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Quantitative Assessment of the Impact of the Strategic Energy Technology Plan on the European Power Sector

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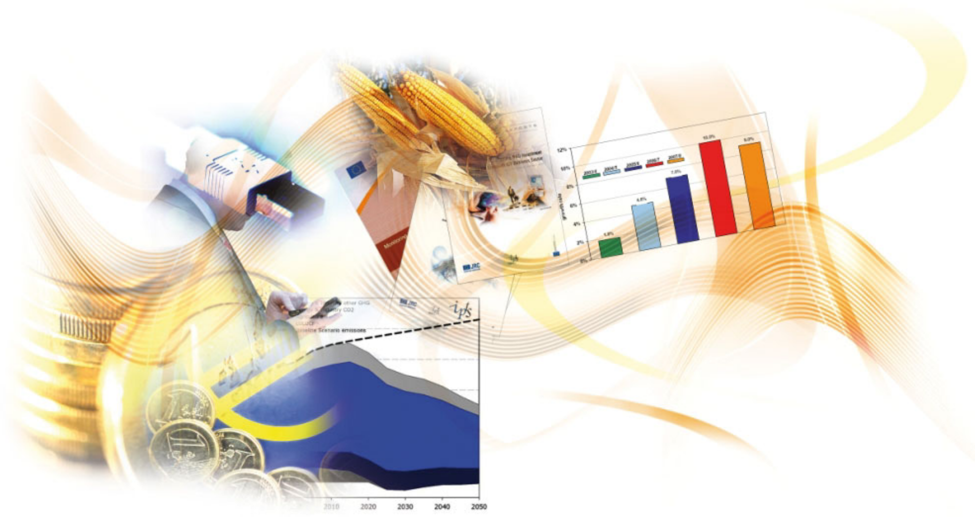

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Executive summary

The European Union has adopted the Strategic Energy Technology Plan (SET-Plan) as the technology pillar of the European climate change and energy policy. The SET-Plan will help to develop promising low-carbon energy technologies and bring them onto the market. This shall be achieved through a variety of measures, including the increase of research, development and demonstration (RD&D) efforts.

The present analysis aims to capture the effect of increasing RD&D efforts for a set of low-carbon power technologies on the development of the European energy sector by 2020 and beyond. In a simplified manner, the report assesses the effect of a global rise in RD&D investments, which for the EU are in line with the needs identified by the SET-Plan, on the investment costs of selected technologies and the power sector as a whole. The technologies for which additional RD&D investments are considered comprise on- and offshore wind energy, photovoltaic and concentrating solar energy use, bioelectricity and carbon capture and storage.

The methodology applied is based on the concept of the Two-Factor-Learning Curve (TFLC) that quantitatively links the cost evolution of a technology to its cumulative volume of production ('learning-by-doing') and the knowledge stock ('learning-by-researching'). From an operational viewpoint this is realized through a multi-step iterative approach, combining a spreadsheet model for technology learning with a partial equilibrium model of the energy sector (POLES). In the first step, the effect of RD&D investment on the economic performance of a given energy technology is quantified. The resulting parameters are then used as an input to the POLES model to evaluate the response of the energy sector, both in terms of technology penetration and costs. Several iterations have been carried so as to ensure convergence between the two models. The results of the present work are nevertheless associated with some uncertainty due to scarce data availability and limitations in establishing a quantified relationship between research efforts and technology improvement due to knowledge spillovers between technological fields and sectors.

The approach has been used to compare two main scenarios that reflect different levels of RD&D investments, but achieve the same shares of renewable energies and similar levels of greenhouse gas emissions by 2020. The *'Global SET-Plan Scenario'* assumes that the RD&D investments into the selected technologies can be increased from the *'reference scenario'* up to a level that is in line with the ones identified by the European Union in the context of the SET-Plan over the period 2010-2020. In order to account for the global nature of the energy technology market and the related learning effects, this scenario assumes that all world regions and technology manufacturers undertake RD&D efforts comparable to the ones of the SET-Plan. Such assumption is underlined by recent commitments from the G8.

The assessment finds that such an increase in research efforts at global level could further reduce the costs of the analyzed technologies by 4% to 13% compared to the investment cost evolution in the reference scenario. In general, the less mature technologies such as offshore wind energy, PV, CSP and biomass gasification would profit over proportionally. As an immediate result, the market entry of those technologies that will be needed in a sustainable energy system beyond 2030 will be accelerated. The same conclusion also holds true for CCS technologies even though the present assessment assumes an additional market pull incentive on top of the research-driven technology push; under these conditions the market entry of CCS would be brought forward by at least five years.

Following from the reductions in technology investment costs, the analysis shows that the SET-Plan allows reaching the European energy and climate change targets at lower costs. The

economic rate of return of the additional SET-Plan investments (in RD&D in EU) would be around 15%, considering a time horizon between 2010 and 2030. The cumulative (discounted) benefit of the measure would be negative in early years before turning positive around the year 2020 and remaining so thereafter.

Note that already in the reference scenario it is assumed that the European energy and climate change targets will be met through a combination of a supportive market environment and availability of technologies. In reality, however, the SET-Plan plays a key role in improving not only the technology costs as assumed here, but also ensure their availability and reliability. Finally, ancillary benefits to consumers and industry beyond the power sector can also be expected, such as cost reductions in other sectors due to the lower CO_2 prices.

1 Introduction

The European Union (EU) is committed to a decisive contribution to the worldwide efforts to combat global warming, and hence set a firm independent target to reduce EU greenhouse gases by at least 20% by 2020 compared to the level of 1990 (European Commission, 2007a). For the long-term, emission reductions in the order of 60-80% are envisaged in developed countries. Given that energy production and consumption remain the largest source of GHG emissions in the EU, its Member States have adopted ambitious policies that aim at reducing energy demand and at decreasing the carbon intensity of energy supply.

There is wide acknowledgement on the need for innovative low-carbon technologies in realising the emission cuts required in the energy sector (European Commission, 2007b; Russ et al., 2007; IEA, 2008). To this end, the EU introduced the European Strategic Energy Technology Plan (SET-Plan; European Commission, 2007c), which aims at supporting Research, Development and Demonstration (RD&D) and market uptake of low-carbon energy technologies. In the context of the implementation of the SET-Plan, the Commission recently estimated the additional volume of RD&D funding needed for implementing the SET-Plan (European Commission, 2009a).

The present study now aims at capturing the effect of increasing RD&D efforts on a set of low-carbon power technologies on the development of the European Energy Sector by 2020 and beyond. In a simplified manner, it assesses the effect of a global rise in research efforts that for the EU are in line with the additional RD&D needs identified by the SET-Plan. To this end, it compares two scenarios that differ mainly in the RD&D investments dedicated to selected technologies, but otherwise share the same characteristics and both achieve an identical share of renewable energies in final energy consumption and the same level of GHG emissions by 2020, while they may slightly differ by 2030.

This main assumption of fixing quantities by 2020 and adapting prices is based on the reasoning that the European near-term targets may be fulfilled with current technologies, and the associated incremental innovation in conjunction with existing or already proposed fiscal and financial incentives (e.g. market pull instrument and carbon values). However, additional research efforts can help in lowering the costs for achieving these targets. In the long run, of course, RD&D efforts will not only contribute to cost reductions but, more importantly, can help to ensure broadening the portfolio of low-carbon technologies. For this reason, the hypothesis of fixed quantities has been removed for the period after 2020. On the global level, which has been considered in order to account for the global nature of technology learning, no fixed targets are assumed.

Additional RD&D efforts are considered in the present study for the low-carbon energy technologies currently prioritized by the European Strategic Energy Technology Plan for the power generation, and for which roadmaps have been developed. They comprise on- and offshore wind energy, photovoltaic and concentrating solar energy use, bioelectricity [1]and carbon sequestration technologies. This scope will be expanded to other sectors and technologies in a future update.

As the proposed nuclear European Industrial Initiative (ESNII) primarily focuses on a next generation of nuclear power plants (GEN IV), which are not expected to enter the market in the time horizon of the present analysis (2030), the proposed additional R&D investment in this field

[1] In the case of bio-electricity both electricity only and co-generation of heat and power are considered. The technologies are further distinguished into conventional and gasification to consider the focus of the SET-Plan European Industrial Initiative on high efficiency heat and power generation through gasification.

has not been analyzed. Nonetheless, nuclear energy is duly considered in this analysis even though the explicit consideration of SET-Plan related nuclear support activities other than increased research efforts lies outside of the scope of the present exercise. Under the assumptions of the present scenarios, nuclear electricity generation would increase in the order of 15% between 2005 and 2030, considering the evolution with the current reactor portfolio available in Europe that is GEN II and GEN III.

The techno-economic assumptions of the present work build on the SETIS Technology Map. Detailed information on the status and prospects of low-carbon technologies can be found in the technology description part of the Technology Map (SETIS, 2009) and is not repeated in this document.

This study constitutes a first coherent and transparent attempt to estimate the impact of SET-Plan like efforts to strengthen research on low-carbon technologies in the EU. The outcome of this work shall indicate the potential contribution of rising research efforts to moving towards a low-carbon power system. Thus, the focus of the assessment lies on the comparison of scenarios with different levels of RD&D investments; the absolute trend in the deployment of individual technologies in any of the scenarios has not been the focus of the present exercise.

2 Methodology

This analysis strives to assess the impact of increased RD&D investment on the deployment of new energy technologies, induced by related improvements of technical performance and cost-competitiveness, and the resulting effect on the EU energy and climate policy goals. While the focus of the analysis and the presentation of its result lie on the EU, the assessment has nevertheless been undertaken on the world level in order to account for the global nature of technology learning processes.

In the frame of this analysis, a multi-step approach has been developed for assessing the effect of RD&D investment on the EU policy goals. The first step aims at identifying the effect of RD&D investment on the economic performances of energy technologies using a two factor curve spreadsheet model (see section 2.1). The resulting parameters are then used as an input to the POLES model, a partial equilibrium model of the energy sector (see section 2.3), to evaluate the response of the energy system.

The input assumptions regarding technology developments are derived from the technology description chapters of the Technology Map, which describe the status of a broad variety of low-carbon technologies and provide an outlook on their potential future development. The impact of additional RD&D efforts triggered by the SET-Plan is provided as parameterized assumptions to the model in the form of improved economics and technical performances of the targeted technologies.

The economic evolution of the technologies is modeled through the concept of the two-factor-learning curve, which takes into account not only the 'learning-by-doing' effect, but also the impact of 'learning-by-researching'. The latter is approximated on the basis of R&D investments.

This approach is operatively convenient; establishing a causal relationship between R&D inputs and technological improvements is nevertheless complex. Spillover effects, time lags and cross-fertilizations from other sectors make it difficult to create a clear relationship between R&D efforts and technological improvements. Furthermore, existing data and learning-by-researching coefficients often carry a high uncertainty. Nevertheless, some studies clearly demonstrate this correlation (Klaassen et al., 2005; Schilling and Esmundo, 2009), which – when combined with deployment schemes – is often described by the so-called 'Two-Factor-Learning-Curve' (Kouvaritakis et al., 2000). At the same time, it is challenging to capture and quantify all benefits to society that can arise from increased research activities, such as an enhanced competitiveness of domestic industries and the creation of lead markets. Hence, the results of the approach applied here shall serve as an illustration of trends and the related orders of magnitude rather than as an exact quantification of the SET-Plan effect.

The policy and market environment used for this analysis builds upon the framework established by the Energy Policy for Europe, and in particular the recently adopted renewable directive (EU, 2009) and the commitment made by the European Council in 2007 to reduce the overall GHG emissions of the Community (European Council, 2007). Hence, the analysis builds on a reference scenario that already assumes that major objectives of the energy and climate policies are met. By 2020, emissions of GHG emissions will be (at least) 20% below the emission levels of 1990 already in the reference scenarios; also the share of renewable energies in final energy demand will come close to the envisaged 20%. Similarly, the scenario also assumes ambitious improvements in energy efficiency.

The same targets are also envisaged in the *Global SET-Plan* scenario. Hence, the renewable energy share and the GHG emissions are fixed across the scenarios. While this limits the impacts of the SET-Plan on the energy sector in terms of demand and fuel mix already by construction, it allows its effect on the costs of achieving the same target levels to be assessed.

2.1 Technological learning

Technological learning describes a concept according to which the unit production costs of a new technology decreases for increasing in cumulative production. In other words, the technology's performance improves as experience with the technology accumulates. Several steps of 'learning' have been identified. Kahouli-Brahmi (2008) describes the most important of those, namely:

i. Learning by doing, firstly introduced by Arrow (1962)
ii. Learning by researching (Cohen and Levinthal, 1989)
iii. Learning by using (Rosenberg, 1982)
iv. Learning by interacting (Lundvall, 1988)
v. Learning by scaling (Sahal, 1985).

