs in most regions, although CSP is projected to be among the most cost-competitive options and also supplying very large potentials in Africa and the Middle East in both the shorter and longer terms, and is very cost-competitive in North America over both periods.

With regard to temporal dynamics of potential size, the curves underline the importance of a long-term perspective and a consequent market introduction policy. Many regions see a several-fold increase in their low-cost renewable energy potential between 2030 and 2050, including an almost doubling in Latin-America, other Asia and other transition economies, over doubling in China and OECD Pacific, 2.5 time increase in Africa, over tripling in India and the Middle East.

10.4.5 Knowledge gaps

A major gap in knowledge is a consistent, dynamic dataset on renewable energy potentials by cost category and region, that breaks down renewable energy options into subtechnologies as well as preferably sites by different cost-effectiveness levels, ideally also as a function of different deployment scenarios. There is very little understanding of what renewable energy potentials are available at different cost levels in the different geographic regions, especially in non-OECD countries. Breaking the potentials down only by major renewable energy technology as is presently depicted in the cost-curves constructed from available datasets provides a misleading picture: such an approach hides much of the most attractive potentials – potentials available in good sites or attractive sub-technologies, and misleadingly may imply condemning conclusions on entire technologies when they maybe very cost-effective in certain sites or sub-technologies.

In general, a major problem is also the availability of information for non-electric renewable potentials and costs. The chapter could not construct cost-curves on thermal or fuel applications of renewable energy due to the lack of sufficient data. In general, there is often a bias in the availability of literature and data towards power applications of renewable energy technologies whereas heat and mobility applications could be equally important. Approximately 40 - 50% of global final energy demand is for cooling and heating (IEA 2007), and several forms of renewable energy can be more efficiently converted to heat or fuels than to electricity. Therefore, a better integration of thermal and fuel applications into mitigation option appraisal, including supply curves, would be important.

Another gap in the literature is the thorough, consistent documentation of the strengths and limitations of energy and abatement supply curves (esp. the latter) for climate change mitigation strategy-setting. These tools have become very popular with the increasing importance of climate targets and for the determination of target-setting and burden-sharing. However, their applicability and limitations for such purposes, as well as guidelines for robust cost-curve methodology frameworks for abatement option prioritization have not been sufficiently elaborated and documented in the scientific literature (as of Fall 2009). In particular, if it comes to GHG mitigation cost curves the missing system perspective necessary to consider the relevant interactions with the overall system behaviour in a proper way is problematic. Besides other aspects that was a reason to focus only on energy supply cost curves in this section.

10.5 Costs of commercialization and deployment

Renewable energies are expected to play an important role in achieving ambitious climate protection goals, e.g., those consistent with a 2°C limit on global mean temperature change compared to preindustrial times. Although some technologies are already competitive (e.g., large hydropower, combustible biomass (under favorable conditions) and larger geothermal projects (>30 MWe), IEA, 2007a, page 6), many innovative technologies in this field are still on the way to becoming mature alternatives to fossil fuel technologies (IEA, 2008a). Currently and in the mid-term, the application of these technologies therefore will result in additional (private) costs[17] compared to energy supply from conventional sources. Starting with a review of present technology costs, the remainder of this subchapter will focus on expectations on how these costs might decline in the future, for instance, due to extended R&D efforts or due to technological learning associated with increased deployment. In addition, investment needs and the associated additional cost of various strategies to increase the share of renewable energies will be discussed.

10.5.1 Introduction: review of present technology costs

In the field of renewable energy usage, the energy production costs are mainly determined by investment costs. Nevertheless, operation & maintenance costs (OMC), and – if applicable – fuel costs (in the case of biomass) might play an important role as well. The respective cost components were discussed in detail in Chapters 2 to 7. The current section intends to provide a summary of technology costs in terms of specific investment costs [expressed in $/kW installed capacity] and levelized costs [expressed in terms of $/MWh] for the generation of electricity, heat and transport fuel (see Table 1) [TSU: Table 10.5.1].

On a global scale, the values of both cost terms are highly uncertain for the various renewable energy technologies. As recent years have shown, the investment costs might be considerably influenced by changes in material (e.g., steel) and engineering costs as well as by technological learning and mass market effects. Levelized unit costs (also called levelized generation costs) are defined as ‘the ratio of total lifetime expenses versus total expected outputs, expressed in terms of the present value equivalent’ (IEA, 2005). Levelized generation costs therefore capture the full costs (i.e., investment costs, operation and maintenance costs, fuel costs and decommissioning costs) of an energy conversion installation and allocate these costs over the energy output during its lifetime. As a result, levelized costs heavily depend on renewable energy resource availability (e.g., due to different full load hours) and, as a consequence, are different at different locations (Heptonstall, 2007). Optimal conditions can yield lower costs, and less favourable conditions can yield substantially higher costs compared to those shown in Table 1. The costs given there are exclusive of subsidies or policy incentives. Concerning levelized costs, the actual global range might be wider than the range given in Table 1, as discount rates, investment cost, operation and maintenance costs, capacity factors and fuel prices vary. Resulting costs depend on the conventional

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[17] Within this subchapter, the external costs of conventional technologies are not considered. Although the term “private” will be omitted in the remainder of this subchapter, the reader should be aware that all costs discussed here are *private* costs in the sense of subchapter 10.6. Externalities therefore are not taken into account.

system (see chapter 8 as well), which can limit, for instance, the feed-in capacity due to grid restrictions or a power plant with insufficient dynamic flexibility.

Table 10.5.1: Current specific investment and secondary energy generation costs. The table is based on IEA, 2008b (Table 5, p. 80 – 83).

Technology	Typical characteristics	Typical current investment costs (USD/kW)	Typical current energy production costs[1] (USD/MWh)	References
POWER GENERATION				
Hydro				
Large hydro	Plant size: 10–18 000 MW	1 000–5 500	30–120	IEA, 2008a
Small hydro	Plant size: 1–10 MW	2 500–7 000	60–140	IEA, 2008a
Wind				
Onshore wind	Turbine size: 1–3 MW Blade diameter: 60–100 meters	1 200–1 700	70–140	IEA, 2008a
Offshore wind	Turbine size: 1.5–5 MW Blade diameter: 70–125 meters	2 200–3 000	80–120	IEA, 2008a
Bioenergy[2]				
Biomass combustion for power (solid fuels)	Plant size: 10–100 MW	2 000–3 000	60–190	IEA, 2008a
Municipal solid waste (MSW) incineration	Plant size: 10–100 MW	6 500–8 500	n/a	IEA, 2007b
Biomass CHP	Plant size: 0.1–1 MW (on–site), 1–50MW (district)	3 300–4 300 (on–site), 3 100–3 700 (district)	n/a	IEA, 2008a
Biogas (including landfill gas) digestion	Plant size: <200 kW–10MW	2 300–3 900	n/a	IEA, 2008a IEA, 2007b
Biomass co–firing	Plant size: 5–100 MW (existing), > 100 MW (new plant)	120–1 200 + power station costs	20–50	IEA, 2008a
Biomass integrated gasifier combined cycle (BIGCC)	Plant size: 5–10 MW (demonstration), 30–200 MW (future)	4 300–6 200 (demonstration), 1 200–2 500 (future)	n/a	IEA, 2008a
Geothermal power				
Hydrothermal	Plant size: 1–100 MW; Types: binary, single– and double–flash, natural steam	1 700–5 700	30–100	IEA, 2008a
Enhanced geothermal system (EGS)	Plant size: 5–50 MW	5 000–15 000	150–300 (projected)	IEA, 2008a
Solar energy				
Solar PV	Power plants: 1–10 MW; Rooftop systems: 1–5 kWp	5 000–6 500	200–800[3]	IEA, 2008a; REN21, 2008
Concentrating solar power (CSP)	Plant size: 50–500 MW (trough), 10–20 MW (tower); 0.01–300 MW (future) (dish)	4 000–9 000 (trough)	130–230 (trough)[4]	IEA, 2008a
Ocean energy				
Tidal and marine currents	Plant size: Several demonstration projects up to 300 kW capacity; some large–scale projects under development	7 000–10 000	150–200	IEA, 2008a

Technology	Typical characteristics	Typical current investment costs	Typical current energy production costs[2]	References
HEATING/COOLING				
Biomass heat (excluding CHP)	Size: 5–50 kWth (residential)/ 1–5 MWth (industrial)	120/ kWth (stoves); 380–1 000/kWth (furnaces)	10–60 MWh	IEA, 2008a; REN21, 2008
Biomass heat from CHP	Plant size: 0.1–50 MW	1 500–2 000/ kWth	n/a	IEA, 2008a; IEA & RETD, 2007
Solar hot water/ heating	Size: 2–5 m^2 (household); 20–200 m^2 (medium/ multi–family); 0.5–2 MWth (large/ district heating); Types: evacuated tube, flat–plate	400–1 250/ m^2	20–200 MWh (household); 10–150 MWh (medium); 10–80 MWh (large)	IEA & RETD 2007, REN21, 2008
Geothermal heating/cooling	Plant capacity: 1–10 MW; Types: ground–source heat pumps, direct use, chillers	250–2 450/ kWth	5–20 MWh	IEA & RETD 2007, REN21, 2008
BIOFUELS (1ST GENERATION)				
Ethanol	Feedstocks: sugar cane, sugar beets, corn, cassava, sorghum, wheat (and cellulose in the future)	0.3–0.6 billion per billion litres/ year of production capacity for ethanol	0.25–0.3/ litre gasoline equivalent (sugar); 0.4–0.5/ litre gasoline equivalent (corn)	REN21, 2008
Biodiesel	Feedstocks: soy, oilseed rape, mustard seed, palm, jatropha, tallow or waste vegetable oils	0.6–0.8 billion per billion litres/ year of production capacity	0.4–0.8/ litre diesel equivalent	REN21, 2008
RURAL (OFF-GRID) ENERGY				
Mini-hydro	Plant capacity: 100–1 000 kW	500–1 200 kW	50–100 MWh	REN21, 2008
Micro-hydro	Plant capacity: 1–100 kW	1 000–2 000 kW	70–200 MWh	REN21, 2008
Pico-hydro	Plant capacity: 0.1–1 kW	n/a	200–400 MWh	REN21, 2008
Biomass gasifier	Size: 20–5 000 kW	n/a	80–120 MWh	REN21, 2008
Small wind turbine	Turbine size: 3–100 kW	3 000–5 000 kW	150–250 MWh	REN21, 2008
Household wind turbine	Turbine size: 0.1–3 kW	2 000–3 500 kW	150–350 MWh	REN21, 2008
Village-scale mini-grid	System size: 10–1 000 kW	n/a	250–1000 MWh	REN21, 2008
Solar home system	System size: 20–100 W	n/a	400–600 MWh	REN21, 2008

Notes:

1. Using a 10% discount rate. Current costs relate to costs either in 2005 or 2006. Costs of off-grid hybrid power systems employing renewables depend strongly on system size, location, and associated items like diesel backup and battery storage.

2. Wide ranges due to plant scale, maturity of technology, detailed design variables, type and quality of biomass feedstocks, feedstock availability, regional variations, etc. Costs of delivered biomass feedstock vary b country and region due to factors such as variations in terrain, labour costs and crop yields.

3. Typical costs of 20–40 UScents/kWh for low latitudes with solar insolation of 2,500 kWh/m2/year, 30–50 UScents/kWh for 1,500 kWh/m2/year (typical of Southern Europe), and 50–80 UScents for 1,000 kWh/m2/year (higher latitudes).

4. Costs for (parabolic) trough plants. Costs decrease as plant size increases. Plants with integrated energy storage have higher investment costs but also enjoy higher capacity factors. These factors balance each other out, leading to comparable generation cost ranges for plants with and without energy storage.

