HELMHOLTZ
ZENTRUM FÜR
UMWELTFORSCHUNG
UFZ

UFZ Discussion Papers

Department of Economics

3/2014

EU climate and energy policy beyond 2020: Are additional targets and instruments for renewables economically reasonable?

Jos Sijm, Paul Lehmann, Unnada Chewpreecha, Erik Gawel,
Jean-Francois Mercure, Hector Pollitt, Sebastian Strunz

November 2014

Publisher:
Helmholtz-Zentrum für Umweltforschung GmbH - UFZ
Permoserstr. 15
04318 Leipzig

ISSN 1436-140X

EU climate and energy policy beyond 2020: Are additional targets and instruments for renewables economically reasonable?

Jos Sijm[1], Paul Lehmann[2],

Unnada Chewpreecha[3], Erik Gawel[2, 4], Jean-Francois Mercure[5], Hector Pollitt[3], Sebastian Strunz[2]

[1] Energy research Centre of the Netherlands (ECN), Radarweg 60, 1043 NT Amsterdam, The Netherlands

[2] Helmholtz Centre for Environmental Research – UFZ, Department of Economics, Permoserstr. 15, 04318 Leipzig, Germany

[3] Cambridge Econometrics, Covent Garden, Cambridge, CB1 2HT, United Kingdom

[4] University of Leipzig, Institute for Infrastructure and Resources Management, Grimmaische Str. 12, 04318 Leipzig, Germany

[5] University of Cambridge, Cambridge Centre for Climate Change Mitigation Research, 19 Silver Street, Cambridge, CB3 9EP, United Kingdom

EU climate and energy policy beyond 2020: Are additional targets and instruments for renewables economically reasonable?[1]

Abstract:

The European Council has proposed to stick to a more ambitious GHG target but to scrap a binding RES target for the post-2020 period. This is in line with many existing assessments which demonstrate that additional RES policies impair the cost-effectiveness of addressing a single CO_2 externality, and should therefore be abolished. Our analysis explores to what extent this reasoning holds in a second-best setting with multiple externalities related to fossil and nuclear power generation and policy constraints. In this context, an additional RES policy may help to address externalities for which first-best policy responses are not available. We use a fully integrated combination of two separate models - the top-down, global macro-economic model E3MG and the bottom-up, global electricity sector model FTT:Power – to test this hypothesis. Our quantitative analysis confirms that pursuing an ambitious RES target may mitigate nuclear risks and at least partly also negative non-carbon externalities associated with the production, import and use of fossil fuels. In addition, we demonstrate that an additional RES target does not necessarily impair GDP and other macro-economic measures if rigid assumptions of purely rational behaviour of market participants and perfect market clearing are relaxed. Overall, our analysis thus demonstrates that RES policies implemented in addition to GHG policies are not per se welfare decreasing. There are plausible settings in which an additional RES policy may outperform a single GHG/ETS strategy. Due to the fact, however, that i) policies may have a multiplicity of impacts, ii) the size of these impacts is subject to uncertainties and iii) their valuation is contingent on individual preferences, an unambiguous, "objective" economic assessment is impossible. Thus, the eventual decision on the optimal choice and design of climate and energy policies can only be taken politically.

Keywords:

Climate policy, energy policy, EU, emissions trading scheme, policy mix, renewables

JEL codes:

C53, Q42, Q43, Q48, Q54, Q58

[1] Research for this publication was carried out in the context of the Helmholtz Alliance ENERGY-TRANS "Future infrastructures for meeting energy demands. Towards sustainability and social compatibility", www.energy-trans.de.

1 Introduction

The EU pursues a set of ambitious climate and energy targets for the year 2020: greenhouse gas (GHG) emissions shall be reduced by 20% compared to 1990 levels, the share of renewable energy sources (RES) in total energy consumption shall be increased to 20%, and energy efficiency shall be improved by 20% (European Commission, 2008). These targets are currently undergoing a process of revision and updating for 2030. The European Council (2014) has agreed to maintain a differentiated GHG target that is binding at the Member State level, and to tighten it to 40% at the overall EU level. The energy efficiency target shall be increased to 27%. The RES target is also slightly raised to 27%. Importantly, however, this target would not be binding anymore. First, this would be due to the fact that the Council suggest not specifying the target on the Member State level. Second, the proposed level of ambition would correspond to the RES share which is expected to be attained under the GHG target anyway (European Commission, 2014). Thus, the European Council has in fact agreed to abstain from a strong and credible RES target in the future. Our study aims to review this proposal critically, particularly the decision to implement an only weak RES target in addition to the GHG target.

The discussion on the 2030 targets can benefit from a large strand of economic studies which analyze the welfare effects of the EU 2020 targets, using computational general equilibrium (CGE) models (Bernard and Vielle, 2009; Boeters and Koornneef, 2011; Böhringer et al., 2009a; 2009b; Kretschmer et al., 2009), energy system optimization models (Aune et al., 2012; Capros et al., 2008; Capros et al., 2011) or partial equilibrium models (Böhringer and Rosendahl, 2011).[2] These studies have been complemented by analyses of post-2020 targets, including the recent assessment mandated by the European Commission (2014) as well as others employing energy system models (Jägemann et al., 2013; Möst and Fichtner, 2010; Unteutsch and Lindenberger, 2014). These studies consistently find that an additional RES target leads to economic excess costs as it impairs the cost-effective attainment of the GHG target. Yet, the decisive question is which policy recommendations can be derived on the basis of this finding. An unambiguous plea to abolish a RES target and corresponding instruments can only be made if (1) technology choice for electricity generation is only distorted by a GHG externality, (2) the GHG externality is perfectly addressed by the GHG targets and instruments chosen, and (3) there are no other policy objectives beyond efficient climate change mitigation. These restrictions are acknowledged by most of the studies. Böhringer et al. (2011) point out, for example, that the excess costs of a RES target may be interpreted as the "price tag […] for the composite of objectives different from emission reduction." This notwithstanding, these rationales are not further examined by the above strand of literature.

Our study aims to shed more light on the role of RES targets and instruments once the above assumptions are relaxed. In particular, we consider a setting with multiple market failures - including the GHG externality as well as technology market failures, other environmental externalities from using fossil and nuclear fuels (e.g., air pollution, land use effects, nuclear hazards), and externalities related to fossil fuel imports – which cannot efficiently be addressed by first-best policies for diverse reasons. In addition, we also take into account policy objectives that are beyond allocative efficiency but may nevertheless be relevant for practical policy-making, such as job creation or decentralized ("democratized") energy supply. In such a setting RES targets and instruments may be justified if (1) they actually help to address the market failure or policy objective, and (2) they are more cost-effective than other feasible policy approaches. For the purpose of our assessment, we first provide a review of possible benefits for using RES targets and instruments. Subsequently, we carry out a quantitative assessment for three policy scenarios, including GHG policies only as well as additional RES targets and instruments. This analysis provides an indication whether an additional RES policy

[2] For a review, see also Tol (2012).

can actually better contribute to addressing diverse market failures and policy objectives than a stand-alone GHG target and instrument.

To carry out our analysis, we employ the *'E3MG-FTT:Power'* model. This model is a fully integrated mix of two separate models, i.e. the top-down, global macro-economic model *E3MG* and the bottom-up, global electricity sector model *FTT:Power*. In contrast to the CGE and energy system models mentioned above, E3MG does not employ an optimization approach but rather simulates on the basis of actual behaviour observed in the past (represented by econometric specifications). Therefore, our study may complement existing macro-economic analyses by relaxing some of their assumptions, such as purely rational decision-making and market clearing.

The remainder of the paper is organized as follows: Section 2 provides a review of possible benefits of RES policies implemented in addition to a GHG policy. Section 3 describes the model. Section 4 introduces the policy scenarios. Model results are presented in Section 5 and discussed in Section 6. Section 7 concludes.

2 Benefits of additional RES targets and instruments – A review

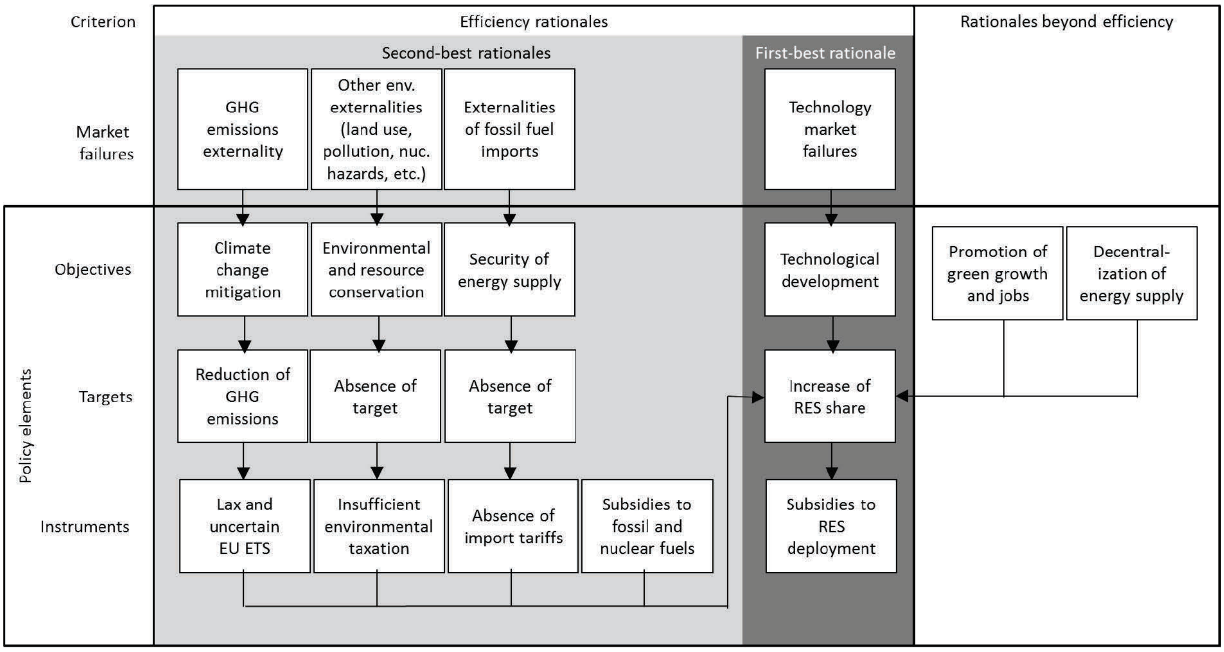
For the purpose of our analysis, it is useful to distinguish three elements of policy design: objectives, targets and instruments (see Figure 1). By *objectives* we refer to the rather general societal goals associated with sustainable climate and energy policy. These include most prominently climate change mitigation, environmental and resource conservation beyond climate change, technology development, the security of energy supply, the promotion of green growth and green jobs and the decentralization (or democratization) of energy supply (European Commission, 2011a). *Targets* are operationalized and usually also quantified values which shall be attained in a certain period of time and are expected to contribute to the overall objectives. In our analysis, we will focus on the RES-E target which coexists with a GHG target for the EU ETS sectors. Finally, *instruments* are those measures which are implemented in order to actually attain the targets – and thereby also the objectives. We will restrict our analysis to RES support schemes in the electricity sector which complement the EU ETS.

Existing assessments of RES targets and instruments relate additional costs primarily to benefits in terms of climate change mitigation (see above). These kinds of benefits are null in a first-best setting where a GHG externality is perfectly addressed by an ETS. However, there may be benefits if the assumptions of a single market failure and perfect policy responses as well as the focus on allocative efficiency are relaxed. Correspondingly, three lines of arguments can be differentiated (see also Figure 1): (1) a first-best setting where the RES policy directly addresses market failure other than a GHG externality, (2) a second-best setting where there are multiple market failures for which first-best policy responses (targets and instruments) are either absent or insufficient for diverse institutional and political constraints, and (3) a setting with policy objectives that go beyond mere allocative efficiency and which may reflect a broader definition of the social welfare function, including, e.g., distributional concerns. In the latter two settings, RES targets and instruments can be justified if they (1) actually generate benefits in terms of correcting market failures or attaining policy objectives, and (2) if they are more cost-effective than other institutionally and politically feasible policy options, including no (additional) policy intervention.

When assessing these potential benefits of a separate RES target and instrument, it is important to consider that the welfare losses from both market and policy failures mentioned above may be quite significant in the long run as suboptimal investments in the electricity sector are perpetuated over decades by strong socio-technical path dependencies (Kalkuhl et al., 2012; Lehmann et al., 2012; Lehmann and Gawel, 2013; Neuhoff, 2005; Unruh, 2000).

The discussion in this section is not meant to assess whether or not an additional RES target and instrument is actually welfare-increasing – nor what the optimal level of such target would be. Instead, it aims to broaden the perspective on which costs and benefits should be taken into account when assessing RES policies.