So far, mainly 'learning by doing' effects, i.e. learning effects due to cumulative manufacturing have been quantified for various technologies[2]. This means that a quantified relationship has been established between the cumulative manufacturing (often approximated by the installed capacity in the energy sector) and the unit production costs. This relation is determined by the learning elasticity (or the learning rate, see below). A usual form to express this relation is through a One-Factor-Learning Curve (OFLC, Kahouli-Brahmi, 2008):

$$C_{t,y} = mQ_{t,y}^{-\varepsilon} \qquad \textit{(Equation 1)}$$

With C = Costs of unit production, €/W
Q = Cumulative Production, W
ε = Elasticity of learning (learning index)
m = normalisation parameter with respect to initial conditions
t = Technology
y = Period (year)

However, a simplified One-Factor-Learning Curve falls short of research and development being another important driver of technological learning, while overestimating the effect of learning by doing as the effect of R&D support is attributed to learning by doing (Jamasb et al., 2007; Kettner et al. 2008). More recently, the relation between cumulative R&D investments and production costs has been assessed. Combining the effects of learning by doing and learning by research leads to a Two-Factor-Learning Curve (Kouvaritakis et al., 2000). Such learning curve can be described as follows for a given technology *t* and time period *y* (Kahouli-Brahmi, 2008, Kypreos 2007):

$$C_{t,y} = aQ_{t,y}^{-\alpha} KS_{t,y}^{-\beta} \qquad \textit{(Equation 2)}$$

With C = Costs of unit production, €/W
Q = Cumulative Production, W

[2] Note that learning effects have often not been separated from the economies of scale even though they are of different natures: the former are seen as dynamic effects; the latter as static effects. In other words, the learning rate depends on the cumulative production, while scale effects refer to the current production output. Only a few studies have tried to separate economies of scale and learning by doing (e.g. Isoard and Soria, 2001) and demonstrated that such separation is necessary in order to avoid overestimation of learning rates.

KS = Knowledge stock (here: approximated through R&D investments, €)
α = Elasticity of learning by doing
β = Elasticity of learning by researching
a = normalisation parameter with respect to initial conditions

The knowledge stock is calculated as the cumulative global R&D investments throughout all times (yet limited by data availability). The depreciation rate of historic R&D investments has been set at 3% following (Klaassen et al., 2005). Any uncertainty introduced with the level of the depreciation rate for the past R&D investments is considered limited because much of the corporate R&D investments have been realized in more recent years. The delay between an increase of the knowledge stock via the rise in R&D investments and the resulting technological improvements has been assumed to be 2 years, following (Watanabe, 1999, 2000; Klaassen et al., 2005). This relatively short time lag can be justified by the fact that all of the technologies considered have experienced substantial research efforts over the past decades, which has led to a considerable R&D infrastructure that can absorb additional investments with limited time delays.

The parameter a is calculated by applying equation (2) for the initial point of the learning curve, i.e. using cost of production ($C_{t,0}$), cumulative production ($Q_{t,0}$) and knowledge stock ($KS_{t,0}$) for the initial year 0. This relation can be expressed as follows:

$$a = \frac{C_{t,0}}{Q_{t,0}^{-\alpha} KS_{t,0}^{-\beta}} \qquad \text{(Equation 3)}$$

An analogous equation is used to determine the normalisation parameter of equation (1):

$$m = \frac{C_{t,0}}{Q_{t,0}^{-\varepsilon}} \qquad \text{(Equation 4)}$$

The parameters α and β in the equation (2) and (3), as well as ε in equation (1) and (4) are the learning elasticities. The so-called learning rates are derived on the learning elasticities and relate to the cost reduction after each doubling of capacity or knowledge stock, respectively. They are defined as:

$$Learning\ Rate_{learning\ by\ doing} = 1 - 2^{-\alpha} \qquad \text{(Equation 5)}$$

$$Learning\ Rate_{learning\ by\ researching} = 1 - 2^{-\beta} \qquad \text{(Equation 6)}$$

$$Learning\ Rate_{OFLC\ learning\ rate} = 1 - 2^{-\varepsilon} \qquad \text{(Equation 7)}$$

An extensive survey by Kahouli-Brahmi (2008) lists 77 learning-by doing rates and 17 learning-by-researching rates for various energy technologies. In general, relatively low learning-by-doing rates in the order of 2-4% prevail for mature technologies such as coal, oil, and lignite-based power production. For new renewable energy technologies, such as PV power production, learning by doing rates in the order of 10-20% are reported. However, it must be noted learning rates are observed also to change along the historical deployment of each technology. For example, early coal deployment showed a rapid learning, while today the learning is rather limited. The ranges for learning by researching rates are based on a much smaller number of studies. They are around 10-15% for wind energy, photovoltaics, hydropower and gas combined cycle turbines.

It is important to remind that the learning rate methodology is associated with some uncertainty. The learning rates can differ significantly for the same data sets across various approaches (Söderholm and Sundqvist, 2007). Also negative learning rates occur (e.g. Neij, 2003 for wind turbines; Claeson, 1999 for CCGT). Furthermore, the learning by doing and learning by researching effects are linked. They act as a virtuous cycle that reinforces itself (Watanabee et al., 2000; Schade, 2006).[3]

2.2 Two factor learning curve spreadsheet model

The goal of the Two Factor Learning Curve Spreadsheet model (TFLC model) is to quantify the effect of R&D investment on the economic performance (*investment cost evolution*) of a given technology. The resulting parameters are then used as an input to the POLES model to evaluate the response of the energy sector, both in terms of technology penetration and system costs.

The TFLC model is able to establish one factor and two factor learning curves for a given technology using specific scenarios of the evolution of the factors that determine the learning of the technology, in this case, the learning-by-doing and/or the learning-by-researching[4].

This model uses a common template for each technology. Each template contains an input section gathering the scenarios of the evolution of the learning factors (historical and future) and two main calculation routines.

The first routine computes (i) a one factor learning curve that links the investment cost and the cumulative deployment for a reference case, and (ii) decouples this curve into a two factor learning curve that links the investment cost with cumulative deployment and knowledge stock. The first calculation is done via iteration with the POLES model, whereas the second calculation uses assumptions of the evolution of public and corporate R&D investments.

The second routine computes a new two factor learning curve for an optimistic scenario based on the two factor learning elasticities (α, β) determined in the first routine (defined as innovation profile, see below). Hence, the spreadsheet model calculates, for this optimistic scenario (see section 3.2 for the definition of the scenarios), a new investment cost evolution and public and private R&D investment that are linked to a new cumulative deployment. Convergence between the two-factor learning curve spreadsheet model and the POLES outcome is achieved through iterations in which the output of the first are used as input to the second and vice versa in the next step.

More specifically, the following steps are performed for each technology:

1) **Calibration of investment costs to cumulative production for the reference case**: Trends in technology investment costs are determined by applying in an iterative process a one-factor-learning (equation 1) to the installed capacities that are taken from scenarios

[3] Overall, taking into account the problem of separating economies of scale from learning, of internal feedback between various ways of learning and technological and national spill-over effect, there is a risk that learning rates are overestimated. This can be of high importance in particular when introduced into energy modelling for assessing the costs of bringing a new energy technology into the market.

[4] It is noted in reality that other factors than R&D efforts and innovation feed-back acquired through market deployment, influence the investment cost evolution of a technology. Market dynamics of raw materials and engineering and building capacities play also an important role. For instance, if the latter factors are constrained, as shown in the recent past, the learning potential stemming from knowledge and experience gains can be offset. However, these factors are not accounted for in this analysis.

generated with the POLES model. The assumption in the model is that the annual installed capacities are equal to the annual production of a given technology. The learning rates applied (OFLC learning rate, equation 7) are derived from the technology assessment described in the respective chapters of this document (summarised in Table 3.7). It is assumed that the resulting one-factor learning curve is representative of technology developments that can be expected from a status-quo of current R&D investments in the future, hence compatible with a reference case.

2) **Decoupling of learning by researching and learning by doing components for the reference case**. The cost evolution determined in step 1 is used to construct a two-factor learning curve that fits the OFLC for the reference case, connecting historical and future investment costs, cumulative installed capacities and R&D investments. A learning-by-researching rate (equation 6) is assumed based on calibration on historic data, literature review and JRC expertise. The learning-by-doing rate (equation 5) is then used as a variable to calibrate the two-factor learning curve (equation 2). Some technologies have not yet entered the market which prevents any econometric estimate based on historic data. In these cases, literature review and JRC expertise is used to determine learning-by-researching rate.

3) **Innovation profile transfer between the two scenarios**. The effectiveness of the main components of the innovation chain as identified in step 2 is assumed not to change significantly between an optimistic scenario and a reference case. Hence, learning-by-researching and learning-by-doing rates are assumed not to change across the scenarios[5]. Changes between the scenarios are therefore triggered by the increase in R&D efforts in monetary terms, while the deployment of a given technology differs between the two scenarios as a response effect computed by the POLES model.

4) **Investment costs forecast for the optimistic scenario**. A two-factor learning curve is constructed for the technologically optimistic scenario based on the previous steps. In other words, the investment costs evolution up to 2020 is calculated using the learning rates from step 3, the R&D investments derived from the assumptions used for the optimistic scenario, and the cumulative installed capacities through iteration loops with the energy system model. Similarly to step 1, the model assumes that the global annual installed capacities are equal to the annual production for a given technology.

5) **Consistency check**. As technology learning is mostly reported in the literature as the elasticity to cumulative production, a new one-factor learning rate is determined for the *optimistic* scenario, using the cumulative capacities and cost evolution from step 4. This enables a direct comparison with ranges reported in the literature (e.g. IEA, 2008; European Commission (2008a, b), but also to measure under a single matrix the difference between the reference case and the optimistic scenario.

As noted for step 1 and 4 an iterative approach is conducted using the POLES model to account for the dependency of the investment costs and the deployed capacities at the system level. To start with, the cost evolution is calculated assuming a certain capacity deployment. The latter is introduced in the POLES model. A convergence loop is then performed to calibrate investments and installed capacities. An overview of the algorithm used and iteration loops involved between the scenario making and the calculation of the investment costs evolution is shown in Figure 2.1.

[5] This assumption can be considered as conservative when considering that the SET-Plan not only aims at supporting higher research investments but targets an improved efficiency of the European innovation system by better exploiting synergies between Member States and between public and industrial actors.

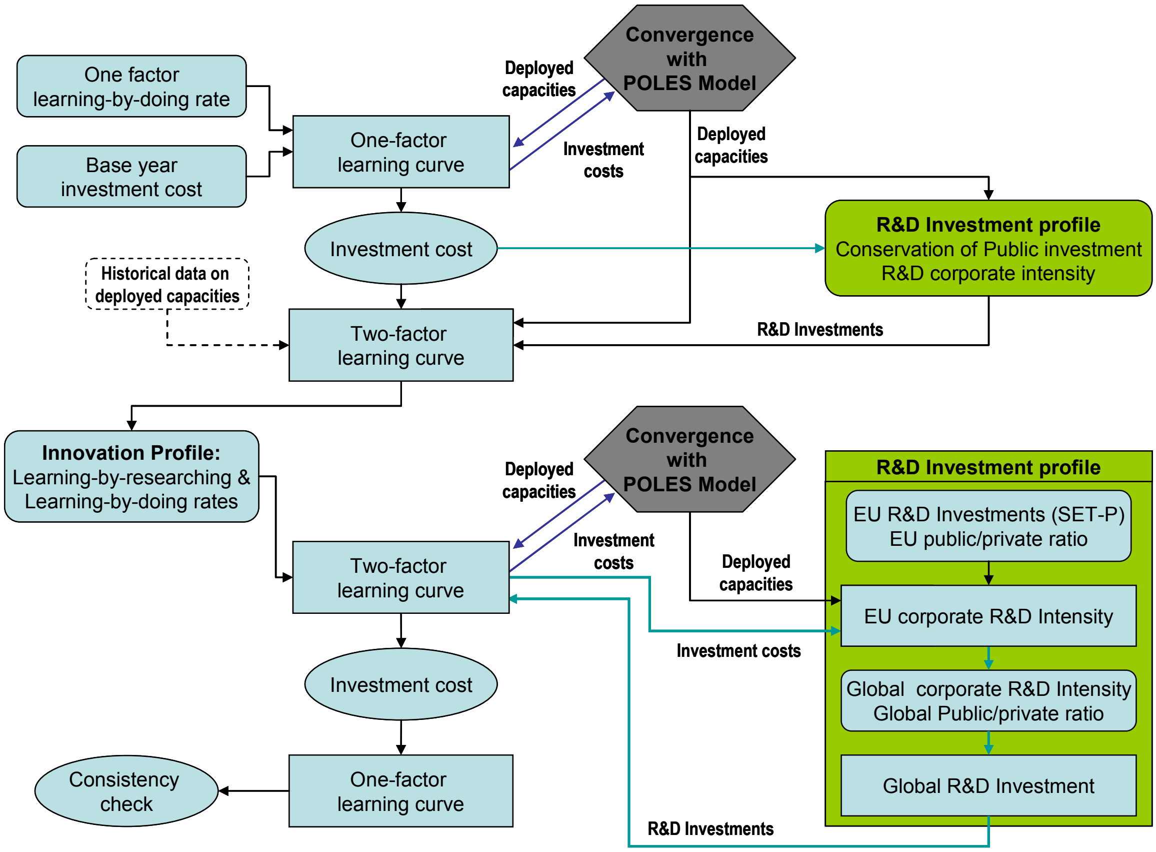

Figure 2.1: Overview of the algorithm used for investment cost forecasting

2.3 The POLES model

The POLES (Prospective Outlook for the Long term Energy System) model is a global sectoral simulation model for the development of energy scenarios until 2050. It is being applied for:

- Scenarios and projections for energy demand, supply and prices (not forecasts), such as the World Energy Technology Outlook (European Commission, 2006a);
- Analysis of CO_2 emission reduction pathways in an international perspective, such as the assessment of Global Climate Policy Scenarios for 2030 and beyond (Russ et al., 2007, 2009)
- Impacts of technological change (e.g. Uyterlinde et al., 2007).

