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Renewable Energy Directive Target

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Renewable Energy Directive Target

DIRECTORATE GENERAL FOR INTERNAL POLICIES

POLICY DEPARTMENT A: ECONOMIC AND SCIENTIFIC POLICY

Renewable Energy Directive Target

STUDY

Abstract

This study investigates the impacts and feasibility of increasing the share of renewables beyond the proposed target of 27% for 2030 through a review of recent studies assessing the future energy system in the EU. The authors examine the impact of selected modelling input factors and modelling approaches on the determination of the optimal share of renewables. This document has been commissioned by Policy Department A at the request of the Committee on Industry, Research and Energy (ITRE) of the European Parliament.

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LIST OF ABBREVIATIONS

EE	Energy efficiency
EU	European Union
EC	European Commision
EU-ETS	EU Emissions Trading system
FEC	Final energy consumption
FED	Final energy demand
GDP	Gross domestic product
GFED	Gross final energy demand
GHG	Greenhouse gas
IA	Impact assessment
LCOE	Levelised costs of electricity generation
O&M	Operation and management
PV	Photovoltaics
RE	Renewable energy
RES	Renewable energy sources
RES-T	Renewable energy sources transport
RES-E	Renewable energy sources electricity
RES-H	Renewable energy sources heat
TPED	Total primary energy demand
WACC	Weighted average costs of capital

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EXECUTIVE SUMMARY

This paper analyses studies available assessing the impacts of renewable energy sources (RES) shares up to 35% in the EU. RES have diverse impacts on the energy system, the wider economy and society. Consequently, several criteria need to be considered covering all sectors and potential impacts at different scales (energy system, macro level, society) to be able to make a well-balanced decision. Impacts are commonly measured by:

- energy system costs,
- avoided carbon dioxide (CO2) emissions,
- avoided fossil fuel imports,
- health effects,
- changes in Gross Domestic Product (GDP) and employment.

The comparison of the outcomes of the various studies is a challenging exercise, as the studies assessed show great variety in terms of their regional and sectoral focus, time horizon and overall objective, e.g. analysing pathways for further decarbonisation, assessing impact of RES or analysing impact on various economic sectors.

Critical factors influencing the RES share and energy system costs

In models applied to assess RES shares and objectives, assumptions regarding technology availability and costs, fuel prices and discount rates can have a significant impact on the resulting competitiveness of RES, and therefore on the economic feasibility of increasing the RES share in the energy system. An illustrative example of cost-optimisation approaches shows that:

- Faster decline in cost for renewable technology compared to costs of alternative technologies for energy conversion and greenhouse gas (GHG) emission reduction results in higher RES shares. RES technology costs tend to prove lower than previously anticipated, at least in the electricity sector. Recent auction results show that they are significantly lower than costs for renewable electricity production in the models. In light of the increasing significance of electricity for heating/cooling and transport in the scenarios, RES will play a crucial role in the power sector. As wind power is likely to be the largest contributor to renewable electricity generation in the EU, its cost development is especially important. Thus, a lower electricity production cost of wind power might considerably affect total energy system costs.
- High discount rates imply higher shares of technologies with low initial investments compared to fuel and maintenance costs, e.g. gas-fired power plants; while low discount rates make capital-intensive technologies (e.g. solar and wind or nuclear power plants) more attractive. Discount rates reflect financing conditions, yet they are also used to represent non-economic barriers in some models. This results in a suppression of capital-intensive technologies with increasing discount rates or to higher energy system costs under ambitious RES targets in these models. Furthermore, it should be noted that energy system costs can be assessed using either social or private discount rates. Social discount rates are applied to assess whether a specific energy system is preferential for society, whereas private discount rates are applied to assess whether business cases are profitable from a stakeholder's perspective. Thus, the choice for a discount rate depends largely on the objective of the analysis.
- Low fossil fuel prices lead to a lower share of renewables and vice versa. Due to the historic price volatility of fossil fuel prices, assumptions regarding their future development have significant uncertainties. This translates into high uncertainties

regarding the cost-effectiveness of renewables and deployment levels calculated with the various models.

- Availability of technology, for example hydrogen in the transport sector, increases the RES-T (transport) share in the transport sector,
- The type of model used in impact assessments (IA) influences results, as e.g. an econometric model tends to report more optimistic results in terms of GDP than equilibrium based models.

Impacts of higher renewable shares on:

- GDP and employment: The impacts of the deployment of RES on GDP and employment are disputed, as they depend on the underlying model philosophy. For the IA of the European Commission (EC) (2016), the results of a 30% RES target assessed by two models indicated a decrease of -0.5% GDP versus an increase of +0.6% of GDP. However, there is another study with a dedicated IA of higher RES targets commissioned by the EC, which forecasts an increase in GDP by 0.3% for a target of 30% and by 0.7% for a target of 35%.
- Fossil fuel imports: studies with a higher RES target result in significant reductions of fossil fuel imports. They report savings of around 1% of GDP per year, which can potentially be sufficient to balance additional investment requirements.
- Health impacts: The impact of RES on reduction of health costs do not differ substantially between the different studies assuming the same level of GHG emission reductions. The impact on health are positive, although rather limited.
- Energy system costs: In general, energy system costs are not clearly defined in the various studies and can, therefore, not be compared easily. Some scenarios include all energy system related expenditures, others focus on generation, RES technologies or additional costs compared to a certain reference. Studies do show that low technology costs and discount rates result in low (system) costs of RES expansion or even savings. Studies further show that, in scenarios with higher shares of RES, but unchanged energy efficiency (EE) and GHG targets, energy system costs do not necessarily increase. Accordingly, a 30% share in RES deployment is possible without further energy system cost increases.
- Consumer prices: the impact of higher RES shares on consumers depends, among others, on the impact on electricity prices. Whether they increase with increasing RES shares depends on the RES policy design and on the assumed technology costs. Even lower electricity prices than today are feasible if the levelised cost of energy and cost of capital are sufficiently low (REmap).
- Industry competitiveness: a higher renewable share implies higher installation rates of renewable energies in the European Union (EU) countries. This could have a positive impact on the profitability and competitiveness of the European manufacturing and service industry in the renewable energy (RE) sector. None of the analysed studies explicitly addressed this issue.
- Security of supply: When increasing the RES share, security of supply in the electricity sector needs to be closely monitored due to increased need for flexibility to ensure that demand and supply are met at all points in time. Thus, a 100% renewable electricity share is technically feasible, but system adequacy needs to be closely monitored.

Conclusions and recommendations

From this study we **conclude** that, from a cost perspective, a more ambitious RES target (30%-35%) appears to be a feasible objective for 2030 as (1) the impacts of a higher RES share on GDP and employment and health are projected to be positive, even though limited, according to most studies analysed, (2) imports of fossil fuels and GHG emissions are projected to decrease (assuming that emission levels are not constrained by an overall emission cap), (3) some studies project low or no increase in overall energy system costs, while one recent study even reports cost reductions.

Based on the assessment conducted for this study, the following recommendations can be made:

- Given higher RES targets, system adequacy in the electricity sector needs to be closely monitored. A higher renewable target in terms of final energy consumption (FEC) leads to a substantial share of variable renewables in the electricity sector. While 100% renewables is technically feasible, the system might need time and additional flexibility to adjust to higher RES shares.
- Targets for GHG reduction, RES and EE need to be coordinated. A significant increase in the RES target without adapting the GHG target can decrease efforts in energy efficiency and other investments in decarbonisation. Thus, if adjusting the RES target, the other targets should also be reassessed.
- Although industrial competitiveness and energy poverty are generally not considered in the studies assessed, these need to be taken into consideration when designing support policies and burden sharing regulation.
- To fully assess the costs and benefits of a higher renewables target, additional modelling with adapted technology costs and potentially social discount rates for assessing aggregated energy system costs is recommended.

1. BACKGROUND AND INTRODUCTION

1.1. The assignment

In 2007, the European Council agreed on its first EU energy and climate package. It was enacted into legislation in 2009 and includes three targets to be met by 2020:

- 20% reduction of Greenhouse gas (GHG) emissions compared to 1990
- 20% of renewables in final energy demand (FED)
- 20% improvement in energy efficiency (EE).

To ensure the expansion of renewable energies (RES), binding national targets based on the renewable shares in 2005 and the countries' gross domestic product (GDP) were set. The countries committed to prepare National RE (renewable energy) Action Plans (NREAPs), including indicative renewable shares to be achieved in different sectors (electricity, heat and transport) as well as policy instruments to reach these shares. Progress regarding target achievement is closely monitored both on the national and EU level[1].

For the timeframe beyond 2020, the legislative process for enacting the legislation of the 2030 climate and energy package is currently ongoing. In 2014, the Energy Council agreed on setting three targets again, more specifically a 40% GHG reduction target, a 27% renewable target and a 27% efficiency target. In 2016, the European Commission (EC) published the "winter package" containing several legislative proposals for implementing the 2030 climate and energy package.

The European Parliament, in its resolution of 5 February 2014 on "A 2030 framework for climate and energy policies" favoured a binding Union 2030 target of at least 30% of total final energy consumption (FEC) from RE sources. In its resolution of 23 June 2016 on "The RE progress report", the European Parliament went further, noting its previous position regarding a Union target of at least 30% and stressing that, in light of the Paris Agreement, it was desirable to be significantly more ambitious.

Model results are currently being questioned because of unexpectedly low requests for financial support in recent auctions (in 2016 and 2017) for renewables across the EU. Only the most recent models (e.g. REmap EU) take this technology cost reduction into account, while those used for impact assessments (IA) on the European level until 2016 do not yet take the cost reductions into account. The declining support requirements allow increasing the share of renewables while maintaining the cost-effectiveness of the framework for climate and energy and at the same time gaining access to positive side effects of increasing RE shares. However, higher renewable targets can be challenging in terms of grid management, especially as a target of 35% implies a share of approximately 66% RE in the electricity sector.

Within this context, the ITRE committee of the European Parliament requires further information about the impacts of RE shares above 27% as well as the feasibility of reaching a threshold beyond this share. The **objective of this study** is to:

- provide an overview of studies available with ambitious RES targets;
- examine the impacts of RES shares on growth and employment, energy system costs, investments, EE and GHG reduction targets; and

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[1] The legislation for enacting the 2020 energy and climate package includes Directive 2009/29/EC (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0029), Directive 2009/28/EC (http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32009L0028), Directive 2009/31/EC (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0031) and Decision No. 406/2009/EC of the Parliament and the Council (http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2009.140.01.0136.01.ENG).

- assess the feasibility of achieving higher RES targets in light of recent developments in the cost of technologies.

The **paper is structured** as follows:

- The remainder of section 1 includes some basic information, such as the systematisation of impacts and interactions between targets.
- Section 2 introduces a review of recent studies assessing the future energy system in the EU.
- Section 3 investigates the impact of selected modelling input factors and modelling approaches on the determination of the optimal renewable share.
- Section 4 gives an overview of modelling results for different renewable shares.
- Section 5 provides conclusions and policy recommendations.

1.2. Some basics before getting started

Box 1: Fundamentals in brief

The deployment of RES has impacts on different levels: energy system, macro-level (impact on the whole economy and society) and micro-level (e.g. burden for different households, companies, etc.).

Impacts are commonly measured through energy system costs, avoided carbon dioxide (CO_2) emissions, avoided fossil fuel imports, health effects and changes in GDP. Due to individual preferences and variety of needs, there is no single criterion that can be used to account for the impact of deploying a higher share of renewable energies for society. For example, actors with a focus on environmental protection and GHG emissions reduction might focus on the impact on CO_2 emissions, while those with a focus on economic development might focus on the impact on GDP.

Furthermore, the interdependence of emission reductions, EE and renewable targets needs to be carefully assessed. Increasing the efficiency target entails more RES in energy consumption for the remaining energy demand. Similarly, higher GHG reduction targets require more use of RES and EE improvements.

1.2.1. Systematisation of impacts of renewables[2]

Renewable energies influence the energy system and the wider economy and society in different ways. Their **impacts** can be categorized into **different levels**, i.e. the energy system level, the macro level and the micro level.

Energy system level:

RES impacts the **energy system** by influencing costs of electricity and heat generation as well as costs for the transport sector. Moreover, RES leads to changes in the environmental impact of the energy system (by reducing GHG emissions as well as other air pollutants, but also by changing land use patterns) and affect security of supply (by reducing dependency on fossil fuel imports, yet also increasing flexibility requirements in the electricity sector)[3].

On the energy system level, the following indicators can be used:

- **Energy system costs:** these system costs comprise the investment, maintenance and operation costs of all technologies that produce, supply and transport energy and

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[2] See among others, Breitschopf et al. (2016) for an overview of effects of RES and related assessment criteria.

[3] Studies assessing the energy system impacts of RES include among others Fraunhofer ISI et al. (2010), Breitschopf et al. (2014), Hirth et al. (2015), Novacheck and Johnson (2015).

reduce energy consumption (e.g. EE options). Some energy system models assess abatement or substitution costs instead. These represent the additional energy system costs needed to achieve a certain GHG reduction target. They are calculated as the difference between a reference situation and a situation with large shares of RES, GHG emissions reductions, etc.

- **Avoided emissions**: avoided emissions from GHG and other air pollutants are expressed in quantity or monetary units. Avoiding GHG is the main driver of all policy efforts and thus a major decision criteria/determining factor.
- **Reduced imports of fossil fuels**: avoided imports of fossil fuels from outside the EU are expressed in quantity or monetary units.
- **System adequacy:** this criterion is a measure to assess the impact of renewables on short term security of supply in the power sector. It refers to the ability of the power system to meet the aggregate demand of all consumers at virtually all times.

Macro level:

RES influence the economy and society as a whole, i.e. they have impacts at the **macro level**. This includes positive as well as negative effects regarding the welfare and wellbeing in a specific country or region. Apart from economic impacts, RES use has socio-environmental aspects such as health effects due to reduced emissions and pollution[4].

Assessment criteria on the macro level are the following:

- **GDP** (gross domestic impact): shows how much a country “earns” or “loses” if more or less RES are used. It is often used as a proxy for welfare.
- **Net employment**: economy-wide impact on the number of jobs due to increase in RES deployment (while gross employment ignores changes in jobs “outside” the energy/RES sector). It is also used as a proxy for welfare. Employment impacts can be given either as cumulated additional jobs over the total period or as the number of jobs in the year(s) of consideration. The latter might vary significantly over time because investment activities result in temporary employment, while operation and maintenance create a small but long-lasting employment effect.
- **Health effects**: often expressed in monetary values, i.e. avoided health expenditures. It is used as a proxy for wellbeing.
- **Avoided emissions**: the assessment at the macro level can include avoided emissions outside the energy system.
- **Land use and biodiversity**: further effects regarding the environment can also be used to evaluate different renewable targets.

Micro level:

RES affects actors at the **micro-level,** i.e. energy consumers, prosumers[5] and generators (households and firms). These actors pay a price for energy which depends on the regulatory framework and the energy system in which RES are deployed. In the electricity sector, currently a large part of the final energy consumers such as households face higher expenditures with RES than without RES, while some industries benefit from decreasing wholesale prices in the electricity sector[6]. At the supply side, some generators or prosumers

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[4] Effects at the macro level in delineation to system effects are for example analysed by IRENA 2016, Burgos-Payan et al. (2013), Wei et al. (2010), Ortega et al. (2015), Breitschopf et al. (2013), Lehr et al. (2012), Barbose et al. (2015).

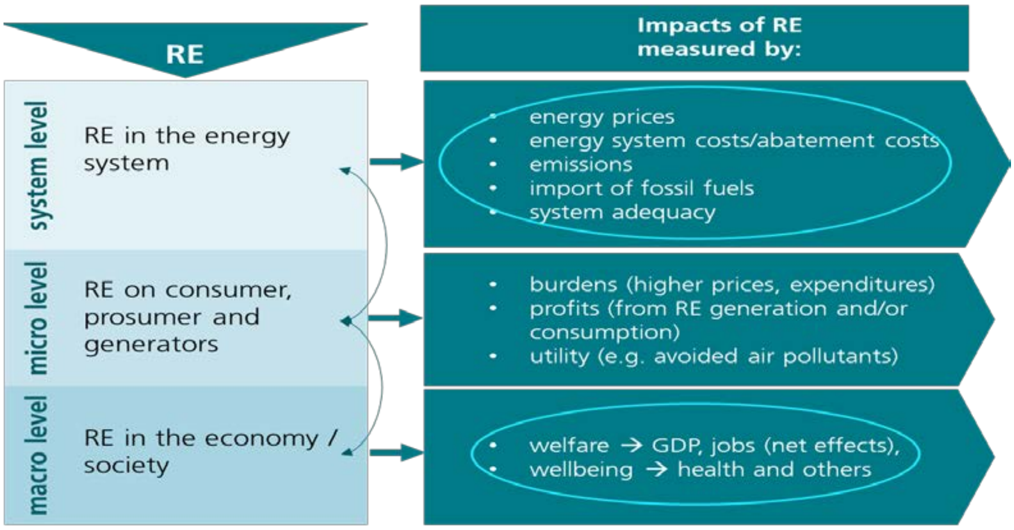
[5] Prosumers are electricity consumers who also generate their own electricity e.g. using a rooftop solar PV plant.