Figure 1: Possible economic rationales for RES targets and instruments in the electricity sector



It is usually assumed that the rationales for implementing a separate RES target and a separate RES instrument are basically the same. In addition, it has also been shown analytically that a mix of emission reduction and RES deployment targets can only be achieved simultaneously and cost-effectively by a mix of an emissions policy and a technology policy (Jensen and Skytte, 2003; Pethig and Wittlich, 2009). On the one hand, one may presume that this reasoning also holds in the second-best setting described in the following where multiple externalities and objectives are to be attained by the GHG and RES target. In order to address the externalities, technology substitution is required, which may be attained more effectively by a technology policy than by an emissions policy. On the other hand, tightening the EU ETS may also help to correct (some of) the externalities. However, this technology-neutral approach would likely induce excessive abatement by other options beyond deploying RES and therefore bring about higher societal costs than an instrument mix. We will explore this policy instrument issue in detail by our quantitative analysis.

2.1 First-best setting: Additional technology market failures

In a first-best setting, the GHG emissions externality is assumed to be properly addressed by the ETS. In this case, an additional RES target may be justified in the presence of additional technology market failures, most notably positive externalities related to learning-by-doing with RES technology deployment. These externalities arise because firms learn to optimize products and production processes as their cumulative output increases, and this knowledge may at least partly spill over to other market competitors (for overviews, see Bennear and Stavins, 2007; Fischer and Newell, 2008; Jaffe et al., 2005; Lehmann, 2012, 2013; Lehmann and Gawel, 2013). Quantitative evidence on the existence of such externalities for RES technologies is still not available.[3] However, anecdotal

[3] There is increasing evidence on knowledge spillovers associated with research and development of renewable energy technologies (Bjørner and Mackenhauer, 2013; Braun et al., 2010; Dechezlepretre et al., 2013; Garrone et

evidence for the RES sector (Hansen et al., 2003; IEA, 2000; Junginger et al., 2005; Neij, 1999) as well as experience with non-renewable energy technologies (Lester and McCabe, 1993; Zimmerman, 1982) and the manufacturing sector in general (Argote and Epple, 1990; Irwin and Klenow, 1994) seem to suggest that learning spillovers may characterize RES deployment also. The potential welfare effects from learning spillovers may be particularly high in the energy sector, as it is characterized by long-term investments with strong path dependencies and lock-in effects (Goldthau and Sovacool, 2012; Kalkuhl et al., 2012). Thus, policy intervention would be more warranted in the energy sector than in other sectors where similar externalities tend to occur as well.

In the presence of positive externalities associated with learning-by-doing in RES technologies, targets and instruments to promote RES deployment are justified. Depending on how the learning process is modelled, a GHG policy has to be supplemented by a technology-specific subsidy to either (i) RES-E generation (Canton and Johannesson Lindén, 2010; Fischer and Newell, 2008; Kalkuhl et al., 2012; Lehmann, 2013), (ii) renewable generation capacity installed (van Benthem et al., 2008), (iii) investments in renewable generation capacity (Kverndokk and Rosendahl, 2007), or (iv) output of manufacturers of RES-E installations (Bläsi and Requate, 2010).

2.2 Second-best setting I: Imperfect internalization of the GHG externality

It may be unclear whether the current GHG targets (20% reduction by 2020, 40% reduction by 2030) and even more ambitious long-term targets are efficient, given the large uncertainties surrounding the costs and benefits of GHG emission reductions (for a sceptical view, see, e.g., Tol, 2012). However, the picture becomes clearer if an ambitious long-term target of 80% emissions reduction by 2050 is accepted as a reasonable target. A model comparison by Knopf et al. (2013) shows that in this case the 2020 GHG target is not ambitious enough, while the 2030 target seems to be in line with cost-effective pathways for achieving the 2050 target.

Even if the targets are set properly, the attainment of these targets will be questionable given the current design of climate policy instruments. Knopf et al. (2013) point out that the trajectory agreed upon for the reduction of the emissions cap under the EU ETS (1.74% annually) is clearly below the levels needed to actually achieve short- and long-term targets. This does not come as a surprise as the cap as well as other design features of the EU ETS have been the result of a political bargaining process – rather than some cost-benefit analysis (Anger et al., 2008; Markussen and Svendsen, 2005; Rudolph, 2009; Skodvin et al., 2010). In addition, the carbon price signal generated by the EU ETS exhibits major short- and long-term uncertainties. Against this background, the EU ETS fails to set sufficient incentives to switch to low-carbon technologies which are needed to attain the long-term targets cost-effectively (for overviews, see Lehmann and Gawel, 2013; Matthes, 2010). Under these conditions, an additional RES policy may serve as a second-best strategy to mitigate climate change cost-effectively in the long run (Bläsi and Requate, 2007; Fischer, 2008; Ulph and Ulph, 2010).

Obviously, the first-best approach would always be to strengthen the EU ETS. This appears to be particularly warranted as RES deployment may bring about significantly higher societal costs than if the policy failures were addressed directly (Borenstein, 2012; Kalkuhl et al., 2013). However, given the past experience with politico-economic decision-making, it is unclear whether the EU ETS emissions cap will actually be reduced to the levels that would be necessary to attain the targets. Moreover, Gawel et al. (2014) show that a separate RES policy may have another advantage in this respect. As RES targets are typically implemented by subsidies, they bring down abatement costs for participants under the EU ETS. These may therefore be willing to accept stronger emissions reductions. Thus, a separate RES target may also help to negotiate a tighter emissions cap.

al., 2010; Popp and Newell, 2012). However, such externalities cannot be properly addressed by general RES deployment targets, but rather by more specific RES-R&D targets and policies.

2.3 Second-best setting II: Imperfect internalization of other externalities

A separate RES target can also be understood as a second-best policy to address externalities beyond GHG emissions if these cannot be corrected directly by appropriate first-best approaches (Edenhofer et al., 2013b; Edenhofer et al., 2013c; Lehmann and Gawel, 2013; McCollum et al., 2011). This type of rationale will be discussed in the following for the two most prominent examples: additional environmental externalities associated with the use of fossil and nuclear fuels and externalities arising from the import of fossil fuels.

Fossil and nuclear fuels also produce *environmental externalities other than climate change*. For fossil fuels, these may be related to damages from fuel extraction (e.g., ecological impacts of open cast coal mining and fracking), transportation (e.g., oil spills), and combustion (e.g., local air pollution) (e.g., Epstein et al., 2011). Similarly, there are hazards associated with the operation of nuclear power plants and the final storage of nuclear wastes (Heyes and Heyes, 2000). These externalities are typically not addressed perfectly by Pigovian tax-like policies. If such externalities are produced by economic activities within the territory of the EU, the absence of direct policies for internalization may be explained by lacking political will (in order to reduce the burden for voters or interest groups). Yet, externalities reducing welfare within the EU may also be related to economic activities outside the EU. Examples include the inter-regional transportation of pollutants or radioactivity by air and ocean currents or the loss of biodiversity. In such cases, the lack of regulation is simply due to the fact that externalities arise beyond the legislative scope of the EU. In both cases, the promotion of RES deployment may help to substitute fossil and nuclear fuels for electricity generation and control externalities indirectly (IPCC, 2011; McCollum et al., 2011; Siler-Evans et al., 2013). Certainly, the actual extent of benefits from RES deployment needs to be assessed with care. First of all, it depends on which types of non-renewable power plants are drawn out of the market and where (Borenstein, 2012). Second, there may be interactions between RES and GHG policies. Under a fixed CO_2 cap, increasing the share of renewable energy sources may drive down the CO_2 price (for an overview, see Lehmann and Gawel, 2013). As a consequence, emitters which are subject to the cap but outside the electricity sector may increase production and generate additional environmental externalities. Finally, RES may produce new types of environmental externalities, such as land use conflicts associated with the installation of wind turbines and biomass production or negative impacts on aquatic ecosystems related to the use of hydropower (IPCC, 2011; Kerr, 2010).

Fossil fuels may also generate externalities in terms of *security of energy supply* if they are imported from politically unstable regions. Sudden supply interruptions may significantly impair importing economies (Borenstein, 2012; Johansson et al., 2012). Estimating these external costs is certainly difficult (see, e.g., Bohi and Toman, 1996; Gillingham and Sweeney, 2010). In theory, such externalities could be corrected directly by tariffs on imported fuels. The ubiquitous lack of such policies may be attributed to the fact that they would oftentimes violate international trade law and may raise political fears of economic sanctions imposed by exporting countries. Against this background, promoting domestic RES to substitute imported fossil fuels may produce benefits in terms of safeguarding the security of supply (McCollum et al., 2011). For electricity generation in the EU, such benefits will primarily arise if natural gas imports from Russia or Northern Africa are substituted (Borenstein, 2012; Edenhofer et al., 2013a). In a theoretical model, Böhringer and Rosendahl (2010, 2011) confirm that a RES policy in fact reduces the share of electricity generation from natural gas. Certainly, the use of RES may also produce new problems of security of supply due to their intermittency.

2.4 Second-best setting III: Direct subsidies to fossil and nuclear fuels

The use of non-renewable energy technologies is also supported directly. This includes subsidies to fuel production and consumption as well as to technology research and development (Ellis, 2010; IEA/OPEC/OECD/World Bank, 2010; OECD, 2011). These subsidies reduce the cost of non-renewable energy sources to inefficiently low levels. Obviously, the first-best solution would again be to abolish the subsidies. However, this may be difficult politically due to opposition from affected mining companies, plant manufacturers and energy utilities, as well as from consumers facing higher electricity prices. Against this background, a RES policy is again a means to establish a level playing field for technology decisions in the electricity sector.

2.5 Objectives beyond allocative efficiency

In the political arena, RES targets are associated with multiple objectives to be attained. Some of them – such as climate change mitigation, environmental and resource conservation and security of supply – may be justified on the basis of allocative efficiency in first- or second-best settings, as they have been outlined in the previous sections. However, there are also policy objectives associated with RES targets – such as green jobs and green growth or the decentralization of energy supply – which may be more difficult to relate to improvements in allocative efficiency or the correction of a market failure. Nevertheless, this finding does not imply that such objectives should be disregarded in economic analyses for at least two reasons: First, these objectives may be highly relevant for practical decision-making. For example, RES policies may only be politically feasible if they also address concerns of employment (Edenhofer et al., 2013b). Analyses neglecting this kind of objectives risk running into a nirvana approach (Demsetz, 1969). Second, the existence of such objectives may also reflect societal preferences beyond allocative efficiency, such as justice, fairness or participation. These may be revealed in a political process of elections and influences from different interest groups (Oates and Portney, 2003) – even though this process is certainly subject to manifold distortions (e.g., Olson, 1965). In these cases, the primary question is not so much whether the objective makes sense economically but rather whether they can be attained cost-effectively by a RES policy.

The most prominent objective in this realm is the stimulation of green growth and green jobs. It will be a hard test to show that this objective can be justified on the basis of market failures, such as imbalances in the labour market (Gillingham and Sweeney, 2010). This notwithstanding, RES policies have certainly promoted gross growth and employment in green industry sectors, such as RES manufacturing. O'Sullivan et al. (2013) estimate that Germany's RES policy has generated 268,000 jobs in RES industry sectors by 2012. Certainly, this comes at the cost that economic development in other economic sectors may be impaired, such that net effects may be quite different. Borenstein (2012) points out that one has to distinguish between a short-term stimulus objective and a longer-term objective of job creation. Creutzig et al. (2013) argue that a European energy transition could have a positive stimulus effect, primarily because RES investments involve large upfront construction costs. In contrast, empirical evidence on net job effects of RES policies is very mixed involving negative as well as positive assessments (EWI et al., 2004; Hillebrand et al., 2006; Lehr et al., 2008; Rivers, 2013; Wei et al., 2010). On the one hand, RES technologies are more labour-intensive for producing energy than the non-renewable technologies they substitute (Borenstein, 2012). On the other hand, RES policies which are refunded by increases in electricity prices (or taxes) crowd out investments elsewhere in the economy (Frondel et al., 2008; Frondel et al., 2010). Thus, using RES policies to promote green growth and employment may be quite costly, which also raises the question whether other available means – such as macroeconomic fiscal and monetary or wage policies – could be more cost-effective in attaining the target.

RES policies are also expected to contribute to a more distributed generation of electricity which is associated with a fairer distribution of, and participation in, the benefits of electricity generation (Alanne and Saari, 2006; Pepermans et al., 2005). Empirical observations seem to confirm this expectation. In Germany, for example, almost half the RES-E capacity installed in 2012 was owned by private individuals, farmers and cooperatives (Trend Research/Leuphana, 2013). Of course, the eventual magnitude of such benefits depends crucially on the specific design of the RES policy, particularly on how investment risks are mitigated (for a discussion, see Lehmann et al., 2012).

2.6 Interim conclusion

The discussion in this section has revealed that there may be multiple benefits from implementing RES targets and instruments in addition to a GHG target and instrument. Economic studies so far rely on a problem framework tackling a single climate-related externality through a perfect ETS instrument, in which additional RES policies indeed create additional costs but no added value. If we relax the underlying assumptions in order to analyse energy policies in a more reality-oriented framework we have to take into account (1) additional, non-climate externalities of energy provision, (2) imperfections of instruments under real-life conditions and (3) policy objectives beyond allocative efficiency touching upon other politically relevant societal concerns. If multiple market failures have to be addressed using imperfect instruments, as it is the case in the real world, additional RES policies can create social benefits compared to a stand-alone ETS policy. These benefits are economically relevant from an efficiency perspective, whereas "political" benefits from different objectives (3) usually are considered irrelevant (political "co-benefits", see Edenhofer et al. (2013b)).