The dynamics of the model are based on a recursive (year by year) simulation process of energy demand and supply with lagged adjustments to prices and a feedback loop through international energy prices.

The model is developed within the framework of a hierarchical structure of interconnected modules at the international, regional and national level. It contains technologically-detailed modules for energy-intensive sectors, including power generation, production of iron and steel, aluminium and cement, as well as modal transportation sectors.

In each sector, energy consumption is calculated both for substitutable fuels and for electricity. Each demand equation contains an income or activity variable elasticity, a price elasticity, captures technological trends influencing the energy demand and, when appropriate, saturation effects. Particular attention is paid to the treatment of price effects.

The world is subdivided into 47 regions, for which the model delivers detailed energy balances. A single world oil market is assumed (the "one great pool" concept), while three regional markets (America, Europe and Asia) are identified for coal in order to take into account different cost, market and technical structures. Natural gas production and trade flows are explicitly modelled on between 14 main regions/countries, hence allowing for the identification of a large number of geographical specificities and the nature of different export routes.

All energy prices are determined endogenously in POLES. Oil prices in the long term depend primarily on the relative scarcity of oil reserves (i.e. the reserves-to-production ratio). In the short run, the oil price is mainly influenced by spare production capacities of large oil producing countries. It must be noted that the endogenous price forming mechanism cannot model the price volatility induced by short term market expectations.

The model is continuously being enhanced both in detail and by regional disaggregation. Recent modifications include the addition of detailed modules for energy-intensive sectors (see, e.g. Szabó et al., 2006), and the extension to cover non-CO_2 greenhouse gases (see Criqui, 2002; Criqui et al., 2006).

The model has been slightly adapted for the present work in order to capture the SET-Plan effect. For example, the possibility of reflecting market-pull mechanisms for CCS has been introduced and a number of technology pathways have been adapted to the techno-economic characteristics provided in the various chapters of the Technology Map.

2.4 Uncertainties

Capturing the factors that drive the learning of a given technology is a multi-dimensional problem. Technology change occurs via a number of technical, social, economical, environmental and organizational factors. Feedback loops occur throughout its life cycle, i.e. production, usage, R&D efforts, interaction between different social actors etc (Grübler, A., 1998). Additionally, market dynamics of raw materials and engineering and building capacities play also an important role, both as accelerator or decelerator of technology learning. For instance, if the latter factors are constrained, as shown in the recent past, the learning potential stemming from knowledge and experience gains can be offset. As such, the modelling approach used in this study based on R&D efforts and innovation feed-back acquired through market deployment is a significant simplification of the technology cycle, purposely developed to meet the objective of analyzing the impact of additional RD&D efforts.

Furthermore, within the defined model, the present work carries as well a number of uncertainties:

- From a *methodological viewpoint*, establishing a quantified relationship between RD&D inputs and technology improvements is difficult due to the existence of spillover effects. Such a relationship has nevertheless been used in the form of a Two-Factor-Learning Curve here. In addition, the knowledge stock is approximated by the cumulative R&D investments (with some adaptation in form of depreciation and time lag), and therefore disregards improvements in the way research is being carried out in the EU even though the latter is one of the shortcomings tackled by the SET-Plan. Finally, the Two-Factor-Learning Curve approach limits the technological trends to cost reductions and therefore does not account for any positive effects on the technological characteristics (such as efficiency improvements).
- From a *market environment point of view*, it is assumed that similar R&D efforts on a trend basis as the ones proposed by the European Union in the context of the SET-Plan are undertaken worldwide. This assumption carries a certain level of uncertainties as not all regions of the world have engaged into similar policies. However, following the

declaration of the leaders of the Major Economies Forum on energy and climate change from 09 July 2009 stating clearly the need to spur development and deployment of low-carbon and climate-friendly technologies at the global level, similar developments are taking place in different parts of the world. For instance, the United States of America (US) have launched ambitious initiatives on this front through the American Recovery and Reinvestment Act of 2009 enacted by the United States Congress in February 2009.

- *Limited availability of data* on historic R&D investments by technology makes it challenged to derive parameters for this Two-Factor-Learning Curve. Due to the lack of a comprehensive dataset of global RD&D investments from public and private funders by technology, these were approximated on the basis of limited data available.
- Rough assumptions had to be developed on the trends in *future R&D investments* by technology under a baseline and an accelerated framework. This task becomes even more challenging as, due to the global nature of technology learning, such assumptions had to be made not only for the EU but for the entire world.
- Similarly, not only the R&D trends but also the *market environment* for new technologies is based on some (simplified) assumptions. For the present exercise, a simplified EU-wide but technology-specific development of renewable energy support schemes has been assumed, which impedes the use of the scenarios as forecasts.

Because of the above mentioned limitations, the results of the present analysis must be interpreted with care and require further exchange on the methodology, data and assumptions. Nevertheless, they constitute a coherent and transparent first attempt to estimate the impact of SET-Plan like efforts to strengthen research on low-carbon technologies in the EU.

3 Historical and assumed future levels of R&D investment

3.1 Historical R&D investments

There is no available database providing technologically disaggregated information on historical data on public and corporate R&D investment in a consistent way. Funding levels have instead been collected technology by technology. When deriving data from different sources, the estimates can only provide an order of magnitude, and should be used only for the purpose of applying the two-factor learning curve in this context.

Two main data sources have been used for approximating historical and current R&D investments both for the EU and globally: the IEA R&D statistics and the latest SETIS capacity map on 'R&D Investment in SET-Plan priority technologies'.

3.1.1 Public historical R&D investments

Information on public R&D investments is mainly taken from the IEA Energy Technology RD&D Statistics Service[6]. The breakdown of the IEA R&D data follows a scientific/technical nomenclature[7] which is in line with the requirements of this report.

Currently, 19 of the 27 EU Member States are IEA members. Consequently, the database systematically contains no data for the other countries, i.e. for: Bulgaria, Cyprus, Estonia, Latvia, Lithuania, Malta, Romania, and Slovenia. Nevertheless, the aggregated R&D budgets of the Member States covered by the IEA database account for almost 99% of the overall EU-27 energy budget according to GBAORD[8], thus limiting the errors incurred by a lack of data in the missing EU Member States. At a global level even more countries are missing; in total, only 28 countries are IEA members. Apart from the European members, these include the large energy R&D funders USA and Japan, but miss e.g. China.

On top of the national public R&D investments, funds through the various Research Framework Programmes have been taken into account for the EU region. A detailed assessment of FP6 is taken from (Wiesenthal et al., 2009), while for FP7 only some provisional figures of the first call have been analysed. Data from previous research framework programmes are taken from a variety of resources, including (Jäger-Waldau, 2009) for PV, (Langlois d'Estainot, 2009) for wind energy, (European Commission, 2004) for CCS under FP5, (European Commission, 2007d) for CSP. For bioenergy (as well as for other low-carbon technologies), estimates of FP5 EC funding are provided by (European Commission, 2006b).

Note that data gaps in the IEA R&D statistics make it difficult to assess the trend of R&D investments over time. This is due to changes in the methodology, the geographical coverage etc. For example, most of the IEA members did not report data in the first years of the statistics. For 1974, data are available for only 10 countries and even less so when looking at the sub-categories that are of interest in the present assessment. In some cases, the regional boundaries or the methodologies vary. For example, the German data prior 1992 do not include the new Länder and France recently changed the methodology applied for calculating its national public research and development expenditure on energy (DGEMP 2007; MEEDDAT, 2008). Other Member

[6] A publicly accessible database on energy R&D, D budgets from the IEA member countries, based on data that are collected from government funders.
[7] See also European Commission (2005) for a comparison of energy R&D statistics in the European Union.
[8] Government Budget Appropriations or Outlays on R&D; Eurostat/OECD database.

States have provided only partial information for few years. For Belgium, data for the years 2000-2006 are missing. Furthermore, any aggregation of national data to R&D investments of regions or the world suffers from some mismatches in the way data are reported across countries. Differences lie in the scope of relevant R&D allocated to energy; the extent to which regional data are captured and the inclusion of institutional funding.

Table 3.1 presents the cumulative R&D investments by technology as approximated with the above-mentioned approach. Note that these figures are in constant $Euros_{2008}$. For their use in the two-factor-learning curve they have been further modified by assuming a depreciation of knowledge of 3% (as explained in section 2.1).

Table 3.1: Cumulative public R&D investment in the EU and global (OECD)

Technology	EU public R&D investment in 2007 (billion EUR_{2008})	Cumulative public R&D investment 1974-2007 (billion EUR_{2008})	
		EU accumulated	Global accumulated (IEA member countries)
Wind energy	0.092	2.2	3.6
Photovoltaics	0.163	3.2	7.2
Concentrating solar power	0.038	0.9	2.6
Bioenergy (excl. biofuels)	0.211	2.1	4.7
CCS	0.056	0.25	0.54

Source: data from IEA; EU figures for 2007 taken from Wiesenthal et al. (2009)
Note: Figures from the IEA have been complemented by relevant investments under the EU Research Framework programmes. In the case of bioelectricity, which consider both bio-electricity only and cogeneration of heat and power, relevant R&D figures are approximated by considering the 'total bioenergy' R&D investments minus those parts related to transport biofuels instead of using figures from the subcategory 'applications for heat and electricity'. A focus on the latter would suffer from a substantial lack of data at that level of detail.

3.1.2 Corporate historical R&D investments

In order to estimate global corporate R&D investments and historic time series, several approaches had to be combined, depending on the type of basic information that was available.
In order to estimate global historic R&D investments, approximations had to be used and some assumptions were made. Except for CCS, where no significant capacities have been installed so far, a three step approach was followed:

1. For every year, the annual installed capacity was identified as a sum of the additional operating capacities and replacement of technology after its lifetime, on both the EU and global level;
2. The turnover of the energy equipment manufacturing industry was approximated by multiplying the specific investment cost in a given year by the annual installed capacity in the same year;
3. The corporate R&D investments were assumed to be a proportion (R&D intensity) of the turnovers made by the different corporate intervening in the region in a given year.

It is noted that the cumulative production should be used to calculate the learning curves (equation 1 and 2). However, as this information is limited, the cumulative installed capacities in the EU and in the Rest of the World (ROW) are used as a starting point (step 1). It is assumed that industrial developments and R&D expenditures are formed regionally following an internal market approach. This allows allocating corporate R&D investments per region based on their turnover. Trade effect, technology import/export and world technology leadership by one part of the world are therefore neglected at this stage. Although the global dynamics of energy technology markets should be considered, this assumption is justified not only by the need to simplify the approach due to the lack of data available, but also by the fact that each scenario assumes similar efforts in each region modelled (EU and ROW). Hence, it can be further assumed that if trade occurs from one region to another region, this may be equally balanced in the reverse direction.

Beyond these simplifications, the approach has further limitations and its results need to be seen in this context. Firstly, it implies a focus on the equipment manufacturer through the way in which the turnover is determined. This neglects R&D efforts carried out by component supplier, unless they are paid for by the manufacturers, and the users (such as electric utilities). Secondly, uncertainties are introduced by estimating the turnover of the industry by applying a certain value per installed/produced capacity (R&D intensity). Thirdly, uncertainties are related to the assumption of a constant R&D intensity over time (but differing between the scenarios). It is likely to assume that companies are more willing to mobilize research efforts for a technology that has achieved a certain degree of technical maturity and thus reduces the investment risks. At the same time the experience from other sectors such as IT shows the importance of high R&D intensities in the early product development. Furthermore, external conditions can have an important influence on the level of and the way in which research is conducted. A number of studies prove e.g. the effect of the liberalization on energy research (EURELECTRIC, 2003; Jamasb and Pollitt, 2005; Markard et al., 2006).