[6] This is due to current regulation regarding cost sharing of renewables extension, for example in Germany, but also in many other countries, RES in the electricity sector are financed by a levy on the electricity price.

also benefit from support policies, for example from feed-in schemes, grants and/or subsidized loans[7].

Even if the RES target increases energy system costs, this does not automatically lead to distributional impacts (i.e. impacts on industrial competitiveness, energy prices and poverty micro level effect). Whether a higher share of renewables has distributional impacts depends on the design of the policy support on the national level – how it is financed – and on implementation (policies). Distributional impacts are therefore not a criterion for setting RES targets at the EU level. When designing and adapting these policies it is necessary to consider the effects on energy prices in general and on energy poverty, in particular. Impacts of renewables on the three levels and the decision criteria for each level are depicted in Figure 1.

Figure 1: Impacts and decision criteria



Source: (own depiction).

The assessment criteria described for the system and macro levels provide the basis for deciding on a suitable target for RES deployment. However, due to the variety of impacts and individual preferences, there is no single quantity or criterion that can be used for summarizing all effects of deploying renewable energies. For example, actors with a focus on environmental protection and GHG emissions reduction might opt for a different level of targets than those with a focus on economic development or cost effectiveness.

In cases where only one indicator is preferred, GDP should be put forward as it is the most commonly (even though sometimes criticised) measure used for welfare. With its coverage of economic effects in all sectors (not only the energy sector), GDP is, in theory, able to reflect all aspects of the economy, provided that all types of impacts such as health and environmental effects are expressed in monetary terms. Progress has been made in this direction with an improved economic assessment of social and environmental impacts.

Energy-intensive industry is however exempted from this levy in order to maintain their competitiveness. On the electricity wholesale market where industrial consumers typically buy their electricity, renewables have a price-depressing effect because they have very low marginal costs. As a consequence, some industrial consumers see a lower electricity price compared to a system without renewables. In that context it is worth mentioning that the biggest part of the current costs of renewables is caused by RES that were installed in the past when their costs were still high compared to conventional power generation. New RES plants create less costs for end consumers because technology costs have decreased substantially in recent years.

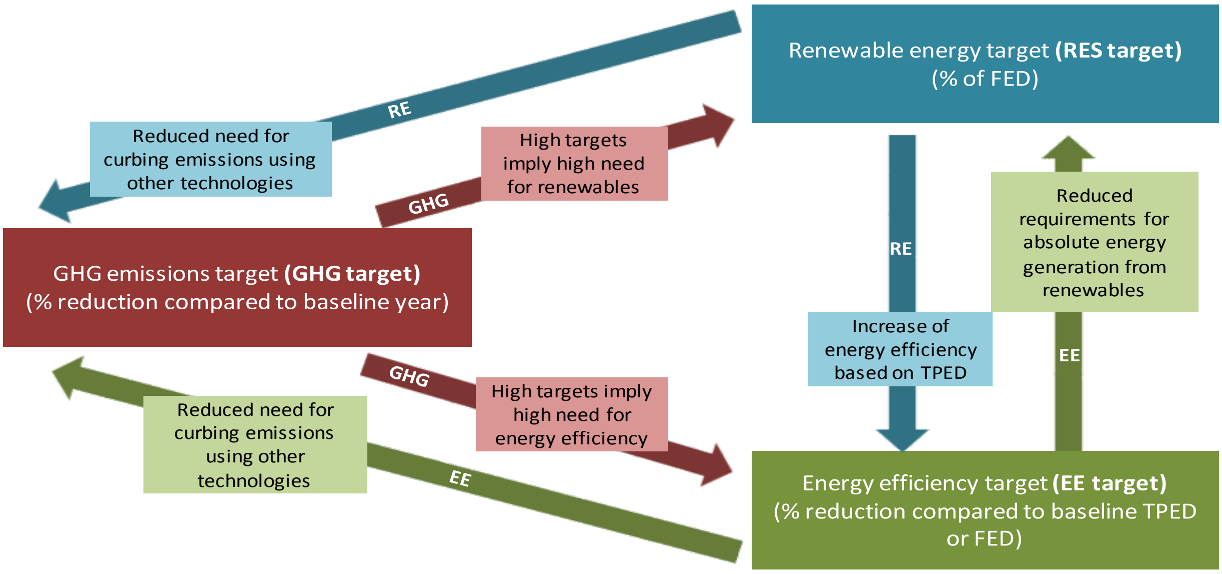
[7] The impact of RES on the micro level e.g. by assessing their impacts on electricity prices are for example assessed by Krozer (2013), Sensfuß et al. (2008), Cludius et al. (2014). Grave et al. (2015) assess their effect on industrial energy costs.

1.2.2. Understanding the interactions between the three EU targets[8]

In the context of the EU climate policy, both, RES as well as (EE) measures will be needed to reach ambitious carbon reduction targets. Furthermore, in the framework of the ETS, additional means are available to reduce GHG emissions: fuel switching as well as adapted and new products and processes. Between these main targets and objectives – i.e. GHG, RES and EE targets –multiple interactions exist (see Figure 2). These interrelations of EE, renewable support policies and carbon pricing mechanisms are generally accounted for in energy system models.

- In the case of very **ambitious RES and EE targets,** the need for curbing emissions by employing new processes, products or fuel switch, may be reduced if the GHG targets are not adapted accordingly. To avoid these kinds of lock-in effects, incentives for low carbon investment and operational decisions in these sectors should be balanced with targets and incentives for RES and EE (see Box 2 for a more detailed explanation of the interactions).
- In the case of **declining RES technology prices** under otherwise unchanged conditions, energy system costs and the CO_2 price decline, RES options become more competitive compared to EE and alternative options (e.g., fuel switch, products, processes) in an Emission Trading System (ETS) only context. When an ETS system is combined with RES and EE targets, policy support costs decrease, and RES options become more competitive as well (Box 2).

Figure 2: Interactions between EU climate and energy targets



Source: Own elaboration. GHG: greenhouse gases, FED: final energy demand, TPED: total primary energy demand, FED: final energy demand.

As a consequence of the interactions between the three targets, it is necessary to define well-harmonized target levels. For the renewable target, this implies that very ambitious targets are potentially only useful in combination with more ambitious GHG reduction and EE targets, as otherwise necessary cost-effective GHG emissions reductions e.g. in industry and agriculture are postponed, and possible stranded investment in CO_2-intensive products and processes might occur.

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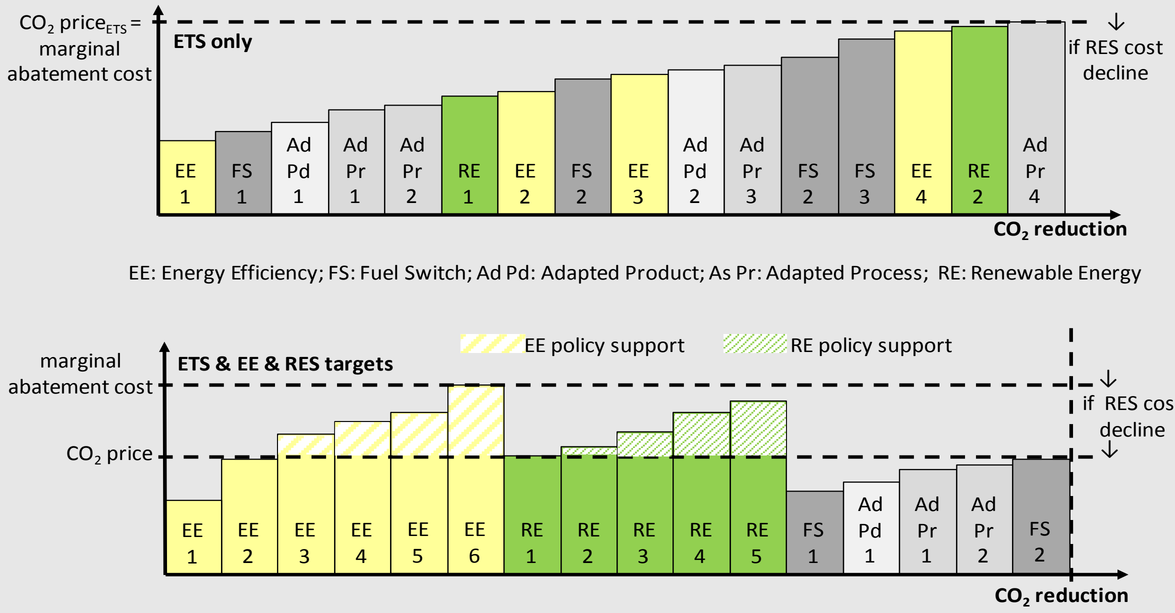
[8] Interactions between the three EU energy and climate targets are among others discussed by Ecofys (2013), Ecofys (2014), Flues et al. (2014), ZEE and FEEM (n.a.).

Box 2: Effects of RES and EE targets in the context of the EU-ETS

Figure 3: Merit order of different options for GHG emissions reduction w/o policies to support renewables and EE measures



EE: Energy Efficiency; FS: Fuel Switch; Ad Pd: Adapted Product; As Pr: Adapted Process; RE: Renewable Energy

Source: Own elaboration.

The umbrella instrument for decreasing emissions in the EU is currently the EU-ETS combined with the Effort Sharing Decision [9]. Figure 3 depicts stylised costs that arise from RES-, EE- and alternative options representing new processes and products aimed at reducing emissions. It is assumed that the GHG targets are the same in both cases.

The upper graph shows the cost of a system with an ETS only, i.e. without any renewables and EE policies. Under the ETS only regime (upper graph), only a few RE projects and EE measures are realized – their costs are benchmarked to the CO_2 certificate price.

The lower graph shows a system in which renewables and EE benefit from additional support through targets and policies. Additional processes and products are adapted and fuel switch occurs (production technology options). In the system with dedicated policies for EE and renewable energies (lower graph) RE and EE policies reduce financing risks and hence generation costs, compensate remaining additional generation costs and subsequently EE and RE options are increasingly employed. However, alternative options (fuel switch, products, processes) are realized to a lesser extent including due to relatively lower certificate prices.[10] When RES and EE targets are not accounted for in GHG target setting, ETS prices decline.

In the case of declining technology costs, for example of RES technologies, RES options become cheaper in relation to EE- and production technology options and CO_2 certificate price as well as abatement costs decline.

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[9] Only ETS sectors are included in the following argumentation. For non-ETS sectors similar arguments apply.

[10] Several factors could have a depressing impact on ETS prices. These comprise low demand for ETS certificates due to the economic crisis (reflected also in electricity prices), large supply of carbon certificates from outside the EU, generous caps and grandfathering, deployment of energy efficiency and renewables. However, in the existing policy framework the different targets were adjusted to each other. This means, the ambition level of the GHG target considers the implemented targets for RES and EE. Since RES and EE are currently not above the agreed target level they are not considered as the main reason for current low certificate prices (Held et al., Towards 2020).

2. OVERVIEW OF EXISTING STUDIES ASSESSING THE IMPACT OF DIFFERENT RENEWABLE SHARES

KEY FINDINGS

- Many studies assessing the impact of renewable, EE or GHG reduction targets have been elaborated during the last years. The studies include scenarios with RES targets up to 35% on FEC in 2030. The studies differ by their regional and sectoral focus, time horizon and overall objective (decarbonisation, RES impact, sector analysis).
- Therefore, comparing outcomes of these scenarios is not straightforward. RES deployment is of particular relevance in the electricity sector currently, and this is expected to be strengthened in the future as electricity is likely to gain market shares e.g. in the transportation sector and for heating/cooling systems.
- In all assessed EU scenarios, wind power is the most important technology for RES in the electricity sector.
- The lower the level of energy consumption, the higher the RES shares in the scenarios.

2.1. Study overview

During recent years, a number of different studies modelling the global or European energy system, or part of it, were published. However, for a comparison of ambitious RES shares not all scenarios are relevant. For example, the studies realized in preparation of the EC's impact assessments in 2014 and 2016 are aimed explicitly at assessing a suitable target level for RES extension in the EU, while the International Energy Agency (IEA) focusses on limiting the global increase in temperature to 2°C in its ambitious World Energy Outlook scenario. Other studies may have a regional focus or include more detailed data on RE technologies, or take different sectoral perspectives. In addition, studies generally differ by their underlying modelling philosophy.

In the following, Table 1 gives an overview of the scenarios included in this document. The table shows which RES shares and which impacts are assessed in the respective scenarios, along with the time horizon considered and publication year. Apart from the studies conducted for the impact assessments[11], no study offers an assessment of all effects of RES - most focus only on certain aspects such as energy system costs, investments, energy generation and consumption. The studies are clustered in three groups.

- The first group includes studies that focus on the EU and are conducted in preparation for the EC's impact assessments for the 2030 climate and energy package and the winter package in 2014 and 2016 for the EU.
- The second group has studies that focus on the EU and are commissioned by the EC in the Horizon 2020 programme and additional tenders as well as by other stakeholders (national governments, individual companies). These studies typically focus on selected aspects of the energy system, such as the electricity sector or on an analysis of selected impacts, e.g. employment or growth effects of renewables.
- The third group consists of studies with a global focus, conducted or commissioned by the EC or other actors, such as business associations, international organisations,

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[11] Regarding the EC impact assessments, some actors criticise their focus on economic and monetary impacts (see for example Ecofys and Coalition for Energy Savings 2017). Thus, it can be argued that, currently, no full assessment of the impact of RES shares above 27% is available.

non-governmental organisations, research institutes. They analyse, for example, potential pathways for a low carbon economy or accelerated RES deployment.

Due to the importance of taking into account the latest changes within the economic and regulatory framework as well as in the fast-changing energy system, studies published before 2013 are not considered in this document.

Table 1: List of studies assessing the impact of RES shares above 27%

Scenario name (time horizon)	Year of publication	Authoring instit-ution	RES shares (%)	Description	Region Sector	Models used	Impacts assessed
EU scenarios commissioned by the EC for the IA of the 2030 targets							
GH40/EE	2014	IA, EC	26.4	Scenarios of the EC's IA	EU Energy System (ES)	Energy system: • PRIMES Macro economics: • • E3ME • • GEM-E3	• energy system costs, • net employment, • net growth, • air pollution and health effects, • fossil fuel import reduction, • impact on energy prices, • investment requirements •
GHG40/EE/RES30			30				
GHG45/EE/RES35			35				
Ref. 2016	2016		24				
euco30			27				
euco3030			30				
CRA			27				
2030Quota (2030, EU)	2017	DG Ener	27 RES-H/C (heating/cooling)	In the Scenario 2030Quota the EU achieves a RES-H/C share of 27% in 2030 based on an EU-wide certificate trade without any other subsidies. This is compared to policies of the current policy scenario (all policies and measures implemented by the end of 2015) continue until 2030, and achieve a RES-H/C share of 26%	EU heat	• Energy System • FORECAST • Invert • Green-X	• GHG emissions • Heating system costs • Fossil fuel imports Green-X
• Additional EU scenarios commissioned by the EC and other stakeholders							
Optimistic (2030)	2014	KEMA Consulting et al.	RES-E (electricity) share: 68	Integration of RE in Europe is characterised by a fast expansion of RES-E based generation	EU Power	Electricity markets: • capacity extension model DSIM	• Electricity system costs

Scenario name (time horizon)	Year of publication	Authoring institution	RES shares (%)	Description	Region Sector	Models used	Impacts assessed
REmap EU (2030)	2017	IRENA	33/34	Cost-effective RE potential for the EU in 2030 (unpublished study Nov. 2017, only presentation (ppt) compares a reference scenario (24% RES share) to a 33% RES share. Under a 30% EE target, RES share amounts to 34%.	EU	Energy system: • REmap tool	• Investment requirements, • • additional energy system costs
GHG40RES30 (2030)	2014	Enerdata	30	Costs and Benefits to EU Member States of 2030 Climate and Energy Targets including a RES share of 30% in 2030, reflecting impacts of each member state meeting their burden share	EU	Energy system: • POLES	• Energy system costs, • fossil fuel imports, • health effects
Power Choices Reloaded-RES target (2030)	2013	Eurelectric	30	RES-target scenario in 2030 of 30%, based on an increase of RES in electricity driven by national policies, compared to Power Choices Reloaded with a RES share of 26% (PRIMES 2013)	EU	Energy system	• Energy system costs, • impact on energy prices
QUO30/GHG40-EE-RES30 (2030, EU)	2014	Fraunhofer ISI et al.	30	Energy system costs of sectoral RES and EE targets in the context of energy and climate targets for 2030: with harmonised support schemes. The CQUO30 scenario includes a RES share of 30% and RES support by means of EU green certificates after 2020. It is compared to a scenario ETS-only with a 27% RES share, both with the EE target of 2020.	ES	Energy system: • Green-X Electricity system: • PowerACE (Enertile)	• Energy system costs, • electricity system costs
SNP30 (2030)	2014	Fraunhofer ISI and TU Wien/ EEG	30	Employment and growth effects of sustainable energies in the EU (EmployRES) in the strengthened national policy (SNP) scenario with continuing policy framework with national RES targets and support schemes mainly	power ES	• PRIMES Macro economics:	• impact on energy prices • health effects • Additional generation costs,