Moreover, it has become obvious that an objective assessment of all costs and benefits of an additional RES policy is nearly impossible. First, the assessment of costs and benefits is impaired by underlying uncertainties and complexities. Second, it eventually always hinges on the value judgments, risk preferences and ethical considerations of individuals or groups of individuals. In this respect, economic analyses of possible benefits and costs under certain assumptions can be used to inform political decision-makers. Yet, the final decision on whether or not a certain policy target makes sense – given possibly additional benefits but also possibly additional costs – can only be taken by the political decision-maker. This has been pointed out for the setting of GHG targets (IPCC, 2014; Knopf and Geden, 2014) – but it equally applies to the setting of (additional) RES targets (Lehmann et al., 2014).

Since social benefits of RES supporting policies are likely under real-world conditions, economic analysis should not only assess possible excess costs in fulfilling the single climate target. Rather, the analysis ought to compare the overall economic performance of energy policies under different scenarios with or without separate RES targets and instruments reflecting multiple externalities and imperfections of instruments in a second-best framework. Therefore, the subsequent model analysis will shed light on the cost and benefits that arise under such policy scenarios. The idea of this analysis is not to determine a specific cost-benefit ratio, which would indicate whether a certain policy (mix) is economically justified. It is neither meant to identify certain optimal characteristics of policy design, such as an efficient level of a RES target. Instead it is meant to provide an indication whether and to what extent additional RES policies may generate benefits beyond that of climate change mitigation. Such benefits would need to be put into relation to the often emphasized excess costs of an additional RES policy.

3 Model

To carry out a quantitative assessment of benefits and costs of different policy scenarios – including GHG policies only as well as additional RES targets and instruments – we use the so-called *'E3MG-*

FTT:Power' model. This model is a fully integrated mix of two separate models, i.e. the top-down, global macro-economic model *E3MG* and the bottom-up, global electricity sector model *FTT:Power*. The characteristics of these two models and their differences to existing approaches to analyze the EU framework for climate and energy policy are described in the following.[4]

3.1 The E3MG model

The E3MG model (Energy-Environment-Economy Model at the Global level) is a computer-based tool that has been constructed by international teams led by Cambridge Econometrics and the University of Cambridge. The model is econometric in design and is capable of addressing issues that link developments and policies in the areas of energy, the environment and the economy. The essential purpose of the model is to provide a framework for policy evaluation, particularly policies aimed at achieving sustainable energy use over the long term.[5] However, the econometric specification that the model uses also allows for an assessment of short-term transition effects.

In terms of basic accounting structure, purpose and sectoral and regional coverage, there are many similarities between E3MG and comparable CGE models, such as GTAP (Hertel, 1999). However, the modelling approaches differ substantially in their treatment of behavioural relationships and the structure of markets. CGE analyses pursue an optimization approach. They typically assume purely rational behaviour of agents with perfect knowledge and foresight. Price adjustments provide for equilibria in all markets, including the labour market. In contrast, E3MG is an econometric model which predicts agents' behaviour on the basis of historical data sets. Thus, E3MG does not assume optimal behaviour. The price is set by mark-up principle and the wage is determined by the wage-bargaining process between employers and employees. These differences have important implications for the possible model results. In CGE models, all resources are fully utilized. Therefore, it is not possible to raise output or employment by government interventions. In E3MG, potentially existing market disequilibria with unused capital and labour resources may allow for regulation to increase investment, output and employment. Thus, E3MG may provide a more realistic assessment of policy performance as it does not depend on the rigid assumptions of CGE models. The major drawback of the E3MG approach is that it hinges on the quality of the time series data sets (Bosetti et al., 2009; Cambridge Econometrics, 2014; Jansen and Klaassen, 2000). Moreover, this approach rests on the assumption that past behaviour can be employed to predict future trends, even under different policy regimes.

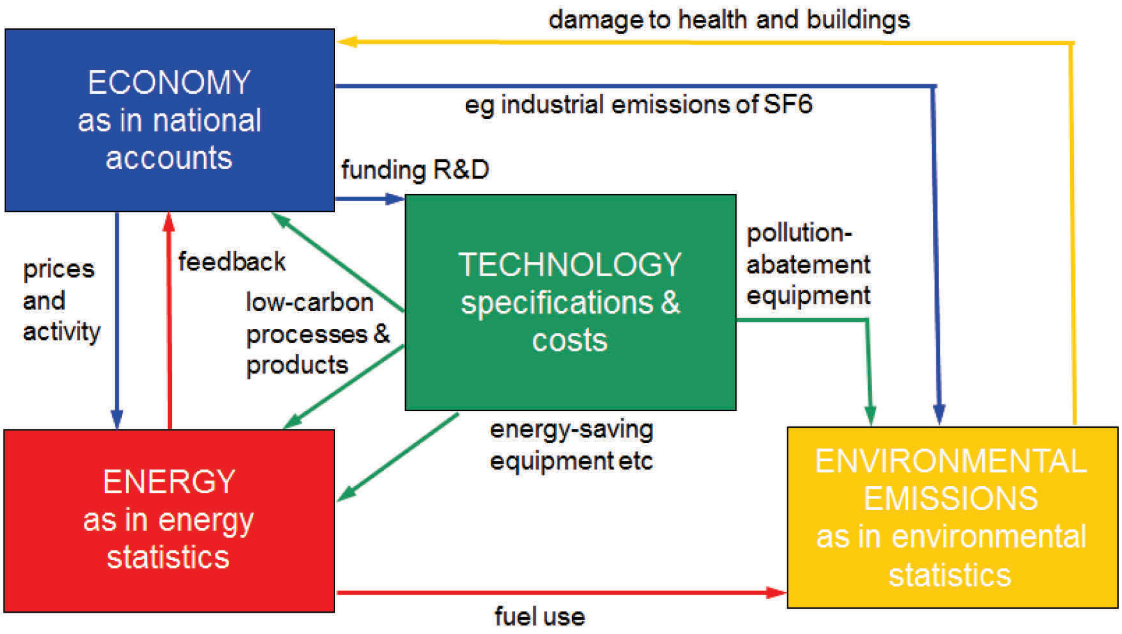
The current version of E3MG covers 22 world regions, although in this analysis we focus solely on the EU. The basic structure of E3MG is presented in Figure 2. The model integrates energy demand and emissions with the economy; fuel demand is determined by prices and economic activity, with feedback through the energy supply sectors. Energy combustion results in greenhouse gas emissions.

---

[4] For further details, see the websites of these models, www.e3mgmodel.com and http://www.4cmr.group.cam.ac.uk/research/FTT/fttpower, as well as the references mentioned there.

[5] E3MG has been employed for policy analysis at European level, including the 2010 European Commission communication on the impacts of moving to a 30% GHG target (European Commission, 2010a). The model has also been used repeatedly for assessing decarbonisation pathways at different international levels (Barker et al., 2008; Barker et al., 2005, 2006; Barker and Scrieciu, 2009) and in the UK (Dagoumas and Barker, 2010). More recently, E3MG was applied in Barker et al. (2012) to provide an economic assessment of the IEA's 450ppm scenario (IEA, 2010). In Japan, E3MG has been applied for an assessment of the economic costs of meeting Japan's Copenhagen pledge of reducing GHG emissions by 25% below 1990 level by 2020 (Lee et al., 2012). Most recently, E3MG has been used for an economic and environmental assessment of future electricity generation mixes in Japan (Pollitt et al., 2014).

Figure 2: E3 interactions with E3MG



Source: Cambridge Econometrics (2014).

The economic module in E3MG contains a full representation of the National Accounts, as formulated by Stone (1951), and formally presented in European Communities et al. (2009). A key feature of E3MG is its sectoral disaggregation, with 42 economic sectors, linked by input-output relationships; this aspect is particularly important in modelling carbon policies, because the different sectors use different fuels in varying degrees of intensity and have different technological options for changing consumption patterns.

E3MG's treatment of energy demand is largely top-down in nature. Econometric equations are estimated for aggregate energy demand and demand for the four main fuel types (coal, fuel oil, natural gas, electricity). Energy demand, for 22 different user groups, is a function of economic activity, relative prices and measures of technology. The model solves all equations simultaneously and adjusts the individual fuels to sum to the total for each user. Feedbacks to the economy are provided by adjusting input-output coefficients and household energy demand.

Emissions are estimated using a fixed coefficient to fuel demand. Non-energy emissions are included in the model so that global totals are met, but are treated as exogenous in this paper.

E3MG includes endogenous measures of sectoral technological progress. The indices used in the model are functions of accumulated capital, enhanced by R&D, an approach adapted from Lee et al. (1990). Endogenous technological progress is allowed to influence several of the model's equation sets, including energy demand, international trade, price formation and the labour market.

As an econometric model with sectoral detail, E3MG requires extensive data inputs. A large time-series database covering each year from 1970 to 2010 has been constructed, based mainly on international data sets. Any gaps in the data are filled by using national figures. The main cross-sectional data (the input-output table and bilateral trade flows) are sourced from the OECD. The main source for energy data is the IEA. CO_2 emissions have also been made consistent with IEA figures.

E3MG consists of 22 estimated sets of equations (each disaggregated by sector and by country). These cover the components of GDP, prices, the labour market and energy demand. The estimation method utilises developments in time-series econometrics, in which dynamic relationships are specified in terms of error correction models (ECM) that allow dynamic convergence to a long-term outcome.

The specific functional form of the equations is based on the econometric techniques of cointegration and error-correction, particularly as promoted by Engle and Granger (1987) and Hendry et al. (1984). In brief, the process involves two stages. The first-stage is a levels relationship, whereby an attempt is made to identify the existence of a cointegrating relationship between the chosen variables, selected on the basis of economic theory and a priori reasoning, e.g. for employment demand the list of variables contains real output, real wage costs, hours-worked, energy prices and a measure of technological progress. If a cointegrating relationship exists, then the second stage regression is known as the error-correction representation, and involves a dynamic, first-difference, regression of all the variables from the first stage, along with lags of the dependent variable, lagged differences of the exogenous variables, and the error-correction term (the lagged residual from the first stage regression).

3.2 The FTT:Power model

FTT:Power is a simulation model of technology diffusion in the electricity sector globally (Mercure, 2012). As opposed to many contemporary models (see, e.g., Messner and Strubegger (1995) for the MESSAGE model and Seebregts et al. (2001) for the MARKAL model), it does not solve a cost-optimisation problem in order to model investor decisions and the composition of the electricity sector. FTT:Power is composed of a decision-making model for power sector investors at the firm level, evaluating decisions made by a diverse distribution of investors influenced by cost and policy considerations. It uses pairwise comparisons of options at the investor level using a stochastic description of component costs, based on 24 technologies in 22 E3MG regions. It includes cost dynamics such as learning-by-doing and natural resource cost-supply curves (Mercure and Salas, 2012), as well as a dynamic model of non-renewable energy commodity price dynamics (Mercure and Salas, 2013).

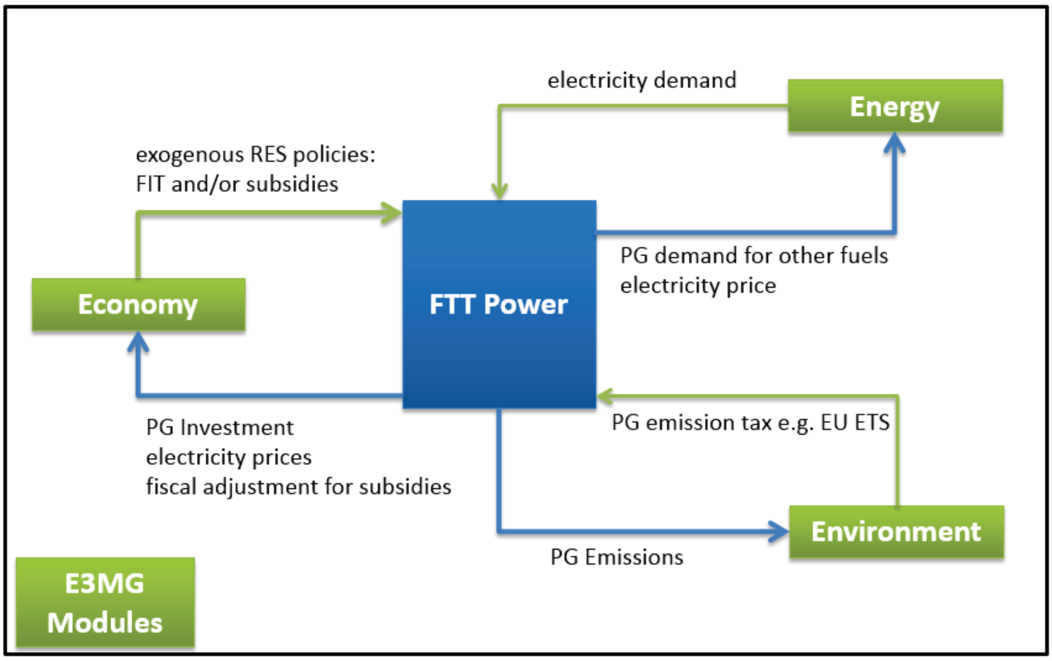
Observed historical diffusion of innovations follows a well-known pattern (e.g., Grübler et al., 1999), which is missed out by cost-optimisation models, the latter not featuring the necessary theoretical underpinning. When contemplating the energy industry, it may be intuitively expected that well established firms with their preferred established technologies and existing technical expertise may be better able to expand in a changing market than small and emerging enterprises selling new technology, despite price considerations. This must be reflected in diffusion rates produced by any model. This is also a reflection of the enduring nature of technology regimes and technical expertise (e.g., Geels, 2002). Given a certain production capacity for new units of particular technologies, power sector investors wishing to venture into projects involving new technologies may be constrained by the availability of technology producers despite their investment preferences. Given these constraints and dynamics, the technology composition of a real system may not always be near the solution of a cost-optimisation calculation.