A comparison of levelized generation costs of renewable energy technologies with current wholesale power prices shows that, with few exceptions, renewable energies are not yet competitive with conventional sources if they both feed into the electricity grid (see Figure 1)

[TSU: Figure 10.5.1]. If the respective technologies are used in a decentral mode, their production cost must be compared with the retail consumer power price (grid parity). In this case, important niche markets exist that facilitate the market introduction of new technologies. The same holds true for applications in remote areas where often no grid based electricity is available.

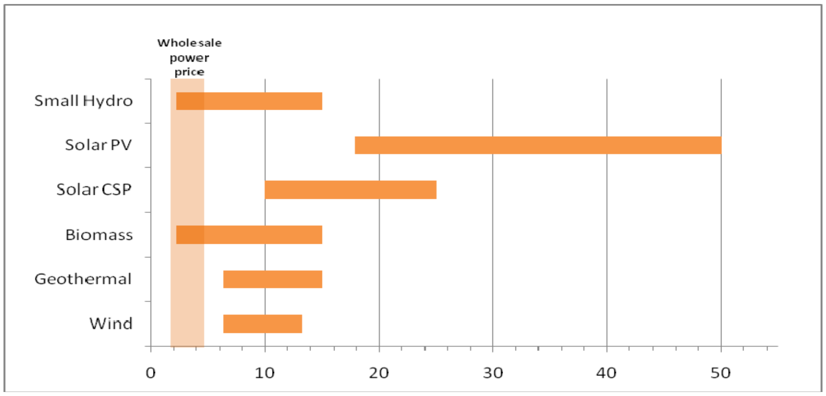


Figure 10.5.1: Cost-competitiveness of selected renewable power technologies. The figure is based on (IEA, 2007a, p. 22).

10.5.2 Prospects for cost decrease

Most technologies applied in the field of renewable energy usage are innovative technologies. Numerous technologies populate different stages of the innovation process (see Figure 2) [TSU: Figure 10.5.2]: Some technologies are still in the research and development stage, the applicability of others is investigated by demonstrations projects, and others have reached the deployment and commercialization phase (see Figure 3) [TSU: Figure 10.5.3]. As a consequence, huge opportunities exist to improve the energetic efficiency of the technologies, and/or to decrease their production costs. Together with mass market effects, these two effects are expected to decrease the levelized energy generation cost of many renewable energy sourcing technologies substantially in the future.

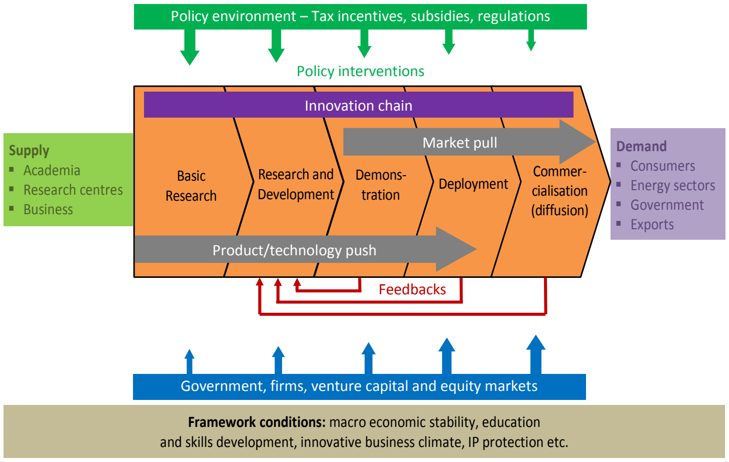


Figure 10.5.2: Schematic description of the innovation process (Source: IEA, 2008a, p. 170).

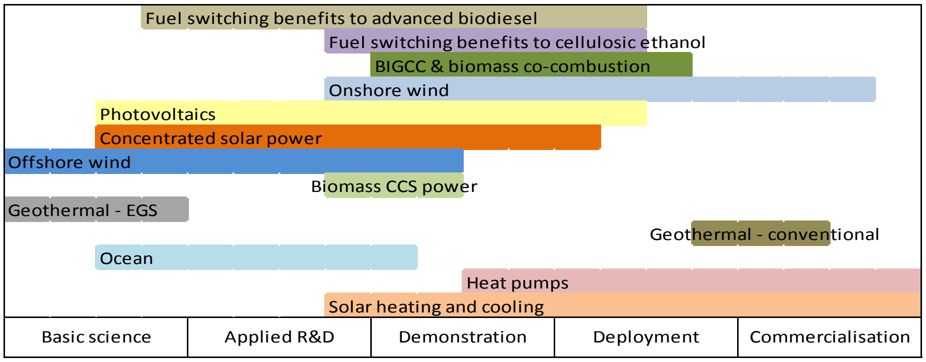


Figure 10.5.3: Relative position of various renewable energy technologies within the innovation chain. (Source: IEA, 2008a, p. 181).

According to Junginger et al. (2006, p. 4026), the list of the most important mechanisms causing cost reductions comprises:

- *Learning by searching*, i.e. improvements due to Research, Development and Demonstration (RD&D) – especially, but not exclusively in the stage of invention,
- *Learning by doing* (in the strict sense), i.e. improvements of the production process (e.g., increased labour efficiency, work specialization),
- *Learning by using*, i.e. improvements triggered by user experience feedbacks occur once the technology enters (niche) markets
- *Learning by interacting*, i.e. the reinforcement of the above mentioned mechanism due to an increased interaction of various actors in the diffusion phase.
- *Upsizing of technologies* (e.g. upscaling of wind turbines)
- *Economies of scale* (i.e., mass production) once the stage of large-scale production is reached.

The various mechanisms may occur simultaneously at various stages of the innovation chain. In addition, they may reinforce each other.

Whereas the above list summarizes different *causes* for technological progress and associated cost reductions, an alternative nomenclature focuses on how these effects can be triggered. Following this kind of reasoning, Jamasb (2007) distinguishes:

- *Learning by research* triggered by research and development (R&D) expenditures which intend to achieve a *technology push* and
- *Learning by doing* (in the broader sense) resulting from capacity expansion promotion programmes that intend to establish a *market (or demand) pull.*

The prospective decrease of levelized costs, however, will not take place autonomously. It is not "manna from heaven". Depending on the respective position in the innovation chain, some technologies will require for instance substantial efforts for RD&D projects funding. This is not a characteristic of renewable energies alone, but holds true for nearly every innovative energy technology. This fact is highlighted by Figures 4a and 4b [TSU: Figures 10.5.4 a) and 10.5.4 b)], which depict the historic support for renewable energy research in relation to other technologies. Note that for fossil and nuclear technologies, the large-scale government support in the early stages of their respective innovation chain (i.e., well before the 1970s) is not shown.

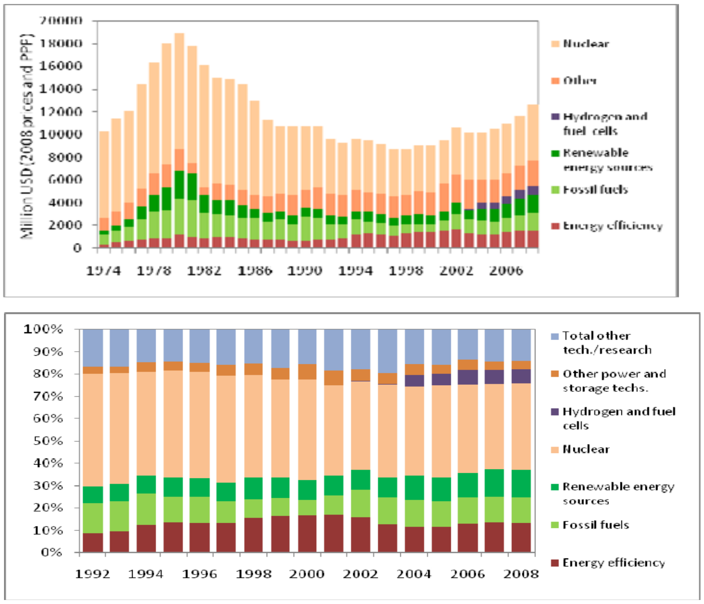


Figure 10.5.4: a) Government budgets on energy RD&D of IEA countries and b) technology shares of government energy RD&D expenditures in IEA countries (cf. IEA, 2008a, p. 172-173, updated with data from http://wds.iea.org/WDS/ReportFolders/ReportFolders.aspx, accessed 29/09/2009). [TSU: b)?]

Whereas RD&D funding is appropriate for infant technologies, market entry support and market push programmes (e.g., via feed-in tariff schemes) are the appropriate tools in the deployment and commercialization phase (Foxon et al., 2005; González, 2008). As a consequence of government aid and private industries expenditures in research and development as well as in improved production technologies and due to the growing demand on the market, many technologies applied in the field of renewable energies showed a significant cost decrease in the past (see Figure 5). This effect is called technological learning. The empirical curves describe the respective relationship of a technology's costs and experience gained expressed as cumulative capacity ever installed. They are therefore called experience (or "learning") curves (see Figure 5) [TSU: Figure 10.5.5]. For a doubling of their cumulative installed capacity, many technologies showed a more or less constant percentage decrease of the specific investment costs (or of the levelized costs or unit price, depending on the selected cost indicator). The numerical value describing this improvement is called the *learning rate (LR).* It is defined as the percentage cost reduction for each doubling of the cumulative capacity. A summary of observed learning rates is provided in Table 2. Frequently, the *progress ratio (PR)* is used as a substitute for the learning rate. It is defined as PR = 1- LR (e.g., a learning rate of 20% would imply a progress ration of 80%). Sometimes, energy supply costs (e.g. electricity generation costs) and the cumulative energy supplied by the respective technology (e.g., the cumulative electricity production) are used as substitutes for capital costs and the cumulative installed capacity, respectively (cf. Figure 5c) [TSU: Figure 10.5.5 c)]. If the learning rate is time-independent, the empirical experience curve can be fitted by a power law. Plotting costs versus cumulative installed capacity in a figure with double logarithmic scales shows the experience curve as a straight line (see Figure 5) [TSU: Figure 10.5.5] in this case. As there is no natural law that costs *have* to follow a power law (Junginger et al. 2006), care must be taken if historic experience curves are extrapolated in order to predict future costs. Obviously, the cost reduction cannot go ad infinitum and there might be some unexpected steps in the curve in practice (e.g. caused by technology breakthroughs). In order to avoid implausible results, integrated assessment models that extrapolate experience cost curves in order to assess future costs therefore should constrain the cost reduction by appropriate *floor costs* (cf. Edenhofer et al., 2006).