Scenario name (time horizon)	Year of publication	Authoring institution	RES shares (%)	Description	Region Sector	Models used	Impacts assessed
				based on technology specific generation costs per country.		• ASTRA • NEMESIS	• net employment, • net growth, • fossil fuel import reduction
SNP35 (2030)			35				
QUO35 (2030)	2015	TU Wien/EEG, Fraunhofer ISI	35	Employment and growth effects of sustainable energies in the EU (EmployRES) with a quota system: harmonised support schemes (QUO) for RES-E, marginal technology sets the price for all RES technologies	EU ES	Energy system: • Green-X	• Additional generation costs, • fossil fuel import savings
• Global scenarios							
WEO 450 (2040), SD/NEP (2040)	2016/17	IEA	39 (2040)	The World's Energy Outlook (WEO) 2016 most ambitious scenario limiting the global increase in temperature to 2°C. It is compared to a current policies scenario in which only current policies in 2016 are employed and not new policies or policy changes are included. In the EU, RES share is 22% (25%), while in the WEO 450 the share in the EU is 37% (39%) of total primary energy demand (TPED) (TFC). In the WEO 2017 the sustainable Development Scenario (SD) is included. The SD is compared to the new energy policy scenario (NPS).	Global ES	Energy system: • WEM	• Investment requirements, • energy expenditures
ETP 2DS (2050) ETP 2DS and B2DS (2060)	2015/16/17	IEA	40 (2050)	The Energy Technology Perspective's (ETP's) scenarios focus on CO2 reductions. The ambitious scenario (2DS) limits the global increase in temperature to 2°C. It is broadly consistent with the WEO 450. All technology options are already commercially available, or at a stage of development that allows using them within the scenario period. Costs of these technologies are expected to fall. The	Global, regions	Energy system: ETP-TIMES	• GHG emission investment requirements

Scenario name (time horizon)	Year of publication	Authoring institution	RES shares (%)	Description	Region Sector	Models used	Impacts assessed
				2DS is compared to 6DS under which no further policy measures as already implemented are assumed, leading to an increase in temperature of 6°C. In the 2017 ETP report, the most ambitious B2DS scenario is an accelerated technology push scenario that avoids lock-in effects and limits global average temperature to 1.75°C. It is compared to the Reference Technology Scenario (RTS) scenario, which takes into account today's commitments by countries to limit emissions, increase energy savings. It includes a 24% RES share and limits temperature increase to 2.7°C.			
E(R) EU (2030)/ ADV E(R) (2050 global)	2014 2015	Greenpeace	44 (PED) 45	Advanced energy (r)evolution for global development and Energy (r)evolution with high RES share for the EU. Reference is the GHG40 scenario of the IA 2014 (RES share of 26.5%).	Global & EU ES	Energy system: • MESAP-PlaNet	• Investment requirements, • electricity generation costs, • fossil fuel imports
GECO 2C (2050)	2016	DG JRC	24 (global) 27% (EU)	Scenario focused on GHG emission reduction. The goal is to limit the global increase in temperature to 2°C. It assumes a fast intensification of policies and shows the impact of climate policies on global energy markets, emissions, use of low carbon sources. Share of RES in gross FED is 20%, 22% and 24% in the global reference-, indicated policies- and 2C scenario, respectively; for the EU: 27% in all three scenarios.	Global (EU) ES	• Global (EU) ES	• abatement costs • GHG emissions • employment and GDP

Source: (own composition based on studies listed in table). Note: PED: primary energy demand.

In general, a direct comparison of the results from these studies is difficult as different methodologies/model philosophies, scopes, perspectives and inputs as well as different reference scenarios are applied. Box 3 outlines the commonalities and differences between these studies. Given the high number of different features, each study is characterised by individual objectives looking at different combinations of targets - RES or EE or GHG reduction targets.

Box 3: Commonalities and main differences between studies

Commonalities

- **Show impacts** of different RES, EE and/or GHG emission targets measured in **economic** (costs, GDP, health), **environmental** (emission) and/or **energy system terms** (resource shares, flexibility, security)

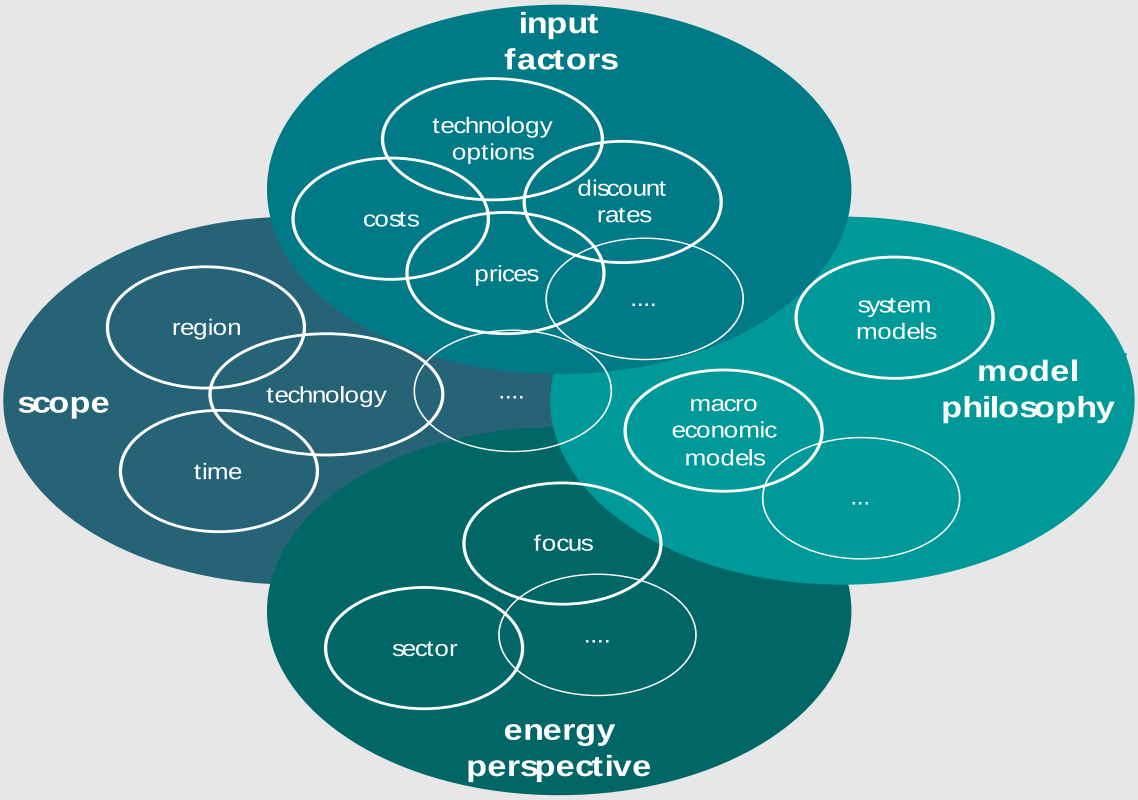
Differences (see Figure 4):

- **Scope: (see Table 1, section 2.1)**
  - Regional coverage: e.g. global, EU, selected countries
  - Temporal coverage: e.g. time horizon from 2010 - 2030, or 2010 - 2050
  - Technology coverage
    - Type of technologies included: e.g. carbon capture and storage (CCS), hydrogen
    - Level of detail of technology
- **Energy system perspective (RES shares per sector) (see Table 1 and section 2.2 and 2.3)**
  - Sector: heat, power, transportation, energy system (all three sectors)
  - Focus: combinations for RES, EE and GHG emission targets
- **Model philosophy (see Table 1 and section 3.4)**
  - System models:
    - Optimisation models: focus on a least cost solution of energy supply for a given RES target and consumption (no interaction between consumption and supply)
    - Simulation model: simulate an interaction between energy supply and demand under given targets (RES, EE, GHG)
  - Macroeconomic models: (see section 3.4)
    - with limited availability of resources such as capital (e.g. equilibrium models)
    - no limitation of the availability of resources such as capital (e.g. econometric models)
- **Input factors (see section 3.1, 3.2, 3.3)**:
  - technology costs
  - fuel prices
  - discount rates
  - technology options and consumption

[Box 3 continues next page]

[Box 3 continued]

Figure 4: Aspects to be considered in scenarios and modelling –commonalities and differences



2.2. Overview of targets and energy consumption of selected scenarios

This section depicts the different features of the scenarios – emission target, energy savings, RES shares as well as fuel consumption – as far as data are available.

Figure 5 illustrates the GHG emission targets, energy savings and RES shares of scenarios that include the EU, showing the targets and shares for the year indicated in the scenario name. Global scenarios in studies such as the WEO or the ETP strive for ambitious emission targets which are in line with RES shares around or above 27%. It is noteworthy that, in some studies, the results for 2030 are only interim results. There are several scenarios that focus on the EU and display a RES share of 30% or higher, such as the REmap EU(IRENA) case, the QUO/SNP30/35 scenarios (TU Vienna/Fh-ISI), GHG40RES30 (Enerdata), euco3030 and GHG40/EE/RES30/35 (PRIMES), and E(R)[12] (Greenpeace). As can be seen in Figure 5, in the EU scenarios high RES-targets go hand in hand with high GHG emission reduction targets, and mostly with energy savings as well.[13] Thus, ambitious GHG reduction targets affect the RES shares and energy savings, and higher RES-shares contribute to higher GHG reductions.

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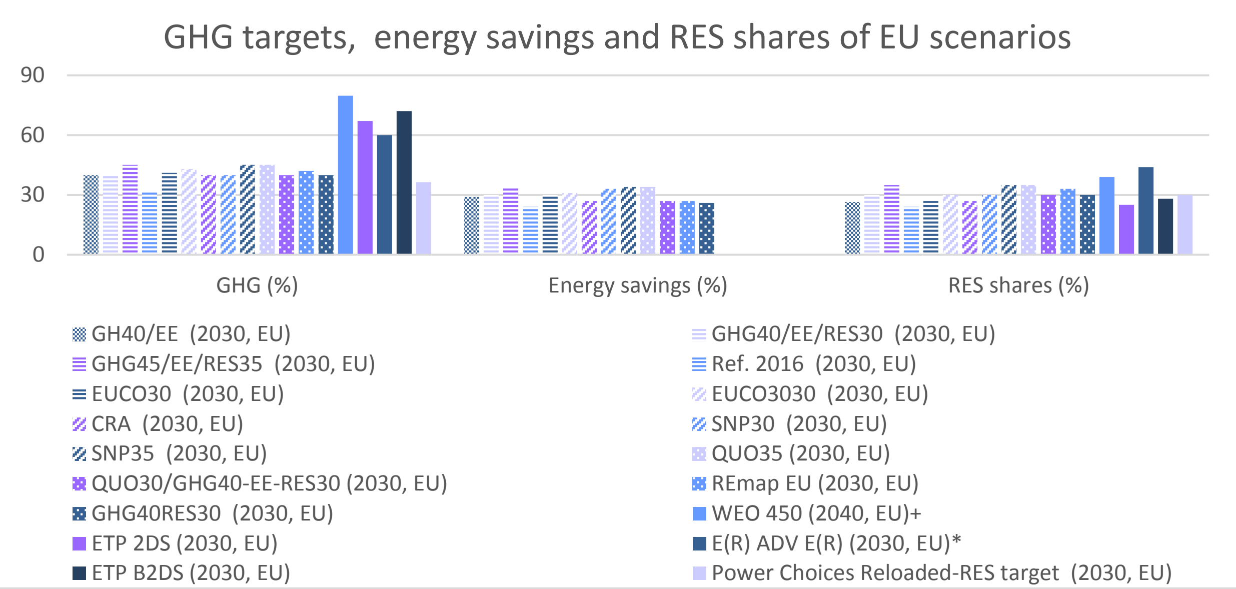
[12] Based on primary energy demand.

[13] It is distinguished between RES targets and RES shares: RES targets represent a constraint in the modelling approach such as a minimum RES level. RES shares are the results of GHG emission reduction, and/or energy efficiency and/or RES targets and are not necessarily identical with RES targets. Thus, in case of a RES target, the RES share is equal or larger than the RES target.

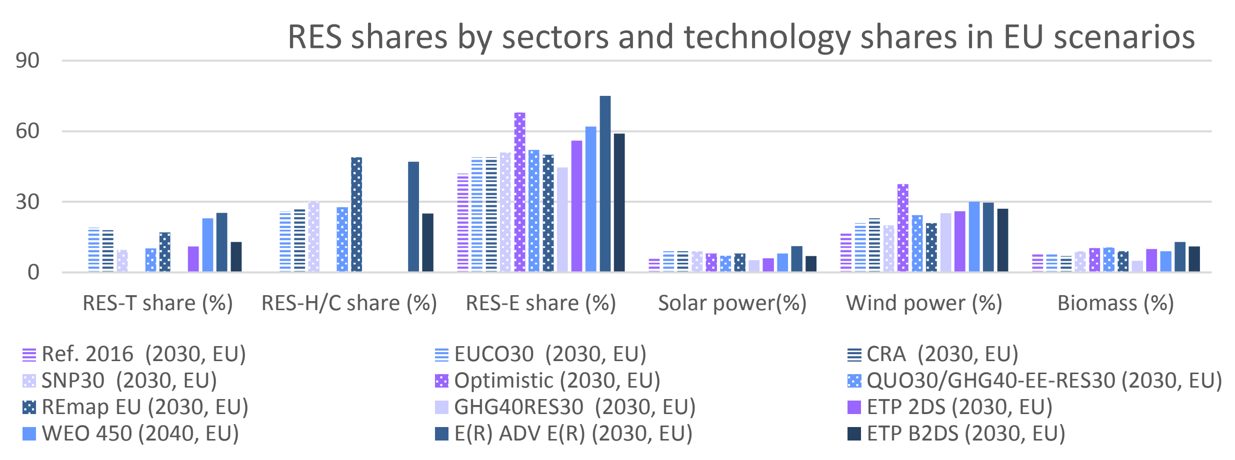
Figure 5: Targets and RES share of scenarios focussing on the EU



Source: own composition based on diverse sources. Note: data show approximate values based on figures, tables and own assessments. *RES in primary energy demand; $^{+}$ 2040

Figure 6 illustrates RES share by sectors and by technologies in the electricity system of EU scenarios. Overall, RES play a very significant role in the electricity sector. In some studies, high shares in transportation (RES-T) and heat/cooling (RES-H/C) depend on the use of electricity and hence on the RES share in electricity generation (RES-E). This applies especially for the E(R), REmap and euco3030 scenarios. Regarding technologies contributing to a high RES-E share, all scenarios consider wind power as the main pillar in RES electricity generation. The Optimistic scenario, in particular, but also the WEO450 and E(R) scenarios rely on wind power. In all EU scenarios, solar power and biomass is considered less dominant - these shares show a moderate variation between scenarios.

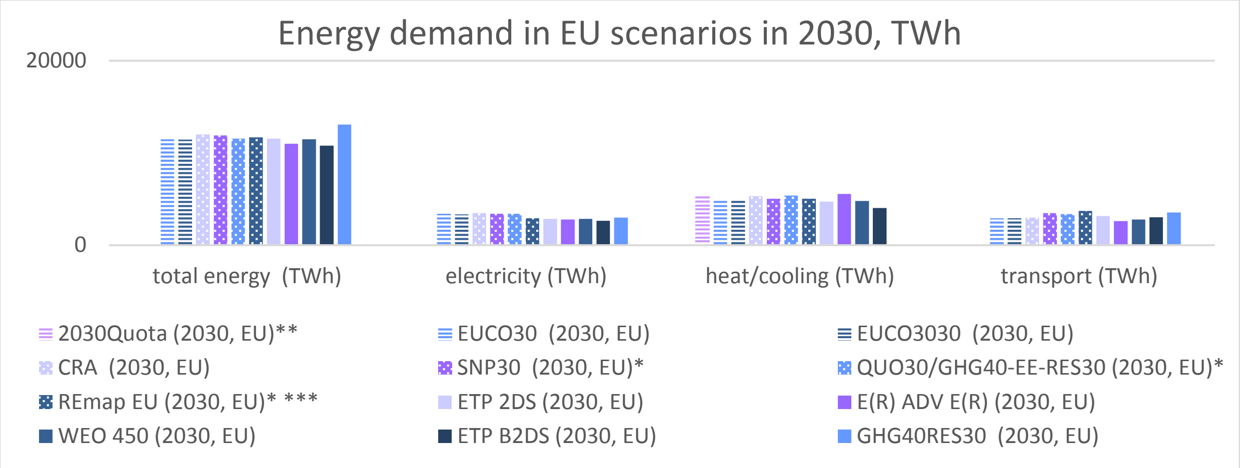
Figure 6: RES share by sectors and RES technology shares in EU scenarios



Source: own composition based on diverse sources. Notes: RES-E, biomass, wind and solar power are based on generation. Approximate values based on figures, tables and assessments.