These considerations are encompassed in a model of technology diffusion, which must, as an output, produce diffusion patterns consistent with empirical observations. This is the fundamental principle underpinning FTT:Power, in which the cost-optimisation driver (the social planner) of investor decisions in common models is replaced by a decision-making model at the investor level. Firms and technologies are assumed to expand or shrink proportionally to their own market share, which leads to a dynamic differential equation description of technology substitutions. In the special case of the competition between two technologies, this produces the archetypical logistic diffusion curve, while when more technologies interact, many possible patterns can emerge. The rate of diffusion is constrained by the rate of adoption as well as the lifetime and expansion time constants of the producers. This theory is described in detail in Mercure (2012).

The advantage of using a decision-making model instead of an optimisation procedure is immediate: in a decision-making model one is in principle able to simply include cost considerations to investors originating from policy (e.g. carbon costs, RES-E subsidies, capital cost subsidies) that influence their decisions. This enables the model to explore the effectiveness of policy instruments, in isolation and in combination, to foster technology diffusion, which occurs at a rate reflecting both technology uptake and technology replacement. In an earlier study we found that, in such a modelling context, strong synergies exist between policy instruments (Mercure et al., 2013), where for instance the effectiveness of a carbon price in fostering the uptake of renewables strongly depends on the full renewables policy context including RES-E subsidies. We find a similar process occurring in the present study.

The FTT model has been fully integrated to the E3MG model with two-ways feedbacks between each of the E3 modules of E3MG. Figure 3 summarises these links.

Figure 3: FTT links to E3MG



(PG – power generators)

Source: (Cambridge Econometrics, 2014).

4 Scenarios

We apply the E3MG-FTT:Power Model to provide a quantitative assessment of potential costs and benefits of implementing a RES policy in addition to a GHG policy. For this purpose, we aim to compare the model results for four scenarios (one baseline and three policy scenarios):

- A baseline scenario where the currently existing 2020 GHG and RES policies are maintained but not tightened beyond 2020 (S0 – baseline);
- A scenario where a more ambitious 2030 GHG target is set for the EU ETS sector and attained by a tightened EU ETS cap (S1 – CO_2/ETS only);
- A scenario where the 2030 GHG target is complemented by a RES-E target, and both are attained only by means of a further tightened EU ETS cap (S2 – CO_2+RES/ETS only);

- A scenario where the 2030 GHG and RES-E targets are attained by a policy mix of the EU ETS and a strengthened RES support scheme (S3 – CO_2+RES/policy mix).

This section introduces the basic assumptions underlying all scenarios and specifies the characteristics and rationales of the baseline and policy scenarios. Table 1 provides an overview of the scenarios. The upper section represents the policy assumptions which we have set for our scenario analysis. The lower section provides the policy characteristics as they result from our model simulation.

Table 1: Overview of scenarios

	S0 (baseline)	**S1 (CO_2/ ETS only)**	**S2 (CO_2+RES/ ETS only)**	**S3 (CO_2+RES/ policy mix)**
Policy assumptions				
2030 GHG target for the EU ETS sectors	No	Yes (1136 $MtCO_2$)	Yes (1136 $MtCO_2$)	Yes (1136 $MtCO_2$)
2030 RES-E target (%)	No	No	Yes (40%)	Yes (40%)
EU ETS	Yes	Yes	Yes	Yes
Technology-neutral RES subsidy	Yes	As in S0	As in S0	Higher than in S0
Policy specifications and outcomes according to model simulations				
ETS cap ($MtCO_2$) in 2030	1512	1136	626	1136
CO_2 price in 2030 (in 2010 prices)	33	100	440	52
RES-E share (%) in 2030	26	32	40	40
Average RES-E subsidy over all electricity produced in 2030 (€/MWh)	2.0	1.2	0.16	7.2
Average RES-E subsidy per MWh of RES-E generated (€/MWh_{RES-E})	7.7	3.8	0.4	18.1

4.1 Common basic scenario assumptions and input variables

The main assumptions and input variables for all scenarios analysed in the present paper include:

- *GDP/sectoral growth rates:* for the EU region, assumptions on the baseline GDP/sectoral growth rates up to 2030 have been derived from and calibrated to DG ECFIN's economic projections up to 2030 in the 2012 Aging Report (European Commission (2012), see the upper part of Table 2). For all other, non-EU regions, these growth rates are obtained from the IEA's baseline or 'Current Policies Scenario' published in its World Energy Outlook 2012 (IEA, 2012);

- *Fuel prices*: assumptions on fuel prices up to 2030 are also derived from the IEA's 'Current Policies Scenario' in its WEO 2012 (IEA (2012); see the lower part of Table 2);

Table 2: Key scenario assumptions on economic growth rates and fuel prices, 2010-2030

Baseline growth rates (average % per annum)	**2010-2020**	**2020-2030**
EU27 GDP	1.4%	1.6%
Industry	1.2%	1.6%
Transport	1.1%	0.9%
Services	1.6%	1.7%
Fuel prices	**2020**	**2030**
Oil (2011$/barrel)	128.3	141.1
Gas (2011$/MBtu)	12.1	13.4
Coal (2011$/tonne)	115.0	125.0

Sources: European Commission (2010b, 2012) and IEA (2012).

- *Climate policies outside the EU*: in all scenarios, we have assumed that countries outside the EU take no action beyond their existing policies and GHG reduction targets that already are in place in the baseline (as in the Current Policies scenario from the IEA WEO 2012 publication). There are some feedbacks from countries outside the EU in the scenario through trade competitiveness. However, the EU climate target alone will not have significant impacts on global energy demand. This implies that, in all scenarios, international energy/commodity prices are assumed to be the same;
- *Allocation of EU emission allowances (EUAs):* for reasons of simplicity, it is assumed in our modelling scenarios that, starting from 2013, all EUAs for the power sector are auctioned and all EUAs for the other (industrial) sectors are allocated for free on a lump sum basis (i.e. not related to current or updated production).[6] Therefore, using these free allowances is regarded as spending so-called 'opportunity costs' and, hence, these costs are passed on to higher output prices, depending on the demand responsiveness, competitiveness and other market conditions of the industries concerned;
- *Banking and borrowing of EUAs:* we have assumed no borrowing, but banking is allowed as long as the 2030 emission target (1,136 MtCO_2) is met;
- *Revenues from EUA auctioning of the power sector:* assumed to be recycled through lump-sum allocations to households, which increase their wealth rather than their direct consumption level. For some scenarios, however, we have conducted a sensitivity analysis in which we have assumed

[6] In reality, however, allocation is more complicated as the power sector in ten Eastern European countries is allowed to receive a (declining) share of its EUAs for free while some industries – not regarded to be exposed to the risk of carbon leakage – have to buy a (growing) share of their EUAs at an auction. For specific details on EUA allocation issues, see the website of the DG CLIMA (European Commission, 2013a).

that half of the EUA auction revenues is recycled to households through lump-sum allocation (increasing their wealth), and the other half through lowering their direct income taxes (increasing their net income and consumer spending) (see Section 5.3);

- *Compensation of indirect carbon costs:* for all scenarios, we have assumed that energy-intensive industries are not compensated for the ETS carbon costs passed through to the electricity prices for industrial end-users;
- *Use of offset credits:* we have assumed that ETS sectors are not allowed to use CDM/JI credits to cover their emissions;
- *ETS coverage:* in all scenarios, the coverage of the ETS up to 2030 is similar to the coverage of the ETS during its third trading phase as specified in the EU ETS Directive of 2009, i.e. including the power sector and energy-intensive industries such as iron and steel, refineries, paper and pulp, glass, bricks, cement, aluminium and some chemical installations. Moreover, in addition to the CO_2 emissions of these installations, the scenarios also include the other GHGs specified by the 2009 ETS Directive (European Commission, 2009). In all scenarios, however, aviation is excluded from the coverage of the ETS.
- *RES-E subsidy:* in all relevant scenarios, RES-E subsidies are in place (but with different subsidy levels). They are defined as a percentage of difference between the average levelised cost (LCOE) of RES-E generation and the current electricity price. Due to the model set-up with inertia related to technology adoption, the percentage is larger than the actual relative difference between the LCOE and the electricity price. Subsidies are funded through uniformly higher electricity prices for households and industries;

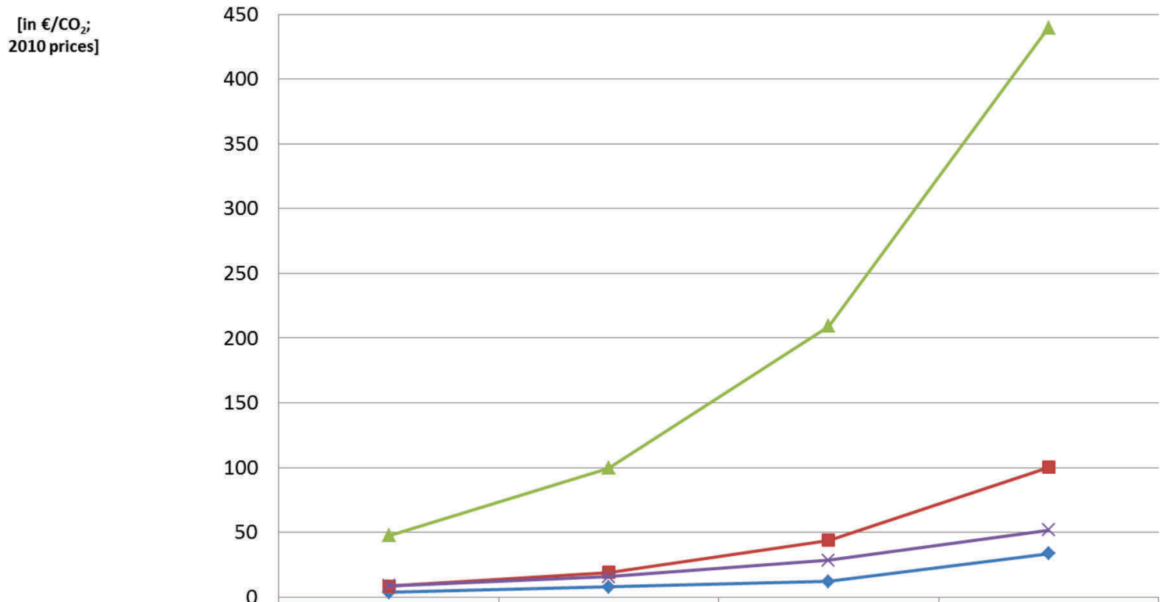
4.2 Baseline scenario

The Baseline Scenario (S0) represents the business-as-usual case in which existing 2020 GHG and RES policies – as well as other policies related to reducing energy consumption or improving energy efficiency – are maintained but not tightened. The EU region has been calibrated to the baseline scenario of the so-called 'PRIMES projections', published by the European Commission (DG Energy) in its *EU energy trends to 2030* (European Commission, 2010b), while all other, non-EU regions have been calibrated to the baseline scenario of the IEA in its World Energy Outlook 2012. For the EU, we have used the 2009 update of the PRIMES projections, which are based on current EU and Member States' policies up to April 2009 and economic expectations by that time. PRIMES 2009 projections, however, have been slightly further updated for this paper by including additional economic data for 2009-10, giving a better short-term representation of the recession. The PRIMES baseline projections include the effects of the ETS and other current policies up to April 2009, notably policies in the fields of energy savings, renewables and GHG reductions in non-ETS sectors. According to these projections, the 2020 target is met for the EU ETS – more or less by definition by assuming compliance to the cap – but not for these other fields of energy and climate policies (European Commission, 2010b).[7] In this baseline scenario, ETS emissions are reduced by 27% (compared to 2005) to 1512 $MtCO_2$ in 2030 (see also Table 1). The CO_2 price increases from 4 €/tCO_2 in 2015 to 8

[7] Besides the baseline scenario, the PRIMES 2009 projections also cover a so-called 'reference scenario' which includes additional policies adopted between April 2009 and December 2009. This reference scenario assumes that the two binding EU targets for 2020 will be met (i.e. the 20% renewable energy target and the 20% GHG reduction target). The results for the reference scenario turn out that only half of the third, non-binding target will be achieved (i.e. 9.5% rather than the target of 20% energy savings by 2020). For more details on the PRIMES 2009 baseline and reference scenario projections, see European Commission (2010a).