In the case of CCS, no similar approach could be followed due to an unknown turnover of the industry. The estimation of corporate R&D investments in CCS relies on a letter of the Chairman of European Technology Platform for Zero Emission Fossil Fuel Power Plants from 21 February 2008, according to which the corporate commitments of the signed companies to the early development of CCS, as well as the achievement of CCS-related efficiency-increase, already amount to a total of more than €635 million over the past five years in aggregate. A comparison with the corporate R&D investments published in (Wiesenthal et al., 2009) of EU-based companies reveals that the EU-based signees of that letter account for around €190-200 million of the total €240 million found in that study. At the same time, however, the signees of that letter also include at least three large non-EU based R&D investors, namely Schlumberger, Statoil and General Electric. In total, we assume that the €635 million can be used a reasonable estimation of the corporate R&D investments of EU-based industries since 2003, and that before this data only limited R&D efforts were carried out by industry (ca. €50 million).

On the basis of this figure, a rough estimation has been made for the global corporate R&D efforts in CCS from the power sector (but neglecting research efforts undertaken by energy-intensive industries). Companies interested in CCS are usually allocated to one of the following six sectors (using the ICB classification): oil and gas producers; oil equipment, services and distribution; electricity; gas, water and multiutilities; electrical components and equipment; industrial machinery. From the EU Industrial R&D investment scoreboard, the 2008 R&D investments for each group could be identified for both EU-based and non-EU-based companies. As the aggregated R&D investment of non-EU based companies from these sectors is around one third above that of EU-based companies, the global corporate R&D investments in CCS has been assumed to be 2.33 times the EU level.

Table 3.2: Cumulative corporate R&D investment in the EU and global (OECD)

Technology	EU corporate R&D investment in 2007 (billion EUR_{2008})	Cumulative corporate R&D investment 1974-2007 (billion EUR_{2008})	
		EU accumulated	Global accumulated (IEA member countries)
Wind energy	0.29	2.2	3.6
Photovoltaics	0.22	0.6	1.2
Concentrating solar power	0.05	0.2	1.1
Bioelectricity	0.06	1.4	3.9
CCS	0.24	0.7	1.6

Note: Figures for 2007 are taken from Wiesenthal et al. (2009)
Data are very rough approximations only and shall be used only for the purpose of the present analysis

3.2 Future R&D investments

3.2.1 Scenario framework

In order to assess the SET-Plan effect, two scenarios are constructed that differ in their level of (cumulative) R&D investments by technology. These distinct cumulative R&D investments result in different developments of investment costs and deployed capacities, following the logic of the two-factor-learning curve. The two scenarios assessed comprise:

1. A *Reference* scenario which assumes the conservation of the current situation with respect to R&D investments, which means that R&D follows business-as-usual trends. In this scenario, corporate entities maintain their R&D intensity at current level while public authorities maintain the amount of funding at today's level;
2. A '*Global SET-Plan*' scenario for the entire globe which assumes that the financial SET-Plan gap of R&D investments on low-carbon energy technologies as identified in the SET-Plan *Communication on Investing in the development of Low Carbon Technologies* for the EU[9] is met, while equivalent R&D efforts are pursued at the global level in a coordinated and harmonised manner. Assuming an ambitious rise in global R&D efforts reflects recent calls from G8 leaders[10]; moreover, it also avoids leakage effects from an EU-focused action only.

Both scenarios build on the iTREN-2030[11] integrated scenario. This means that overarching trends on economic development of the EU and its Member States already incorporate the recent economic crisis. Furthermore, the iTREN-2030 integrated scenario already simulates all major European energy, transport and climate change policies that are implemented by now or that have a high probability to become implemented between now and 2025 (see section 4.1 for more details). Beyond 2020, it is assumed that the investment level in the global *SET-Plan scenario* is the same as in the reference case, allowing capturing the effect up to 2030 of the additional R&D investments made during the period 2010 to 2020[12].

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[9] COM(2009) 519

[10] This scenario builds on the recommendation of Stern report issued in the context of the G20 to establish a global SET-Plan initiative.

[11] This scenario has been developed in the context of the FP6 research project íTREN-2030. A key task of iTREN-2030 was to generate a consistent reference development until 2030 that is integrates and harmonizes technological developments on the energy and transport side, energy prices and economic trends with demand for energy and transport and their environmental impacts.

[12] It is noted that, the level of variability of power supply is likely to increase between the two scenarios due to the increased share of wind and photovoltaics. The extent of additional investments to accommodate this variability is

3.2.2 Reference scenario

In the Reference scenario R&D investments are assumed to follow business-as-usual trends. It means that public R&D investments in the period 2010-2020 are assumed to remain at a level equal to the public investments in 2007. This is justifiable as for public R&D investments, no clear trend (except probably for CCS) can be observed over the past decades that would allow a prediction on the further development until 2020 and beyond; in general, public energy R&D investments declined over the past two decades before slightly rising again in more recent years. Yet, this largely depends on the R&D priorities assigned to specific energy technologies, which cannot be predicted. Furthermore, any such prediction becomes even less certain when considering the recent changes induced by recovery measures taken by most governments and the resulting public dept, which have the power to drastically change past trends and thus impede an extrapolation to the future.

For industry, we assume that R&D intensities remain at the same level as the ones determined for the year 2007 in the Capacities Map 2009[13]. Hence, corporate R&D investments develop in line with the net sales of the industries. Nonetheless, the current economic downturn will not be conducive for additional efforts in R&D.

In computational terms, the annual corporate R&D investment is derived for the EU and the Rest of the world based on the turnover by considering the projected investment cost and the annual deployment in each region, following the same procedure as described in section 3.1.2. Hence, the calculation of corporate R&D investments depends on the actual installed capacities, which requires iteration loops with the POLES model Table 3.3 shows the set of R&D intensities assumed for the Reference scenario.

Table 3.3: Corporate R&D intensity for Reference scenario

Reference scenario	Corporate R&D intensity, Global
Wind	2.6%
Photovoltaics	2.5%
Concentrating solar power	2.5%
Bioelectricity	2.5%
CCS	2.5%

Note: R&D intensity is defined as R&D investments over turnover

3.2.3 Global SET-Plan scenario

The Global SET-Plan scenario assumes that all world regions and technology manufacturers, over the period 2010-2020, undertake similar R&D efforts on a trend basis as the ones proposed by the European Union in the context of the SET-Plan. While, at first glance, this seems to be overly optimistic, it should be seen in the context of the recent commitments from the G8 to increase their R&D investments in low-carbon technologies. The declaration of the leaders of the major economies forum on energy and climate change from 09 July 2009 states that '*We will dramatically increase and coordinate public sector investments in research, development, and demonstration of these technologies, with a view to doubling such investments by 2015, while recognizing the importance of private investment, public-private partnerships and international cooperation, including regional innovation centers*'. Furthermore, Edenhofer and Stern (2009)

still a matter of research. Different mitigation options are available ranging from demand side management, grid reinforcement, storage more flexible generators. Such analysis is beyond the scope of the present work and would require the use of additional models such as grid and dispatching models.

[13] The R&D intensity for wind and photovoltaics is based on the corporate R&D investments found for EU-based companies in the latest Capacity Map (Wiesenthal et al., 2009). For the other sectors, where such information was not available, an R&D intensity of 2.5% was assumed.

recommended to the G8 the 'development of a G20 Strategic Energy Technology Plan, modelled on the European example'. Furthermore, it may be likely to assume that other world regions would react to unilateral European technology push efforts in order to prevent loosing their market position.

The level of public and private R&D investments under the global SET-Plan scenario up to 2020 is determined using a three steps iterative approach:

(1) Determination of the total R&D investment for the EU in the period 2010-2020;

(2) Assuming a ratio of public-private R&D funding for each technology based on (Wiesenthal et al., 2009), the corporate R&D investments are estimated. Putting them into context with the projected turnover, which in return relies on the installed capacities, R&D intensities are calculated;

(3) Calculation of a corporate R&D intensity for the EU considering constant public/private ratio for the EU;

(4) Calculation of the global R&D investments by assuming the same corporate R&D intensities as for EU-based companies and applying them to the turnover based on projected globally installed capacities. The public R&D investment is estimated by assuming the same ratio of public and private R&D funding as for the EU.

With respect to step 1, the designated level of R&D investment in the EU is determined using the SET-Plan R&D investment needs for achieving the respective sectoral technology objectives recently published in "A Technology Roadmap"[14] and are summarised in the Table 3.4 below[15].

Table 3.4: Estimated RD&D investment needs for the period 2010-2020 in the EU

Technology	R&D investment needs (bn Euros)
Wind energy	6.0
Photovoltaics	9.0
Concentrating solar power	2.3[16] (+4.7 as deployment investment)
Bioelectricity	2.0[17]
CCS	3.0[18] (+10.5 as support for first-of-a-kind investment)

Source: Based on SEC(2009) 1297; refined with the assumptions noted above

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[14] SEC(2009) 1295

[15] It is noted that the actions foreseen in the different roadmaps vary in nature (applied research, demonstration etc.) according to the needs and specificities of the technologies. The present analysis does not analyse the impact of each actions separately. It values the impact on market roll-out and deployment of all constitutive actions of the roadmap as an integrated R&D, D -cycle.

[16] Only the innovative part of the total investment presented in the roadmap is considered in this analysis. As published in the sector proposal for a European Industrial Initiative on CSP ("Solar Power from Europe's Sun Belt", ESTELA, 2009), the innovative part is estimated as one third of the total investment costs (2.31 bn Euros out of 7 bn Euros).

[17] There is no technology roadmap focusing on bioelectricity. Instead, the roadmap focuses on all energetic uses of bioenergy, including its use as transport fuel, for heat and for electricity. The present model-based analyses, however, is restricted to the power sector(including for bio-energy the cogeneration of heat and power). It has thus been necessary to break down the indicative costs for achieving the Bioenergy technology objectives so as to match bioelectricity. As many of the technology objectives relate to biofuels, we estimate the upper limit of the R&D investments required for bioelectricity to be €2 billion.

[18] Note that only a part of the total investments presented in the roadmap, i.e. investments for longer term R&D activities, is considered to contribute to the knowledge stock, on top of the R&D investment forecasted to be made in the reference scenario which is assumed to be made also in the Global SET-Plan scenario. The remaining part the total investment presented in the roadmap, dedicated to cover the additional cost of first-of-a-kind CCS plants compared to the similar conventional technology, is accounted in the economic assessment of the scenario.

The investments considered as part of the knowledge stock are those related to technology development up to the first commercial unit. In line with this assumption, for CSP technologies, only the innovative part of the total investment presented in the roadmap is considered in this analysis. The remaining amount is considered in the analysis as a deployment investment of commercial units, hence is duly accounted for. The 10.5 b€ presented in the CCS roadmap is designed to cover the additional cost of first-of-a-kind CCS plants compared to the similar conventional technology. A specific demonstration scheme has been modelled as a support to the production costs instead of a one-off investment in order to account also for the higher variable costs of CCS plants, which is accounted in the economic assessment of the scenario.

As noted in the Impact Assessment of the EC Communication on investing in the development of low carbon technologies (European Commission, 2009b), current R&D investment can cover some part of the future financial RD&D needs pointed out by the various technology roadmaps while for the remainder additional efforts are necessary. Nonetheless, not all of today's research activities focus on the objectives pointed out in the various roadmaps; hence only a fraction of present R&D investments would contribute to their financial needs. This fraction of existing investments is estimated to range between 50% and 70%. In the present study, this level is kept constant over time for the sake of simplicity. However, one can expect an increasing part of these R&D investments to get refocused on the technology objectives of the roadmaps and the knowledge stock from 'neighbouring' areas to spill over. Nonetheless the exact proportion is unknown and such dynamic evolution has not been assumed in this exercise.

Table 3.5 shows the total R&D investments foreseen in the EU for each technology, for the period 2010-2020. It comprises the financing needs proposed in the SET-Plan and the R&D investments foreseen in the reference case, but which do not to directly contribute to the SET-Plan European Industrial Initiatives focus as elaborated above.

Table 3.5: Assumed total R&D investments in the EU for the SET-Plan scenario in the period 2010-2020 (including the investments that do not focus on the SET-P technology objectives)

Technology	Total R&D investments foreseen in Europe (bn Euros)
Wind energy	8.5
Photovoltaics	10.5
Concentrating solar power	2.5
Bioelectricity	3.6
CCS	6.2

In order to determine the distribution between private and public investments for the EU over the period 2010-2020, the ratio of corporate investments over the total R&D expenditures is assumed to be preserved at the same level as the ratio corresponding to the year 2007 in the Capacities Map 2009. R&D intensity is then calculated as the intensity which provides the level of corporate investment required to reach the total R&D investments foreseen in the EU under the SET-Plan (Table 3.5). The R&D intensity is derived through an iterative process, aiming at achieving a convergence between the three elements 1) knowledge stock through the future cumulative R&D investments, 2) the production stock by considering the capacities projected with the POLES model and 3) the specific investment costs calculated with the two-factor learning curve. Table 3.6 shows the calculated R&D intensities for the Global SET-Plan scenario, as well as the assumed ratios of corporate investments over the total R&D expenditures. This means that the corporate R&D intensity increases for all technologies compared to the reference case. This indicates the magnitude of the investment challenge required for meeting the policy goals and the expectation that industry will invest more[19], while the values are compatible although on the lower end with other industries having a strong innovation base such as the IT industry.