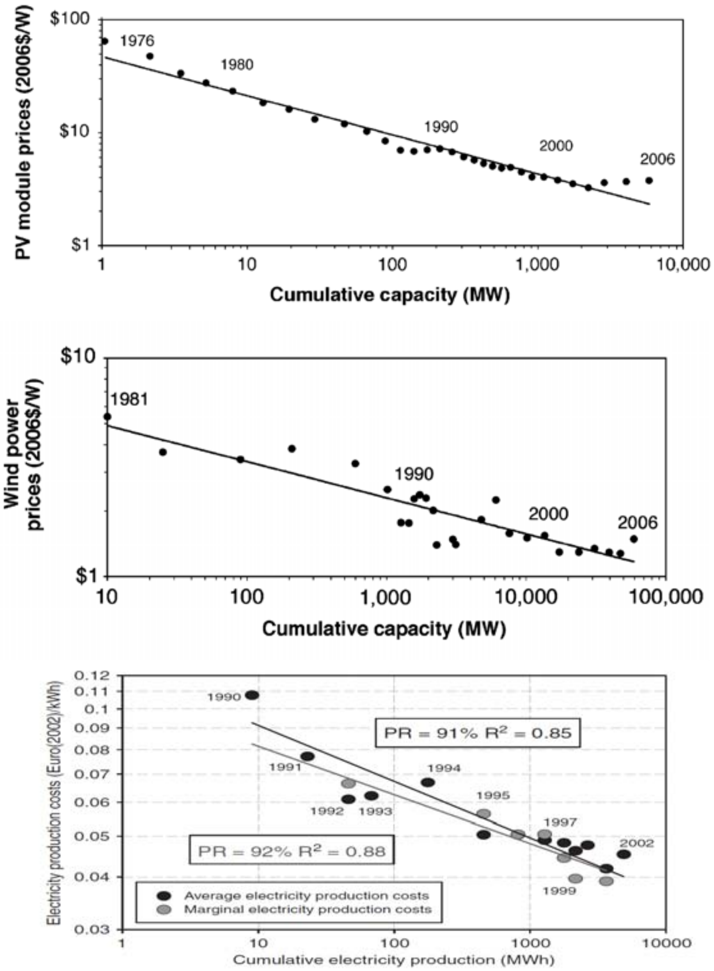
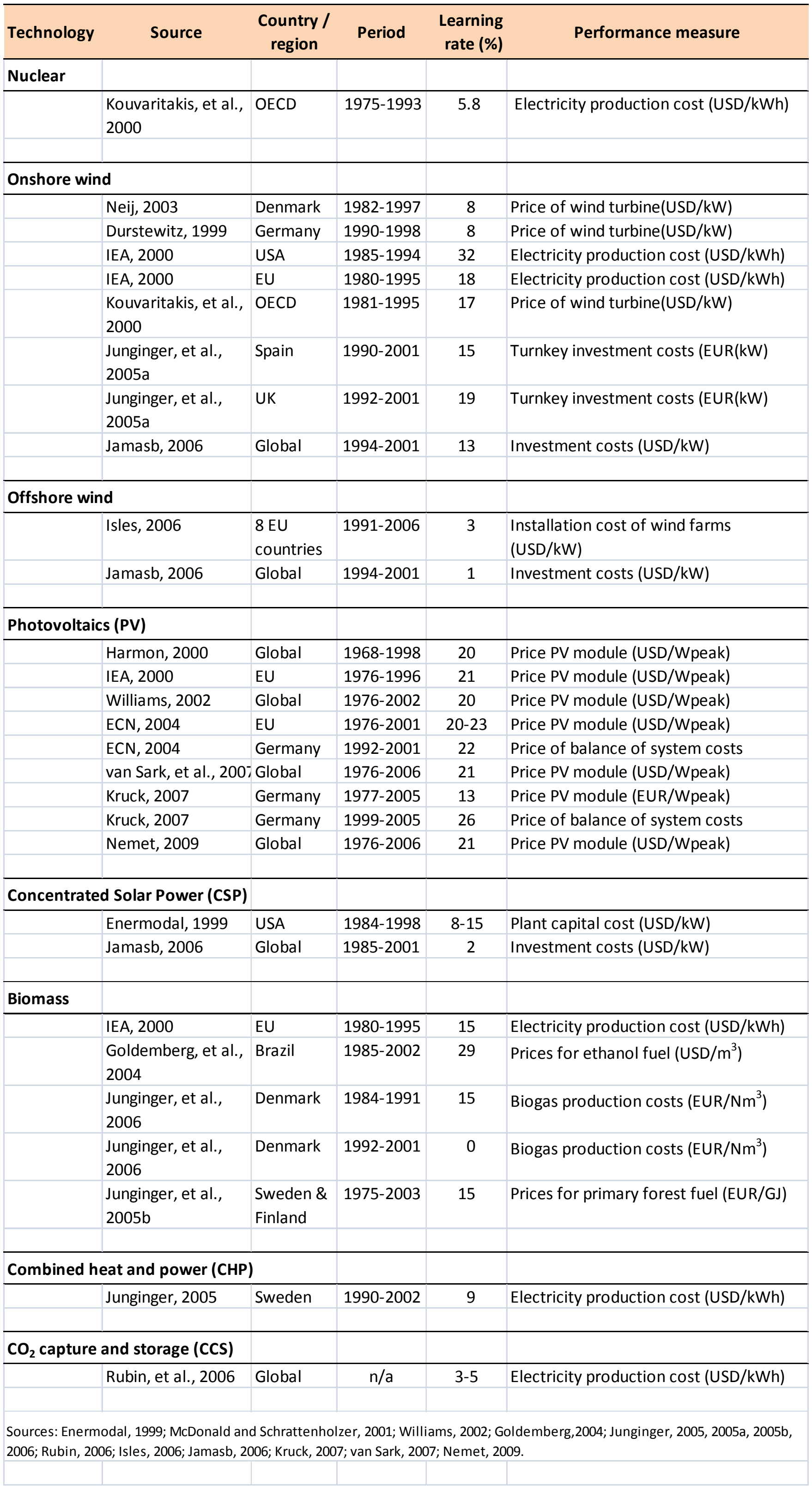


Figure 10.5.5: Illustrative learning curves for a) photovoltaic modules, b) wind turbines and c) Swedish bio-fuelled combined-heat and power plants. Source: Nemet, 2009, Junginger et al. 2006.

Unfortunately, cost data are not easily obtained in a competitive market environment. Indicators that are intended to serve as a substitute, e.g., product prices do not necessarily reveal the actual improvement achieved. Instead, they might be heavily influenced by an imbalance of supply and demand. This refers to both the final product itself (e.g., if financial support stipulates a high demand) and the cost of product factors, which might be temporarily scarce (e.g., steel prices due to supply bottlenecks). A deviation from price-based experience curves as recently observed for photovoltaic modules and wind energy converters (see Figure 5.a and 5.b) [TSU: Figure 10.5.5 a) and 10.5.5 b)], therefore does not imply that a fundamental cost limit has been reached. Instead, it might simply indicate that producers were able to make extra profits in a situation where, for instance, feed-in tariff systems led to a demand that transgressed the production capabilities of the respective manufacturers. As these extra profits can be maximized by further cost reduction efforts, the incentive to achieve actual reductions is not diminished even in the high price phases recently observed. According to some researchers (Junginger et al., 2005, referring to the Boston Consulting Group), the cost reduction achieved in the background might reveal itself after the supply and production bottlenecks are removed or the market power of the prime producer was destroyed in the so-called “shakeout” phase. In this case, the deviation from the long-term experience curve might be largely or completely removed. Short term deviations that can be explained by supply bottlenecks and/or high demand therefore should not immediately lead to a corresponding decrease of the learning rates used by energy models, integrated assessment models or macro-economic models.

Table 10.5.2: Observed learning rates for various electricity supply technologies (extended and updated version of the table given in IEA, 2008a, p. 205).



Technology	Source	Country / region	Period	Learning rate (%)	Performance measure
Nuclear					
	Kouvaritakis, et al., 2000	OECD	1975-1993	5.8	Electricity production cost (USD/kWh)
Onshore wind					
	Neij, 2003	Denmark	1982-1997	8	Price of wind turbine(USD/kW)
	Durstewitz, 1999	Germany	1990-1998	8	Price of wind turbine(USD/kW)
	IEA, 2000	USA	1985-1994	32	Electricity production cost (USD/kWh)
	IEA, 2000	EU	1980-1995	18	Electricity production cost (USD/kWh)
	Kouvaritakis, et al., 2000	OECD	1981-1995	17	Price of wind turbine(USD/kW)
	Junginger, et al., 2005a	Spain	1990-2001	15	Turnkey investment costs (EUR(kW)
	Junginger, et al., 2005a	UK	1992-2001	19	Turnkey investment costs (EUR(kW)
	Jamasb, 2006	Global	1994-2001	13	Investment costs (USD/kW)
Offshore wind					
	Isles, 2006	8 EU countries	1991-2006	3	Installation cost of wind farms (USD/kW)
	Jamasb, 2006	Global	1994-2001	1	Investment costs (USD/kW)
Photovoltaics (PV)					
	Harmon, 2000	Global	1968-1998	20	Price PV module (USD/Wpeak)
	IEA, 2000	EU	1976-1996	21	Price PV module (USD/Wpeak)
	Williams, 2002	Global	1976-2002	20	Price PV module (USD/Wpeak)
	ECN, 2004	EU	1976-2001	20-23	Price PV module (USD/Wpeak)
	ECN, 2004	Germany	1992-2001	22	Price of balance of system costs
	van Sark, et al., 2007	Global	1976-2006	21	Price PV module (USD/Wpeak)
	Kruck, 2007	Germany	1977-2005	13	Price PV module (EUR/Wpeak)
	Kruck, 2007	Germany	1999-2005	26	Price of balance of system costs
	Nemet, 2009	Global	1976-2006	21	Price PV module (USD/Wpeak)
Concentrated Solar Power (CSP)					
	Enermodal, 1999	USA	1984-1998	8-15	Plant capital cost (USD/kW)
	Jamasb, 2006	Global	1985-2001	2	Investment costs (USD/kW)
Biomass					
	IEA, 2000	EU	1980-1995	15	Electricity production cost (USD/kWh)
	Goldemberg, et al., 2004	Brazil	1985-2002	29	Prices for ethanol fuel (USD/m^3)
	Junginger, et al., 2006	Denmark	1984-1991	15	Biogas production costs (EUR/Nm^3)
	Junginger, et al., 2006	Denmark	1992-2001	0	Biogas production costs (EUR/Nm^3)
	Junginger, et al., 2005b	Sweden & Finland	1975-2003	15	Prices for primary forest fuel (EUR/GJ)
Combined heat and power (CHP)					
	Junginger, 2005	Sweden	1990-2002	9	Electricity production cost (USD/kWh)
CO$_2$ capture and storage (CCS)					
	Rubin, et al., 2006	Global	n/a	3-5	Electricity production cost (USD/kWh)

Sources: Enermodal, 1999; McDonald and Schrattenholzer, 2001; Williams, 2002; Goldemberg,2004; Junginger, 2005, 2005a, 2005b, 2006; Rubin, 2006; Isles, 2006; Jamasb, 2006; Kruck, 2007; van Sark, 2007; Nemet, 2009.

10.5.3 Deployment cost curves and learning investments

According to the definition used by the IEA (IEA, 2008a, p 208), "deployment costs represent the total costs of cumulative production needed for a new technology to become competitive with the current, incumbent technology." As Figure 6 shows, these costs are equal to the integral below the learning curve (blue line), calculated up to the break-even point. As the innovative technologies replace operation costs and investment needs of conventional technologies, the learning investments are considerably lower. The learning investments are defined as the additional investment needs of the new technology. They are therefore equal to the deployment costs minus (replaced) cumulative costs of the incumbent technology.

Although not directly discussed in IEA, 2008a, the cost difference could be extended to take into account variable costs as well. Because of fuel costs, the latter is evident for conventional technologies, but this contribution should also be taken into account if the renewable energy usage implies considerable variable costs – as in the case of biomass. Once variable costs are taken into account, avoided carbon costs contribute to a further reduction of the additional investment needs (see Figure 6; the figure depicts the different unit costs associated with carbon prices that are expected for two differing illustrative climate protection strategies.)