Figure 7 displays energy demand in the EU in total and by sectors in 2030. Overall, energy consumption does not differ significantly between scenarios. The GHG40RES30 (Enerdata) scenario ranges are at the upper bound of total energy consumption. Without this scenario, the correlation between energy consumption and RES share is high, underpinning the interdependence between energy savings and RES deployment: the lower energy consumption, the higher RES shares.

Figure 7: Energy demand in 2030 by EU scenario, TWh



Source: own composition based on diverse sources. Notes: scenarios of the EU show total energy as final energy demand (FED), and sectoral energy as gross final energy demand (GFED); EU scenarios commissioned by the EU show total energy as GFED, and sectoral energy as FED; other scenarios show final energy consumption (FEC) or FED; * FED; ** without electricity; ***heating/cooling includes buildings, industry in FED without electricity.

2.3. Studies in detail

This section presents the studies individually. A detailed description of the models used in the studies can be found in Section 4.1. The quantitative results regarding the impacts of different RES shares are presented in Section 5.

2.3.1. European Commission Impact Assessments (EC 2014 and EC 2016)

To prepare the IA (**Impact assessments of the EC**) of the targets and policy packages proposed by the EC in 2014 and 2016 a number of different policy scenarios were evaluated using the PRIMES modelling suite. The main objective of the 2014 modelling was to define suitable levels for all three EU climate and energy targets. Therefore, the impact of the combination of different target levels was assessed. The modelling includes an analysis of a 30% renewables target in combination with a 40% GHG target as well as a 35% renewables target in combination with a 45% GHG target. In the 2016 assessment, the highest share of RES assessed was 30%, with most scenarios focussing on the effects of the previously defined 27% RES target. An overview of these scenarios is given in Table 1. For these studies, the energy system model PRIMES is combined with the macroeconomic models E3ME and GEM-E3[14]. These assessments shows that scenarios with higher EE standards imply RES levels above 27%, which confirms the theoretical linkages between the different targets described in Section 2.3.

In addition, the **Global Energy and Climate Outlook (GECO)** is a study of the Joint Research Center (JRC). It aims to provide evidence-based scientific support to the European policy-making process by examining the effects on GHG emissions and international energy markets of a reference scenario (current trends continue beyond 2020) and other scenarios at a global level. One of these scenarios is the 2C scenario, which is in line with keeping global warming below a temperature increase of 2°C. In the 2C scenario all regions realise domestic emission cuts to stay below 2°C. Global efforts to reduce emissions appear to go

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[14] The PRIMES modelling suite also includes models for the agricultural sector, land use change and non-CO2 gases. However, the results from these models are not part of this document. A description of the full modelling suite is available at https://ec.europa.eu/clima/policies/strategies/analysis/models_en.

hand in hand with economic growth as regions draw economic benefits from shifting expenditures for fossil fuels to low-carbon investments. For the analysis, the POLES and GEM-E3 models are applied, with the latter maximising economic welfare under emission targets.

Mapping and analyses of the current and future (2020-2030) heating/cooling fuel deployment (fossil/renewables) is a study commissioned by the EC. It provides an assessment of the entire heating/cooling sector in the EU by including detailed analyses of residential and non-residential buildings, industrial processes and district heating and with a focus on economic impacts until 2030. The Current Policy scenario describes the current implementation of policies, while the three remaining scenarios focus on supplier obligations for RES heating and cooling deployment, each with alternative design options. They all rely on the same economic assumption as the EU reference scenario 2016. The scenario 2030Quota EU is based on certificate trade and allows for trade among suppliers in different Member States in order to reach a uniform quota of 27% on EU level. The obligation scenarios assume that current subsidies for H/C are phased out after 2020, including subsidies for installing technologies. The obligation schemes defined enter into force in 2020.

2.3.2. Commissioned studies

Employment and growth effects of sustainable energies in the EU (EmployRES) (Fraunhofer ISI and TU Wien/EEG 2014)

This study assesses the employment and growth effects of different renewable shares. In the study, five scenarios are analysed. The baseline scenario implies a gradual phasing-out of the current policy framework and a RES share of 27% is reached in 2030. RES shares of 30% and 35% are modelled based on two different policy assumptions - a continuation of national technology-specific policies on the one hand and a switch to a technology-neutral EU-wide quota scheme on the other hand. In order to assess the impacts of these different renewable shares, the energy system model Green-X is combined with the two macroeconomic models Astra and NEMESIS.

Estimating energy system costs of sectoral RES and EE targets in the context of energy and climate targets for 2030 (Fraunhofer ISI/ISE, TU Wien/ EEG, ITT Comillas, Prognos, ECN, 2014)

This report entails a similar analysis based on the energy system model Green-X only. A baseline scenario, in line with the Primes scenario GH40EE of the IA 2014 and called “ETS-only” scenario is compared to policy scenarios with a RES share of 30%. The policy scenarios differ by their RES policy, i.e. after 2020 RES support continues by means of an EU green certificate scheme or a balanced RES support across countries with a feed-in premium.

Integration of RE in Europe (KEMA Consulting et al. 2014)

This study analysis the effects of five scenarios with differing RES-E shares and electricity demand levels on the electricity system. In order to do this, a capacity extension model is combined with a dynamic system investment model (DSIM) to analyse electricity system costs including generation and transmission. The study does not include any impacts beyond the electricity system.

2.3.3. NON-EC studies

World Energy Outlook 2016/2017 (IEA 2016/17)

The World Energy Outlook 2016 models three scenarios using the IEA's own World Energy Model (WEM). The first scenario includes policies already in place (Current policies scenario), the second includes policies in an advanced planning phase (New policies scenario) and the third scenario is based on the objective of limiting global warming to 2°C (450 scenario). The first two scenarios aim at showing policy makers whether the policies already in place or decided on are sufficient to limit climate change. For the calculation of the third scenario, additional policies are defined in a way that reduces GHG emissions from the energy system. For the EU, further RES support policies as well as additional support for CCS projects is assumed. The World Energy Outlook 2017 includes a sustainable development scenario which starts with a vision on how the "new" energy system/sector is supposed to look like in 2040 and then goes back to the present. It has a special focus on universal energy access and emissions and their impacts on human health. The sustainable development scenario is compared to the new policy scenario. As policies are exogenously defined, resulting scenarios are not necessarily the most cost-effective ones. Results of the scenarios include the investment requirements[15] as well as impacts on consumer energy prices and expenditures.

Energy Technology Perspectives 2015/16/17 (IAE 2015/16/17)

The Energy Technology Perspective (ETP) models three scenarios using the ETP-TIMES model. This is a bottom-up model covering 28 world regions. It depicts a detailed supply side technology portfolio and is based on the TIMES model generator (integrated MAKRAL-EFOM system). Primary energy supply is converted into FED by end-use sectors and end-use service demands. Scenarios are based on back-casting and forecasting. The first displays plausible pathways to a desired end state, i.e. the paths are the results of the modelling effort. In the forecasting approach the end state is the result of the modelling effort. The objective is to identify the most economical way to reach a desired outcome. However, due to constraints and political and societal aspects it does not provide a least-cost solution.

REmap - Cost-effective RE potential for the European Union in 2030 (IRENA 2017)

Based on potentials and generation costs, IRENA's REmap project analyses the cost-effective potential for renewables in different countries and world regions. Thus, it does not set RE targets, but explores feasible shares. The final results for the EU will be published by the end of 2017, yet draft results are already available. For the EU roadmap, the approach relies on existing REmap studies of 10 EU Member States and an aggregated high-level analysis for the other 18 EU Member States. For the power sector, this high-level analysis employs the 2016 Reference Scenario of the PRIMES model modified by a RE uptake based on expected potential and technology developments. For these EU REmap options, the renewable technology potential is identified on a country-by-country basis with country experts. Based on the REmap tool, possible renewable shares in the energy system are estimated. Results include investment requirements and additional generation costs or savings of energy generation, while additional investments in infrastructure and back-up capacities are not included. The approach does not account for the intermittency of renewable sources.

Power Choices Reloaded (Eurelectric 2013)

In this study by Eurelectric, several scenarios are assessed using the PRIMES model. While most scenarios assess systems with 27% RES in 2030, one scenario incorporates a RES target of 30% in 2030. The effects of this target on energy system costs, health effects, fossil fuel imports, investment requirements and energy prices are assessed.

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[15] The investment requirements for the EU are however not published for all scenarios. The values are only available for the New policies scenario so that a comparison between scenarios and thus an analysis of the effects of a higher RES share is not possible.

Roadmap for Europe - Towards a sustainable and independent energy supply (Greenpeace 2014)

In this study, Greenpeace assesses the impact of a scenario with higher EE and a higher RES share on investment requirements, energy system costs and fossil fuel imports. The analysis is based on the MESAP-PlaNet tool, which can imply differing degrees of detail. Unfortunately, no detailed information about the model setup is available in the published study. In 2015, Greenpeace conducted a global study on RES use in which they included a very ambitious global RES scenario for 2050 (100% RES share). However, this study does not provide a scenario for the EU, it only describes energy demand, generation and impacts on employment within the energy sector (gross employment) for European OECD member states.

Estimating energy system costs of sectoral RES and EE targets in the context of energy and climate targets for 2030 (Fraunhofer ISI et al. 2014)

This study (RES Cost/QUO30) commissioned by the German Federal Ministry for Economic Affairs and Energy assesses the impact of different RES shares and degrees of EE on energy system and electricity system costs (EU wide assessment). To do so, the energy system model Green-X is combined with the electricity system model PowerACE (now renamed to Enertile).

Costs and Benefits to EU Member States of 2030 Climate and Energy Targets (Enerdata 2014)

This study commissioned by the former UK Department for Energy and Climate Change assesses the effects of a separate RES target using the energy system model POLES (EU wide assessment). The modelling includes an analysis of the national burden sharing if a 2030 RES target is included. Burden sharing is assumed to follow the same approach as for the 2020 target.

3. CRITICAL FACTORS INFLUENCING THE OPTIMAL RENEWABLE TARGET

KEY FINDINGS

- Fuel prices influence the relative cost of conventional and RE conversion. In a cost optimisation approach, low fossil fuel prices lead to a lower share of renewable shares and vice versa. However, *fossil fuel prices* are very uncertain due to their historically high price volatility. This also results in high uncertainty regarding the cost-effectiveness of renewables and deployment levels calculated with the various models.
- *Discount rates* influence the cost of capital. High discount rates imply higher shares of technologies with low initial investments compared to fuel and maintenance costs (e.g. gas-fired power plants). Low discount rates make capital-intensive technologies (e.g. solar and wind or nuclear power plants) more attractive. Discount rates reflect financing conditions, but in some models (e.g. PRIMES) they are also used to represent non-economic barriers.
- Energy system costs of renewable targets can be assessed using social or private discount rates. The choice of discount rate depends on the objective of a study. Social discount rates are applied to assess whether a specific energy system is preferential for society, whereas private discount rates are applied to assess if business cases are profitable from stakeholder perspective.
- Given the recent auction results for renewables in the electricity sector, there is evidence that *technology costs* have declined. Although market conditions play a role for auction participants the difference between current assumptions regarding technology costs and costs assumed by market players is significant. These cost reductions are so far only taken up in the REmap model. Applying them to other scenarios could reduce costs of RES deployment. If the cost of renewables sink faster than costs of alternative technologies for energy conversion, the renewable share will be higher under a cost-minimising approach.
- Assumptions regarding the *availability of technologies* with high uncertainty regarding their future development and acceptance by society (e.g. nuclear, CCS or hydrogen) have a significant impact on the resulting share of renewables within the various scenarios, e.g. high RES-T (transport) share in the energy (r)evolution scenario due to hydrogen and electricity use.

The type of model used to assess the impacts, e.g. on GDP, affects results, as can be seen by the differing modelling results in the IA 2016 (e.g. euco3030:E3ME:+0.6% GDP; GEM-E3: -0.5% GDP) and the EmployRES (e.g. SNP35: Astra: +0.2% GDP; NEMESIS: +0.8% GDP) study.

In this section, some important input factors are described first with examples from different studies and assessed regarding their validity in the context of RE targets and recent developments in the energy system. Then, the different models used in the assessed studies are described and their impacts on the results are discussed.

3.1. Technology and fuel costs

Assumptions regarding technology cost developments are not only crucial for technologies that are currently still in the last research and development phase (such as new nuclear, CCS), but also for more established technologies (wind, photovoltaics (PV)). The relative development of costs of different technologies especially influences the cost-effectiveness of renewables. If cost of renewables sink faster than costs of alternative technologies for energy conversion, the renewable share will be higher under a cost-minimising approach. Technology costs depend on assumptions made regarding diffusion and technological learning as well as other factors such as availability of land, other resources or fuel costs. In the following subsection, we compare recent auction results with PRIMES assumptions and illustrate existing uncertainties regarding fuel cost developments.

3.1.1. Auction results and technology cost assumptions

Since the PRIMES scenarios published in 2016, a number of auctions for electricity generation from renewable energies were conducted in EU countries. Average auction results for renewables are in most cases significantly lower than assumed prices in the PRIMES scenarios and other studies assessed in this document (see Table 3 with the example of PRIMES assumptions). These recent results are one of the reasons why a renewable target above 27% is considered economically feasible by a number of stakeholders. That is, with decreasing costs, RE technologies become competitive on the market and represent an interesting technology option.

Table 2: Auction results

	Year of auction	Year of delivery	Country	Average of auction results in €ct/kWh	Primes Reference 2016, LCOE in 2030 €ct$_{(2013)}$ / kWh[16]
PV	2017	2018	Germany	5.2	9.5
	2016	2017			
	2016	2018	Denmark		
	2017		France		
	2016		Greece	9.1	6.5
Wind offshore	2017	2025	Germany	3.9	10.5
	2016	2021	Denmark		
	2016		Netherlands		
	2016		Italy	16.2	10.5
Wind onshore	2017		Germany	5.0	8.0
	2016		Italy	6.6	8.0

Source: Agora 2016, PRIMES 2016, own research

Differences between auction results and, for example, the updated PRIMES 2016 shown in Table 2 are substantial, however. PV in Germany was auctioned at 4.91 €c/kWh on average in the last auction round in October 2017, 5.7 €c/kWh in June 2017, this after a steady decrease from 9.2 €c/kWh in April 2015. The French PV auction in March 2017 resulted in a comparable support level of 6.3 €c/kWh. In comparison to these results (average of 5.1 €c/kWh), PRIMES assumptions for 2030 with 9.5€c/kWh in 2030 seem very high. The differences between current auction results for onshore and offshore wind and the PRIMES assumptions for 2030 are of a similar magnitude.

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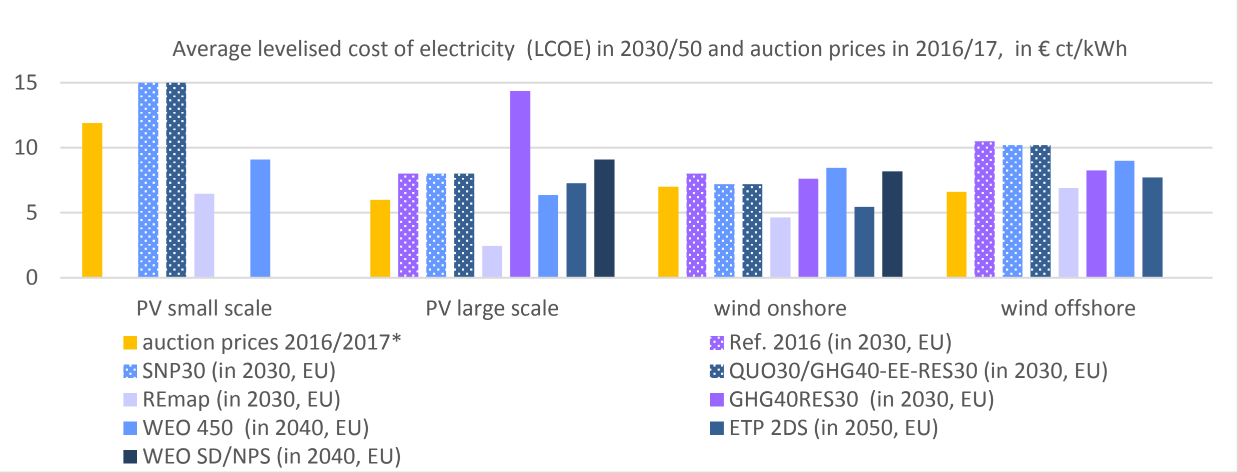
17 Average rate including the results of Italy (16€ ct/kWh).