€/tCO_2 in 2020 and 33 €/tCO_2 in 2030 (see Figure 4).[8] In this baseline scenario, the RES-E share amounts to 26% in 2030. The average RES-E subsidy is 2.0 €/MWh.

Figure 4: ETS carbon price, 2015-2030



	2015	2020	2025	2030
S0 (Baseline)	4	8	12	33
S1 (CO2/ETS only)	8	19	44	100
S2 (CO2+RES/ETS only)	47	100	209	440
S3 (CO2+RES/policy mix)	9	16	28	52

4.3 Policy Scenarios

In *Scenario 1 (S1 – CO_2/ETS only)*, only a GHG target is in place, which is to be attained by the EU ETS. This scenario represents the reference line to assess subsequently to what extent an additional RES target (either addressed by a tightened EU ETS, as in Scenario S2, or by an additional RES-E support scheme, as in Scenario S3) produces additional benefits or costs. Compared to S0, this scenario is implemented by reducing the emissions cap for the EU ETS to 1,136 $MtCO_2$ in 2030, which corresponds to an emissions reduction in the ETS sector of 45% compared to 2005. According to Knopf et al. (2013), this target corresponds to the median of a set of model scenarios if overall GHG emissions in the EU are to be reduced by 40% by 2030 and 80% by 2050 – as mandated by the EU "A *roadmap for moving to a competitive low carbon economy in 2050*" (European Commission, 2011b). The resulting ETS carbon price increases from 8 €/tCO_2 in 2015 to 19 €/tCO_2 in 2020 and to 100 €/tCO_2 in 2030 (see Figure 4).[9] In 2030, S1 results in a RES-E share of 32%. The average RES-E subsidy is 1.2 €/MWh. It is lower than in S0 because the electricity price increases (see below) and its difference to the LCOE of RES-E decreases in S1.

[8] This price patterns conforms largely to the most recent PRIMES projection of the so-called 'EU Reference Scenario 2013', which gives an ETS carbon price of 5, 10 and 35 €/tCO_2 in 2015, 2020 and 2030, respectively (European Commission, 2013a).

[9] The major reason why the ETS carbon price in 2015 and 2020 is higher in S1 (and the other policy scenarios) than in the baseline – while the ETS cap in these years is similar in all scenarios – is that the assumed policy changes up to 2030, and the resulting ETS carbon prices up to 2030, lead to different EUA banking patterns over the years 2015-2020 and, therefore, to other CO_2 price patterns over these years.

In *Scenario 2 (S2 – CO_2+RES/ETS only),* an additional, EU-wide RES-E target of 40% (i.e., this target is not differentiated by technology or Member State) is to be achieved by 2030. This target is also taken from Knopf et al. (2013), and corresponds to the lower bound of RES-E targets of a set of model scenarios. It is meant to be in line with the EU "*Energy Roadmap*" (European Commission, 2011a, 2013b), according to which the RES share in primary gross final energy consumption has to be increased to 30% to be on track for a RES share of at least 55% in 2050 (the Roadmap is not specific on how these targets translate into electricity generation targets). The additional RES-E target is assumed to be achieved by means of the ETS only. This scenario, as a reference case, allows us later to specify the potential gains of a policy mix in a setting with two separate targets, as implemented in Scenario S3. For this purpose, the ETS cap is reduced beyond the level in S1 to 626 $MtCO_2$ in 2030, or by 70% compared to 2005 emissions. The ETS carbon price rises up to 440 €/tCO_2 (see Figure 4). Compared to S0 and S1, the average RES subsidy again slightly decreases to 0.2 €/MWh. As for S1, this is again due to increasing electricity prices and decreasing differences between these prices and the LCOE of RES-E.

Scenario 3 (S3 – CO_2+RES/policy mix) is similar to the previous scenario (S2) in that both an GHG target of 1,136 $MtCO_2$ for the ETS sector and the 40% RES-E target are to be attained simultaneously in 2030. In contrast to S2, however, the two targets are to be achieved by a mix of two policy instruments: the ETS and a technology-neutral feed-in subsidy (per kWh generated) for all RES-E technologies in all Member States across the EU.[10] In this scenario, the resulting level of the uniform RES subsidy which is paid for each MWh of power fed into the grid (in addition to the wholesale electricity price) amounts to approximately 18 €/MWh (in 2010 prices). It is introduced in 2014 and kept constant in real terms up to 2030. This subsidy is implemented in our model by increasing the reference LCOE value, on the basis of which the subsidy is calculated, over that assumed in S0, S1 and S2 (see above). The corresponding ETS carbon price is 53 €/t CO_2 in 2030 (see Figure 4). It is significantly lower than in S2 (because the RES-E target is not attained by means of the EU ETS but by the additional subsidy), and also below the level in S1 (due to interaction effects between GHG and RES-E policies).

By including Scenarios 2 and 3 and comparing them in parallel to Scenario 1 we aim to assess the performance of a single ETS in comparison to a policy mix. ETS only approaches are often promoted as the regulatory ideal for cost-effective sustainable climate and energy policy. We explore whether this holds true in a setting with multiple market and policy failures next to a GHG externality.

5 Impact assessment

5.1 Macro-economic results

5.1.1 Aggregate results

Figure 5 presents macro-economic outcomes of the three policy scenarios by 2030 for the EU27 as a whole (in % difference from the baseline). It shows that the difference in performance between the baseline and policy scenarios – but also among the policy scenarios themselves – are generally small, notably for variables such as GDP, investment or employment. For instance, GDP in 2030 is 0.3% lower in S1 and S3, while the impact on employment is even smaller. For some other macro-economic variables, however, the impact is somewhat larger. For instance, total EU27 imports of fossil fuels in 2030 decline by 5.2% in S2.

[10] Note that, in modelling terms, this RES-E policy is exactly similar to setting an EU-wide RES-E quota (of 40% by 2030) with an EU-single green certificate trading system in which the certificate price is similar to the uniform feed-in subsidy level

Figure 5: Macro-economic outcomes by 2030 (in % difference from the baseline)

	GDP	Investment	Employment	Consumer prices	EU imports of fossil fuels	EU domestic supply of fossil fuels
S1 (CO2/ETS only)	-0.30	-0.32	-0.06	0.48	-1.92	-2.04
S2 (CO2+RES/ETS only)	-0.64	-0.57	-0.12	1.26	-5.23	-6.06
S3 (CO2+RES/policy mix)	-0.17	0.04	-0.03	0.48	-1.68	-1.25

There are several reasons why the macro-economic outcomes of the three policy scenarios are generally small. These reasons include:

- The outcomes refer to changes compared to the baseline scenario, i.e. they are relative changes induced by relative policy changes, in particular by policy induced changes in the ETS carbon price and, to a lesser extent (in S3), by changes in RES-E support levels. The changes in ETS carbon prices by 2030 are relatively modest, ranging from 33 €/tCO_2 in the baseline to 100 €/tCO_2 in S1. Only in S2, the carbon price is substantially higher, i.e. 440 €/tCO_2. This scenario also shows the relatively largest (negative) impact on macro-economic variables such as GDP, investment and employment (although even in this scenario this impact is smaller than 1%);
- Industry and the energy sectors account for a relatively small share of GDP, and this will be smaller still in 2030. In the baseline scenario, the services sectors are estimated to contribute 72% of gross value added in the EU in 2005, rising to 75% in 2030 (European Commission, 2010b);
- Energy-intensive sectors account for quite a small share of manufacturing output. The energy-intensive sectors (chemicals, basic metals, construction materials, pulp and paper) represent a small share in total value added, i.e. 3.4% in 2005, declining to 2.7% in 2030. The share of the non-energy-intensive industries is projected to remain around 13.5% throughout the period 2005-2030 (European Commission, 2010b);
- Even for the energy-intensive sectors, energy is often not a very large share of costs (at the 2-digit level energy costs are usually less than 5% of turnover for all sectors except power and aviation);

As noted, the impact of the policy scenarios on employment is generally even smaller than the impact on GDP and investment. Basically, there are three reasons for this. First, this is due to the econometric parameters describing the relationship between output and employment in our model. Because of economies of scale and technological progress, changes in output are correlated with relatively smaller changes in employment (the so-called Verdoorn-Kaldor's law). Second, in the medium or long run, a negative impact on employment is mitigated by a downward adjustment of the wage rate, thereby enhancing labour demand (employment) in the long run. Third, a higher ETS carbon price has a (small) negative impact on GDP and, hence, also on employment. The negative impact on employment, however, is mitigated by the fact that a higher ETS carbon price also implies that the relative cost of energy versus labour become higher, resulting in a (small) substitution of energy by labour and, therefore, enhancing employment.[11]

The scale of the macro-economic impacts is quite standard for this type of analysis. It should not be interpreted as saying that there will not be substantial localized impacts – the second and third bullet points above are saying that macro-economic impacts are small because a small number of (sub)sectors/groups is affected, not that all (sub)sectors/groups are affected in a small way.[12] Moreover, in absolute terms, the difference in performance between the policy scenarios may be substantial. For instance, compared to the baseline, the decrease in GDP by 2030 amounts to about € 30 billion in S3 and approximately € 120 billion in S2, i.e. an absolute difference of about € 90 billion between these two scenarios.

Comparing the three policy scenarios, Figure 5 shows that the performance in terms of GDP, investment and employment is generally worst for scenario 2 (RES-E/ETS only) and best for scenario 3 (CO_2 and RES-E). The major reason for this performance is the ETS carbon price up to 2030, which is highest in S2 (rising to 440 €/tCO_2 in 2030) and lowest in S3 (52 €/tCO_2 in 2030). In terms of imports and domestic supply of fossil fuels, however, the performance is best for S2 and worst for S3. This relatively best performance for S2 can also be explained by the relatively highest ETS carbon price in this scenario, which depresses economic activity and increases fossil energy costs, both reducing fossil energy use, including imports and domestic supply of fossil fuels. Hence, between S2 and S3 there seems to be a trade-off between energy security and macroeconomic performance.

Figure 6 provides a slightly more detailed picture of changes in domestic supply and imports and exports of fossil fuels under the policy scenarios in absolute terms (i.e. in billion €). Some major observations from this figure include:

- In all policy scenarios, both EU imports and EU domestic supplies of fossil fuels decline in absolute terms (compared to the baseline). In all cases, the decline in fossil fuel imports refers predominantly to a decline in imports of oil/gas and, to a lesser extent, a decrease in imports of coal. Domestic coal production is not affected in our model because by assumption changes in coal use are compensated by changes in coal imports first. While coal is generally imported from politically more stable countries, this is not necessarily the case with oil/gas. This implies that all policy scenarios result in some improvement in EU energy security in terms of reducing reliance on imports of oil/gas.[13]
- As indicated above, the best performance in terms of improving energy security – i.e. of reducing imports of fossil fuels, notably of oil/gas – is recorded for S2 (due to the high ETS carbon price of this scenario). More specifically, in S2 EU imports of fossil fuels in 2030 decline by € 39 billion (i.e. -5.2%, compared to the baseline), consisting of a decline of EU imports of coal by € 6.1 billion (-22%) and of oil/gas by € 33 billion (-4.6%).

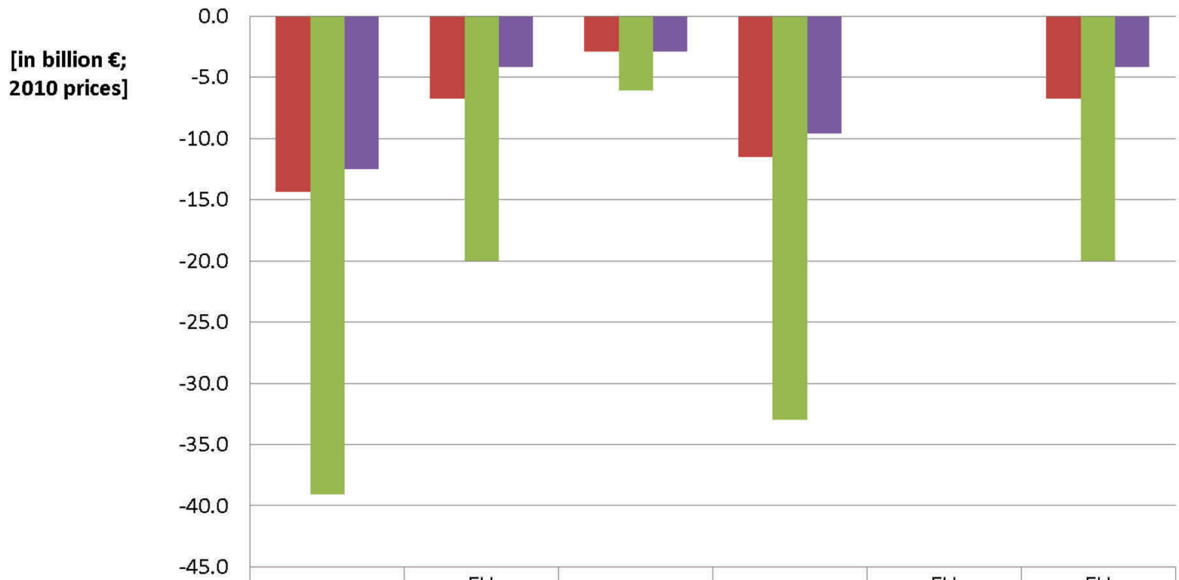
[11] In some cases (or in some sectors), the overall impact of a higher ETS carbon price on employment may even be (slightly) positive due to the positive labour-energy substitution effect. Moreover, depending on the assumptions on the allocation of emission allowances (auctioning versus free allocation) and, in case of auctioning, on the recycling of auction revenues, the overall impact of ETS carbon pricing policies may even be positive on both GDP and employment (see Section 5.3).