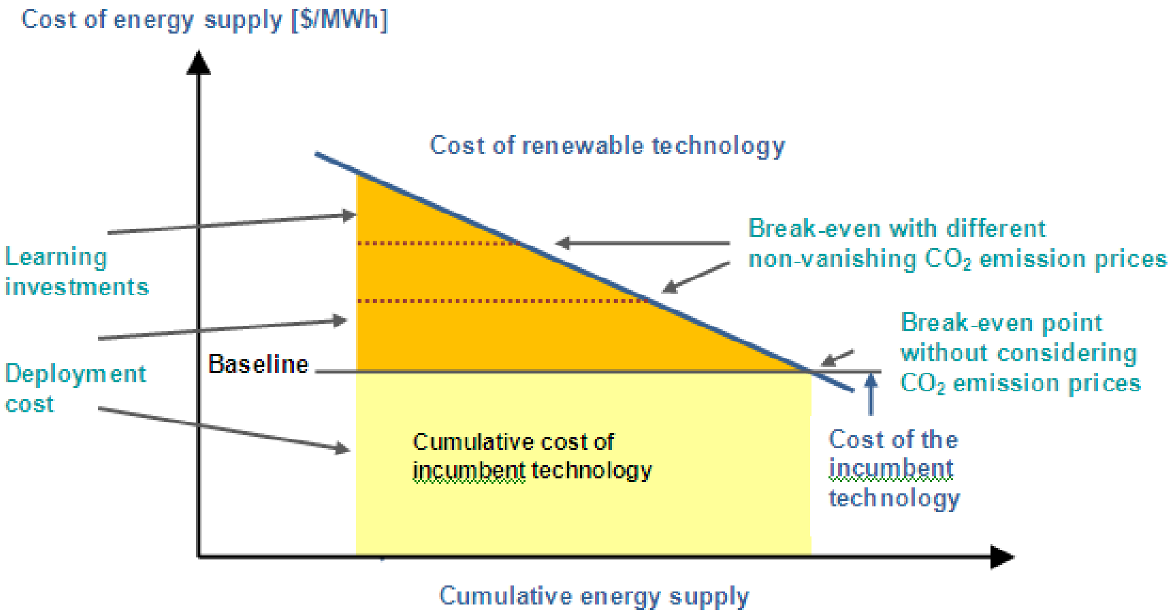


Figure 10.5.6: Schematic representation of learning curves, deployment costs and learning investments (modified version of the diagram depicted in IEA, 2008a, 204).

Unfortunately, many of the existing global energy scenarios do not calculate technology specific mitigation costs in a comprehensive way. Therefore, there is a severe lack of economic assessments, in general, and additional costs of technology specific mitigation paths, in particular. The IPCC AR4 highlights the overall GDP losses of different mitigation paths (referring to given scenarios), but does not specify the resulting transition costs of specific renewable energy penetration strategies. In order to fill this gap, the present report focuses at least using illustrative examples on the cumulative and time dependent expenditures that are needed in the deployment phase in order to realize ambitious renewable energy pathways.

10.5.4 Time dependent expenditures

If available at all, cost discussions in the literature mostly focus on investment needs. Unfortunately, as already mentioned before, many studies neither display total cost balances (including estimates about operational costs and cost savings) nor externalities like social, political and environmental costs (e.g. side benefits like employment effects). Although some assessment of the kind discussed here have taken place at a national level, a comprehensive global investigation is highly recommended.

In the following, deployment cost estimates are shown for different emission mitigation scenarios discussed in Chapter 10.3. As discussed before, deployment costs indicate how much money will be spent in the sector of renewable energies once these scenarios materialize. The given numbers therefore are important for investors who are interested in the expected market volume. Data on the energy delivered by the corresponding scenarios can be found in Chapter 10.3.

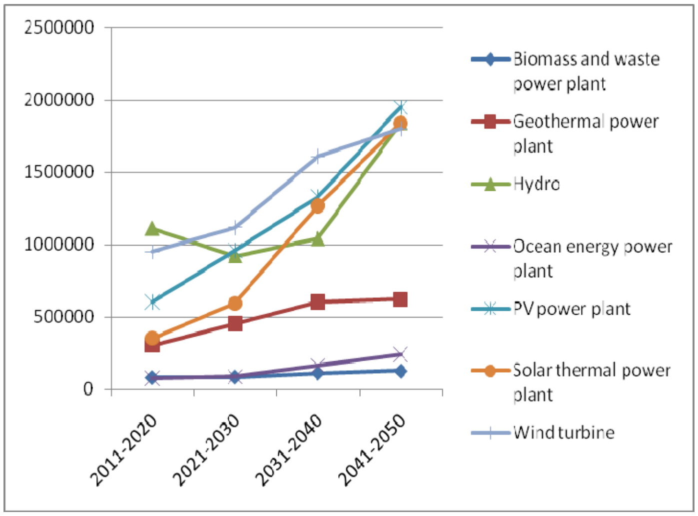


Figure 10.5.7: Illustrative global decadal investment needs (in Mio US $\$_{2005}$) in order to achieve ambitious climate protection goals. Source: Greenpeace, 2007. AUTHOR COMMENT: [Editorial note: In the second order draft, this diagram will be replaced by common assessment of various top-down studies discussed in Chapter 10.3. The corresponding deployment cost ranges will be depicted similar to Fig.8 [TSU: Figure 8 not found]of Chapter 10.3 that shows the total primary energy supply for different renewable energy sources.]

Figure 7 depicts the decadal investment needs associated with renewable energy deployment strategies that are compatible with a goal to constrain global mean temperature change to less than 2°C compared to the preindustrial level. In order to achieve this goal, worldwide greenhouse emissions are reduced by 50% below 1990 levels by 2050.

Investing in renewable energies does not only reduce the investment needs for conventional technologies. In addition, fossil fuel costs (and OMC) [TSU: Operation and Maintenance Costs] will be reduced as well. A comprehensive approach therefore would have to take into account avoided fuel costs as well, especially as these costs are expected to increase significantly in the future. As a consequence, deployment costs do not indicate the mitigation burden societies face if these scenarios are realized. In calculating this burden, saved variable costs (e.g., fossil fuel costs and related OMC) must be considered as well. As the saved variable costs are dependent on the development of fossil fuel prices, the overall net cost balance could be positive from a mid or long term perspective.

Although a few scenarios considered in Chapter 10.3 provide technology specific data on the total primary energy supply (see Figure 8 in Chapter 10.3) [TSU: Figure 10.3.8 not found] and the associated (investment) needs (Figure 7, this chapter) [TSU: Figure 10.5.7], no global scenario currently is able to deliver the fossil fuel cost that are avoided by the deployment of the various renewable energy technologies – and to attach the respective share to the considered technology.

Although this information would be extremely useful in order to carry out a fair assessment of learning investments and (net) deployment costs, up to now, it is not standard to calculate the associated avoided fuel cost "wedges". Future scenario exercises therefore should focus on delivering the respective data. Albeit some assumptions concerning the mixture of the avoided fossil fuels must be made, the calculation of "carbon dioxide emission reductions wedges" nowadays is standard; an observation which proves that the associated problems (e.g., concerning the contribution of energy efficiency measures) can be solved.

Due to the lack of global data, illustrative results of a German study (Nitsch, 2008) will be discussed in the following. The purpose is to emphasize that the upfront investment in renewable energies should be compared with fossil fuel costs that can be avoided in the long-term.

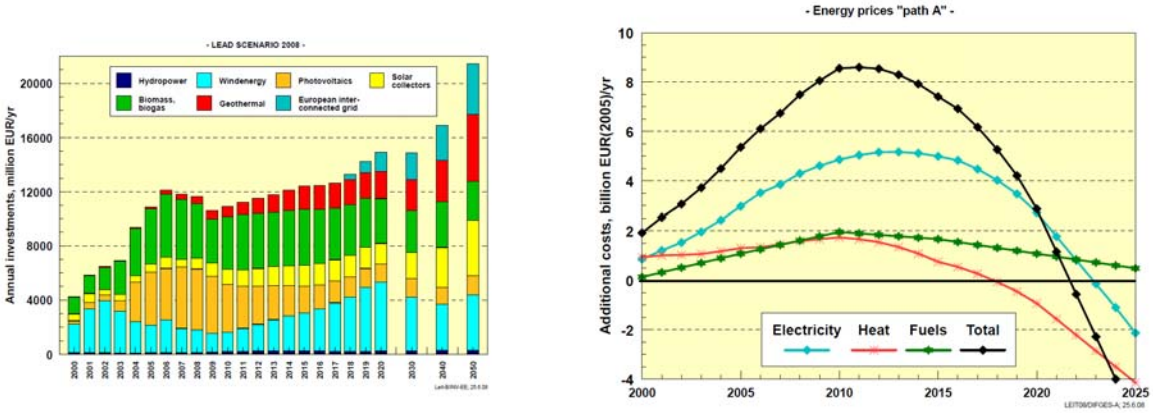


Figure 10.5.8: a) Annual investment volume for renewable installations for electricity and heat supply (including investments for local district heat networks) according to the Lead Scenario 2008. b) Additional costs of renewable energy expansion in all sectors according to the Lead Scenario 2008 (Nitsch, 2008, p. 26 and 28).

The lead study describes the cost evolution which is shown in Figure 8 [TSU: Figure 10.5.8] as follows: "The annual additional costs of the entire expansion of renewable energies amounted to 6.7 billion €$_{2005}$/yr in 2007. Of these, 57% were incurred for electricity supply. On price path A, they rise further to 8.5 billion €$_{2005}$/yr in 2010 (of which 4.8 billion €$_{2005}$/yr for the electricity sector, 1.7 billion €$_{2005}$/yr for the heat sector and 2 billion €$_{2005}$/yr for the fuels sector) and then drop sharply. No additional costs arise any longer around 2020. Renewable energies then meet almost 20% of total final energy demand and already avoid 200 million t CO_2/yr. Over the period from 2021 to 2030 renewables, which continue to expand, already save the national economy 6 billion €$_{2005}$/yr, a sum which otherwise would have to be expended for the additional fossil energy requirement. In the period from 2031 to 2040 these savings grow further to 27 billion €$_{2005}$/yr." (Nitsch, 2008, p. 27-28).

10.5.5 Market support and RDD&D [TSU: RD&D]

In the beginning, additional costs are expected to be positive ("expenditures"). Due to technological learning and the possibility of increasing fossil fuel prices, additional costs could be negative after some decades. A least cost approach towards a decarbonized economy therefore should not focus solely on the additional costs that are incurred until the break-even point with conventional technologies has been achieved. After the break-even point, the innovative technologies considered are able to supply energy with costs lower than the traditional supply. As these costs savings occur then (after the break-even point) and indefinitely thereafter, their present value might be able to compensate the upfront investments (additional investment needs). Whether this is the case depends on various factors and technology. In the context of mitigation scenarios relevant factors are the selected atmospheric concentration ceiling for greenhouse gases (in particular the related policies) and the deployed discount rate. Unfortunately only innovative integrated assessment models – which model technological learning in an endogenous way – are capable of assessing the overall mitigation burden associated with a cost optimal application of renewable energies within the context of ambitious climate protection strategies (Edenhofer et al., 2006). That is why only limited results are available so far.

The results obtained from these modelling exercises indicate that – from a macro-economic perspective – significant upfront investments in innovative renewable energy technologies are often justified if these technologies are promising with respect to their renewable resource potential and their learning capability. Being obtained by models that seek to maximize global welfare, the respective investment paths are optimal from a perspective that takes into account the dynamic efficiency of the transition path. Unfortunately caused by other decision factors that's not necessarily be undertaken by private investors. Two market failures are mainly responsible for this imperfect performance of liberalized markets: As long as external environmental effects are not completely internalized, the usage of fossil fuel is cheaper than justified. The incentive for investments in climate-friendly technologies therefore is reduced. Independent of any environmental aspects, several private sector innovation market failures distort private sector investments in technological progress (Jaffe et al., 2005). The main problem here is that private investors developing new technologies might not be able to benefit from the huge cost savings that are related with the application of these technologies in a couple of decades. An optimal strategy therefore has to combine two complementary approaches which address the two market failures mentioned above (environmental pollution and the market failures associated with the innovation and diffusion of new technologies). Together these market failures provide a strong rationale for a portfolio of public policies that foster emissions reduction (e.g. by emission trading or carbon taxes) as well as the development and adoption of environmentally beneficial technologies (e.g., by economic incentives like feed-in tariffs, Jaffe et al., 2005).