Finally, given that the assumption of equivalent R&D efforts being pursued at the global level, and that both industrial and public actors will increase their R&D investments in a similar fashion as the EU, the corporate/public ratio and corporate R&D intensity is assumed for the rest of the world at the same level as for the EU. The results of such an approach are detailed in section 0.

Table 3.6: R&D intensity and ratio of corporate investments for Global SET-Plan scenario

Global SET-Plan scenario	Corporate R&D intensity (EU and RoW)	Ratio of corporate investments over the total R&D expenditures in the EU and RoW
Wind	3.5%	75%
Photovoltaics	8.5%	60%
Concentrating solar power	4.5%	75%
Bioelectricity gasification	4.5%[20]	75%
CCS	7.0%	80%

3.3 Comparison of R&D investments between scenarios

Table 3.7 shows the parameters of the two-factor learning curve constructed for each technology according to the above-described methodology for the reference scenario. It is assumed that this innovation profile (i.e. separate learning rates) is also valid for the Global SET-Plan scenario (see section 2.1). The table also indicates the matching one-factor learning rate used as input for each technology in the Reference scenario. It also includes the one-factor learning rate corresponding to the investment cost evolution determined for the Global SET-Plan scenario for comparison purposes with ranges reported in the literature (e.g. IEA, 2008; European Commission, 2008a, b).

[19] Speaking points of Commissioners Potočnik at the Joint Press conference by Commissioners Potočnik and Piebalgs "Investing in low carbon energy technologies": “Where does EU stand at the moment? Our estimates for 2007 show that total public and private investment, from national and EU level, in the SET Plan priorities technologies amount around €3.2 bn. Studies also show that corporate and public R&D investments in these technologies largely concentrate in only few Member States. The industry finances around 69% of non-nuclear research activities but the R&D intensities – being between 2.2% and 4.5% - remain well below the intensities of other industrial sectors that have been booming lastly: for instance, the IT-related sectors experienced R&D intensities in the order of 8% to 18% over the last 5 years. So, if we are serious about reaching our political environmental objectives, this is simply not enough.” (SPEECH/09/448, Brussels, 7 October 2009)

[20] It is noted that R&D intensity is related only to the biomass gasification. For the conventional technologies of biomass combustion is assumed same intensity as for the Reference scenario, i.e. 2.5%.

Table 3.7: Learning rates for the scenarios and related experience curves

	Reference scenario			
	OFLC learning rate (eq. 7)	Global SET-Plan Scenario		
		Two-factor learning curve		OFLC learning rate (eq. 7)
		Learning-by-doing rate (eq. 5)	Learning-by-researching (eq. 6)	
Wind Onshore	7.0%	3.0%	10.0%	9.5%
Wind Offshore	7.5%	2.0%	10.0%	10.5%
Photovoltaics	20.0%	18.0%	9.5%	25.0%
Concentrating solar power	7.5%	5.0%	10.0%	10.5%
Bioelectricity - conventional	12.5%	7.0%	11.5%	12.5%
Bioelectricity - gasification	12.5%	3.5%	11.5%	14.0%
CCS	2.0%	1.0%	10.0%	3.5%

Cumulative total R&D investments (corporate and public) for the two scenarios, at the EU and global level, are summarized in Table 3.8. In addition, Table 3.9 provides for the *Global SET-Plan* scenario the additional R&D investments to the Reference scenario. These figures are presented separately for both corporate and public, and also for the EU and the rest of the world. Overall, the SET-Plan scenario foresees an additional R&D investment in the technologies considered here of €61 billion at a global level, of which €15 billion for the EU and €46 billion for the rest of the world. On top of this, it is assumed that around €10 billion are invested for the market deployment of CCS power plants, which can be considered as dedicated public-private shared market pull instrument rather than as an R&D investment.

Note that the differences in European R&D investments between the two scenarios are in line with the R&D needs shown in Table 3.4. Finally, the additional cost reduction to the Reference scenario, resulting from increased R&D investments in the Global SET-Plan scenario are given in Table 3.10.

Table 3.8: Global and EU cumulative R&D investments in billion Euros, historical and for two scenarios

Cumulative R&D investments [bn $€_{2008}$]	Historic investments (1974- 2007)		Reference scenario (1974-2020)		Global SET-Plan scenario (1974-2020)	
	Global	EU	Global	EU	Global	EU
Wind energy	7.2	4.4	27.0	10.5	40.0	13.5
Photovoltaics	8.4	3.8	17.0	8.0	38.5	15.0
Concentrating solar power	3.7	1.1	16.5	2.5	31.0	4.0
Bioelectricity	8.6	3.5	21.5	6.5	25.0	7.0
CCS	2.1	0.9	11.5	4.5	20.0	7.5

Table 3.9: R&D investments for Global SET-Plan scenario additional to the Reference scenario in period 2010-2020, for the EU and Rest of the world (RoW), in billion Euros

Global SET-Plan scenario [bn $€_{2008}$]	EU			RoW (Global - EU)		
	Corporate	Public	**Total**	Corporate	Public	**Total**
Wind energy	2.0	1.0	**3.0**	5.5	4.5	**10.0**
Photovoltaics	4.0	3.0	**7.0**	7.5	7.0	**14.5**
Concentrating solar power	1.0	0.5	**1.5**	7.0	6.0	**13.0**
Bioelectricity	0.4	0.1	**0.5**	2.0	1.0	**3.0**
CCS	2.5	0.5	**3.0**	4.5	1.0	**5.5**
Total	9.9	5.1	**15.0**	26.5	19.5	**46.0**

Table 3.10: Investment cost evolution in the Reference and global SET-Plan scenarios up to 2030, in Euros per kW

	Investment cost in Reference scenario [$€_{2008}$/kW]			Global SET-Plan: additional cost reduction compared to the Reference scenario values for 2020 and for 2030	
	2007[21]	2020	2030	2020	2030
Wind Onshore	1150	1000	950	5%	2%
Wind Offshore	2500	1400	1300	9%	4%
Photovoltaics	3900	1700	1350	13%	9%
CSP	5900	3150	3050	11%	10%
Bioelectricity - conventional	2800	2300	2000	0%	0%
Bioelectricity - gasification	4800	2200	1800	7%	2%
CCS, PCC	-	2300	2150	8%	7%
CCS, IGCC	-	2000	1700	8%	7%
CCS, CCGT	-	1250	1100	8%	7%

[21] The investment costs derived from the technology map chapters have been harmonised for an investment year in 2007 using the methodology developed in the context of the second Strategic Energy Review (European Commission, 2008a) This methodology includes the effect of raw materials engineering and building capacities constraints as experienced in the recent years through the use of the chemical engineering plant cost index. It is noted, however, that the cost evolution in the future does not account for this effect as explained in section 2.1

4 Scenario results

In the following, the main differences between the *Global SET-Plan* and the reference scenarios will be assessed. The focus of the assessment lies on the trends in the SET-Plan priority technologies in the European power sector as well as on the economic assessment.

The effect of the SET-Plan investment is expected to become more pronounced in the time beyond 2020. This is due to the assumption that additional R&D spending until 2020 will start to materialize only with a delay of two years and the technological advantage developed in the previous decades influences the following years; furthermore, while until 2020 the trends in the European energy sector are similar *by construction* due to the precondition of both scenarios meeting similar targets by 2020, this condition has been dropped thereafter. In order to capture also the longer term effects of the SET-Plan, the assessment therefore takes into account trends beyond 2020.

The section starts with a brief description of the overall development of the energy sector in the reference scenario and the underlying macro-economic assumptions. It then defines the *Global SET-Plan* scenario and the sensitivity runs undertaken and compares their outcomes with the reference scenario. It looks into detail in the changes observed for relevant low-carbon technologies and the overall energy sector. It concludes with an economic assessment of the *Global SET-Plan* in relation to the reference case.

4.1 The reference scenario

The reference scenario largely builds on the integrated scenario constructed within the iTREN-2030 project[22]. It is characterized by four key elements:

- It incorporates the effects of the economic crisis: the GDP forecasts and associated value added of the various economic sectors reflect the recent economic downturn. This lowers energy demand and tends to lower energy-related CO_2 emissions.
- It endorses an ambitious climate change policy: it is assumed that the binding unilateral European greenhouse gas reduction target for 2020 (i.e. -20% below 1990 levels; European Council, 2007) will not only be reached, but even be over fulfilled. A domestic emission reduction in the order of 24%[23] as assumed here is in line with the more stringent EU target of a 30% reduction by 2020 which becomes reality under the condition of an international climate change agreement. In the model, these targets are achieved through a sector- and time-dependent carbon price following the example of the emission trading scheme (ETS); by 2020, the price would reach some 40 $€_{2000}$ per tonne of CO_2.
- It takes for granted an active renewable energy policy: the reference scenario will meet the European target of a 20% share of renewables in final energy demand. For model-related reasons, the target share of renewable energies in final energy consumption was

[22] A more detailed presentation of this scenario as well as a comparison with developments under baseline assumptions will become accessible as deliverable D5 of the iTREN-2030 project, published under http://www.isi.fraunhofer.de/projects/itren-2030/deliverables.htm. Differences to the iTREN-2030 integrated scenario mostly concern the assumptions on GDP trends that were taken from PRIMES here, while iTREN-2030 used figures from ASTRA. Nevertheless, these differences are of limited nature.

[23] A 30% target implies a domestic reduction of GHG emissions in the order of 22% (Russ et al., 2009), with the remaining reduction being realised through the use of flexible mechanisms. Due to the lower GHG emission levels that result from the economic crisis, the domestic GHG emission reductions in the EU are set at around 24% here.

set at around 18.7% instead of 20%, as the POLES model in its current version does not consider some emerging technology options[24]. The renewable energy policy has been approximated by assuming harmonised technology-specific renewable energy support premiums across the EU, which are based on information from the Green-X model (Resch et al., 2009). Note that these simplified assumptions on the future development of renewable energy policy support in the EU are well suited for the *instrumental use* of constructing a reference and a *Global SET-Plan scenario* that both meet the EU's energy and climate targets. At the same time, however, they do not allow to interpret the scenarios as outlooks on the likely deployment of individual technologies.

- Energy efficiency policies: Following the energy efficiency action plan, important improvements in energy efficiencies are assumed.
- Elevated fossil fuel prices: even though oil prices have been decreasing since their peak at about 150$/bbl in 2008, supported by the global economic downturn, rising demand from fast developing regions and uncertainty about the future availability of cheap resources are suggesting that crude oil prices will not fall back to the low levels observed before 2007. It is therefore assumed that the oil price remains at high levels with around 97 $€_{2007}$/bbl in 2020 and around 106 $€_{2007}$/bbl in 2030.

Even though the focus of the present analysis lies on the development of the European power sector, global developments are non-neglectable due to their interactions via fuel prices or technological learning that is triggered by global capacities etc. In line with the trends assumed for the EU, an active renewable energy and climate change policy has been assumed to be implemented also in many other world regions. Assumptions for non-European macro-economic trends and the related CO_2 values build on the global emission reduction pathway scenario that was developed with the POLES model and is documented in Russ et al. (2009).

The above assumptions mean that the European total energy demand will remain close to 2005 levels by 2030. The stabilization of energy consumption is largely achieved by a break in the historic trend of a continuously growing transport energy demand; transport energy consumption may even experience some slight reductions after 2010 due to lower transport activities and the introduction of new technologies. The economic crisis also largely affects industrial activities and so lowers the final energy demand of industry, while the residential and service sector are expected to further increase their energy consumptions. Unlike final energy consumption, the demand for electricity will continue to rise throughout all sectors, following the development in the past years. The fastest growth is expected for the households and services sector, given the trend towards more and bigger appliances in private households and the rising economic importance of the tertiary sector.

On the global level, energy consumption would further increase, driven by the rising demand in India and China and other emerging economies. Yet, energy growth would be limited to 26% by 2020 and 43% by 2030 compared to the year 2005, while under a baseline scenario significantly higher increases could be expected (see e.g. Russ et al., 2009 leading to a growth of 33% and 56% over the same periods under business as usual conditions).

[24] In a comparison between renewable energy scenarios done with the POLES and the GreenX models, it was found that these missing categories account for 1.2-1.3% of renewables in final demand by 2020 (Resch et al., 2009).