It must be noted that, in theory, prices proposed by auction reflect levelised costs of electricity (LCOEs), as auction participants need to cover their costs when receiving the defined support levels. However, there are some caveats when interpreting auction results directly as future generation costs.

- First, auction participants need to estimate future market prices and technology costs when calculating their bids. While they might have better information regarding the development of costs than a central entity, this information is not perfect. They might, therefore, underestimate the necessary revenue levels.
- Secondly, winning an auction does not necessarily mean that plants are built. While recent auctions try to reach high realization rates by penalties and prequalification criteria, in certain cases, less favourable market price and technology cost developments (and thus higher LCOE) might prohibit the realization of plants if penalties are lower than expected losses.
- Thirdly, auction results also reflect the current market competition and firm strategies. For some companies (and given a high competition in the auction) bidding below costs in an auction is a market-entry strategy.

Figure 8 illustrates assumed LCOE from wind and solar power in 2030/40/50 of the EU scenarios and compares them to recent average auction results (2016/17) of PV and wind power in the EU. The LCOE depend strongly on the assumed technology costs and discount rates applied. While technology costs are driven by technological learning and thus diffusion or deployment of RES technology, discount rates depend on the cost of capital, barriers and risks. As Figure 8 shows, the lowest LCOE are assumed in the REmap scenario; for PV and wind onshore they are even lower than recent auction results. In other scenarios, the LCOE for wind power are about 50% higher than in the REmap scenario, for PV even higher. The low LCOE values in the REmap depend among others on the low discount rate (4%) used in this assessment (see section 3.2). The IEA (2017) assumes a decrease in LCOE of wind onshore of about 15% (2030) in a number of regions. Given an average auction price of 7 €ct/kWh[17] in the EU (Figure 8), the LCOE might decline to about 6 €ct/kWh in 2030. This value is above the LCOE in the REmap case.

Figure 8: LCOE in selected scenarios compared to recent auction results



Source: own compilations based on diverse sources: Note: * averages based on auctions in some EU countries; LCOE represent approximate values, depicted for 2030/40/50

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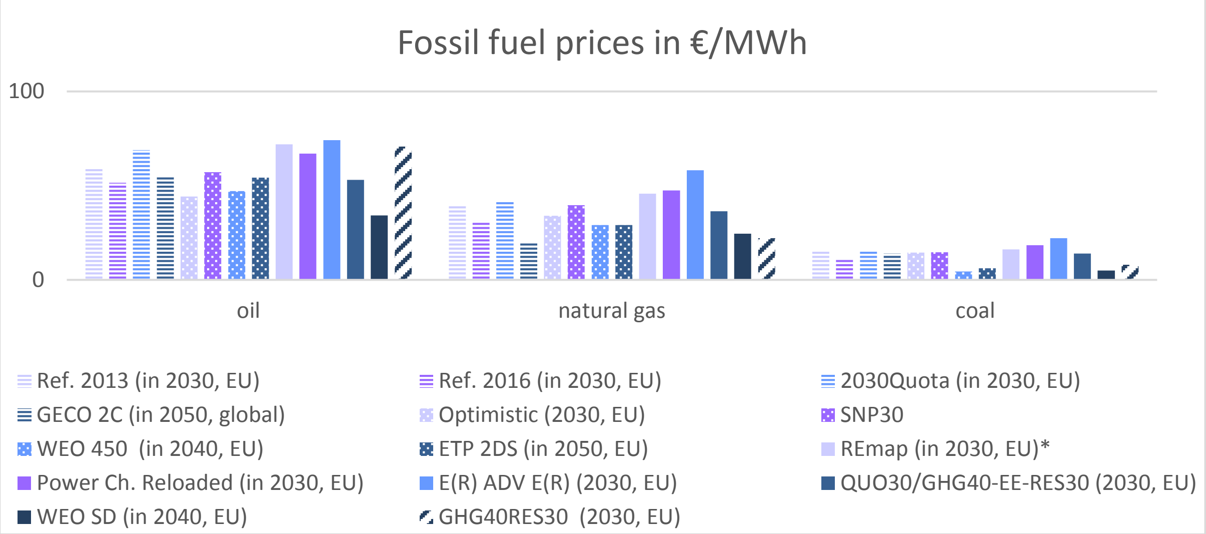
[17] Average rate including the results of Italy (16€ ct/kWh).

3.1.2. Uncertainties regarding future fossil fuel prices

The PRIMES Reference scenario 2016 assumes lower fossil fuel prices (see Figure 9) compared to the Reference scenario from 2013[18]. The changes occurring between the modelling rounds illustrate the high uncertainties regarding the cost of fuel. The same is true for other repetitive studies like, for example, the World Energy Outlook (see Figure 9, WEO 450 and SD). The reload of the Eurelectric Power Choices Scenario was among others conducted due to unexpected changes in international fuel prices (Eurelectric 2013). The changes in fuel cost assumptions over time make it clear that there are high uncertainties, especially regarding the future development of oil and gas prices. In general, the assumed fuel prices in PRIMES are slightly higher than those calculated in the World Energy Outlook of the IEA. The differences are most pronounced when the policy scenario (450 ppm) is compared to PRIMES input data. As a consequence, higher RES shares might be reached in the PRIMES model. Similarly, the energy revolution and the REmap scenario display high fossil fuel prices (see Figure 9) while fossil fuel prices are low in the GECO 2C and optimistic scenarios as well. Thus, higher fossil fuel prices make RES relatively cheap, leading to higher RES shares and low costs in the scenarios and vice versa.

Figure 9: Fuel prices for 2030 in selected scenarios



Source: own compilation based on diverse sources. Notes:* refers to petroleum instead of oil

However, applying fixed fossil fuel prices across different scenarios relies on the assumption that changes in the scenario do not impact global demand for fossil fuel. For European studies, this assumption might hold if only the EU realizes measures for GHG reduction, but other world regions remain on the business-as-usual pathways. The potential change in fuel costs if countries globally act for climate mitigation (GECO 2C, WEO, Enerdata) is considerable, however. The lower fuel prices again have an influence on the relative cost of conventional and RE conversion and, thus, all else equal would reduce cost-optimal renewable shares.

3.2. Discount rates

Discount rates are a crucial factor in energy system models. They reflect the cost of capital and the expected rates of return for individual investors. Assumed discount rates have a twofold impact on model results:

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[18] The PRIMES Reference Scenario 2016 lists the major changes on p. 43. Especially costs for PV and onshore wind were reduced while cost assumptions for nuclear and CCS were increased.

- First, they influence the resulting technology mix in an energy system under a cost minimising approach, as they are used in the calculation of costs for each technology (costs are discounted over the lifetime of the assets).
- Secondly, they are used to determine the total energy system costs, i.e. to show how expensive the energy use with the given technology mix is.

In models aiming at cost minimization:

- high discount rates imply higher shares of technologies with low initial investments compared to fuel and maintenance costs (e.g. gas-fired power plants) and
- low discount rates make capital-intensive technologies (e.g. solar and wind or nuclear power plants) more attractive.

As a result, if low discount rates are applied, investment in EE and renewable energies (with the exception of biomass[19]) becomes more attractive than coal or gas. The same applies for CCS and nuclear technologies.

Discount rates differ between actors. For industrial and commercial actors, discount rates can be set based on the respective company's expected return. The level of suitable discount rates for households is more contested. On the one hand, households usually expect a lower rate of return to investment than commercial or industrial investors. Thus, for households the cost of capital can be a suitable indicator for setting the model discount rate. These differ between households mostly based upon household income. On the other hand, households are often risk-averse and face non-economic barriers (such as a lack of information) when undertaking investment decisions. Such barriers hampering the diffusion of new technologies and products can be depicted by higher discount rates[20]. However, it is disputed whether this approach is correct because higher discount rates lead to higher energy system costs, but barriers are non-economic effects and do not increase system costs the way cost of capital does (compare Steinbach et al. 2015).

In addition to individual discount rates, social discount rates are used to assess policies from a societal point of view. The social discount rate is typically lower than private discount rates as, among others, the interests of future generations need to be included in the social evaluation especially if long term developments such as climate change are assessed. Social discount rates are typically set to 1-7%[21].

In PRIMES calculations, typically, diversified interest rates are used for different sectors for the calculation of the energy system. These interest rates are used for the individual assessment of investment choices. Thus, the results represent a probable development of the energy system based on investment decisions by individuals and companies from different sectors. In a second step, annualized system costs are calculated using a reduced uniform discount rate of 10% for investment expenditures of all final energy consumers[22].

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[19] Biomass plants are not necessarily very capital-intensive, yet they also face substantial fuel costs that are likely to increase in the future due to a higher demand.

[20] Alternative approaches for incorporating non-economic barriers and risk-aversion in modelling exist, but are often more time and computationally-intensive. Adjusting the discount rate level is, therefore, common practice in modelling not only the energy sector. Nevertheless, some authors (e.g. Steinbach) argue that this approach is not correct.

[21] See, among others, Stern 2006 for a general overview on social discount rates

[22] In the PRIMES Reference scenario 2013, the same individual discount rates were used for both simulating the investment decisions and cost accounting. This approach was changed in 2016 to avoid an effect of non-economic barriers on total system costs. The PRIMES Reference scenario 2016 report contains a detailed explanation of discount rates applied and the reasons for using such discount rate including numerous references (PRIMES 2016).

While highly diversified private discount rates are used in PRIMES modelling, two important aspects influencing these rates are not considered:

- First, different _country risk profiles_ can have an impact on private discount rates. In countries where renewable support policies and financing conditions are perceived as stable, lower discount rates should apply as compared to countries with higher perceived risks. A quantification of differences in various risks categories across EU member states was implemented in the framework of the project DIA-Core[23] project. Results show large deviations between different EU countries with rates diverging between 3.5% to 4.5% in Germany and 12% in Croatia and Greece.
- Second, also the _type of support system_ influences the level of risk and thus the discount rate. There are substantial differences between the types of support policies among countries. A study by Imperial College London investigated the differences in financing costs depending on country, renewable policy and support system. For example in the UK, depending on the type of RE policy[24], the weighted average cost of capital (WACC) differs by 1.2 percentage points for PV and 1.5 percentage points for wind offshore[25]. These results are in line with findings from the DiaCore project, where differences in the WACC range around 1.5 percentage points (wind) due to different RE policy designs.

In Green-X modelling, a standard discount rate of 7.5% is applied. This corresponds to a relatively high social discount rate or a relatively low private discount rate. The basic discount rate is however adapted based on policy and technology risks. In Enertile modelling, a flat discount rate of 7% is used[26] while in REmap 4% are applied to account for the social perspective of sustainable energy use.

The discount rate level in a model has a substantial impact on the resulting total energy system costs and the resulting contribution of the various technology. High discount rates lead to high costs and low shares of capital-intensive technologies, such as renewables (except for biomass), EE, nuclear and CCS. The selection of a suitable discount rate depends on the objective of the study. For assessing energy systems regarding their benefits for society, social discount rates are applied. For modelling individual investment decisions and the effects of different policy settings, individual discount rates are applied. A good proxy for these discount rates are costs of capital or/and including non-economic barriers, risk aversion and opportunity costs. PRIMES mimics individual investment decisions displaying the effects and effectiveness of different policy scenarios. The PRIMES modelling is not taking the perspective of a social planner and does not follow an overall least cost optimization of the

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[23] Boie, I., B. Breitschopf, A. Held, M. Ragwitz, S. Steinhilber and et.al. (2016), 'Policy Dialogue on the Assessment and Convergence of RES Policy in EU Member States: Final Report of DIA-CORE. Contract N°: IEE/12/833/SI2.645735', accessed 11 November 2016, at www.diacore.eu/images/files2/DIACORE_Final_Report.pdf

[24] RE policies implying the lowest risk are typically feed-in tariffs, which guarantee the plant operators a fixed income for every unit of electricity they generate. Sliding premiums also imply a relatively low risk as deviations in market prices influence the income of the plant operator only to a very low extent. In quota schemes low market prices can be balanced by higher certificate prices, but only to a limited extent. Thus, the risks for the plant operator increase. With fixed premiums or capacity-based support (i.e. investment subsidies) risks are even higher.

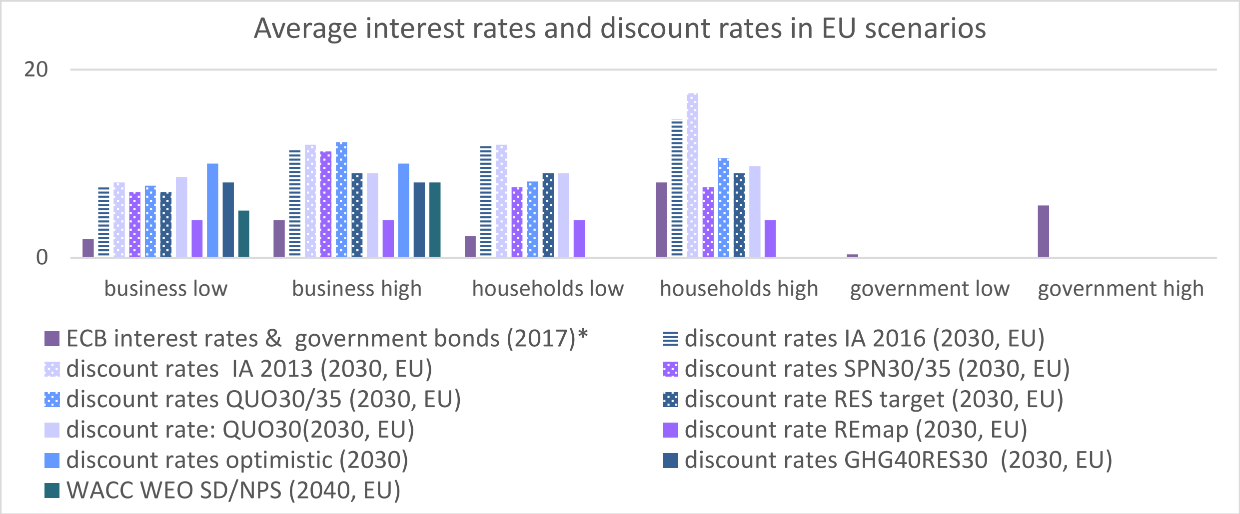
[25] In one of the PRIMES scenarios, different WACC assumptions were used to evaluate the impact of high country and technology risks. Two variants of the CRA scenario (CRA_techspec and CRA_countryspec) use reduced WACC for specific technologies and countries respectively which have higher risk rates in the original CRA scenario. While the impact on overall system costs in both cases is low, in CRA_techspec the technology mix changes with significantly higher offshore shares. In CRA_countryspec the geographical distribution of RES investments is much broader when compared to the CRA baseline where most investments are realized in low-risk countries.

[26] Discount rates used in the other studies assessed in this document are not publicly available, as far as we know.

entire energy system in the long-term. Thus, PRIMES offers an in-depth assessment, but if the core objective is to optimize the total system costs for society, then another approach should be favoured.

Figure 10 depicts the minimum and maximum interest rates of medium/long-term lending for corporations and households of EU countries (European Central Bank) and compares it to the discount rates applied in the different EU scenarios. Assuming low technology risks, small investment barriers due to credible policies and moderate country risks, the discount rates applied in the scenarios should not deviate much from the interest rates. However, only the REmap discount rate reflects a similar level than the lending rate, all other discount rates obviously include much higher risks and investment barriers.

Figure 10: Discount rates applied in EU scenarios in comparison to interest rates (EU)



Source: own compilation based on diverse sources. Notes: *cost of borrowing for non-financial corporations, households in EU, European Central Bank, 9/2017. WACC used to calculate LCOE.