[12] See also Section 5.1.2, discussing some impacts at the sectoral level.

[13] Note that in relative terms, i.e. as a percentage of total oil/gas imports in the baseline, the decline in oil/gas imports by 2030 varies from -1.3% in S3 to -4.6% in S2.

- A striking result is that the worst performance in terms of reducing imports of fossil fuels, notably of oil/gas, is recorded for S3. Whereas imports of oil/gas decline by € 9.6 billion in S3 (i.e. -1.3%, compared to the baseline), they decrease by almost € 12 billion in S1 (-1.6%) and, as noted, by € 33 billion in S2 (-4.6%). A major reason for the relatively higher imports of oil/gas in S3, in particular compared to S1 and S2, is the lower ETS carbon price in S3.

Figure 6: Changes in EU imports and domestic supply of fossil fuels

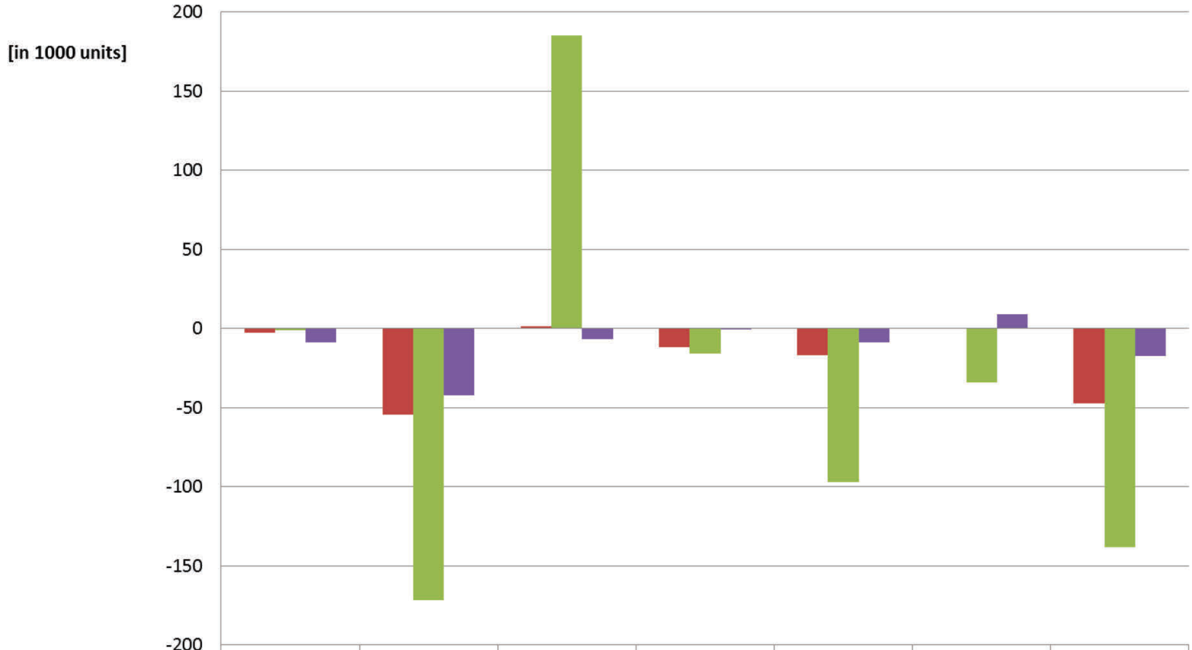


	EU imports of fossil fuels	EU domestic supply of fossil fuels	EU imports of coal	EU imports of oil/gas	EU domestic supply of coal	EU domestic supply of oil/gas
S1 (CO_2/ETS only)	-14.4	-6.7	-2.9	-11.5	0.0	-6.7
S2 (CO_2+RES/ETS only)	-39.1	-20.0	-6.1	-33.0	0.0	-20.0
S3 (CO_2+RES/policy mix)	-12.5	-4.1	-2.9	-9.6	0.0	-4.1

5.1.2 Sectoral employment

Figure 7 shows the policy-induced changes in EU employment in some major EU sectors. In general, these changes are negative and relatively small (i.e. in percentage terms), but occasionally substantial in absolute figures. For instance, in S2, employment in the sector utilities and mining declines by 171,000 units (i.e. 6%), compared to the baseline, while it increases by more than 180,000 units (i.e. 0.6%) in the manufacturing industries.

Figure 7: EU sectoral employment, 2030 (in absolute differences from the baseline)



	Agriculture	Utilities mining	Manufacturin g industries	Constructions	Distributions and retails	Transport	Business services
S1 (CO2/ETS only)	-3	-55	2	-12	-17	0	-47
S2 (CO2+RES/ETS only)	-1	-171	185	-16	-97	-34	-138
S3 (CO2+RES/policy mix)	-9	-42	-7	0	-9	9	-17

In some cases, the changes in sectoral employment may be positive, whereas the change in sectoral output is negative. For instance, in S2, output in manufacturing industries decrease by 1.4% whereas employment increases by 0.6%. These opposite effects can be explained by the policy-induced increase in the ETS carbon price and the resulting increase in energy costs – notably of electricity – which, on the one hand, leads to a loss of industrial output (due to a deterioration of industrial competitiveness and economic activity) and, on the other hand, to a higher demand for labour (due to a substitution of energy by labour and adjustments in wages).

5.2 Power sector results

5.2.1 Levelised costs of electricity

For each scenario, Table 3 presents both total and average levelised costs of electricity generation per MWh (LCOE) in the EU27 by 2030 from a private sector perspective.

Table 3: Levelised cost of electricity (LCOE), private generator perspective, 2030

	S0 (Baseline)	S1 (CO2/ ETS only)	S2 (CO2+RES/ ETS only)	S3 (CO2+RES/ policy mix)
Total LCOE (in billion €, 2010 prices)				
Total LCOE, excluding carbon costs and RES-E subsidies	263.2	253.6	236.0	274,8
Total carbon costs	*30.2*	*64.1*	*128.5*	*31,2*
Total LCOE, including carbon costs	293.3	317.7	364.5	306,1
Total RES-E subsidies	*7.9*	*4.5*	*0.5*	*27,0*
Total LCOE, including carbon costs and RES-E subsidies	285.5	313.2	364.0	279,1
Average LCOE (in €/MWh, 2010 prices)				
Average LCOE, excluding carbon costs and RES-E subsidies	67.1	68.7	73.6	73,6
Average carbon costs	*7.7*	*17.4*	*40.1*	*8,4*
Average LCOE, including carbon costs	74.8	86.0	113.7	82,0
Average RES-E subsidies	*2.0*	*1.2*	*0.2*	*7,2*
Average LCOE, including carbon costs and RES-E subsidies	72.8	84.8	113.6	74,8

Some observations from Table 3 include:

- Excluding carbon costs and RES-E subsidies, total LCOE is lowest – € 275 billion – in S2, mainly due to the relatively lowest electricity use in this scenario, and highest – € 319 billion – in S3, resulting largely from the more expensive RES-E technologies deployed in this scenario. Average LCOE, excluding carbon costs and RES-E subsidies is highest in S2 and S3 (74 €/MWh) but lowest in the baseline (67 €/MWh).
- In the baseline the average LCOE, excluding both carbon costs and RES-E subsidies, amounts to 67 €/MWh. In S1 (CO_2/ETS only), it increases to 69 €/MWh and in S2 (RES-E/ETS only) even to 74 €/MWh. This increase in the average LCOE is due to the increase in the ETS carbon price by 2030, i.e. from 33 €/tCO_2 in the baseline to 100 €/tCO_2 in S1 and to 440 €/tCO_2 in S2, resulting in a substitution of more carbon-intensive technologies by less carbon-intensive, but more expensive technologies (excluding carbon costs).[14]
- In S3 (CO_2 and RES-E), the average LCOE excluding carbon costs and RES-E subsidies increases to 74 €/MWh in 2030, but this time the shift towards more expensive (RES-E) technologies results

[14] Note, however, that the increase in the average LCOE may be mitigated to some extent by a counter-effect. Due to the increase in the ETS carbon costs, the electricity price increases and, consequently, the demand for electricity decreases. As a result, market equilibrium is obtained at a lower point of the power production merit order and, hence, the increase in the average LCOE, excluding carbon costs, is mitigated.

predominantly from the implementation of the RES-E support instrument as the increase in the ETS carbon price is relatively modest (and even smaller than in S1).

- Total carbon costs vary from € 30 billion in the baseline to almost € 130 billion in S2, i.e. on average 8 €/MWh and 40 €/MWh, respectively. Total RES-E subsidies show an opposite pattern. They range from € 0.5 billion in S2 to € 59 billion in S3, i.e. on average 0.16 €/MWh and €/MWh, respectively.[15]
- From a private generator perspective, the increase in the average LCOE due to including the carbon costs is lowest (8 €/MWh) in the baseline (with an ETS carbon price of 33 €/tCO_2) and highest (40 €/MWh) in S2 (with a carbon price of 440 €/tCO_2).
- Similarly, the decrease in the average LCOE due to including the average RES-E support per MWh is lowest (0-2 €/MWh) in the baseline and policy scenarios 1 and 2 (which include RES-E support policies introduced before April 2009) and highest (7.2 €/MWh) in S3 (where RES-E support levels are substantially increased to reach the 40% RES-E target by 2030).
- From the perspective of the private generator, total LCOE including carbon costs and RES-E subsidies vary from € 255 billion in S3 to € 364 billion in S2, i.e. on average 75 €/MWh and 114 €/MWh, respectively.
- Across all scenarios, total/average LCOE excluding carbon costs and RES-E subsidies are among the highest in S3 (CO_2 and RES-E). From a private generator perspective, however, they become lowest in this scenario when including both carbon costs and RES-E subsidies.

5.2.2 Electricity price for industrial end-users

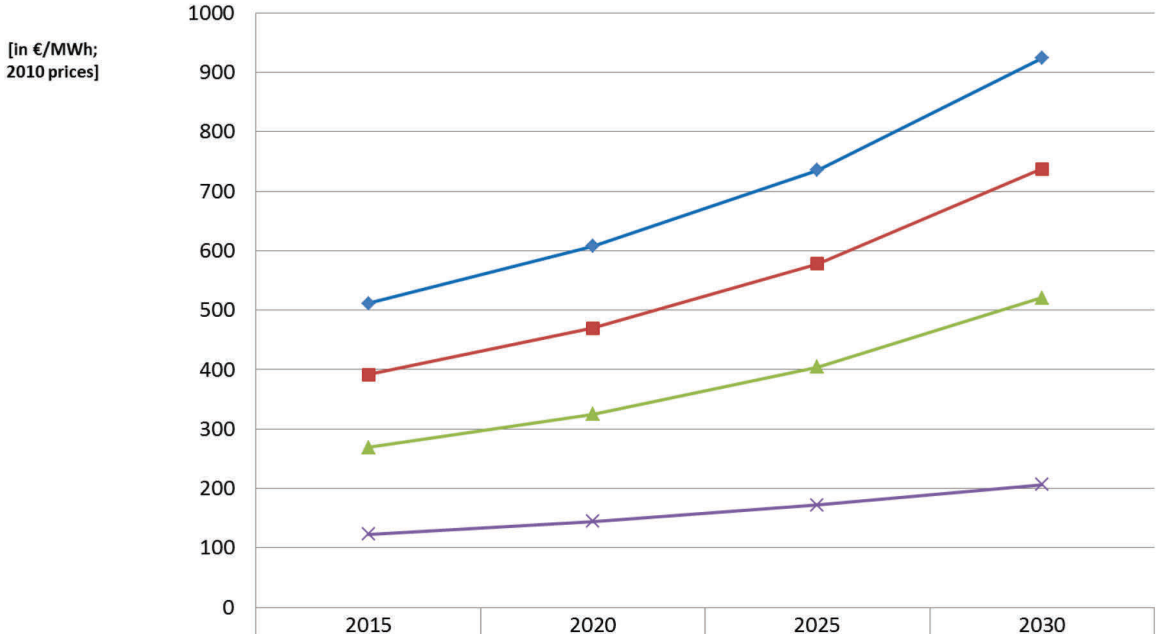
Figure 8 presents the evolution of the average EU27 electricity price for industrial end-users over the period 2015-2030.[16] This price is based on the average levelised cost of generating electricity (LCOE), including investment costs, fuel costs and other operational costs, as well as on the average power transmission and distribution costs and the average tax level, including a surcharge to cover the costs of the RES-E feed-in subsidies. Therefore, the electricity price for industrial end-users – as well as the similar, but higher electricity price for households – includes the cost effects of the policies implemented under scenarios 1 up to 3.