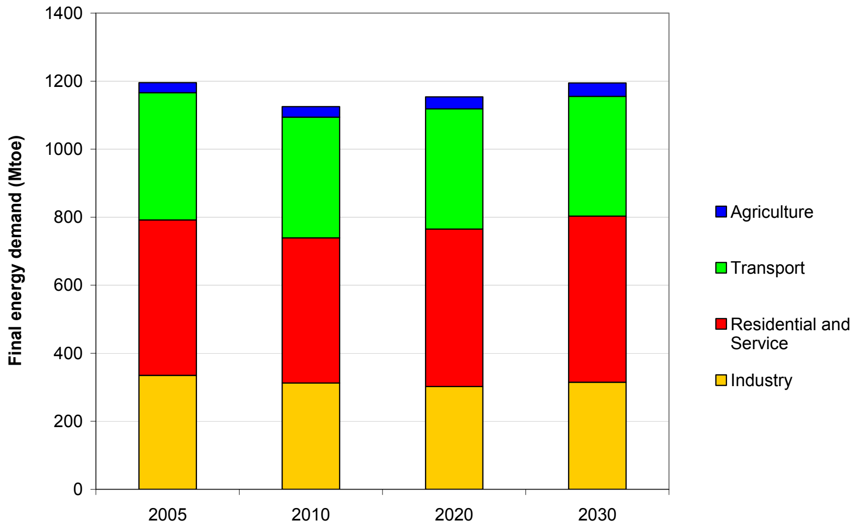

Figure 4.1: Trends in final energy demand in the reference scenario (EU-27)

On the supply side, the energy sector in general, and the power sector in particular, strongly react to the rising carbon dioxide price and the renewable energy policy by substituting carbon-intensive fuels with low-carbon alternatives. Coal-based power generation would be reduced by around one third between 2005 and 2030 while at the same time electricity generated by renewable energy generation (without large hydropower) increases by a factor of 7. Consequently, renewable sources would account for 37% of total electricity generation by 2020 in the EU, rising further to 43% by 2030. This compares to 27% and 29%, respectively, at a global level by the same dates.

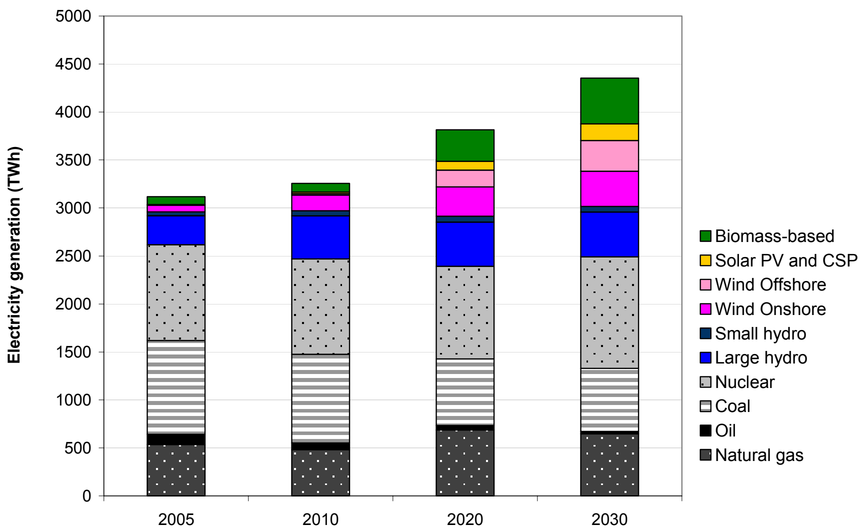

Figure 4.2: Electricity generation by fuel in the reference scenario (EU-27)

The combination of stagnating energy demand and decreasing carbon intensity of power generation leads to substantial reductions in the emission of greenhouse gases both compared to a baseline and the 1990 levels. By 2020, emissions would be 24 % below the emissions in 1990 in line with the targets set for the scenario. They will fall further to be 29% below 1990 levels by 2030. Major parts of the emission reductions are realized in the power sector (-36% between 2005 and 2030) but also in the residential sector (-34% over the same period).

On a global level, emissions would increase further until 2020 before they also start to decrease. By 2030, emissions would be 14% above the emissions of the year 2005. This can be indicatively compared to a rise in emissions of almost 60% in a baseline scenario over the same time period; however, note that the latter scenario has not been developed in the context of the present assessment (but in Russ et al., 2009) and can therefore not be directly compared.

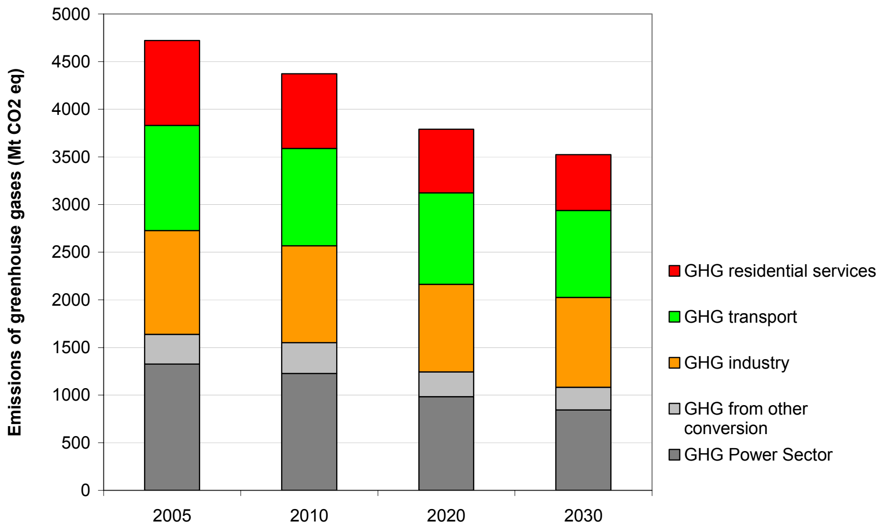

Figure 4.3: Development of GHG emissions (EU-27)

Overall, the reference scenario can be summarized as an ambitious development of the European (and global) energy system that encounters the challenges of drastic emission reductions and higher fossil fuel prices with a further switch towards low-carbon fuels and higher energy efficiency. At the same time, the consequences of the present economic downturn play an important role in reducing energy demand, especially over the coming decade.

4.2 The Global SET-Plan scenario and sensitivity runs

The Global SET-Plan scenario builds on the reference scenario with the following changes:

1. Investment costs of the SET-Plan priority technologies considered are reduced up to 2030 as described in Table 3.10. These cost reductions directly result from the increased global R&D investments and subsequent changes in installed capacities.
2. For the case of CCS, a dedicated demonstration scheme is assumed in the *Global SET-Plan* scenario on top of the additional R&D efforts, addressing the part of the production costs that stems from carbon capturing process for some demonstration plants. This demonstration scheme is capped at €10 billion for the EU[25]. At the global level, similar efforts are done in line with the roadmap developed by the IEA[26].

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[25] The specific demonstration scheme has been modelled as a support to the production costs instead of a one-off investment in order to account also for the higher variable costs of CCS plants. This scheme is assumed over the lifetime of the (few) plants considered. Nevertheless, for the economic evaluation the entire sum of €10 billion is allocated to the time period 2010-2020 as it is appropriated to that purpose even if actual payments may not occur before 2015 and could go beyond 2020.

[26] The IEA roadmap proposes that 'OECD governments increase funding for CCS demonstration to achieve an average annual investment of USD 3.5 bn to USD 4 bn from 2010 to 2020'. At the same time there should be an 'annual investment for CCS of USD 1.5 bn to USD 2.5 bn from 2010 to 2020 in non-OECD regions via the establishment of new financing strategies'. Over the ten year period 2010-2020 this would amount to 50-65 bn USD. We assume the lower value at an exchange rate of 1.25 USD=1 Euro. Subtracting from the global amount the

3. In the EU, renewable energy premium tariffs and the CO_2 price are adapted so as to achieve the same renewable energy and climate change target by 2020 as in the reference scenario.

Fixing these targets (point 3) across the scenarios allows investigating the impact of the global SET-plan effect on the costs of achieving them. The additional R&D efforts reduce the investment costs of several low-carbon technologies. Hence, the cost curve, which schematically reflects the cost and potentials of the available low-carbon energy options, is lower in the *Global SET-Plan* scenario than in the reference scenario (see Figure 4.4 for illustration). This leads to savings in the costs for achieving the same reduction of GHG emissions and of renewables by 2020 via the CO_2 permit price and specific renewable energy premiums, which can then be compared to the additional R&D investments in the SET-Plan (section 4.2.3).

By construction, this approach also implies that changes to the EU energy sector in terms of demand and supply are limited at least until 2020 (section 4.2.1). However, even though the overall share of renewables and emissions will not change between the scenarios by 2020, the SET-Plan affects the deployment of individual innovative technologies both at the EU and the global level, which are the reason for the lower cost curve in the *Global SET-Plan* scenario. This is analysed in section 4.2.2.

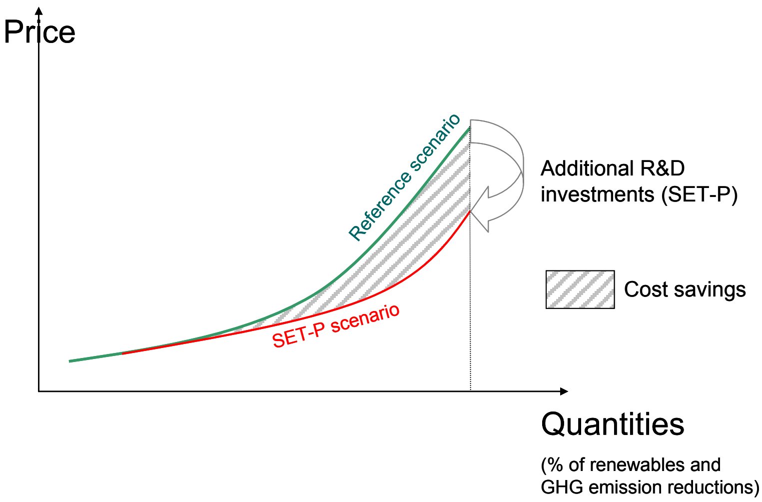

Figure 4.4: Schematic set-up of the two main scenarios analysed

Note: the chart is a simplification as the cost-resource curve is a step-function rather than a continuous curve. Moreover, the scenarios do not fix the quantities of renewables but their share in final energy demand, which nevertheless hardly varies across the scenarios.

In addition to the *Global SET-Plan* scenario, a sensitivity run called *'SET-P fixed prices'* has been performed in which the higher RD&D investments of the *Global SET-Plan* scenario are assumed while at the same time the restriction of fixed targets is abolished. Unlike in the *Global SET-Plan* scenario, support schemes and CO_2 prices remain at the level of the reference scenario. As a consequence of the reductions in technology costs triggered by the additional research activities assumed and the unchanged market environment, more CO_2 emissions will be avoided and the share of renewables will be higher than in the reference and *Global SET-Plan* scenarios[27].

investments considered for the EU (€ 10 bn) leads to the assumption of € 30 bn to be invested in the rest of the world.

[27] The differences in the penetration levels of renewables and the higher GHG emission reductions renders an economic comparison of the SET-P fixed prices and the SET-P PV plus scenarios with the reference scenarios such as the one undertaken in section 4.2.3 impossible.

An additional sensitivity run called *'SET-Plan PV plus'* has been developed in order to further assess the deployment of PV under more optimistic conditions. It assumes that the premium paid for electricity generated from PV is some 40% above the levels of the reference scenario by 2010, with an annual decrease of 4% thereafter. Furthermore, the scenario *SET-Plan PV plus* postulates a doubling of the PV potential on the building stock while it simultaneously increases the share of new dwellings being equipped with PV. Following the construction of the *Global SET-Plan* scenario, the premiums paid for electricity from other renewables were adapted in order to achieve the same share of renewables in final demand by 2020 as in the reference scenario.

4.2.1 Changes to the energy sector in general

By construction of the scenarios, renewable energies shall achieve a share of 18.7% of the European final energy demand by 2020 in both scenarios[28]. Changes to the European energy sector will therefore remain of minor nature in 2020 and the electricity generation remains similar to the one of the reference scenario in broad terms in the present assessment (see Figure 4.5).

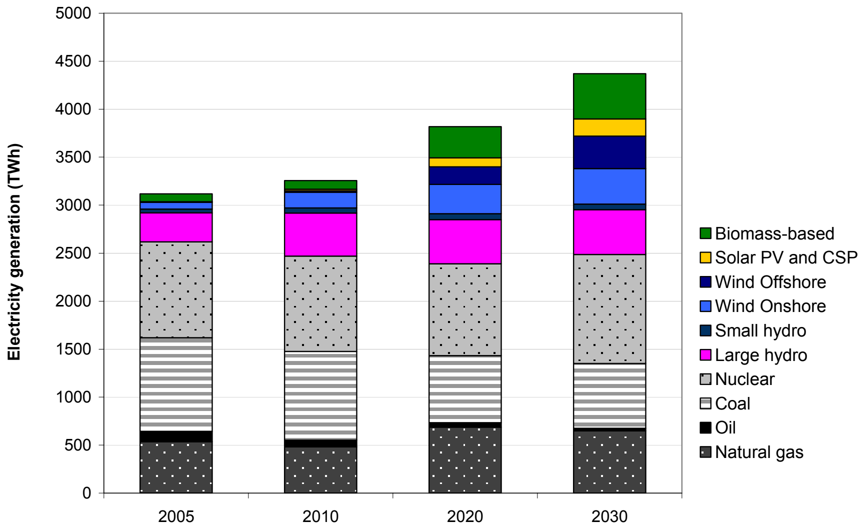

Figure 4.5: Electricity generation by fuel in the Global SET-Plan scenario (EU-27)

Nevertheless, the enhanced competitiveness of selected renewable energy power generation technologies leads to a slightly higher share of renewables in gross electricity consumption than in the reference scenario. This is achieved despite the fact that overall electricity demand slightly increases (+ 0.1% by 2020) in the *Global SET-Plan* scenario compared to the reference case, caused by lower electricity prices induced by reduced technology costs. Following the precondition of fixed renewable energy shares and of stable GHG emission reduction this cost reduction implies a reduction in the European CO_2 price and the specific renewable energy premium tariffs (see also section 4.2.3) which in return bring about a lower electricity prices when they are passed through to the consumers.