3.3. Availability of technologies

Apart from the methodology used, assumptions regarding the availability of technologies are an important driver for model results concerning RE. The availability of different technologies can, for example, be restricted due to uncertain technological developments or political decisions[27]. Technological availability influences the share of renewables necessary to reach GHG reduction targets. The most contested technologies in the electricity sector are CCS and nuclear energy. In the case of CCS, the high costs of existing pilot projects make its wider use uncertain and therefore more “unlikely”. While nuclear energy has no carbon emissions, there are other environmental issues due to the radioactive waste, which also implies high costs. In the wider energy sector, the necessity and availability of hydrogen may also play an essential role for future energy supply. Also, the future availability of unconventional resources, such as shale gas, is heavily disputed. This uncertainty in the future availability of technology options which are currently not mature make it necessary for modellers to set some assumptions about their future development which can then have significant impact on resulting energy outcomes.

For example, in previous versions of the World Energy Outlook, the role of CCS was assumed to be much more prominent than in current versions (IEA 2016). On the contrary, shale gas

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[27] If technologies with high uncertainties regarding future developments are included in the modelling, higher technological risks are typically modelled by increasing assumed technologies. As a consequence, technologies with uncertain future developments are less likely to be a part of the model solution and vice versa.

forecasts from the U.S. Energy Information Administration (EIA) decreased substantially between 2011 and 2013 (EIA 2013). The energy (r)evolution scenario assumes a high share of hydrogen and electricity in the transport sector, thus achieving RES-T share around 60% in 2040.

In addition, as energy system modelling often extends far into the future, some technology options that are likely to develop by 2030 and beyond are subject to high uncertainty, one example for such technologies being nuclear fusion. Others might not yet be known and, therefore, not included in the modelling.

Box 4: The case of CCS, electric mobility and hydrogen in PRIMES and others

The PRIMES modelling includes both CCS and nuclear in the electricity sector as well as electric mobility and hydrogen in the transport sector. Nuclear and CCS are included in the PRIMES model, but in the PRIMES Reference scenario 2016, market-driven investment in new nuclear or CCS plants does not take place because of the high costs of these technologies. Also, the role of hydrogen is negligible. Some PRIMES policy scenarios result in a slight increase of nuclear capacity and generation in the period until 2030, however.

Most other modelling studies (with the exception of the Greenpeace energy (r)evolution scenario) allow to simulate the same technology options. Depending on cost assumptions and the GHG emissions reduction ambition, generation from nuclear power plants is also increasing slightly in the EU countries until 2030 (e.g. IEA ETP 2017 2DS and B2DS scenarios) in some scenarios. Also, a small share of electricity in 2030 is generated from coal and gas plants with CCS in some scenarios (e.g. IEA ETP 2DS). Thus, PRIMES assumptions lead to similar conclusions as other modelling approaches in this regard.

3.4. Conceptual considerations – models used to depict impacts

The type of model used as well as assumptions regarding future development of input factors significantly influence results of different models. Models can take into account uncertainties regarding input factors by using special techniques, but these techniques require time and have computational restrictions. Therefore, in energy system modelling, typically, only one set of input factors is used and the robustness of the results is partly tested via sensitivity analysis. Therefore, such modelling outcomes should never be interpreted as forecasts, but only be understood as a set of plausible developments.

The models used in the papers assessed can be grouped in two main categories - energy system models and macroeconomic models. Additional models that are being used, such as the GAINS model used in the PRIMES modelling suite, that depict the atmospheric distribution of air pollution are not included in this overview[28].

3.4.1. Energy system models

On the energy system level, **simulation models** generally represent developments of the future energy system based on costs, policies, potentials and barriers. **Optimisation models** provide rather a least-cost solution to reach a given objective e.g. a minimum RES share. Thus, they take the perspective of a central planner and ignore non-economic barriers and behavioural aspects. In addition, there are more **simplified approaches,** e.g. restricted to cost comparisons, focussing on a more limited scope (e.g. RES only) or taking a global

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[28] In the PRIMES modelling suite, health effects are calculated using the model GAINS, land use impacts are modelled using the model GLOBIOM/ G4M. These models are however very complex and therefore not described in this document. A description of GAINS and GLOBIOM/ G4M can be found here : https://ec.europa.eu/clima/policies/strategies/analysis/models_en.

perspective based on more aggregated data[29]. In the following subsections, the energy system and electricity system models used in the studies assessed are briefly described and evaluated.

a. PRIMES[30]

In PRIMES, individual actors (e.g. households, companies or energy providers) optimise their profits based on perceived costs (technology and fuels), perceived risks (e.g. technology or country risks) and income (e.g. electricity prices, support payments). First, the demand level is simulated. The simulation of the supply side follows. Policies are exogenous to the model and influence pricing and costs. PRIMES includes very detailed modelling of technologies in the different energy sectors. It covers the EU region. Intertemporal variation in demand and generation from variable renewables is modelled by including the hourly demand and supply situation on some typical days. Constraints, e.g. a minimum share of RES in the energy system, can be defined in the model.

As PRIMES is a simulation model (with optimisation elements at the actor level), it is very well suited to assess different policy pathways and reference scenarios. The missing representation of all hours of the year and the exogenous provision of network infrastructure (e.g. power grid, gas infrastructure, CO_2 storage) can potentially increase the costs of incorporating renewables in the system when compared to full optimisation models. The effects of individual discount rates are discussed in Section 3.2.

b. World Energy Model (WEM)[31]

The WEM is also a simulation model. It is a global model incorporating global markets for fossil fuels and biomass as well as demand sectors. Policies influence the individual decisions and result in different demand levels, which are met with energy supply. Technology development and costs are exogenous in WEM. To reach a certain GHG emissions target (e.g. in the 450 scenario), policies need to be defined exogenously. The WEM is well suited for giving an overview for the effect of existing and planned policies on the global energy markets. However, results do not necessarily represent cost-optimal solutions and the model setup limits the potential for variable renewables[32].

c. Green-X[33]

Green-X is a simulation model relying on dynamic cost-resource curves allowing for technological learning and investigating policy impacts and integrating non-cost deployment barriers. It develops scenarios in which energy consumption is exogenously set and provides model outputs, such as investment in and trade of RE technologies, policy support costs, additional generation costs, operation and maintenance costs of RES use, biofuel expenditures. Green-X is calibrated for the EU 28.

d. REmap[34]

REmap is an Excel-based tool that assesses the costs of an ambitious RES shares. It takes into account recent changes in technology costs, energy price changes, realistic RES potentials, expert knowledge and includes energy supply as well as the end-use sector. It

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[29] See, for example, Sensfuß (2008) for a discussion of different modelling approaches. A comparison between PRIMES and POLES can be found in Desprès (2015).

[30] Additional information on the PRIMES model can be found in E3Mlab (2016).

[31] Additional information about WEM is available here: http://www.iea.org/weo/weomodel/

[32] WEO 2017, WEM documentation 2017, p. 43ff; http://www.iea.org/media/weowebsite/2017/WEM_Documentation_WEO2017.pdf

[33] A detailed description of Green-X can be found here: http://www.green-x.at/

[34] The REmap approach is explained here: http://irena.org/remap/

represents the energy system with a special focus on generation; it does not include, for example, adjustments in infrastructure and of the power system to integrate RES-E. Therefore, the REmap results tend to underestimate the total energy system costs. The general approach relies on assessing substitution costs of RES options, i.e. the difference between annualised investment, operation and maintenance costs of RES use and conventional energy. The energy system costs are the product of the substitution costs and the RES potential. It is the only approach that shows significant negative “costs” of an ambitious RES share, i.e. it is the only one in which using RES up to 33% is in sum cheaper than the reference options.

e. POLES[35]

POLES is a partial equilibrium simulation model of the energy sector, covering 54 individual countries and 12 additional country groupings for global coverage. For each country, the evolution of the whole energy value chain is calculated endogenously, from the supply side to the demand of various sectors, and with energy price calculations as a result of the equilibrium. While energy demand is determined top-down through econometric relationships linking energy to sectoral activity and prices, electricity generation follows a bottom-up approach with more than 30 technologies modelled. In POLES, policies are defined exogenously and their impact is assessed in scenario analyses (e.g. subsidies, carbon pricing mechanisms).

f. METIS[36]

The optimisation model, METIS, is used by the EC in combination with PRIMES scenarios to assess their compatibility with short-term considerations of the electricity generation sector. Generally, METIS is used to assess a specific year (e.g. 2020 or 2030) with a high temporal resolution and allows testing, e.g. the role of variable renewables and how generating units are dispatched.

g. Enertile (PowerACE)[37]

Enertile is an optimisation model that finds cost-minimal solutions for electricity supply based on a number of restrictions such as minimum RES-E shares or CO_2 reduction. A social discount rate is applied for all technologies. The model also includes demand side management options and links to the heating sector as heat grids are incorporated in the optimization problem. The model has a high spatial and time resolution, which improves the modelling of effects of variable renewables in the power sector.

Optimization models are well suited to derive cost-effective RES target levels from the energy system perspective. Using such models, different RES targets can be tested with regards to their effect in system costs. However, future decline of energy consumption affects the cost-optimal level of the RES target. As calculating a cost-optimal demand level is very challenging, a simulation of different demand levels based on a diverse framework conditions is a suitable first modelling step. This type of two-step approach is implemented in PRIMES. However, when analysing cost-effective energy systems from a societal perspective, the use of social interest rates instead of individual private interest rates is preferable. In addition, energy system models only consider system costs in the optimization. Therefore, the cost-effective renewable shares must not necessarily be optimal with regard to reduced emissions.

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[35] POLES is explained in more detail here: https://www.enerdata.net/solutions/poles-model.html

[36] More information about METIS can be found here: https://ec.europa.eu/energy/en/data-analysis/energy-modelling/metis

[37] Enertile is explained in more detail here: http://www.enertile.eu/enertile-en/index.php

3.4.2. Macro models[38]

At the **macro-level,** a variety of approaches or model types exists to assess impacts of RES shares on GDP and/or employment.

Some studies use accounting approaches to derive the effect of increased renewable shares on growth and employment. These are very simple approaches based on coefficients. For example, a certain installed capacity of solar PV in a certain country and combined with a certain level of economic activity is assumed to generate a certain number of additional jobs in the sector. Accounting approaches are, for example, used by Greenpeace in their global Energy (R)evolution study (Greenpeace 2015). The resulting job effects are gross effects[39] as no price effects are taken into account and other sectors of the economy are not considered. Therefore, these results are not suitable to assess the full impact of higher RES levels.

Box 5: From gross to net

When assessing different renewable targets, it is important to look at **net impacts** of RES use, which show the “sum” of all positive and negative effects including impacts of higher prices or investments. In contrast, gross effects – mainly gross employment - show the effects on the energy or “RES-sector” i.e. in manufacturing, construction, installation and operation of RES. They ignore negative effects, especially the price effect on consumption, which has consequences outside the RES/energy sector as well.

To analyse the net impacts of RES, three main effects must be considered: 1) higher renewable shares imply the development of economic activities, including investments, operation and maintenance and, therefore, provide positive impulses to the economy. 2) decreasing investments in conventional energy generation might slow down some economic activities. 3) rising energy prices or expenditures due to RES use make production more expensive (companies) and reduce the available budget for consumption (households) and thus depress the economy in both cases. Overall, the combination of these enabling and depressing effects results into the net economic effects of RES. For an economic decision on the use of RES, the net impacts are more relevant as they show the effects for the whole economy and society.

More complex macroeconomic models analyse the macroeconomic impacts of developments in the energy sector. The models are dynamic, because they allow interactions between sectors and between actors over time. Models can be roughly classified into three main model groups:

General equilibrium models are based on neoclassical theory assuming equilibrium between demand and supply of all sectors. The main feature of these types of models is the assumed limitation of production factors, e.g. capital. Subsequently, large investments in the energy system crowd out investments elsewhere. Because of these crowding–out effects, equilibrium models tend to show smaller or negative effects of ambitious RES-deployment. The integration of different financing options can mitigate the observed crowding-out effects. GEM-E3 is an example of such a model.

Econometric models rely on historical data and behavioural economics and assume imperfect markets. They are not bound to equilibrium conditions and depict short- to long-

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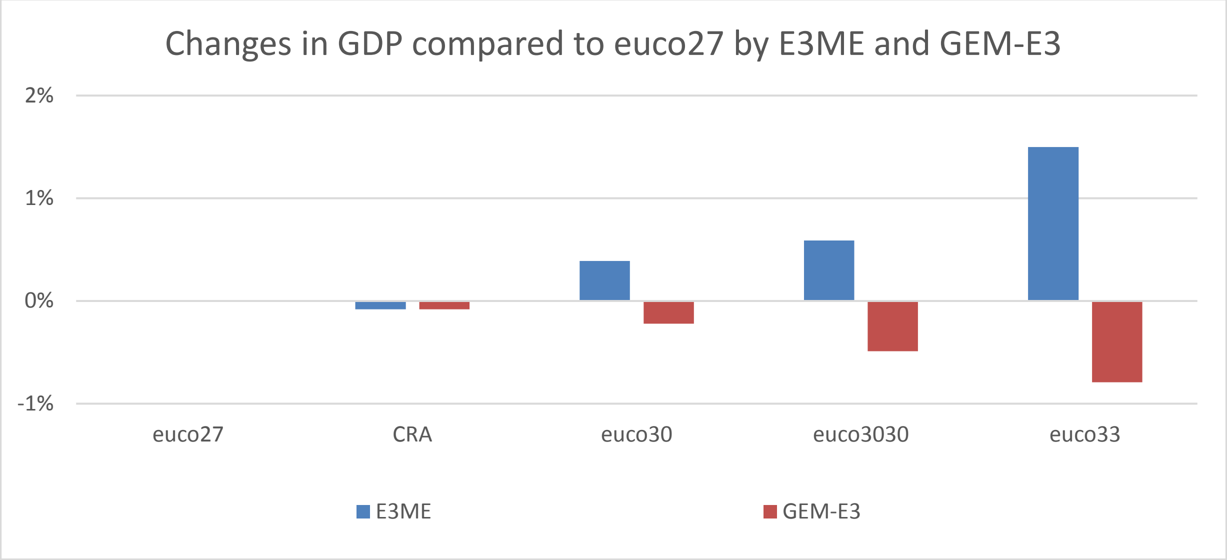
[38] A description of different macroeconomic models can for example be found in Breitschopf et al. (2011) and Mercure et al. (2016).

[39] See Box 4 for the differences between gross and net effects.

term effects based on estimated parameters and empirical validations. Capital for investment is unlimited, such that large investments in the energy system do not crowd out investments elsewhere. To account for this unrealistic assumption of unlimited investment activities, a threshold for investment activities can be set. These models tend to report more positive impacts of higher renewable shares when compared to general equilibrium models. E3ME is an example for an econometric model.

Hybrid models combine different features of the two modelling approaches. For example, they account for behavioural aspects, but also imply some market clearing aspects. These models are rather flexible in depicting market actions, but they miss a clear theoretical foundation. For example, Astra is a system dynamics-based model, using neoclassical production functions with endogenous technological changes. NEMESIS is an econometric simulation model based on Post-Keynesian approaches. No such models are used for the EC IA.

Figure 11: Macroeconomic impacts of different scenarios on GDP, modelled by E3ME and GEM-E3 under different constraints of availability of capital



Source: (own depiction based on Technical Reports by E3MLab 12/2016, Cambridge Economics 2016). Notes: euco: cost-effective development: **euco27**: 41% GHG target, 27% EE target, 27% RE target; **euco30**: 41% GHG reduction, 30% EE target, 27% RE target; **euco3030**: 43% GHG reduction, 30% EE target, 30% RE target; euco3030 assumes the same carbon prices as in euco30. **euco33**: 44% GHG reduction, 33% EE target, 28% RE share. **CRA**: country specific risk premiums, policy support, 41% GHG target, 27% EE target, 27% RE target.

Due to the complexity of the economy as a whole, results of macro-economic models can vary widely. Figure 11shows the substantial differences regarding the results of the two main modelling approaches. It compares the macroeconomic effects (GDP and employment) calculated by GEM-3E and E3ME[40]. It becomes clear that under euco3030 the impacts on GDP are of similar magnitude in both models but with a reversed sign. Similar to the GEM-E3 and E3ME comparison, the model outputs of NEMESIS and Astra also show differing results (see Section 4, Figure 12). It is therefore useful to use different model types to analyse the effects of certain policies.

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[40] For the figure, the most similar results from the two models have been selected, i.e. in GEM-E3 the constraint on capital availability has been relaxed, and in E3ME a partial constraint on investments has been included40. Under alternative settings, the differences are even more pronounced.