Figure 8 shows that the electricity price for industrial end-users is lowest in the baseline, increasing gradually (in real 2010 prices) from 120 €/MWh in 2015 to 186 €/MWh in 2030. On the other hand, due to the pass-through of the carbon costs, the electricity price for industrial consumers is highest in S2, rising steadily from 146 €/MWh in 2015 to 314 €/MWh in 2030. In scenarios 1 and 3 , the industrial power price takes an intermediate position, i.e. between the baseline and S2.

[15] Note that the average figures are expressed in terms of total power generation, including production from both RES and non-RES. As, for instance, the share of RES-E in total generation is 40% in scenarios 2 and 3, the data for average RES-E subsidies in Table 3 have to be multiplied by a factor 2.5 to get the average RES-E subsidies per MWh of RES-E generated (see Table 1).

[16] A similar picture – showing similar trends and differences across the scenarios – can be shown for the evolution of the average EU27 electricity price for households. Although the electricity price for households is based on similar cost components as for industrial end-users (see main text), the average electricity price is about 50% higher for households than for industrial end-users due to higher transmission/distribution tariffs and higher tax rates per MWh for households.

Figure 8: EU27 electricity price for industrial end-users, including tax, 2015-2030



	2015	2020	2025	2030
S0 (Baseline)	120	138	157	186
S1 (CO2/ETS only)	123	144	174	217
S2 (CO2+RES/ETS only)	146	180	232	314
S3 (CO2+RES/policy mix)	123	145	172	206

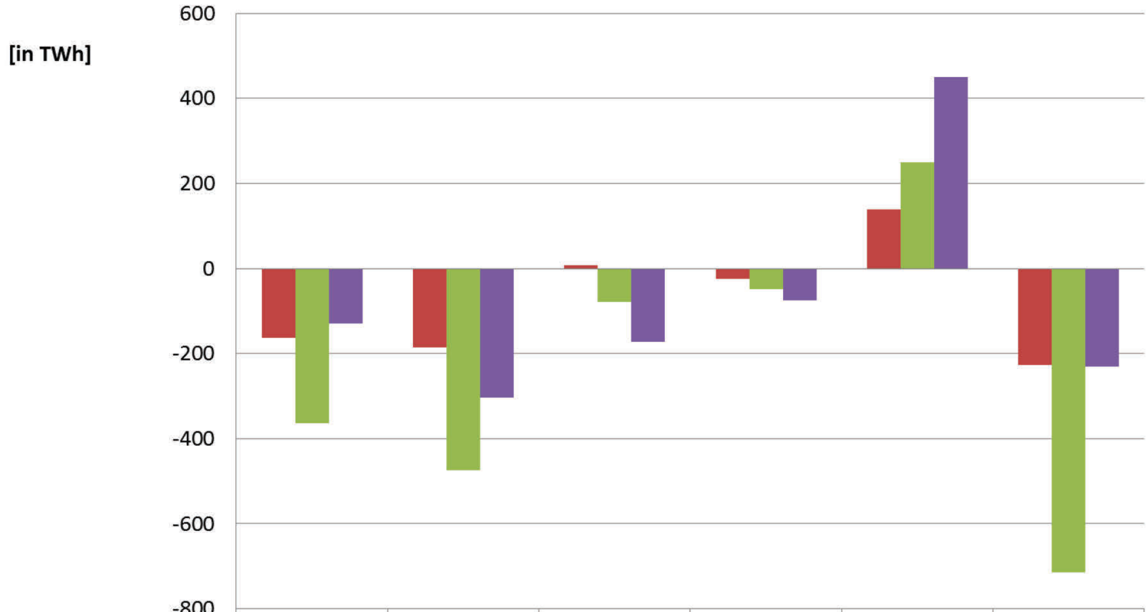
5.2.3 Changes in mix of power generation technologies

Figure 9 presents an overview of the major changes in the EU power generation mix by 2030 in the three policy scenarios (in absolute differences, i.e. in changes of TWh output, compared to the baseline). In each scenario, power generated from coal and gas (CCGT) is substantially reduced. For instance, in S2 – with an ETS carbon price of 440 €/tCO_2 – power from coal is reduced by more than 360 TWh, i.e. -81% compared to the baseline, while gas-fuelled generation decreases by more than 470 TWh (-53% compared to the baseline). The reduction in power from coal and gas, however, is much smaller in S3 where the CO_2 price is much lower than in S2 and where the 40% RES-E target is predominantly achieved by an additional RES-E instrument rather than by the ETS only. For instance, in S3 power from coal is reduced by some 130 TWh (-29%) while gas-fuelled generation decreases by 304 TWh (-34%).

Compared to the baseline, nuclear output declines in all policy scenarios, except S1 (Figure 9). This is due to the accumulation of two effects mentioned above, i.e. (i) the decline in total power demand in the policy scenarios (due to the policy-induced higher end-user electricity prices), and (ii) the increase in RES-E output in the policy scenarios. As a result, the need for non-RES-E output – including nuclear – declines substantially in all policy scenarios.

Note that the decline in nuclear output is lower in S2 than in S3, despite the higher decline in total power demand in S2. This is due to the fact that in S2 nuclear improves its competitive position compared to coal/gas resulting from the high ETS carbon price of this scenario (and, hence, the reduced need for non-RES-E output is largely met by reducing coal/gas-fired generation), whereas the RES-E support in S3 does not affect the competitive position of nuclear versus coal/gas (while the positive impact of the ETS carbon price on nuclear is much lower in S3). In S1, the positive impact of the ETS carbon price on nuclear is even larger than the cumulative, negative effects of the decline in total power demand and the increase in total RES-E supply, resulting in a small increase (7 TWh) of nuclear output in S1.

Figure 9: EU power generation by major technologies, 2030 (in absolute differences from the baseline)



	Coal	Gas (CCGT)	Nuclear	Other non-RES	RES-E	Total
S1 ($CO2$/ETS only)	-163	-186	7	-23	138	-227
S2 ($CO2$+RES/ETS only)	-363	-475	-78	-48	249	-715
S3 ($CO2$+RES/policy mix)	-130	-304	-172	-75	450	-231

On the other hand, for each policy scenario – but particularly for S3 - Figure 9 shows a significant increase in power from RES-E technologies such as wind, biomass and hydro. More specifically, RES-E output increases by almost 140 TWh (i.e. +13%) in S1, compared to the baseline, and by some 450 TWh in S3 (i.e. +44%).

On balance, total electricity output declines in all policy scenarios, compared to the baseline, varying from -230 TWh in S1 and S3 (-6%) to -720 TWh in S2 (-18%).

As noted, the 40% RES-E target by 2030 is achieved in both scenarios 2 and 3, although in different ways:

- In *Scenario 2*, the RES-E target is achieved by means of the ETS only, i.e. by lowering the cap and, hence, raising the ETS carbon price (up to 440 €/tCO_2, compared to 33 €/tCO_2 in the baseline). As the carbon costs are passed through to end-users' electricity prices, this results in a significant decline of final electricity use (about 20%, compared to the baseline). Therefore, the increase in the RES-E share from 26% in the baseline to 40% in S2 is for a substantial part (almost half) achieved by reducing total electricity use (the denominator of the equation) and for the remaining part by increasing RES-E production (the numerator). As the increase in carbon costs on fossil-fuelled generation – and the resulting increase in electricity prices – acts as a general, uniform incentive improving the competitiveness of all RES-E technologies, only the less expensive, (nearly) market competitive RES-E technologies – such as onshore wind, biomass or hydro – benefit from this incentive.
- In *Scenario 3*, the 40% RES-E target is obtained primarily by a feed-in subsidy, per MWh generated, which is uniform for all RES-E technologies regardless their pre-support cost level, and

– to a lesser extent – by the ETS carbon price (i.e. 52 €/tCO_2 by 2030, which is slightly higher than in the baseline but substantially lower than in S2). Although the costs of the feed-in support are passed through to end-users' electricity prices (through a surcharge), in S3 these prices increase much less than in S2 and, hence, final electricity use is reduced much less. Hence, the total amount of RES-E production has to be increased much more in order to achieve the 40% RES-E target. Similar to the ETS carbon price, the uniform RES-E subsidy also acts as a general, uniform incentive improving the competitiveness of all RES-E technologies in a uniform way. Therefore, also in S3, only the less expensive, (nearly) market competitive RES-E technologies benefit from the policy-induced incentives of this scenario (both RES-E and ETS).

Overall, the shares of coal and gas (CCGT) in the total EU generation mix decline in all policy scenarios, but particularly in S2 (due to the high ETS carbon price in this scenario). For instance, the share of coal declines to less than 3% in S2, compared to more than 11% in the baseline, while the share of gas (CCGT) decreases from 23% in the baseline to 13% in S2.

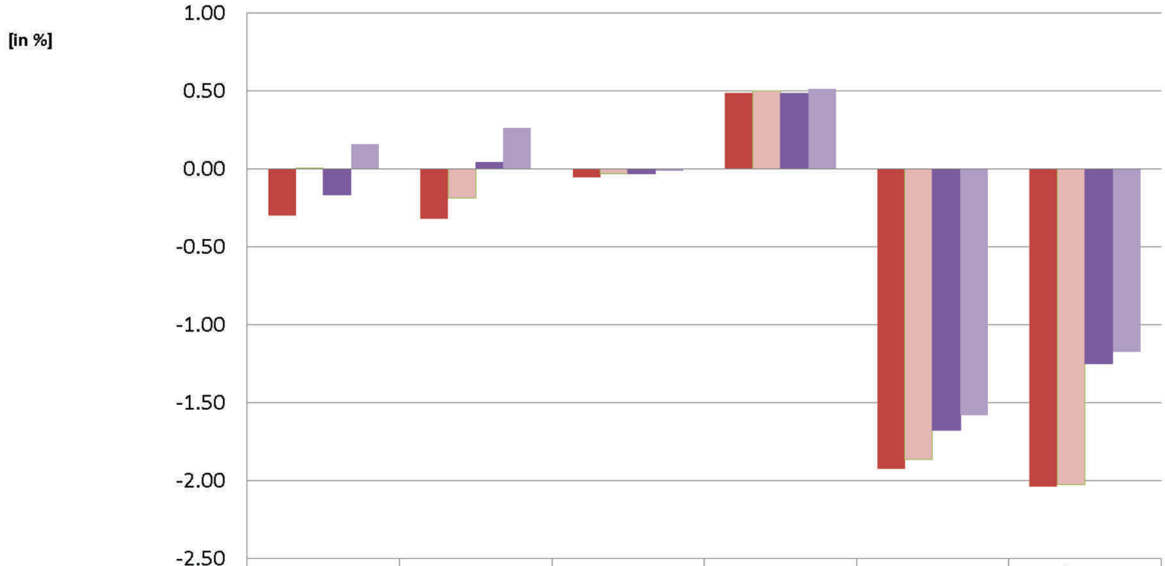
The share of nuclear increases in S1 and S2, i.e. from 34% in the baseline to 36% in S1 and even to 39% in S2. In these two policy scenarios, all low-carbon technologies – including nuclear – benefit from the increase in the ETS carbon price, while total electricity use declines. Yet, in scenario S2 the fuel switch from fossil to nuclear fuels is overcompensated by the overall reduction in electricity use, such that nuclear generation declines in absolute terms. In scenario S3 the share of nuclear decreases to 31%. In this policy scenario, only RES-E technologies benefit from the increase in RES-E support, while total electricity use declines also in this scenario.

5.3 Sensitivity analyses

One of the major assumptions of the policy scenarios discussed above concerns the recycling of ETS auction revenues (see Section 4.1) . More specifically, it is assumed that these revenues are recycled through lump-sum allocations to households, which increase their wealth rather than their direct consumption level. In order to assess the sensitivity of the model outcomes to this assumption, we have analysed the implications of an alternative assumption for two scenarios (S1 and S3), i.e. we have assumed that half of the EUA auction revenues is recycled to households through lump-sum allocations (increasing their wealth), and the other half through lowering their direct income taxes (increasing their net income and consumer spending).

The results of the sensitivity analyses are presented in Figure 10 in terms of some major macro-economic outcomes, where the labels S1 and S3 refer to the original scenarios 1 and 3, based on the original assumption with regard to the recycling of ETS auction revenues, and the labels S1a and S3a to the corresponding, alternative scenarios 1a and 3a, based on the alternative assumption regarding revenue recycling.

Figure 10: Sensitivity analysis of some macro-economic outcomes, 2030 (in % difference from the baseline)



	GDP	Investment	Employment	Consumer prices	EU imports of fossil fuels	EU domestic supply of fossil fuels
S1 (CO2/ETS only)	-0.30	-0.32	-0.06	0.48	-1.92	-2.04
S1a (CO2/ETS only)	0.00	-0.19	-0.03	0.50	-1.87	-2.03
S3 (CO2+RES/policy mix)	-0.17	0.04	-0.03	0.48	-1.68	-1.25
S3a (CO2+RES/policy mix)	0.16	0.26	-0.01	0.51	-1.58	-1.18

Figure 10 shows that the differences in macro-economic outcomes between the original and the corresponding, alternative scenarios are usually rather small.[17] In general, the outcomes are generally slightly more favourable – i.e. less negative or more positive – for the alternative scenarios in terms of GDP, investment and employment, while being less favourable in terms of consumer prices, EU imports of fossil fuels and EU domestic supply (use) of fossil fuels.[18] This difference in outcomes can be explained by the difference in the assumption regarding the recycling of ETS auction revenues, where the alternative assumption leads to a lowering of direct income (from labour) taxes and an increase in consumer spending, which on the one hand stimulates GDP, investment and employment, but on the other hand enhances inflation as well as EU imports and EU use – including domestic supply – of fossil fuels.