By 2030, these changes become more noticeable as for that point in time the condition of similar targets between the scenarios is abolished. The share of renewables in European electricity consumption will thus increase by 0.3 percentage points in the *Global SET-Plan* scenario.

[28] This is equivalent to a 20% share of renewables in final energy demand, taking into account that the POLES model does not include some emerging renewable energy technologies as described above.

Moreover, the accelerated deployment of CCS plants in the *Global SET-Plan* scenarios will realize additional emission savings. By 2030, GHG emissions in the power sector would be almost 1% below the reference scenario in the EU. In the case of fixed prices as assessed in the scenario *SET-Plan fixed prices*, the effects on emissions (-2% compared to reference in the power sector) and the deployment of renewables would be slightly more pronounced.

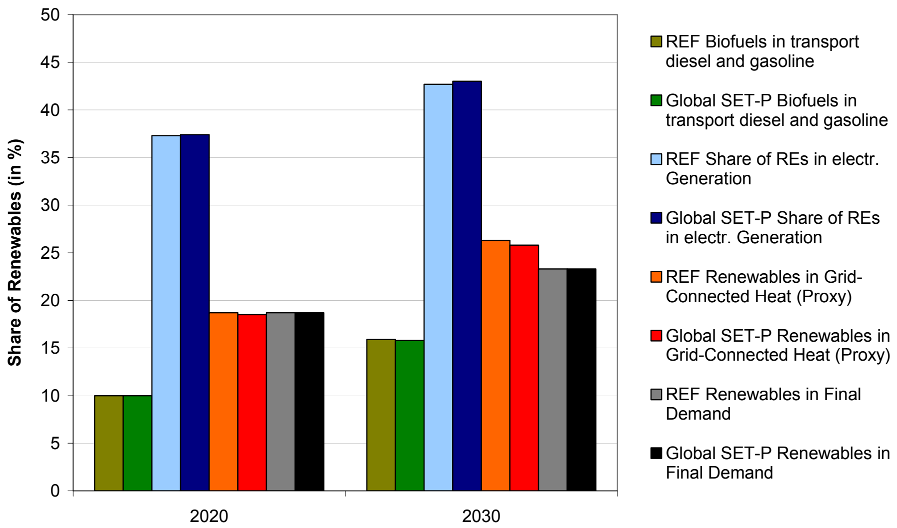

Figure 4.6: Share of renewable energies by 2020 and 2030 (EU-27)

Even if the present study focuses on the impact of additional R&D efforts at European level, it is worth to see some trends also at the global level. For all world regions outside of the EU, both the renewable energy support schemes and the CO_2 prices are kept constant across the scenarios. This implies an accelerated market penetration of several low carbon technologies. A global R&D programme following the SET-Plan could then lead to additional emission reductions of 1.4% in the power sector by 2030 worldwide. The global share of electricity produced from renewable energies increases by 0.3 percentage points by 2030 compared to an already ambitious reference scenario (28.7%).

4.2.2 Changes to SET-Plan priority technologies

In both scenarios, hydropower, wind energy and biomass based electricity generation account for more than 90 % of the total renewable electricity production in the EU by 2020. In spite of this general picture prevailing across both scenarios, the SET-Plan shows a mild shift towards more innovative renewable energy technologies. In particular CSP, wind offshore, PV and biomass gasification experience a positive SET-Plan effect (see Figure 4.7). The counter-intuitive effect of (slightly) lower biomass thermal electricity production capacities is due to the fact that this technology hardly reduced its investment costs under the SET-Plan, and thus becomes less competitive under the regime of reduced renewable energy premiums compared to other renewable energy technologies.

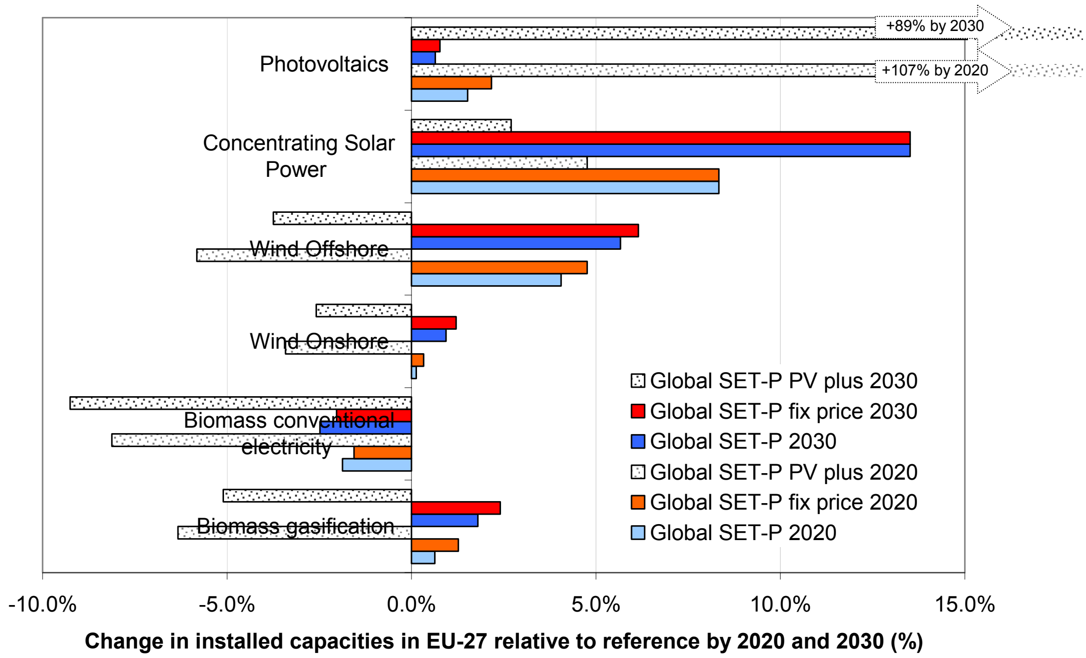

Figure 4.7: Changes in installed capacities between the Global SET-Plan, the SET-Plan fixed price and the reference scenario in 2020 and 2030 in the EU

If the central restriction of fixed renewable shares and GHG targets were abandoned and consequently the renewable energy premiums were kept constant at its reference levels despite the lower technology investment costs initiated by additional R&D efforts (scenario *SET-P fixed prices*), the market take-up of the low-carbon technologies considered would be accelerated further. This effect can also be observed for conventional biomass thermal electricity production; nevertheless, this technology would still experience some slight reductions in installed capacities compared to the reference case due to the much steeper cost reductions of biomass gasification, which imply that the relative competitiveness of biomass gasification would increase compared to conventional biomass electricity generation technologies.

In the sensitivity run *SET-P PV plus* with more optimistic assumptions for the deployment of PV, the installed PV capacity would double compared to the reference case by 2020. This implies that by 2020, around 15% of all dwellings would be equipped with PV panels, compared to some 7% in a reference scenario. Given that the *SET-P PV plus* scenario targets the same share of renewables in final energy demand by 2020 as the reference and *Global SET-Plan* scenarios, the rise in PV capacities goes at the expense of other renewable energy technologies, such as biomass and wind.

A comparison with other studies indicates that the scenarios developed here can be considered as ambitious. This becomes evident for the EU-27 from Table 4.1, which compares selected results from the present exercise with a baseline and target scenario developed with PRIMES, an energy market equilibrium engineering-economic model used for the long term and the study of structural changes in energy markets of the EU Member States and other European countries[29].

[29] For more details and the report describing the PRIMES scenarios used here for comparison see http://www.e3mlab.ntua.gr/

Table 4.1: Installed Renewable Energy Capacities in the Global SET-Plan scenario compared to PRIMES results, in the EU-27

Installed capacities in EU (GW)	Global SET-Plan 2020	Global SET-Plan 2030	PRIMES target 2020	PRIMES target 2030	PRIMES base 2020	PRIMES base 2030
Wind onshore	152	184	162	262	120	146
Wind offshore	59	110				
PV	47	78	13	44	9	15
CSP	9	13				
Bioelectricity[30]	47	77	85	138	36	51

Source: PRIMES figures taken from model-based analysis of the 2008 EU Policy Package on Climate Change and Renewables; Baseline and EC proposal with JI/CDM and RES trading; note that this is not directly comparable due to different assumptions on the overall economic developments and of energy prices.

On the global level, where – unlike in the EU – the deployment of renewable energies is not capped by hypothesis, the SET-Plan effect is more visible. By 2030, the overall installed renewable energy capacity in the power sector increases by 1.5% compared to the reference scenario. It is driven by the faster deployment of innovative renewable energy carriers thanks to their accelerated cost competitiveness due to higher R&D investments. Here, in particular CSP would largely benefit from the additional research efforts, in line with the fact that the learning by researching leads to the most intense cost reductions for CSP (see Table 3.10). By 2030, global installed capacities of CSP could reach almost 170 GW. Also offshore wind power would grow faster; benefiting from additional research efforts.

In Table 4.2, globally installed capacities of selected renewable energies following the *Global SET-Plan* scenario are compared with a baseline and the BLUE MAP scenario developed by the International Energy Agency. The BLUE Map scenario describes significant and far-reaching technological shifts towards low-carbon options in order to halve CO_2 emissions from current levels until 2050; the resulting deployment of renewables can thus be considered as ambitious. Given that the *Global SET-Plan* scenarios comes close to the BLUE map deployment levels for key technologies, also the latter can be classified as optimistic scenario.

Table 4.2: Installed Renewable Energy Capacities in the Global SET-Plan scenario compared to IEA energy technology perspectives, at global level

Installed capacities, global (GW)	Global SET-Plan 2020	Global SET-Plan 2025	Global SET-Plan 2030	IEA Baseline	Blue Map Scenario
Wind onshore	488	615	714	300 GW by 2030	900 GW by 2025 (over 2000 GW by 2050)
Wind offshore	190	319	423		
Photovoltaics	113	159	218	below 60 GW by 2030	above 150 GW by 2030 (1150 by 2050)
Concentrating Solar Power	147	163	166	below 10 GW around 2030	250 GW around 2030

Source: IEA 2008: Energy Technology Perspectives. Baseline and Blue Map scenario

The introduction of Carbon Capture and Storage (CCS) technologies strongly depends on the construction of a number of demonstration plants. The *Global SET-Plan* scenario assumes the construction of up to 12 demonstration plants in the EU starting from 2015, following the Technology Roadmap for CCS. Here, we assume that additional R&D efforts are directed to CCS in the order of €3.5 billion while another €10 billion are dedicated to the market introduction of CCS plants. The results clearly show that under this assumption, CCS plants

[30] Please note that the numbers for the SET-PLAN scenario as compared to the PRIMES numbers do not include capacities for the cogeneration of heat and power.

would enter the market some 5 to 10 years before its market introduction in the reference scenario. Hence, by 2015 as much as 1.7 GW could be installed in the *Global SET-Plan* scenario in the EU, four times the quantities projected in the reference scenario even though the carbon price is higher in the latter. By 2020, the SET-Plan effects would have led to an even higher gap in the CCS capacities installed in the EU, reaching 5.5 GW by then[31].

Also at the global level additional efforts to scale up CCS were introduced for the *Global SET-Plan* scenario in a similar manner as for the EU, with up to of €30 billion assumed to be available for these deployment schemes in world regions other than the EU in line with the IEA who called for almost 100 CCS demonstration plants (IEA, 2009). As a result, by 2020 25 GW of demonstration plants equipped with CCS could be operational compared to 9 GW in the reference scenario.