4. IMPACTS OF HIGHER RENEWABLES SHARES

KEY FINDINGS

- The consequences of the deployment of RES on GDP and employment is disputed, as they depend on the underlying model philosophy. However, its impact is small considering the range of variation in model outcomes; and most models show a small positive impact of higher shares of RES.
- The impact of RES on reductions in health costs do not differ substantially from those of other options to reduce GHG emissions.
- Higher RES targets reduce fossil fuel imports. Scenarios show savings of ~1% of GDP per year, which can potentially be sufficient to balance additional investment requirements.
- Energy system costs are generally not clearly defined in the various scenarios and can, therefore, not be compared easily. Some scenarios include all energy system-related expenditures, others focus on generation, RES technologies or additions. Studies do show that low technology costs and discount rates display low (system) costs of RES expansion or even savings. Studies further show that, in scenarios in which higher shares of RES, but unchanged EE and GHG targets, energy system costs do not necessarily increase. Accordingly, a 30% share in RES deployment is possible without further energy system cost increases.
- Whether electricity prices increase with increasing RES shares depends on the RES policy design and on the technology costs assumed. Even lower electricity prices than today are feasible if the levelised cost of energy and cost of capital are sufficiently low (REmap).
- A higher renewable share implies higher installation rates of renewable energies in the EU countries and can have a positive impact on the profitability and competitiveness of the European manufacturing and service industry in the RE sector.
- When increasing the RES share, security of supply in the electricity sector needs to be closely monitored due to more difficult investment conditions and increased need for flexibility to ensure that demand and supply are met at all points in time.
- While 100% RES-E are technically feasible, system adequacy needs to be closely monitored.

As described in Section 2, besides reducing the GHG emissions of the energy sector, renewable energies influence the energy system, economy, and society in a variety of ways.

First, on the macro level they impact growth and employment as well as health costs due to reduced air pollution. As RE conversion technologies replace fossil fuels in the energy mix, higher renewable shares decrease dependency on fossil fuel imports and reduce health effects, which occur due to air pollutants emitted by combustion processes. However, other GHG reduction measures have very similar effects, so that differences in health costs or fossil fuel imports are very similar across scenarios with similar levels of GHG emission reductions. If renewable shares are increased and all other measures to reduce GHG emissions are maintained, lower health costs and fossil fuel imports will be reached.

Second, on the energy system level they impact energy system costs and decrease import dependency from fossil fuels, yet pose new challenges to system adequacy, especially in the electricity sector where flexibility requirements increase with higher shares of variable renewables.

On the micro level, impacts of increasing renewable shares are very diverse. For example, such impacts include the need for industry to put more financial resources in energy supply, households getting the chance to generate their own electricity and directly participate in the energy system as prosumers, but also put more resources into disputes about wind turbines and PV plants impacting landscapes and nature.

This section summarizes the main effects of increasing renewables in the energy sector on the macro and energy system level. The IA is mainly based on results from the different PRIMES scenarios. In addition and where applicable, results from other studies are added for comparison. The very diverse micro effects are not covered in this overview as they are less important for setting targets, but do need consideration when implementing policies to achieve the targets.

4.1. Impacts on macro level

4.1.1. Economic growth and employment

While increasing RES deployment affects growth and employment through impacts on manufacturing, construction, fuels and energy services and overall consumption, only a few studies combine the energy system modelling with macroeconomic impact analyses (see Table 3). Overall, apart from the PRIMES GEM-E3 model results, the impacts of RES deployment and other targets on GDP and employment are mostly positive. For the EU, the analysis in preparation of the EC IA in 2014 and 2016 provide interesting information, because the macroeconomic impact has been conducted with two different macroeconomic models.

Table 3: Impacts on GDP and employment – assessments based on macroeconomic models

Scenarios compared to baseline in 2030	% change in GDP compared to baseline	% change in jobs compared to baseline
GHG40/EE	0.55%	0.12%
GHG40/EE/RES30	0.46%	0.09%
GHG45/EE/RES35	0.53%	0.09%
euco30*	0.39%	0.17%
euco3030	0.59%	0.18%
CRA	-0.08%	-0.03%
Optimistic	not quantified	not quantified
SNP30	0.40%	0.32%
SNP35	0.80%	0.67%
QUO30	0.34%	0.30%
Power Choices Reloaded (2030, EU)	not quantified	not quantified
QUO30/GHG40-EE-RES30 (2030, EU)	not quantified	not quantified
2030Quota (2030, EU)**	0.07%	0.02%
WEO 450 (global, 2040)	not quantified	not quantified
ETP (2DS, 2050)	not quantified	not quantified
REmap EU 2030	not quantified	not quantified

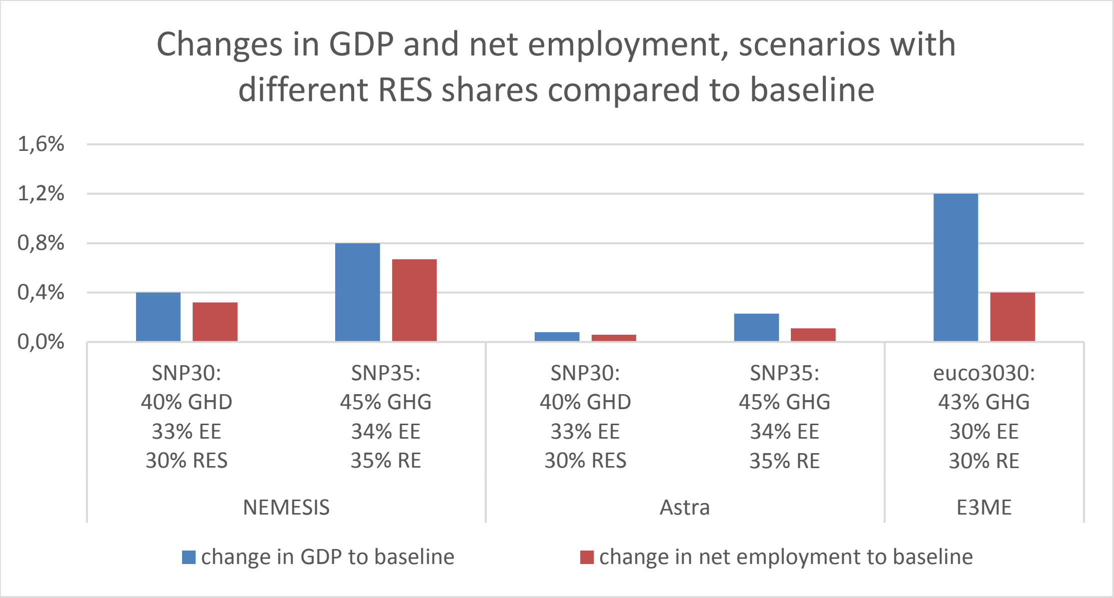
Scenarios compared to baseline in 2030	% change in GDP compared to baseline	% change in jobs compared to baseline
ADV E(R) (2030, OECD Europe)	not quantified	+1.7 mio. jobs in 2030 in the energy sector
GECO 2C (2030, EU/global)	-0.2% to 0% (EU)	- 0.17% (global)
GHG40RES30 (2030, EU)	not quantified	not quantified

Source: own compilation based on diverse sources. Notes: euco and GHG Primes scenarios shows results of the E3ME model; SNP and QUO show results of the NEMESIS model * compared to euco27; ** only RES-H

Apart from the EC IA in 2014 and 2016, the EmployRES study analyses the effect of RES shares above 27% on GDP and net employment. No other study analysing EU-wide the macro-economic effects of renewable shares above 35% in 2030 has been found. Section 3.4 describes the impacts of RES targets (above 27%) on GDP and net employment modelled with macroeconomic models GEM-3E (equilibrium model), E3ME (simulation model), Astra and NEMESIS (hybrid models) are compared.

Figure 12 depicts the changes in GDP and net employment of 30% and 35% RES targets compared to a reference situation with a 26% RES share (Astra and NEMESIS) and 30% RES target compared to a reference situation with 24% RES share (E3ME).

Figure 12: Changes in GDP and net employment to baseline scenario



Source: own depiction based on Duscha et al. 201, EmployRES (2014). Notes 2016. SNP: Separate National Policies, GHG: Greenhouse Gas Reduction, EE: EE target, RE: RE target, GDP: Gross domestic product. Note: * country/techn. specific policies and risk premiums; reference situation Astra/NEMESIS: 26% RES, 33% EE, 40% GHG from GreenX; reference situation E3ME: Primes Reference 2016 (24% RES, 24% EE)

Figure 13 depicts the changes in GDP and in net employment from a 30% RES target compared to the euco27 scenario, with a 27% RES share and 27% EE target[41]. The results are obtained with the models GEM-3E and E3ME.

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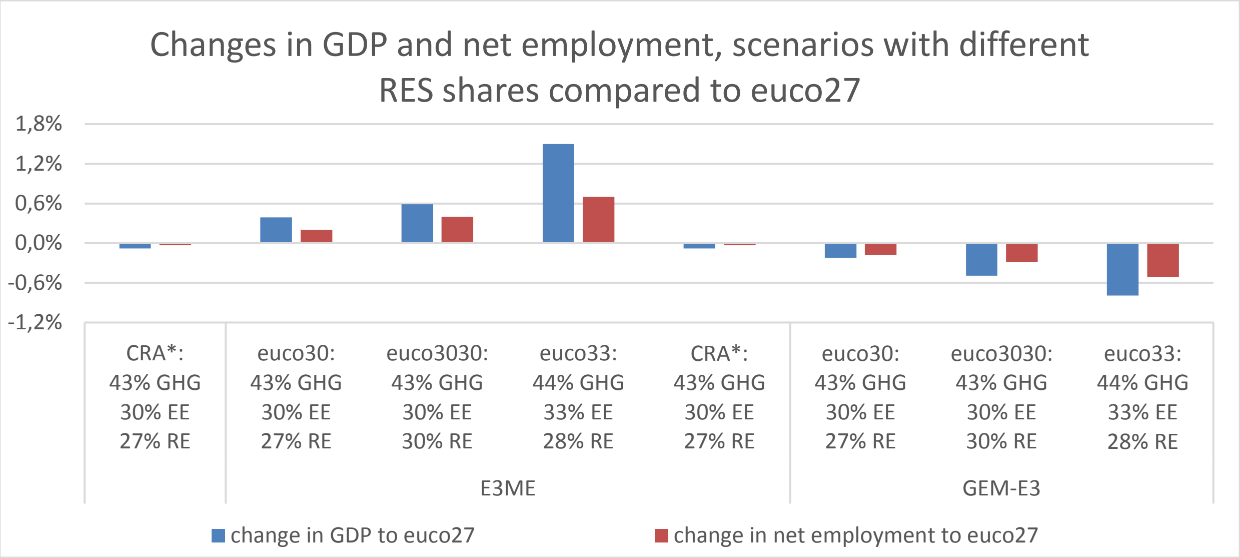
[41] Euco30 has an energy efficiency target of 30% and a RES target of 27%; euco33 has a 33% efficiency target, which entails a slightly higher RES share (28%); and euco3030 includes a 30% RES target in addition.

Figure 13: Changes in GDP and net employment in euco27 scenario



Source: own depiction based on IA RED 2016, IA EED 2016.

Overall, the examples of a more ambitious RES target, beyond the 27%, selected reveal that:

- In general, GDP increases compared to the reference situation in three (E3ME, Astra and NEMESIS) out of four models (Figure 12 and Figure 13).
- Increasing the RES target from:
  - 27% to 30% leads to changes in GDP between -0.05% (GEM-E3) and 0.06% (E3ME)
  - 24% to 30% leads to changes in GDP of 1.2% (E3ME)
  - 26% to 35% leads to changes in GDP between 0.1% (Astra) to 0.7% (NEMESIS)
- The impact on net employment is smaller in magnitude, but similar to GDP in all models, with a maximum growth of 0.4% for an increase of RES share of 7 percentage points.
- The euco30 scenario reflects the effects of a higher efficiency target on GDP.

The modelling results selected show that the macroeconomic impacts of increasing RES shares is model-type sensitive. Consequently, even if a GDP change of 0.6% (Euoc3030) is considered significant in reality, it cannot be interpreted as significant because the variation between the models is of similar magnitude. Overall, it can be concluded that impacts of RES shares (30% and 35%) on GDP are small. Similarly, the impacts on employment are not significant, and smaller than the impacts on GDP (see Figure 13).

4.1.2. Health effects

The effects renewables have on health costs due to reduced air pollution were quantified in the EC's IA 2014 as well as by Enerdata (2014) and in the REmap EU scenario. Other scenarios/studies have not quantified the health impacts as can be seen in Table .

However, according to Enerdata (2014), health costs are not influenced by the level or inclusion of a RES target. Different scenarios with the same GHG reduction lead to the same health costs. The IA 2014 (EC 2014) shows similar results. Health effects are influenced by EE and higher decarbonisation levels (GHG40EE and GHG45EERES35 scenarios), but the additional RES target in the GHG40RES30 scenario does not decrease health damage costs (compare scenarios in Table 4). REmap shows a large range of avoided costs, which underpins the substantial uncertainty of assessing health impacts in monetary terms.

Table 4: Avoided health damage costs of different scenarios compared to baseline scenario

Scenarios 2030	avoided health costs compared to baseline (bn €)
GHG40	7.2 to 13.5
GHG40/EE	17.4 to 34.8
GHG40/EE/RES30	16.7 to 33.2
GHG45/EE/RES35	21.9 to 41.5
euco30	n.a.
euco3030	n.a.
CRA	n.a.
Optimistic	n.a.
SNP30	not quantified
SNP35	not quantified
QUO30	not quantified
Power Choices Reloaded-RE target 2030	not quantified
QUO30/GHG40-EE-RES30 (2030, EU)	not quantified
2030Quota (2030, EU)	not quantified
WEO 450 (global, 2040)	not quantified
ETP (2DS, 2050)	not quantified
REmap EU 2030	17-65
E(R) ADV E(R) (2030, EU)	not quantified
GECO 2C (2050, global)	not quantified
GHG40RES30 (2030, EU) (Enerdata)	18

Source. on compilation based on diverse sources. Note: indicated in constant prices (2010/2013)

While uncertainties regarding health costs are substantial (Enerdata 2014), based on existing model results, higher RES shares do not imply lower heath costs at a given GHG reduction target and EE level.

4.1.3. Reduction of fossil fuel imports

In contrast to health effects, reduction of imports of fossil fuels are estimated in several scenarios as their assessment is less complex. Apart from the EC's impact assessments, Enerdata (2014), SNP/QUO, REmap quantify the effect of RES shares above 27% on fossil fuel import bills[42].

Results from the different studies are summarized in Table 5. They show the reduced imports in 2030 either in monetary terms or as % below the baseline. It is noteworthy that higher

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[42] Fraunhofer ISI et al. (2014) assesses the effect on fossil fuel requirements, but does not analyse fossil fuel imports. Greenpeace (2014) quantifies the effects of the energy (r)evolution scenario on fossil fuel import bills (30 bn€ yearly), but these results cannot be clearly assigned to the higher RES share as energy demand is reduced simultaneously.

GHG reduction targets combined with higher RES shares further reduce imports of fossil fuels. Thus, in scenarios with increasing GHG reduction targets and RES shares, the reduction of fossil fuel imports s cannot be clearly attributed to the higher RES share.

The analyses by the EC, REmap and Enerdata show that higher RES shares indeed reduce fossil fuel imports. According to EC (2016) an increase in the RES share from 24% to 30% (Ref2016 to euco3030) leads to average annual savings of 29 bn€. In the scenarios calculated by EC (2014), the increase in the RES share from 24% (Ref2014) to 30% (GHG40EERES30) implies fossil fuel import savings of 20 bn€ annually. Enerdata finds a more pronounced effect of 6.0 bn€ savings in 2030 linked to an increase of 1% in the RES share (GHG40 to GHG40 RES30). A higher GHG reduction combined with a higher RES target in the GHG45EERES35 scenario further decreases fossil fuel import bills. The REmap shows avoided fossil fuel imports in 2030 compared to the baseline.

Table 5: Changes in fossil fuel import bills due to higher RES shares

Scenarios 2030	reduced energy imports compared to baseline [bn €], annual average 2021-2030
GHG40/EE	20
GHG40/EE/RES30	22
GHG45/EE/RES35	27
euco30	22
euco3030	29
CRA	32
Optimistic	n.a.
SNP30	22
SNP35	38
QUO30	20
Power Choices Reloaded (EU 2030)	129
QUO30/GHG40-EE-RES30 (2030, EU)	not quantified
2030Quota (2030, EU)	37 (compared to 2012)
WEO 450 (global, 2040)	not quantified
ETP (2DS, 2050)	not quantified
REmap EU 2030	62 in 2030 compared to baseline in 2030
E(R) ADV E(R) (2030, EU)	in 2030 compared to today (2010): oil imports: -50% gas imports: - 30% coal imports: - 45%
GECO 2C (2030, EU)	imports ranging around 1% of GDP; -15% compared to 2010
GHG40RES30 (2030, EU)(Enerdata)	6

Source: own compilation based on diverse sources. Note: indicated in prices (2010/13/14/16)

Overall, the overview shows higher RES targets reduce fossil fuel import requirements. While savings are probably below 1% of GDP per year, they can potentially be sufficient to balance additional investment requirements (Fraunhofer ISI et al. 2014).