Typical instruments to foster the diffusion of renewable energy technologies are, for instance, feed in tariffs. With a view to the considerable financial support renewable electricity supply systems are gaining via feed-in tariffs or other instruments all over the world, the question has been raised whether this support is still justified if emission trading schemes are acting in parallel (cf., German Monopolies Commission, 2009). In order to clarify the relationship between emission trading (or other schemes that led to an internalization of carbon costs) and technology specific support schemes for renewable energies (e.g., feed-in tariffs or quota systems), Figure 9 [TSU: Figure 10.5.9] should be considered.

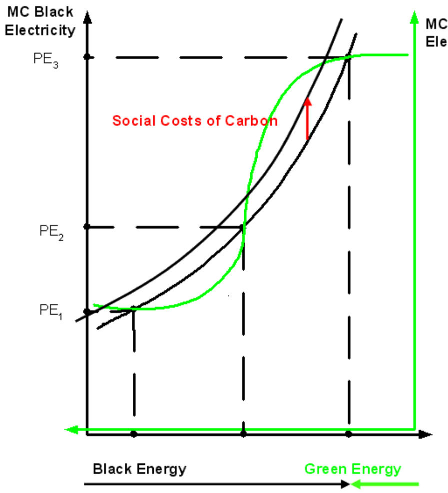


Figure 10.5.9: Equilibrium solutions for innovative technologies showing learning effects (Source Bruckner and Edenhofer, 2009).

The black curve depicts the cost of electricity produced from fossil-fuels. The respective supply curve shows the classical behaviour: marginal costs rise with increasing output. Cheap supply options are limited; we therefore have to mine more expensive commodities in case higher supply shares are requested. Small contributions from renewable energies can be found at the right hand side of the figure; the market shares for renewable electricity therefore increase from the right to the left. As long as technological learning is not taken into account, supply curves for power from renewable sources would exhibit a behaviour which is similar to that for conventional electricity. If technological learning in the field of renewable energies is taken into account, the supply curve changes significantly. Due to learning effects, an increasing market share (and a corresponding larger experience) initially causes a gradual decrease of marginal cost. As good sites are limited and system dependent additional integration costs become more and more important for higher market penetration levels, the marginal cost might exhibit a minimum for a specific market share and an increasing trend beyond (e.g., to the left of) that value. As a consequence, the supply curve for electricity from renewable energy sources could be S-shaped – as depicted in Figure 9 [TSU: Figure 10.5.9].

At the intersection points the absolute values of the marginal costs for “black” and the “green” energy are equal (note that marginal costs are nothing other than the derivative of total costs with respect to the market share). Speaking in mathematical terms, total costs exhibit a relative (or local) minimum at the intersection points (PE1 and PE3).

To the right of the intersection point PE3, marginal costs of renewable energies are smaller than those for electricity from conventional sources. Within the corresponding niche markets renewable energies are competitive and total costs can be decreased by increasing the share of renewable energies. Within market economies, this improvement potential would be exploited up to the point where equal marginal costs are achieved. As long as subsidies are not taken into account, private investors would have no incentive to increase the share of renewable energies beyond that point (i.e., towards the left-hand side).

The internalisation of the external costs of fossil fuel usage, e.g. via an emission trading scheme (or via carbon taxes) would increase the marginal cost of electricity from fossil fuels (the related shift is indicated by the red arrow in Figure 9). The intersection point PE3 would shift to a new equilibrium value exhibiting a higher market share of renewable energies. Unfortunately, the respective increase will be small. The introduction of an emission trading scheme could therefore improve the competitiveness of renewable energies, but it does not necessarily trigger a transition to point PE1, which corresponds to another local cost minimum – which might be the absolute optimum in case that sufficiently ambitious climate protection goals are prescribed. Without accompanying measures an inter-temporal market failure has to be assumed in this case. The true social optimum (PE1) would not be adopted. The cost of climate protection would be higher than necessary.

In order to achieve the absolute cost minimum PE1, additional instruments (e.g. feed-in tariff systems or quota systems) therefore are necessary that are capable to increase the market share of renewable electricity up to PE2. Beyond this point, renewable electricity is cheaper than electricity from conventional sources. As a result, autonomous market forces would increase the share of renewables until PE1 is achieved. In the short term, the additional instruments will lead to an increase of the total costs, but in the long run the upfront investment costs could be more than compensated by the cost reduction induced by technological learning.

Obviously, the static sketch shown in Figure 9 is not able to prove *quantitatively* that upfront investment costs of a specific technology are really compensated by the expected avoided fuel costs. Whether this is the case depends, inter alia, on the selected climate protection goal, the assumed learning capability, the long-term resource potential and the performance of competing mitigation technologies. Integrated assessment models – which model technological learning in an endogenous way – are able to determine emissions mitigation technology portfolios that are cost effective form a long-term dynamic point of view. These models therefore might help to identify those innovative technologies which deserve an additional, technology specific support in the context of a prescribe climate protection goal (Edenhofer et al., 2006).

10.5.6 Knowledge gaps

Experience curves nowadays are used to inform decisions that involve billions of public funding. Although the notion that learning leads to cost reductions is well supported by many empirical studies, the application (and extrapolation) of learning curves in order to guide policy is not generally accepted (Nemet, 2009). In addition, there is a severe lack of information which is necessary to decide whether short-term deviations from the experience curve can be attributed to supply bottlenecks – or whether they already indicate that the cost limit is reached.

Small variations in the assumed learning rates can have a significant influence on the results of models that are using learning curves. Empirical studies therefore should strive to provide error bars for the derived learning rates (van Sark et al, 2008).

10.6 Social, environmental costs and benefits

10.6.1 Background and objective

Energy production typically causes direct and indirect costs and benefits for the energy producer and for society. Energy producers for instance incur private costs, such as plant investment and operating costs, and receive private benefits, such as income from sold energy. Private costs and benefits are defined as costs or benefits accounted by the agents responsible for the activity. The operations of energy producers often cause external impacts, which may be beneficial or detrimental but which are not covered by the energy producers. The costs and benefits due to external impacts are called external costs or external benefits, correspondingly (for the definition, see Glossary). The external costs are usually indirect and they arise, for example, from pollutant emissions. The reduction of detrimental impacts caused by pollutant emissions can be seen as an external benefit when renewable energy replaces some more detrimental energy sources. Additionally external benefits might occur if energy production and consumptions results in positive effects for the society (e.g. job creation in the energy sector). The social costs are assumed to include here both private costs and external costs (ExternEE 2004, NEEDS 2008), although other definitions have also been used in the past (e.g. Hohmeyer 1988). Figure 10.6.1 below shows a possible representation of the different definitions of costs and benefits.

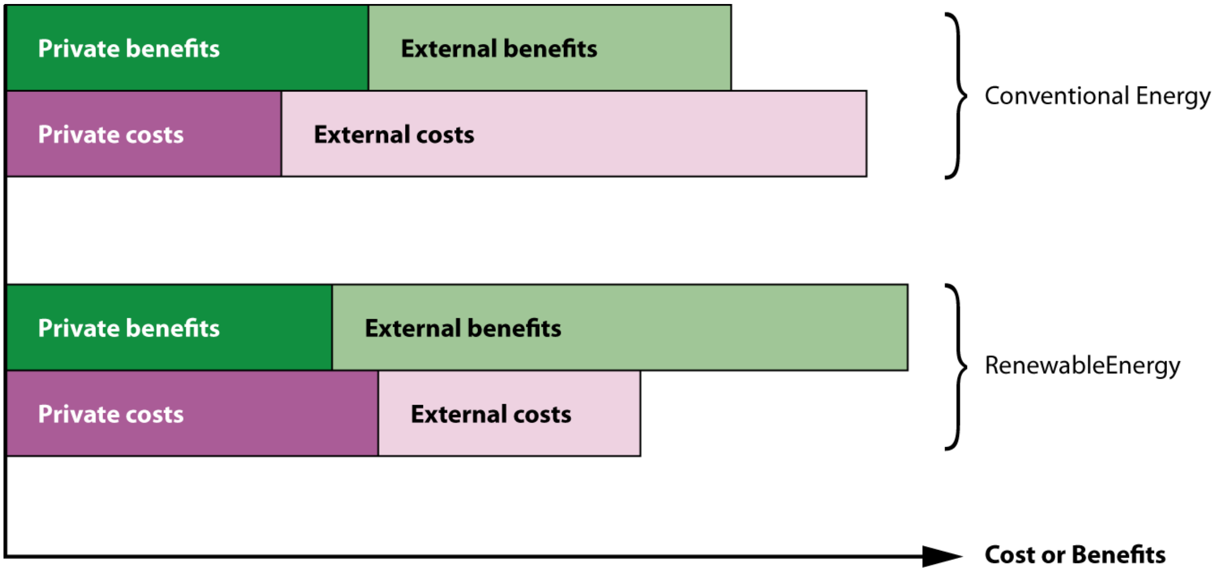


Figure 10.6.1: Simple representation of cost and benefits in the context of conventional and renewable energy sources. [TSU: No Source]

In conventional non-renewable energy production the private costs are usually lower than the private benefits, which means that the energy production is normally profitable. On the other hand, the external costs can be high, on occasions exceeding the total (social) benefits. Energy derived from renewable energy forms on the other hand can often be unprofitable for the energy producer. If the external costs (including environmental costs) are taken into account, the production of renewable energy can, however, as a whole be more profitable from a social point of view than conventional energy production (e.g. Owen 2006).

Typical factors causing external costs include the atmospheric emissions of fossil-fuel-based energy production. The emissions can, among other things, consist of greenhouse gases, acidifying emissions and particulate emissions. These types of emissions can often but not always (e.g. biomass) be lowered if renewable energy is used to replace fossil fuels (e.g. Weisser 2007)[18]. Increasing the share of renewable energy often contributes positively to access to energy[19], energy security and the trade balance and it limits the negative effects from fluctuating prices of fossil-based energy (Chen et al. 2007; Bolinger et al. 2006, Berry & Jaccard 2001). Further, increasing renewable energy may also contribute to external benefits, e.g. by creating jobs especially in rural areas (e.g. in the fuel supply chain of bioenergy). However, various types of renewable energy have their own private and external costs and benefits, depending on the energy source and the technology utilised (e.g. NEEDS 2009a).

Costs and benefits can be addressed in cost-benefit analyses to support decision-making. However, the value of renewable energy is not strictly intrinsic to renewable technologies themselves, but rather to the character of the energy system in which they are applied (Kennedy 2005). The benefits

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[18] One has to keep in mind that in particular biomass applications can also cause particulate emissions.

[19] There are still about 1 to 2 billion people without access to energy services (IEA), the renewable energy sources due to their distributed character can at least to some extent help to alleviate this problem.

of an increased use of renewable energy are to a large part attributable to the reduced use of non-renewable energy in the energy system.

The coverage and monetarisation of the impacts in general is very difficult. Especially the long time spans associated with climate change and its impacts are difficult to consider in cost-benefit analyses (Weitzmann 2007; Dietz & Stern 2008). Further, many environmental impacts are so far not very well understood or very complex and new for people and decision-makers, and their consideration and monetary valuation is difficult. This might limit the use of cost-benefit analysis and require other approaches, such as public discussion process and direct setting of environmental targets and cost-benefit or cost-effectiveness analyses under these targets. (Grubb & Newberry 2007; Söderholm & Sundqvist 2003; Krewitt 2002).