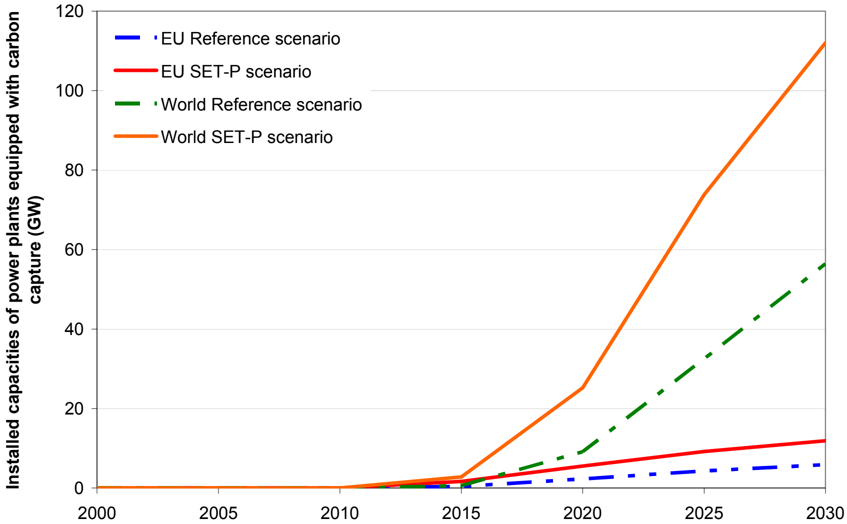

Figure 4.8: Deployment of CCS technologies with and without SET-Plan in the EU-27 and worldwide

4.2.3 Economic assessment

In the *Global SET-Plan* scenario, the costs of achieving the European climate change and energy targets are reduced compared to the reference scenario. Due to lower investment costs of various low-carbon technologies that are realized through the additional research efforts and a faster deployment of CCS, the European CO_2 price that is in line with achieving the same GHG emission levels would drop by 0.9 $€_{2000}$ /t CO_2 below the reference value. At the same time, the renewable energy premium tariff per kWh would be reduced, even though in total terms the faster market uptake of more innovative, more expensive renewable energies means that the absolute amount of the renewable energy support remains more or less constant. As a consequence, electricity production costs fall up to 1% in the *Global SET-Plan scenario*.

A simplified assessment of the economic differences between the *Global SET-Plan* scenario and the reference case can be undertaken by comparing the additional costs due to the increased R&D efforts with the benefits to the sector in form of reduced electricity production costs.

Δ Net benefits = Δ Benefits - Δ Costs *(Equation 8)*

Δ Benefits = Δ Electricity Production Costs *(Equation 9)*

[31] This compares to 5.5 GW (or 9 projects) in the IEA Blue Map Scenario for Europe (IEA, 2009).

Δ Costs = Δ R&D investments$_{corporate}$ *+ Δ R&D investments*$_{public}$ *(Equation 10)*

As Figure 4.9 indicates, there are significant cumulative net costs in the first years. This is due to the additional R&D investments that are needed as from 2010 onwards, while their benefits in terms of reduced electricity production costs materialize only with some delay. After a period of negative values the (discounted) cumulative net benefit turns positive between 2020 and 2021. By 2030, it would reach billion 11.5 €$_{2000}$. The internal rate of return (IRR) of the changes triggered by the additional R&D investments modeled in the *Global SET-Plan* scenario is some 15% when considering the period 2010-2030. In order to also capture the benefits beyond 2030 to the extent possible, the assessment has been extended to the year 2040[32]. Taken this longer time period into consideration, the IRR would increase to 16% and the discounted cumulative net benefits would reach almost billion 16 €$_{2000}$.

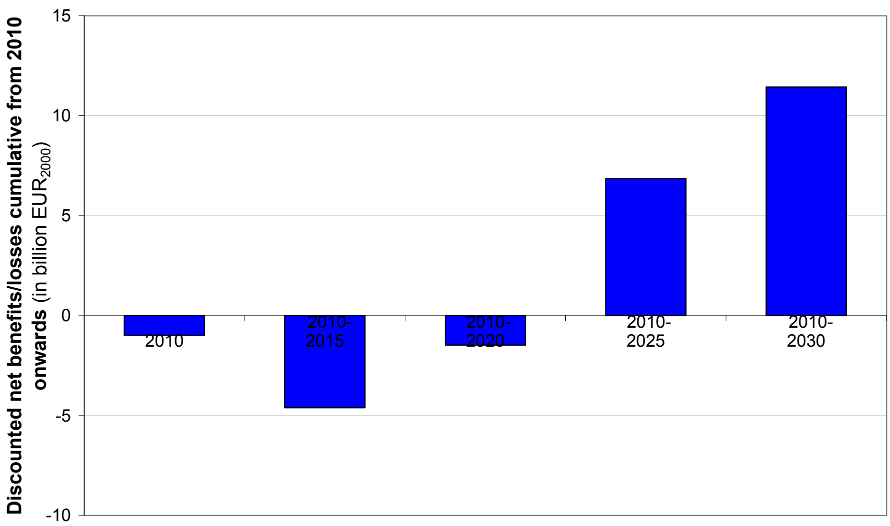

Figure 4.9: Discounted (3%) net benefits cumulated from 2010 onwards, EU-27

Unfortunately, the boundaries of the analysis do not directly allow for a comprehensive assessment of economic impacts for different stakeholders. In order to nevertheless roughly estimate the net benefits on the side of the producers and the public, equation (8) has been expanded further:

Δ Net benefits = Δ Net Social Benefits + Δ Net Producer Benefits *(Equation 11)*

For this allocation of benefits to various actors, a number of additional assumptions had to be made. With regard to the producers, a complete pass-through of the costs to the consumers is assumed both for the renewable energy support and for the CCS deployment scheme. Moreover, it is simulated that electric utilities would pass on their additional R&D investments to the consumers via an add-on to the electricity price, and would transfer this compensation to the manufacturers of the equipment who increased its R&D investments. This add-on is calculated assuming an Internal Rate of Return (IRR) of 12% and starting five years after the increase in R&D, i.e. from 2015 onwards; beyond 2020, it would decrease with 3% per year. Note that these assumptions largely influence the results of the analysis by stakeholder.

[32] Macro-economic assumptions beyond 2030 could not be taken from the iTREN-2030 project; instead, they are adapted from Russ et al., 2009. However, the trends in the techno-economic characteristics of power technologies are extended until 2040 in line with the learning rates described before.

The calculation in the differences of net social benefits focuses on the consumer and the additional costs to the taxpayer that arise from the public R&D expenses.

$$\Delta \text{ Net Producers Benefits} = \Delta \text{ Producer Income} - \Delta \text{ Electricity Production Costs} - \Delta \text{ R\&D investments}_{corporate} \quad \text{(Equation 12)}$$

$$\Delta \text{ Net Social Benefits} = - \Delta \text{ Consumer Expenses for Electricity} - \Delta \text{R\&D investments}_{public} \quad \text{(Eq. 13)}$$

It is assumed that the SET-Plan will not lead to any differences in the tax levels on electricity. Consequently, consumer expenses for electricity have been calculated on the basis of an electricity price without taxes. From this follows that

$$\Delta \text{ Consumer Expenses for Electricity} = \Delta \text{ Producer Income} \quad \text{(Equation 14)}$$

Under this assumption, equation (11) can be transformed to equations (8), (9) and (10). This more detailed, assumption based assessment of the net benefits occurring for different stakeholders reveals why a SET-Plan like effort may require public action in order to be initiated. The IRR to the producers would be 8% for the period 2010-2030 (and 10% over the period 2010-2040). Hence, it remains below the levels of the IRR in other projects of the sector, which means that industry might invest less in R&D without an additional stimulus, in particular when also taking into account the uncertainties related to the pay-back of research efforts and the question on whether a full passing-through of additional R&D expenses to the consumers could be realized.

For society, and here in particular the consumer of electricity, gains could be expected from around 2020 onwards, resulting mainly from the reduced electricity prices. Note that there is an additional benefit to the consumers due to their higher electricity consumption, which could not be further analyzed here.

Under the *Global SET-Plan* scenario, further ancillary benefits would occur, which could not be analyzed in the scope of the present analysis. They include:

- Benefits to other (energy-intensive) industries from lower electricity prices;
- Cost reductions due to the lower CO_2 prices also in other sectors than the ones analysed here; for the industry sector the reduction in the CO_2 price could mean a saving of around 0.4 € billion in 2020 and 0.3 € billion by 2030[33].

Furthermore, it should be stressed that the research efforts considered to be undertaken within the SET-Plan are viewed by the sectors as crucial to ensure the availability of and help in improving the technical maturity and competitiveness of low-carbon technologies that will form the backbone of the future power system when striving for higher greenhouse gas emission reductions in line with a 2 degree target pathway. Hence, the differences between the reference case and SET-plan scenario in terms of technological availability and maturity could be more pronounced than those considered in the context of this exercise.

In addition, the *Global SET-Plan* efforts considered have been limited to those proposed for the 2010-2020 period. In practice, considering the long-term vision of the SET-Plan, the new innovation dynamics that will be implemented in the considered period, including the efforts dedicated to long term research through the European Energy Research Alliance could be expected to be continued beyond 2020, hence departing from the return to a reference pattern considered in this exercise.

[33] This may be considered as a conservative estimation as only emissions of CO_2 and not those of other GHG are considered.

5 Conclusions

The present assessment shows that an ambitious increase in global research efforts along the line of the European Strategic Energy Technology Plan will reduce the costs of innovative low-carbon technologies. The low-carbon power technologies that were the focus of the present analysis will experience an additional reduction in investment costs of in-between 4% and 13% compared to reference trends due to higher RD&D investments. In general less mature technologies such as offshore wind energy, PV, CSP and biomass gasification would profit over proportionally. As an immediate result, the market entry of those technologies that will be needed in a sustainable energy system beyond 2030 will be accelerated.

The same conclusion also holds true for CCS technologies even though the present assessment assumes an additional market pull incentive on top of the research-driven technology push. *Global SET-Plan* efforts would bring forward the market entry of CCS by at least five years. At the same time, the present analysis clearly indicates that rather than 'technology push policies' the assumed 'demand-pull' mechanisms such as premium renewable energy tariffs largely determine the market deployment of renewable energies.

We assume here that both the reference and the *Global SET-Plan* scenarios will achieve the same share of renewable energies and a similar level of GHG emissions reductions that are in line with the European energy and climate change objectives set for 2020. The research-induced cheaper technology costs mean that these targets can be achieved at CO_2 prices and renewable energy premium-tariffs that are below the levels of the reference scenario in the *Global SET-Plan* scenario; these gains are passed on to the consumers.

Considering a time horizon between 2010 and 2030, the internal rate of return (IRR) of the SET-Plan initiative would then be in the order of 15% in the EU. The cumulative benefit of the measure would be negative in early years before turning positive around the year 2020 and remaining so thereafter. A more detailed (but at the same time more assumption-based) analysis indicates that the private IRR of the producers' cash flow would be smaller. This together with the level of risk associated with corporate RD&D investments on innovative technologies and delays to materialise suggests that there is a need for public support to trigger the additional corporate research efforts.

Ancillary benefits to consumers and industry beyond the power sector can also be expected, such as cost reductions in other sectors due to the lower CO_2 prices. Moreover, already in the reference scenario it is assumed that the European energy and climate change targets will be met through a combination of a supportive market environment and availability of technologies. In reality, however, the SET-Plan plays a critical role in improving not only the technology costs as assumed here, but also their availability and reliability.

Although limited due to the ambition of the reference scenario, sensitivity analyses indicate that the SET-Plan could also trigger additional reductions in the emissions of greenhouse gases and further (limited) increases in the share of renewable energy, as observed in the scenarios for the global level and a scenario that assumes no change in the market environment compared to the reference case. For methodological reasons, however, no economic assessment could be performed for these sensitivity runs.

Finally, the analysis suggests that the increase in R&D investments, partly put in practice by additional public R&D efforts that shall leverage corporate R&D investments, may have a self-reinforcing effect. Research efforts contribute to technological learning, therefore lowering the specific costs and thus increasing the market penetration of the technologies considered. This in return implies a higher turnover of the sector, which, at constant R&D intensities, results in additional R&D investments.

The present assessment needs to be considered as experimental and its results are associated with elevated uncertainties. Available data are scarce and crucial assumptions therefore often rely on small samples. At the same time, the concept of the Two-Factor-Learning Curve contains some uncertainty and cannot sufficiently capture spill-over effects from other sectors. The hypothesis of *global* research efforts along the lines of the European SET-Plan may be considered as overly optimistic even though it is backed by recent developments such as in the USA, while the exclusion of improvements in the efficiency of R&D is a pessimistic assumption. Hence, the methodology and the underlying data basis would need to be further developed and improved to better capture the SET-Plan effects in future work. Besides, the analysis demonstrates the complexity of estimating the impact of research efforts; its findings can therefore not be extrapolated to other levels of RD&D investments than the ones assessed here. Nonetheless, the present results provide a first indication of the trends initiated by SET-Plan-alike efforts and therefore are considered valuable information for decision-making despite the associated uncertainties.

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Abstract

The goal of this analysis is to capture the effect of increasing research, development and demonstration (RD&D) efforts for a set of low-carbon power technologies on the development of the European energy sector. The report finds that an increase in research efforts on a global level, that for the EU are in line with the additional RD&D investments proposed in the context of the European Strategic Energy Technology Plan, will contribute to reducing the costs of currently less mature low-carbon technologies, and therefore accelerate their market entry. Following from the lower technology investment costs, the economic rate of return of the additional SET-Plan investments in the EU would be positive, reaching around 15% for a time horizon between 2010 and 2030. The cumulative (discounted) benefit of the RD&D investments would be negative in early years before turning positive around the year 2020 and remaining so thereafter.

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