4.2. Impacts on energy system level

4.2.1. Energy system costs

Assessed energy system costs can differ substantially across models, as different modelling approaches, e.g. different discount rate assumptions, as well as the exact definition of system costs influence the results.

The EC Impact assessments (EC 2014 and EC 2016) and Eurelectric (2013) include results on system costs using the PRIMES modelling suite. Enerdata (2014) also compares total energy system costs resulting from different scenarios while the SNP/QUO scenarios, REmap, indicate additional generation costs or substitution costs for RES. Table 6 gives an overview of results regarding energy system costs. Again, scenarios are only included that differ regarding the RE share only[43].

Table 6: Changes in annual average energy system costs

EU scenarios, 2030	change in average annual energy system costs compared to reference (bn €)
GH40/EE (2030, EU)	22
GHG40/EE/RES30 (2030, EU)	22
GHG45/EE/RES35 (2030, EU)	35
euco30 (2030, EU)	24
euco3030 (2030, EU)	28
Optimistic (2030, EU)*	n.a.
SNP30 (2030, EU)**	5
SNP35 (2030, EU)**	7
QUO30 (2030, EU)**	3
Power Choices Reloaded RE target (2030, EU) (Eurelectric)*****	31
QUO30/GHG40EERES30 (2030, EU)**	-2
2030Quota (2030, EU)***	n.a.
REmap (2030, EU)****	-25
E(R) ADV E(R) (2030, EU)*****	n.a.
GHG40RES30 (2030, EU)(Enerdata)******	41

Source: own compilation based on diverse sources. Note: indicated in prices of 2010/13/14/16 *annualised, infrastructure and generation;** in RES technologies;*** only heating and cooling;**** additional investment in RES;****** power sector

Table 6 depicts cost differences between the baseline scenario and the respective policy scenario. These costs differ in their scope, i.e. some encompass the total energy system – power generation, transmission, distribution as well as EE measures – others refer only to some aspects, such as generation cost, or RES technologies. As no information is available in the study about the time distribution of costs, the same cost difference for all years was assumed. As Table 6 shows, TU Wien/EEG and Fraunhofer ISI (2015) assessed additional

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[43] The scenario by E3Mlab/ICCS (2014) is not included in the table. This scenario entails the same targets as the GHG40EERES30 scenario but assumes lower discount rates and a market stability reserve for the ETS (E3Mlab/ICCS 2014). The energy system costs of this scenario are the same as in the reference scenario and below those of the GHG 40 scenario.

generation costs comparing scenarios with a GHG reduction target of 40% and a RES share of 30% with their reference scenario (RES share of 21%). Depending on the policy regime (national policies or a harmonized quota respectively), this implied additional yearly generation costs of about 3 to 5 bn€. Scenarios with a GHG reduction target of 45% combined with a RES share of 35% imply additional yearly generation costs of 5 to 7 bn€$_{2010}$ compared to the baseline scenario. According to IRENA (2016) an increase in the RES share from 25% to 33% even implies cost savings of 25 bn€ per year. To highlight the impact of RES shares on energy system costs, scenarios that only differ by the RES share, and not by GHG emission reductions or EE targets, are compared. These scenarios are listed in Table 7:

- the euco30 versus euco 3030,
- GHG40EE versus GHG40EERES30,
- the Power Choice Reloaded versus RES target and
- the GHG40 versus GHG40RES30.

The comparison of the absolute and relative changes in costs and per RES share indicates that costs vary significantly between the scenarios, and that the RES share could be increased with zero costs (EC 2013). Taking into account the REmap scenario in which the costs are negative, an increase in RES deployment even results in savings.

Table 7: Comparison of energy system costs of scenarios with only RES share changes

Energy system costs change between scenarios	EC (2016)		EC (2013)		Eurelectric (2013)		Enerdata (2014)	
Scenario	**euco 30**	**euco 3030**	**GHG 40EE**	**GHG 40EE RES 30**	**Power Choices reloaded**	**RES target in 2030**	**GHG 40**	**GHG40RES 30**
Absolute change* (bn€ per year)		4		0		30.8		11.0
Relative change* (%)		0.2		0		n.a.		n.a.
Additional costs of RES share* (bn€ / % RES)		1.3		0.0		7.7		11
RES share (%)	28	30	26	30	26	30	29	30

Source: own depiction. Note: given in prices (2010/13/14/16), EUCO30: scenario with 30% EE target, euco 3030: scenario with 30% EE target and 30% RES target; GHG 40EE: scenario with 40% GHG reduction, GHG 40EERES30: scenario with 40% GHG reduction and 30% RES target. 40% GHG: scenario with 40% GHG reduction target, 40% GHG + 30% RES: scenario with 40% GHG reduction target and 30% RES target. * compares first to second scenario of each modelling family

As differences between scenarios are very small and many factors influence the model results, e.g. the assumptions regarding risk reduction by specific renewable and EE policies, existing modelling results regarding total system costs do not provide strong indications of the suitability of higher RES targets.

4.2.2. Investment requirements

As described above, higher RES shares increase the annual investment requirements for energy systems due to the higher capital intensity of renewables compared to fossil fuels. While this might be challenging in terms of capital availability, increased investment typically has positive effects on GDP and employment. Furthermore, similar to energy related costs, energy related investments differ by their scope and over time. As no distribution over time is available, an annual constant investment is assumed (see Table 8). According to Table 8 significant investments do not necessarily coincide with high RES shares and vice versa. This gives evidence that other factors, such as energy savings or GHG reduction targets, drive investment expenditures in these scenarios as well.

There are no studies apart from the EC's impact assessments that compare and provide data on investment requirements in two scenarios that only differ regarding the RES share. Subsequently, investment expenditures in these scenarios do not only show only the effect of higher RES shares, but also the effect of higher ambitions regarding climate change in general.

Table 8: Differences in investment requirements compared to baseline scenarios

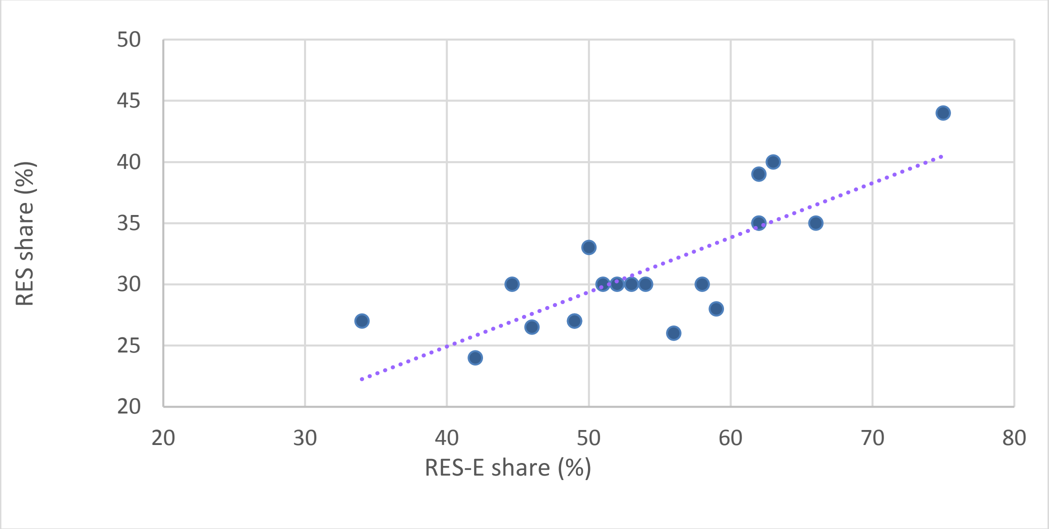
EU scenarios, 2030	additional average annual investments (bn €)	RES shares (%)
GH40/EE (2030, EU)	59	27
GHG40/EE/RES30 (2030, EU)	63	30
GHG45/EE/RES35 (2030, EU)	93	35
Ref. 2016 (2030, EU)		24
euco30 (2030, EU)	177	27
euco3030 (2030, EU)	190	30
SNP30 (2030, EU)**	68	30
SNP35 (2030, EU)**	87	35
QUO30 (2030, EU)**	85	30
QUO30/GHG40-EE-RES30 (2030, EU)**	69	30
REmap (2030, EU)****	40	33
E(R) ADV E(R) (2030, EU)*****	12	44
GHG40RES30 (2030, EU)******	81	30

Source: own compilation based on diverse sources. Note: given in prices (2010/13/14/16) *annualised, infrastructure and generation;** in RES technologies;**** additional investment in RES;****** power sector

4.2.3. Impacts on the electricity sector

Based on the available data in the different scenarios reviewed in this study, Figure 14 shows the ranges of renewable shares in the electricity sectors in relation to the overall RES share. The share of renewable energies in the electricity sector (RES-E) is typically higher than the overall RES share. According to Figure 14, a RES share of 30% implies a RES-E share of around 50%. For a RES share of 35%, a RES-E share of between 60 and 65% is implied.

Figure 14: RES-E shares compared to RES shares in 2030



This significant increase in RES-E has significant impacts for the whole electricity system structure and functioning, as variable RES-E are not fully dispatchable and therefore cannot follow demand in the same way as conventional or biomass plants. As a result, flexibility requirements in the electricity system increase to ensure that demand and supply match at all points in time (system adequacy). Additional flexibility can be provided by conventional power plants, flexible demand side assets, increased interconnection capacities and storages. Modelling of the electricity sector typically shows that grid extensions are the most cost-effective form of supplying additional flexibility. If shares of variable renewables increase very fast (as possibly in the case of high 2030 renewable targets) and grid expansion is slower, the additional flexibility needs might result in higher costs for the energy system. In general, with increasing variable renewables, system flexibility should be closely monitored in order to maintain short term security of supply. While 100% RES-E is technically feasible, the system might need time to adapt to the new circumstances or new technological solutions.

4.3. Impacts on industries and households

A higher renewable share implies higher installation rates of renewable energies in the EU countries and can have a positive impact on the profitability and competitiveness of the European manufacturing and service industry in the RE sector (EWEA 2015).

Through their impacts on energy system costs, different renewable shares also influence energy costs and prices for industries and households. In the case of industries, potentially higher energy prices as well as carbon or efficiency obligations can decrease international competitiveness[44]. Such higher prices can also increase fuel poverty among households. The IEA (2016) finds in its World Energy Outlook 2016 that while in the 450 scenario, electricity

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[44] In the longer term higher energy prices might induce technological improvements, efficiency, product or process innovations, which in turn are strengthening the competitiveness of industries.

prices increase by 15 USD/MWh, yearly household expenditures for electricity decrease from 880 USD to 750 USD due to lower electricity consumption.

Eurelectric (2013) estimates an increase in end user electricity prices of 5 € on average when the 30% RES target for 2030 is introduced. However, this average increase implies a price reduction of 3 €/MWh for industry and an increase of 9 €/MWh for households.

According to the IA 2014, the introduction of a 30% RES target in addition to the GHG reduction target of 40% leads to an increase of average electricity prices of 1.8 €/MWh; the more ambitious GHG reduction target of 45% and a RES target of 35% imply a further increase of 10.2 €/MWh.

The IA 2016 implies an electricity price increase of 3% additionally in the euco3030 scenario with a 30% RES share compared to the euco30 scenario with a 27% RES share. Average annual energy purchases by industry are 1 bn€ lower in the euco3030 scenario; purchases by the residential sector increase by 3 bn€.

In the REmap, electricity costs amount to 0.13US$/kWh for industry and to 0.17US$/kWh for households, showing a decline in electricity prices compared to today, because higher RES deployment in this scenario reduces energy related costs. (see section 4.2.1) In contrast, the new policy scenario of WEO 2017 depicts a wholesale price in 2040 of around 8 €ct/kWh, retail prices of about 13 €ct/kWh for industry and of 25 €ct/kWh for households with an RES-E share reaching almost 60% in 2040.

Fraunhofer ISI and TU Wien/EEG (2014) find that the impact on electricity generation costs of a higher renewables share depends substantially on the policy regime used to reach the RES target. In 2030, a European-wide support scheme leads to electricity generation costs of 1 €/MWh below the scenario without RES support, national support schemes increase the generation costs by 2 €/MWh to 65 €/MWh.

This last finding is very important for setting a suitable RES target in light of the possible effects on industry and households. In general, distributional effects and the question of who pays for higher system costs do not only depend on the target level, but mainly on the policies that are used to implement these targets. In addition, distributional effects can be mitigated by additional interventions, especially if GDP increased as a result of a higher RES target. When designing RES support policies, both the question of industrial competitiveness and the important problem of fuel poverty need to be taken into account.

5. SUMMARY, CONCLUSIONS & RECOMMENDATIONS

5.1. Summary

- This paper analyses studies available assessing the impacts of RES shares up to 35% in the EU. Studies differ by their regional and sectoral focus, time horizon and overall objective (decarbonisation, RES impact, sector analysis), therefore comparing the outcomes of these scenarios is not straightforward.

- RES have diverse impacts on the energy system and the wider economy and society. Consequently, no single quantity or criterion exists that can be used to fully assess the effects of different RES shares. Rather, criteria need to be considered covering all sectors and potential impacts at different scales (energy system, macro level, society) to be able to make a well-balanced decision.

- In models applying a cost-optimisation approach, assumptions regarding technology costs, fuel prices and discount rates can have a significant impact on the resulting competitiveness of RES, and therefore, the economic feasibility of increasing the RES share in the energy system.

    - Fuel prices influence the relative cost of conventional and RE conversion. In a cost-optimisation approach, low fossil fuel prices lead to a lower share of renewables and vice versa. Due, in part, to the historic price volatility of fossil fuel prices, assumptions regarding their future development have significant uncertainties. This also results in high uncertainty regarding the cost-effectiveness of renewables and deployment levels calculated with the various models.

    - Discount rates influence the cost of capital. High discount rates imply higher shares of technologies with low initial investments compared to fuel and maintenance costs (e.g. gas-fired power plants). Low discount rates make capital-intensive technologies (e.g. solar and wind or nuclear power plants) more attractive. Discount rates reflect financing conditions, yet in some models (e.g. PRIMES) they are also used to represent non-economic barriers.

    - Technology cost and availability: If the cost of renewables sink faster than costs of alternative technologies for energy conversion, the renewable share will be higher under a cost-minimising approach. RES costs tend to prove lower than previously thought, at least in the electricity sector. Recent auction results are significantly lower than costs for renewable electricity production in the models. In light of the increasing significance of electricity for heating/cooling and transport in the scenarios, RES will play a crucial role in the power sector. As wind power is likely to be the largest contributor to renewable electricity generation in the EU, its cost development is especially important. Thus, the lower electricity production cost of wind power might considerably affect total energy system costs. Overall, higher RES shares can probably be achieved at lower system costs and result in more positive GDP impacts.

- It must be noted that assumptions made when defining models inputs can be subject to bias: for example, the future development of technology and fuel costs are highly uncertain and, therefore, cover a broad range.

- The studies show that a share of RES between 30% and 35% is a feasible objective, as the impacts of a higher RES share on GDP and employment and health are projected to be small (but positive according to most studies analysed), and the impact on imports of fossil fuels and GHG emissions positive. Moreover, as actors have individual preferences, e.g. environmentalist might opt for resource savings, an economist opts for cost efficiency, positive impacts on emissions are decisive as long as GDP impacts are not negative.

- It is not clear/obvious from these studies to what extent higher RES deployment affects energy system costs. While some studies suggest zero costs when increasing RES to 30%, other recent studies that do not consider all components of an energy system report benefits. However, given the recent auction results and the capital cost in the EU, relatively low additional costs are expected as a result of a further RES expansion. Therefore, from a cost perspective, a more ambitious RES target (30%-35%) appears to be a feasible objective for 2030.
- When increasing the share of renewables in the electricity sector, there is an increased need for flexibility to ensure that demand and supply are met at all points in time.

5.2. Recommendations

Based on the assessment conducted for this study, the following recommendations can be made:

- Given higher RES targets, system adequacy in the electricity sector needs to be closely monitored. More renewable electricity production leads to a substantial share of variable renewables in the electricity sector. While 100% renewables is technically feasible, the system might need time and additional flexibility to adjust to higher RES shares.
- Targets for GHG reduction, RES and EE need to be harmonized. A significant increase in the RES target without adapting the GHG target can decrease efforts in EE and other investments in decarbonisation. Thus, if adjusting the RES target, the other targets should also be reassessed.
- Although industrial competitiveness and energy poverty are generally not considered in the studies assessed, these need to be taken into consideration when designing support policies and burden sharing regulation.
- To fully assess the costs and benefits of a higher renewables target, additional modelling with adapted technology costs and potentially social discount rates for assessing aggregated energy system costs is recommended.

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