The production and use of energy can be considered from the viewpoint of sustainable development. [TSU: see chapter 9] Sustainable development is often divided into three aspects, namely environmental, economic and social sustainability. Renewable energy often has synergistic effects with the aspects of sustainable development. However, this is not necessarily always the case. For example, biomass, if extended widely, can be controversial as an energy source because of competition on land use. The land used to produce energy crops is not available for other purposes, e.g. food production and conservation of biodiversity (Haberl et al. 2007, Krausmann et al. 2008, Rathmann et al. 2010) although other references indicate that both food and fuel demand can be met in many cases at some reasonable level (Sparovek et al. 2008). Futhermore, the use of biomass can result in non-negligible or even relatively high GHG emissions (through various means, like production of fertilizers, energy use for harvest and processing, N_2O-emissions from agricultural land and land use changes). If used in a non-suitable manner the land clearing for biofuel production can cause in some cases considerable emissions (“biofuel carbon debt”) the compensation of which with biofuel use replacing fossil fuel can take long time spans (Fargione et al. 2008; Searchinger et al. 2008, Adler et al. 2007).

When the response to climate change is considered, renewable energy can be linked to the changing climate in regard to both climate change mitigation and adaptation (IPCC 2007b). On the other hand, climate change can have a great impact on renewable energy production potentials and on costs. Examples include biomass, wind and hydropower. The potential of biomass depends on climate changes affecting biomass growing conditions like temperature and soil humidity, the potential of wind power depends on wind conditions, and the potential of hydro on precipitation conditions, specially in the case of run-off into rivers (Figure 10.6.2) (Bates at al. 2008; Kirkinen et al. 2005; Lucena et al. 2009a, 2009b, 2010; Venäläinen et al. 2004).

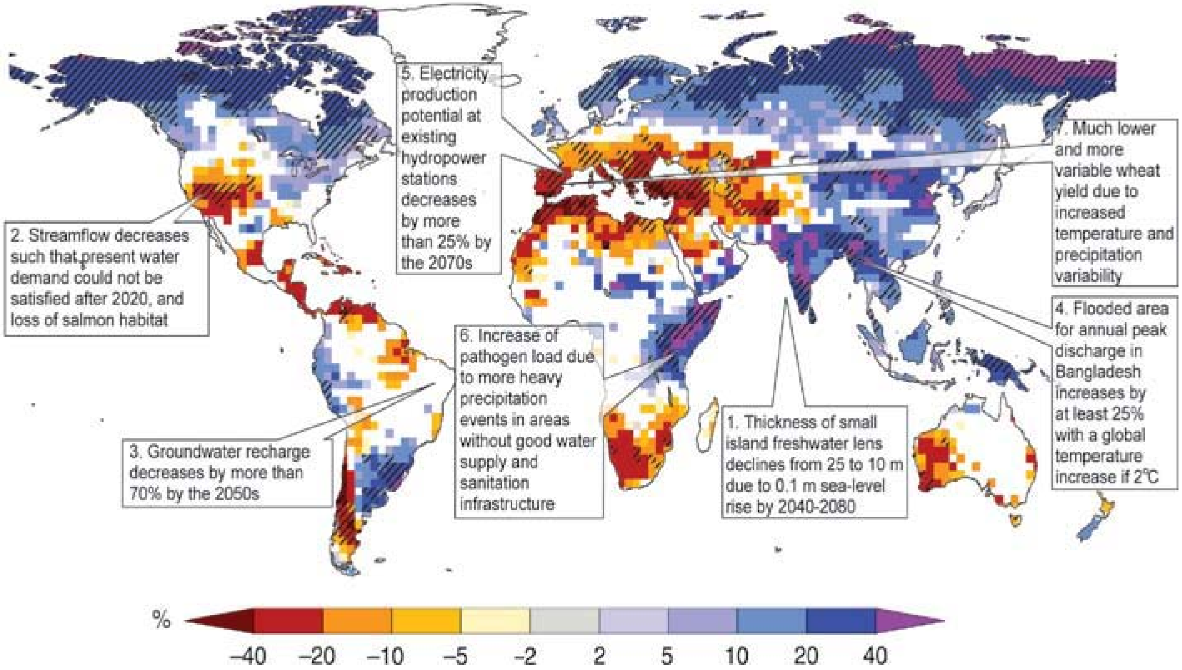


Figure 10.6.2: Illustrative map of future climate change impacts related to freshwater which threaten the sustainable development of the affected regions. Ensemble mean change in annual runoff (%) between present (1980–1999) and 2090–2099 for the SRES A1B emissions scenario. Areas with blue (red) colours indicate the increase (decrease) of annual runoff. (Bates et al. 2008.)

The greatest challenges for energy systems are guaranteeing the sufficient supply of energy at fair price and the reduction of the environmental impacts and social costs, including the mitigation of climate change. Renewable energy can markedly contribute to the response to these challenges. The understanding of these possible contributions is crucial for transformation in cost terms.

Behind that background the objective of Section 10.6 is to make a synthesis and discuss external costs and benefits of increased renewable energy use in relation to climate change mitigation and sustainable development. The results are presented by technology at global and regional levels. Therefore the section defines the cost categories considered and identifies quantitative estimates or qualitative assessments for costs by category type, by renewable energy type, and as far as possible also by geographical area. (regional information is still very sparse).

This section has links to the other chapters of SRREN, such as Chapter 1 (Introduction to Renewable Energy and Climate Change) and to Chapter 9 (Renewable Energy in the Context of Sustainable Development). Parts of this section (10.6) consider the same topics, but from the viewpoints of social costs and benefits.

10.6.2 Review of studies on external costs and benefits

Energy extraction, conversion and use cause significant environmental impacts and social costs. Many environmental impacts can be lowered by reducing emissions with advanced emission control technologies (Amann et al. 2008).

Although replacing fossil-fuel-based energy with renewable energy can reduce greenhouse gas emissions and also to some extent other environmental impacts and social costs caused by them, renewable energy can also have environmental impacts and external costs, depending on the energy source and technology (da Costa et al. 2007). These impacts and costs should be lowered, too and of course should be considered if a comprehensive cost assessment is requested.

This section considers studies by cost and benefit category and presents a summary by energy source as well. Some of the studies are global in nature, and to some extent also regional studies will be quoted which have been made mostly for Europe and North America. The number of studies concerning other parts of the world is still quite limited. Many studies consider only one energy source or technology, but some studies cover a wider list of energy sources and technologies.

In the case of energy production technologies based on combustion, the impacts and external costs, in particular the environmental costs arise mainly from emissions to air, especially if the greenhouse impact and health impact are considered. The life-cycle approach, including impacts via all stages of the energy production chain, is, however, necessary in order to recognise and account for everything important. In the case of non-combustible energy sources, the life-cycle approach is also very important when considering the total impact (WEC 2004; Kirkinen et al. 2008, NEEDS 2009a).

The assessment of external costs is often, however, very difficult and inaccurate. As a result the cost-benefit analysis of some measure or policy, where the benefit arises from decreases in some environmental or external impacts, is often very contentious. On the other hand, the difference between benefits and costs can be clear even though the concrete numbers of the cost and benefit terms are uncertain. The benefits and costs can often be distributed unevenly among stakeholders, both at present and over time. Discounting of impacts over long time-horizons is at least to some extent problematic. Also, there are usually no compensation mechanisms which could balance costs and benefits between different stakeholders. (Söderholm & Sundqvist 2003)

10.6.2.1 Climate change

Carbon dioxide is the most important anthropogenic greenhouse gas. The growth of its concentration in the atmosphere causes the greatest share of radiative forcing (NOAA 2008). The damage due to changing climate is often described by linking carbon dioxide emissions with the social costs of their impacts, sc. social costs of carbon (SCC), which is expressed as social costs per tonne of carbon or carbon dioxide released. A number of studies have been published on this subject and on the use of SCC in decision-making. Recent studies have been made e.g. by Grubb & Newbery (2007), Anthoff (2007) and Watkiss & Downing (2008).

The monetary evaluation of the impacts of the changing climate is difficult, however. To a large extent the impacts manifest themselves slowly over a long period of time. In addition, the impacts can arise very far from a polluter in ecosystems and societies which are very different from the ecosystems and the society found at the polluter's location. It is for this reason that, for example, the methods used by the Stern Review (2006) for damage cost accounting on a global scale are criticised. Beside the question about discount rate which is quite relevant considering the long term impacts of greenhouse gas emissions there is considerable uncertainty in areas such as climate sensitivity, damages due to climate change, valuation of damages and equity weighting (Watkiss & Downing 2008).

A German study dealing with external costs (Krewitt & Schlomann 2006) uses the values of 14, 70 and 280 €/tCO_2 for the lower limit, best guess and upper limit for SCC, respectively, referring to Downing et al. (2005). Watkiss & Downing (2008) assess that the range of the estimated social costs of carbon values covers three orders of magnitude, which can be explained by the many different choices possible in modelling and approaches in quantifying the damages. As a benchmark lower limit for global decision-making, they give a value of £35/tC (about 10€/tCO_2). They do not give any best guess or upper limit benchmark value, but recommend that further studies should be done on the basis of long-term climate change mitigation targets.

The price of carbon can also be considered from other standpoints, e.g. what price level of carbon dioxide is needed in order to limit the atmospheric concentration to a given target level, say 450 ppm. Emission trading gives also a price for carbon which is linked to the total allotted amount of emission. Another way is to see the social costs of carbon as an insurance for reducing the risks of climate change (Grubb & Newbery 2007).

Renewable energy sources have usually quite low greenhouse gas emissions per produced energy unit (WEC 2004; Krewitt & Schlomann 2006; IPCC 2007b), so the impacts through climate change and the external costs they cause are usually low. On the other hand, there can also be exceptions, e.g. in the case of fuels requiring long refining chains like transportation biofuels produced under unfavourable conditions (Soimakallio et al. 2009b; Hill et al. 2006). Land use change for increasing biofuel production can release carbon from soil and vegetation and in practice increase net emissions for decades or even longer time spans (Edwards et al. 2008; Fargione et al. 2008; Searchinger et al. 2008). In some cases the organic matter at the bottom of hydro power reservoirs can cause methane emissions, which can be significant (Rosa et al. 2004; dos Santos et al. 2006). Often case specific studies are needed in order to achieve realistic estimates concerning the greenhouse gas emissions of certain renewable energy technology applications.

Increasing the use of renewable energy sources often displaces fossil energy sources which have relatively high greenhouse gas emissions and external costs (Koljonen et al. 2008a). This can be seen to cause negative external costs, or positive external benefits if the whole system is considered. In other words, the positive impacts of the increase of the renewable energy depend largely on the properties of the original energy system (Kennedy 2005).

10.6.2.2 Health impacts due to air pollution

Combustion of both renewable fuels and fossil fuels often cause emissions of particulates and gases which have health impacts (e.g. Krewitt 2002; Torfs et al. 2007; Amann et al. 2008). Exposure to smoke aerosols can be exceptionally large in traditional burning, e.g. in cooking of food in developing countries (Bailis et al. 2005). Also, emissions to the environment from stacks can reach people living far from the emission sources. The exposure and the number of health impacts depend on the physical and chemical character of the particulates, their concentrations in the air, and population density (Krewitt &Schlomann 2006). The exposure leads statistically to increased morbidity and mortality. The relationships between exposure and health impacts are estimated on the basis of epidemiological studies (e.g. Torfs et al. 2007). The impact of increased mortality is assessed using the concept of value of life year lost. The monetary valuation can be done e.g. by using the willingness-to-pay approach.

The results depend on many assumptions in the modelling, calculations and epidemiological studies. Krewitt (2002) describes how the estimated external costs of fossil-based electricity production have changed by a factor of ten during the ExternE project period between the years 1992 and 2002. The cost estimates have been increased by extension of the considered area (more people affected) and by inclusion of the chronic mortality. On the other hand, the cost estimates have been lowered by changing the indicator for costs arising from deaths and by using new exposure-impact models. It can be argued that the results include considerable uncertainty (e.g. Torfs et al. 2007).

The specific costs per tonne of emissions have been assessed in reference (Krewitt & Schlomann 2006) to be for SO2 about 3000€/t, for NOx about 3000€/t, for Non-Methane VOC about 200€/t and for particulates PM_{10} about 12000€/t. The NMVOC emissions contribute to the formation of ground-level ozone, which has detrimental effects on health. Sulphur dioxide and nitrogen oxide emissions form sulphate and nitrate aerosols which also have detrimental health impacts.

When renewable energy is used to replace fossil energy, the total social costs of the total energy system due to health impacts usually decrease, which can be interpreted to lead to social benefits linked to the increase of renewable energy. However, this is not always the case as discussed in this subchapter but requires a more detailed analysis.

10.6.2.3 Impacts on waters

Thermal condensing power plants usually need water, e.g. from a river. This causes thermal loading of the river on a local scale. If the thermal load is too big, cooling towers although more expensive than the use of river water, can be used so that the heat is discharged to the atmosphere. In terms of renewable energies cooling water demand is relevant in particular for biomass combustion plants. However, the unit size of bioenergy plants is usually small which may limit the thermal loading peaks.

Hydropower plants, especially if the water must be stored or regulated, can have detrimental impacts on fishing and other water-based livelihoods. The detrimental impacts can be lowered to some extent by compensating measures such as fish passes and plantations. (Larinier 1998)

The environmental and social impacts of hydropower projects vary considerably from case to case, leading to variable external costs and benefits. Environmental Impact Assessment (EIA) requirements defined in many national legislations of countries can be used as a tool for assessing the impacts on environment and society of a planned hydropower station. (Wood 2003, DDP 2007)

10.6.2.4 Impacts on land use, soil, ecosystems and biodiversity

Some large hydropower projects need considerable water reservoirs, which can have a clear impact on land use on a local to regional scale, although in the case of small hydropower plants the impacts are usually small. The reservoirs can cover settlements, agricultural land and land used for other livelihoods (Fearnside 1999, 2005).

The use of bioenergy can be increased by utilising residues from agriculture and forestry as well as by increasing the efficiency of land use and using set-aside lands. A large increase in bioenergy use, however, requires an increase in the land area designated to energy crops, resulting in competition with other activities like food, fodder and fibre production as well as with land use for biodiversity conservation and settlement. (Haberl et al. 2007; Krausmann et al. 2008; Rathmann et al. 2010, Searchinger et al. 2008; Sparovek et al. 2008).

On the other hand, many residues from agriculture or forestry or even energy crop plantations, such as straw and slash, can be used to maintain or improve the quality of the soil. In contrast, excessive harvesting of forest residues for example can lower the nutrient and carbon content of the soil (Korhonen et al. 2001, Palosuo 2008).

Sulphur dioxide and nitrogen oxide emissions from energy production can also cause acidification and eutrophication of ecosystems. Air pollutants such as nitrogen dioxides and NMVOC emissions (which may result from the use of some renewable energy options) can have impacts on the productivity of agriculture and on materials used in man-made structures. The external costs of these impacts are considerably lower than the costs of health impacts, according to Krewitt & Schlomann (2006).

10.6.2.5 Other socio-economic impacts

Benefits of energy sources include the facilitation of many services like illumination, heating and cooling of room space, food storage and cooking, the possibility to use information and communication technologies, and benefits in industries and other sources of livelihood. A secure access to energy is crucial for the functioning of modern societies and for a high standard of living.

The world population is increasing (UNPD 2008). By 2050 it is expected to be about 9 billion. There will likely be strong growth in demand for energy primarily in the developing economies. (IEA 2008a)

The depletion of the limited energy reserves of fossil fuels (WEC 2007; VTT 2009) and bottlenecks in the energy infrastructure as well as a high centralization of resources can cause wide fluctuations in the price of energy and also risks in the availability of energy. Therefore, many countries are striving to improve energy security and promote the use of domestic energy sources. These challenges can often be responded to by increasing the share of renewable energy (Berry & Jaccard 2001; Koljonen et al. 2008b; BIWARE 2005; VTT 2009).

Generally, long-term measures to increase energy security focus on diversification, reducing dependence on any one source of imported energy, increasing the number of suppliers, exploiting indigenous fossil fuel or renewable energy resources, and reducing overall demand through energy conservation. Renewables, as part of a cleaner energy mix, are growing in importance. Renewables cover a wide spectrum of energy sources, e.g. wind, solar, hydropower, geothermal, biomass, and ocean energy that contribute to security of energy supply.

Increasing the production and use of renewable energy creates jobs in R&D and manufacturing (Monni et al. 2002; BMU 2006a, b). The supply of bioenergy fuels has also important role in the creation of jobs. The supply of local and domestic energy also has an impact on the economy of the area and even the country and its trade balance (Berry & Jaccard 2001; Bergmann et al. 2006; Koljonen et al. 2008b). Moreover there is not only a possible employment effect due to the production process of renewable energies, but a general possibility that access to energy and in particular renewable energy enables the creation of new jobs especially in rural areas (e.g. business opportunities in small scale commercial applications).

On the other hand, the number of new jobs, e.g. in hydropower, can be quite small after the construction period. And the changes in energy system can result in loss of jobs in the fossil sector and in loss of jobs in the overall economy due to the effects of higher energy prices on other parts of the economy (Soimakallio et al 2009a).

Use of local energy sources improves access to energy (Berry & Jaccard 2001, BIWARE 2005, Sahay 2009), enhances energy security and reduces the impact of energy price volatility in international markets (Koljonen et al. 2008b). Access to energy is especially important in many developing countries where hundreds of millions of people live without modern energy services.

The biggest impacts of renewable energies on the built environment (on landscape aspects) might be caused by wind power, hydro dams and large biomass plantations which may even have an impact on property prices in the neighbourhood. The production units for renewable energy are mostly small and quite discrete, except for wind turbines and possibly some constructions needed for big hydropower plants (in the future maybe as well for centralized photovoltaics plants and solar thermal plants). Older wind power plants may also cause some noise in their vicinity. On the other hand, wind power can offer some positive image values. (Möller 2006). Biomass plantations might not be as visible from far away as wind mills are, but they require a huge amount of land and are often in the form of monocultures, leading to corresponding negative impacts on biodiversity.

10.6.3 Regional considerations of social costs and benefits

Most of the studies covered in this section consider North America (Gallagher et al. 2003; Roth & Ambs 2004; Kennedy 2005; Chen et al. 2007; NRC, in press) and Europe (Groscurth et al. 2000, Bergmann et al. 2006, Krewitt & Schlomann 2006, NEEDS 2009a), while some are more general without a specific geographical area.

Some studies consider developing countries, especially Brazil. Da Costa et al. (2007) discuss social features of energy production and use in Brazil. Fearnside (1999, 2005) and Oliveira & Rosa (2003) study big hydropower projects and the energy potential of wastes in Brazil, respectively. Sparovek et al. (2008) investigate the impacts of the extension of sugar cane production in Brazil. Bailis et al. (2005) consider biomass- and petroleum-based domestic energy scenarios in Africa and their impacts on mortality on the basis of particulate emissions. Amann et al. (2008) study cost-effective emission reduction of air pollutants and greenhouse gas emissions in China.

Studies concerning different areas of the globe are still sparse. More studies, articles and reports are needed to provide information on social costs and their possible variation in the ecosystems and societies of different geographical areas.

10.6.4 Synergistic strategies for limiting damages and social costs

Many environmental impacts and external costs follow from the use of energy sources and energy technologies that cause greenhouse gas emissions, particulate emissions and acidifying emissions – fossil fuel combustion being a prime example. Therefore, it is quite natural to consider the reduction of the impacts due to emissions with combined strategies (Amann et al. 2008; Bollen et al. 2007).

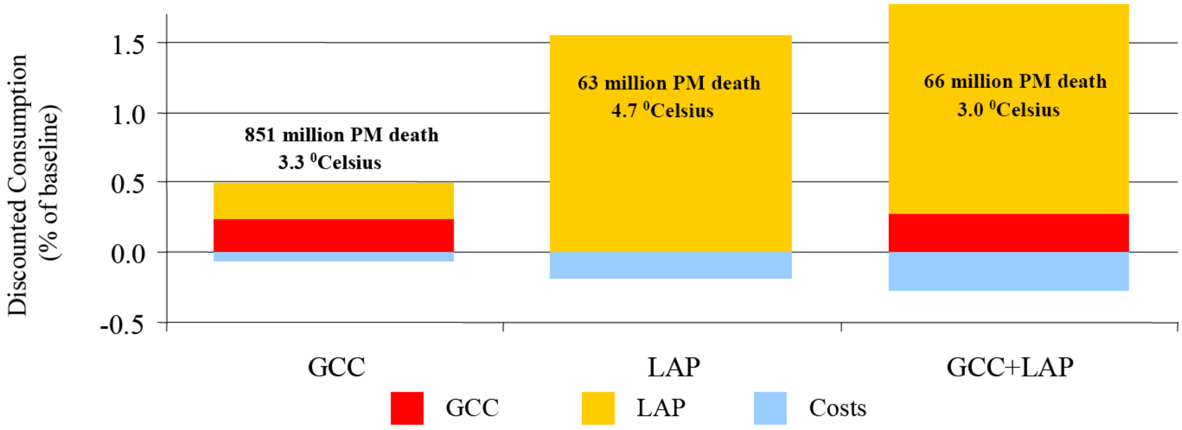


Figure 10.6.3: Changes in costs, benefits and global welfare for three scenarios (GCC, LAP, GCC+LAP), expressed as percentage consumption change in comparison to the baseline (Bollen et al. 2007). In the scenario GCC the social costs of Global Climate Change (GCC) have been internalised, in the scenario LAP the social costs of Local Air Pollutants (LAP) have been internalised, and in the scenario GCC+LAP both social cost components have been internalised. For each scenario the number of deaths due to particulate matter (PM) emissions and temperature rise due to greenhouse gas emissions is shown in the Figure. In the baseline the number of particulate matter (PM) deaths due to air pollutants would be 1000 million and the temperature rise 4.8 C.

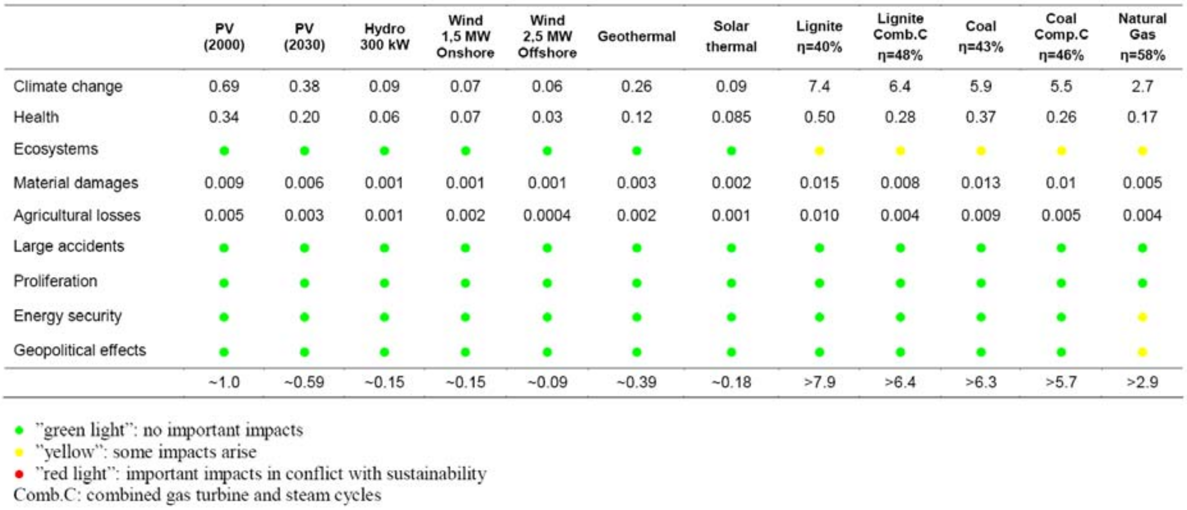
Bollen et al. (2007) have made global cost-benefit studies using the MERGE model (Manne & Richels 2004). In their studies the external costs of health effects due to particulate emissions and impacts of climate change were internalised. According to the study (Figure 10.6.3), the external benefits were greatest when both external cost types were internalised, although the mitigation costs were high as they work in a shorter time frame. The discounted benefits from the control of particulate emissions are clearly larger than the discounted benefits from the mitigation of climate change. The difference is, according to a sensitivity study, mostly greater by at least a factor of two, but of course depends on the specific assumptions (in particular on the discount rate chosen). The countries would therefore benefit from combined strategies quite rapidly due to reduced external costs stemming from the reduced air pollution health impacts.

Amann et al. (2008) have reached quite similar conclusions in a case study for China. According to the study, the reduction of greenhouse gas emissions in China causes considerable benefits when there is a desire to reduce local air pollution. Also a study (Syri et al. 2002) considering the impacts of the reduction of greenhouse gas emissions in Finland stated that particulate emissions are also likely to decrease.

10.6.5 Summary of social and environmental costs and benefits by energy sources

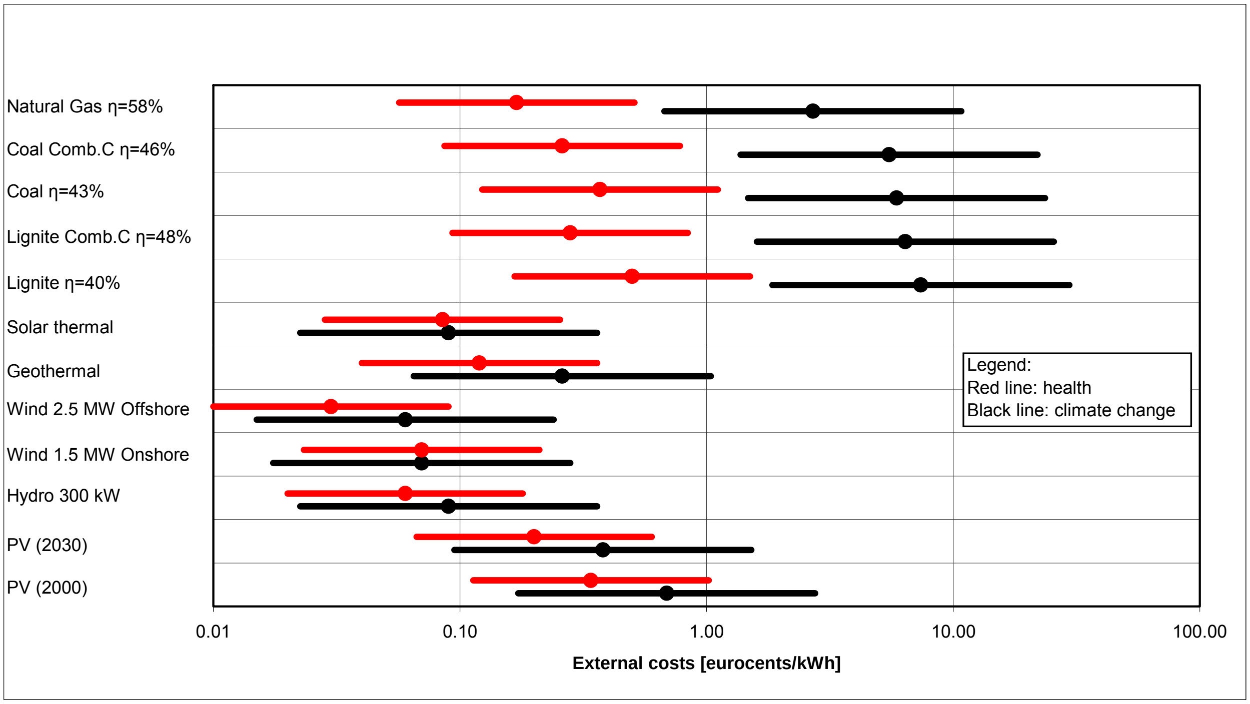
To calculate the net impact in terms of social costs of an extension of renewable energies two things have to be done. First, (a) the external costs and benefits can be assessed on the basis of the life-cycle approach for each technology in the conditions typical for that technology so that only the direct impacts of that technology are taken into account (NEEDS 2009a; Krewitt & Schlomann 2006; Roth & Ambs 2004; Pingoud et al. 1999). The other thing (b) is to consider the renewable energy technologies as parts of the total energy system and society, when the impacts of a possible increase in the use of the renewable energy technologies can be assessed as causing decreases in the use and external costs of other energy sources. (Koljonen et al. 2008a; Kennedy 2005; Loulou et al. 2005).

Table 10.6.1: External costs (eurocents/kWh) due to electricity production based on renewable energy sources and fossil energy. Valuation of climate change is based on an SCC value of 70 €/tCO$_2$. (Krewitt & Schlomann 2006).



	PV (2000)	PV (2030)	Hydro 300 kW	Wind 1,5 MW Onshore	Wind 2,5 MW Offshore	Geothermal	Solar thermal	Lignite η=40%	Lignite Comb.C η=48%	Coal η=43%	Coal Comp.C η=46%	Natural Gas η=58%
Climate change	0.69	0.38	0.09	0.07	0.06	0.26	0.09	7.4	6.4	5.9	5.5	2.7
Health	0.34	0.20	0.06	0.07	0.03	0.12	0.085	0.50	0.28	0.37	0.26	0.17
Ecosystems	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟡	🟡	🟡	🟡	🟡
Material damages	0.009	0.006	0.001	0.001	0.001	0.003	0.002	0.015	0.008	0.013	0.01	0.005
Agricultural losses	0.005	0.003	0.001	0.002	0.0004	0.002	0.001	0.010	0.004	0.009	0.005	0.004
Large accidents	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Proliferation	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Energy security	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟡
Geopolitical effects	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟡
	~1.0	~0.59	~0.15	~0.15	~0.09	~0.39	~0.18	>7.9	>6.4	>6.3	>5.7	>2.9

🟢 "green light": no important impacts
🟡 "yellow": some impacts arise
🔴 "red light": important impacts in conflict with sustainability
Comb.C: combined gas turbine and steam cycles



Comb.C: Combined gas turbine and steam cycles

Figure 10.6.4: Illustration of external costs due to electricity production based on renewable energy and fossil energy. Note the logarithmic scale of the figure! The black lines in dicate the external cost due to climate change and the red lines indicate the external costs due to health effects. External costs due to climate change dominate in fossil energy. Valuation of external costs due to climate change is based on the SCC value of 70 €/tCO_2 and its lower limit of 15 and upper limit of 280 €/tCO_2. The uncertainty for the external costs of health impacts is assumed to be a factor of three. (Based on Krewitt & Schlomann 2006; Krewitt 2002)

An assessment of external costs is presented in Table 10.6.1 (Krewitt & Schlomannn 2006) and in Figure 10.6.4. It can be seen that the social costs due to climate change and health impacts dominate in the results in Table 10.6.1. The other impacts make a lesser contribution to the final results having in mind that not all impacts are quantifiable. If a lower value of social costs of carbon of 15 €/tCO_2 is used in Table 10.6.1 instead of 70 €/tCO_2, the climate impact still dominates in the total social costs of fossil-based technologies, but for renewable technologies the health impacts would be dominant. Figure 10.6-4 show the large uncertainty ranges of two dominant external cost components of Table 10.6.1, namely climate related and health related external costs. A recent extensive study (NRC, in press) arrives at almost similar results than Krewitt & Schlomann (2006) for natural gas based electricity production but clearly higher external cost level for coal based production due to higher non-climate impacts.

Results of an other study in Figure 10.6.5 show somewhat lower external costs for different technologies (NEEDS 2009a,b) than shown in Table 10.6.1. However, the results are within the uncertainty ranges given in Figure 10.6.4. Small scale biomass fired CHP plant considered in the study causes relatively high external costs due to health effects via particulate emissions. Nuclear energy and offshore wind energy cause smallest external cost in this study. The nuclear alternative does not include external cost impacts due to proliferation nor due to risks due to terrorism. Inclusion of these impacts could raise the external cost level of nuclear power.

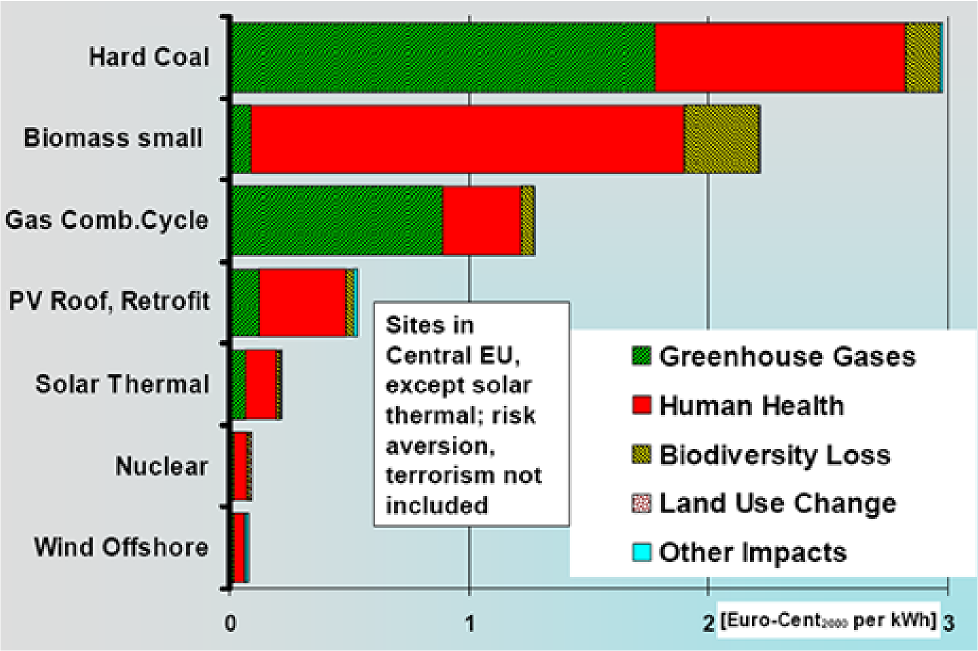


Figure 10.6.5: Quantifiable external costs for some electricity generating technologies. Estimation of external impacts and their valuation include considerable uncertainties and variability (NEEDS 2009a,b).

As only costs of individual technologies are shown in Table 10.6.1 and Figures 10.6.4 and 10.6.5, benefits can be derived when assuming that one technology replaces another one. Renewable energy sources and the technologies using them have mostly lower external costs per produced energy than fossil-based technologies. However, case-specific considerations are needed as there can also be exceptions. For example, in some cases biomass use can cause relatively high greenhouse gas emissions (Fargione et al. 2008) and particulate emissions (NEEDS 2009a).

When the share of renewable energy sources is increased in the energy system and when the use of fossil energy is decreasing, the external costs of the energy system per unit of energy usually decrease and the external benefits increase. This change can be roughly estimated in respect to climate change with the use of SCC. When renewable energy replaces fossil energy the carbon dioxide emissions from the total energy system decrease and so too do the total external costs (social benefits increase).

Increased usage of renewable energy is usually synergistic with sustainable development. In most cases the environmental damages and costs decrease when fossil fuels are replaced by renewable energy. Also the social benefits from the supply of renewable energy usually increase. In some cases, however, there can be trade-offs between renewable energy expansion and some aspects of sustainable development. Therefore, it is important to carry out Environmental Impacts Assessment (EIA) studies on renewable energy projects in consideration in order to be sure that sufficient requirements for the implementation of the projects are met.

10.6.6 Knowledge gaps

There are considerable uncertainties in the assessment and valuation of external impacts of energy sources.

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