A major finding of Figure 10 is that the change in the model assumption on recycling ETS auction revenues does not change the relative ranking of the scenarios in terms of the indicated macro-economic outcomes. For instance, the performance of S3 and S3a is better compared to S1 and S1a, respectively, in terms of GDP and investment, while being worse in terms of EU imports of fossil fuels.

6 Discussion

Based on the results presented before, we now aim to discuss two questions with respect to the proposed EU climate and energy policy package up to 2030: (1) Does our model simulation suggest implementing an additional RES target, or should the EU rather stick to a single GHG target? (2) If the

[17] For the other model results discussed in the previous sections, the differences in outcomes between the original and alternative scenarios are generally even smaller or even (nearly) absent.
[18] In one case, i.e. GDP in S3 versus S3a, the modeling outcomes even show opposite signs, i.e. GDP in 2030 declines by 0.17% in S3, compared to the baseline, whereas it increases by 0.16% in S3a (Figure 10).

RES target is set, should it be addressed by an additional RES policy (i.e. a policy mix) or rather by the EU ETS alone according to the model results? To answer these questions, we compare the performance of scenarios S2 (GHG+RES/ETS only) and S3 (GHG+RES/policy mix) in parallel to S1 (GHG/ETS only). We shed light on monetized benefits and costs as indicated by our model. In addition, we address non-monetized results provided by our modelling exercise which can be interpreted as additional benefits or costs. Table 4 provides an overview of the scenario comparison.

Table 4: Performance of policy scenarios S2 (GHG+RES/ETS only) and S3 (GHG+RES/policy mix) compared to S1 (GHG/ETS only)

	Impact variables		S2 (GHG+RES/ ETS only)	S3 (GHG+RES/ policy mix)
Monetized effects	Increasing GDP		–	+
	Increasing investment		–	+
	Controlling consumer prices		–	0
	Controlling total LCOE incl. carbon costs and subsidies		–	+
Non-monetized effects	Mitigating climate change	Reducing ETS-GHG emissions	+	0
	Mitigating other environmental externalities	Reducing nuclear generation	+	++
		Reducing coal combustion	+	–
		Reducing oil/gas combustion	++	+
		Reducing domestic coal production	0	0
		Reducing domestic oil/gas production	+	–
	Mitigating security of supply externalities	Reducing coal imports	+	0
		Reducing oil/gas imports	+	–
	Promoting employment		–	+

Legend:

++ strong positive impact (in case both policy scenarios produce positive impacts)
\+ positive impact
0 no impact
– negative impact

6.1 Is an additional RES target economically reasonable?

Table 4 illustrates that neither of the two scenarios incorporating a RES target in addition to a GHG target is strictly superior or inferior to a scenario with a GHG target only. Thus, our model results neither affirm nor deny unambiguously that an additional RES target is economically reasonable. The eventual decision needs to be taken by a multi-criteria assessment aggregating the diverse positive and negative impacts. Particularly for the non-monetized effects, this would require attaching values to impacts, which is beyond the scope of our study. Moreover, such analysis is by nature subjective and therefore always dependent on the preferences of the decision-maker. Our results also show that the impacts of an additional RES target crucially hinge on the policy instrument chosen to attain this target because the diverse benefits and costs are distributed unequally across the *GHG+RES/ETS only* (S2) scenario and the *GHG+RES/policy mix* (S3) scenario. We outline this comparison in detail in the next section.

These restrictions notwithstanding, our analysis also clearly indicates that an additional RES target cannot be rejected a priori as welfare-decreasing if it is meant to address multiple market and policy failures (beyond GHG externalities). Notably, none of the monetized and non-monetized impacts summarized in Table 4 is strictly negative for both policy scenarios including an additional RES target. Moreover, some general statements, which appear to be robust across our policy scenarios, can be made with respect to selected impacts.

First, implementing an additional RES target produces only minor macro-economic impacts (in terms of changes in GDP, investment and employment), and these may be even positive. This is in contrast to existing CGE studies which strictly predict macro-economic excess costs in such settings, even though sometimes also only to a modest extent (Bernard and Vielle, 2009; Boeters and Koornneef, 2011; Böhringer et al., 2009a; Kretschmer et al., 2009). This difference can be explained by the basic assumptions of our model: Policy interventions (no matter whether by EU ETS or RES-E subsidies) may stimulate the use of unemployed resources in the economy, and may thereby lead to increases in GDP, investment and employment. However, as changes in employment are generally small with an additional RES target, our model does not confirm a strong green jobs hypothesis.

Second, there are some impacts which are positive in both the *GHG+RES/ETS only* (S2) and the *GHG+RES/policy mix* (S3) scenario, compared to the *GHG/ETS only* (S1) scenario. First, nuclear generation is reduced in either case. Thus, our results suggest that implementing a RES target may mitigate nuclear risks no matter by what type of instrument the target is actually attained. Similar benefits of additional RES policies have also been shown in other studies (Jägemann et al., 2013; Möst and Fichtner, 2010). Likewise, oil- and gas-fuelled electricity generation – and thus presumably also the externalities associated with the combustion of these fuels, such as air pollution, – are reduced across the board.

6.2 Should an additional RES target be addressed by an additional RES instrument?

Attaining the RES target by the ETS only, instead of a separate RES-E subsidy, clearly impairs welfare in terms of the monetized macro-economic impacts computed by our model. As has been pointed out above, both the EU ETS and the RES-E subsidy may lead to economic growth in our model compared to the reference scenarios because they may stimulate the use of unemployed resources. However, this benefit is overcompensated in the *GHG+RES/ETS only* (S2) scenario by the depressing effect which excessively increasing carbon and power prices have on output, investment and employment. The high carbon price also implies that this scenario performs worse than the *GHG+RES/policy mix* scenario in terms of power sector costs expressed by LCOE.

The policy scenario comparison yields ambiguous results when the non-monetized impacts are considered. On the one hand, the *GHG+RES/policy mix* (S3) scenario brings about a stronger reduction in nuclear generation, and thus of nuclear risks. This is because a technology-specific policy such as a RES-subsidy is more effective in crowding out nuclear than a technology-neutral emissions policy, which favours emission-free nuclear just as RES-E technologies. On the other hand, the *GHG+RES/ETS only* (S2) scenario brings about a significant additional reduction in GHG emissions. Moreover, tightening the ETS cap to attain the RES target is more effective in reducing the production, import and use of fossil fuels. Thus, if the eventual intuition behind the RES target is to mitigate environmental and energy security externalities produced by fossil-fuelled generation, a reduction of the EU ETS cap may generate more benefits than a corresponding RES subsidy. Thus, our study cannot reject the finding made in the European Commission's (2014) assessment that an additional RES target addressed by a supplementary RES-E subsidy may actually reduce pollution control and health benefits. In our model, this observation can be explained by the fact that supplementing the EU ETS by a RES subsidy reduces the carbon price. This results in a relative advantage of coal over gas. As a consequence, coal-fired generation is even higher in the *GHG+RES/policy mix* (S3) scenario than in both the *GHG/ETS only* (S1) and the *GHG+RES/ETS only*

(S2) scenario. This finding confirms the "green-serves-the-dirtiest" hypothesis by Böhringer and Rosendahl (2010). Moreover, a reduced carbon price allows increasing emissions and fossil fuel use of ETS participants outside the electricity sector as well as (mediated via commodity prices) in the non-ETS sectors. This clarifies why imports of coal, gas and oil are higher in the *GHG+RES/policy mix* (S3) scenario, and the RES-E subsidy does not reduce import dependencies.

These explanations reveal that when choosing a policy instrument to attain a RES target, decision-makers face a trade-off between addressing non-monetary benefits more effectively and controlling macro-economic and power sector costs. This trade-off also has important politico-economic implications. Under the *GHG+RES/ETS only* (S2) scenario, carbon prices would rocket to €440 per tonne of CO_2 in 2030, compared to €50 per tonne under the *GHG+RES/policy mix* (S3) scenario. Similarly, electricity prices for industrial end-users would increase by 50%. The *GHG+RES/ETS only* (S2) scenario would therefore significantly impair the rents of industrial interest groups with a strong political weight. This makes the *GHG+RES/ETS only* (S2) scenario a policy option which most likely is not politically feasible – despite its potential benefits pointed out above. Against this background, the policy mix approach may then be the only feasible approach to realize at least some of the welfare gains beyond climate change mitigation. Eventually, the RES policy then also helps to enforce the attainment of more ambitious GHG target politically, as has been pointed out analytically by Gawel et al. (2014).

7 Conclusion

The European Council has proposed to stick to a more ambitious GHG target but to scrap a binding RES target for the post-2020 period. This is in line with many existing assessments which demonstrate that additional RES policies impair the cost-effectiveness of climate policies, and should therefore be abolished. Our analysis shows that this reasoning may be flawed for a variety of reasons. First and most importantly, we argue that attaining a RES target may produce benefits beyond climate change mitigation if a second-best setting with multiple externalities related to fossil and nuclear power generation and policy restrictions and imperfections is assumed. In this context, a RES policy may help to address externalities for which first-best policy responses are not available. These economically relevant benefits have been typically neglected in economic studies so far. Our quantitative analysis confirms that pursuing an ambitious RES target may mitigate nuclear risks and at least partly also negative non-carbon externalities associated with the production, import and use of fossil fuels. In addition, we demonstrate that an additional RES target does not necessarily impair GDP and other macro-economic measures if rigid assumptions of purely rational behaviour of market participants and perfect market clearing are relaxed. This balance may turn even more positive in the long run beyond 2030 if RES-E costs are continuing to decline. Overall, our analysis thus demonstrates that RES policies implemented in additional to GHG policies are not per se welfare decreasing. To the contrary, there are plausible settings in which an additional RES policy may outperform a single GHG/ETS strategy.

Our study also reveals that simplistic policy heuristics may not be helpful if multiple externalities are to be addressed and policy choices are constrained. Neither a single EU ETS approach nor a policy mix is by definition the best regulatory approach to promote sustainability in the energy sector. The eventual decision on whether complementing a GHG policy by a RES policy makes sense can only be taken after a careful investigation of the diverse benefits and costs pointed out in our paper.

Certainly, our analysis fails to assess the cost-benefit ratio of implementing an additional RES policy in an unambiguous and quantitative manner. Yet, the same limitation would apply to studies pointing out the cost-effectiveness of a stand-alone ETS if these considered all impacts that are economically relevant in a second-best setting. Thus, arguments to stick to a single ETS until the economic superiority of a policy mix strategy is proven cannot be convincing. Due to the fact that (i) policies may have a multiplicity of impacts, (ii) the size of these impacts is subject to uncertainties, and (iii) their valuation is contingent on individual preferences, an unambiguous, "objective" economic assessment is impossible. Thus, the eventual decision on the optimal choice and design of climate and energy policies can only be taken politically.

References

Alanne, K., Saari, A., 2006. Distributed energy generation and sustainable development. Renewable and Sustainable Energy Reviews 10, 539-558.

Anger, N., Böhringer, C., Oberndorfer, U., 2008. Public Interest vs. Interest Groups: Allowance Allocation in the EU Emissions Trading Scheme, Discussion Paper. Zentrum fuer Europaeische Wirtschaftsforschung (ZEW), Mannheim.

Argote, L., Epple, D., 1990. Learning curves in manufacturing. Science 247, 920-924.

Aune, R., Dalen, H.M., Hagem, C., 2012. Implementing the EU renewable target through green certificate markets. Energy Economics 34, 992-1000.

Barker, T., Anger, A., Chewpreecha, U., Pollitt, H., 2012. A new economics approach to modelling policies to achieve global 2020 targets for climate stabilisation. International Review of Applied Economics 26, 205-221.

Barker, T., Foxon, T.J., Scrieciu, S., 2008. Achieving the G8 50% target: modelling induced and accelerated technological change using the macro-econometric model E3MG. Climate Policy 8, S30-S45.

Barker, T., Pan, H., Köhler, J., Warren, R., Winne, S., 2005. Avoiding dangerous climate change by inducing technological progress: scenarios using a large-scale econometric model, in: Schellnhuber, H., Cramer, W., Nakicenovic, N., Wigley, T., Yohe, G.W. (Eds.), Avoiding Dangerous Climate Change. Cambridge University Press, Cambridge, UK.

Barker, T., Pan, H., Köhler, J., Warren, R., Winne, S., 2006. Decarbonizing the Global Economy with Induced Technological Change: Scenarios to 2100 using E3MG. Energy Journal Special Issue, 143-160.

Barker, T., Scrieciu, S., 2009. Unilateral climate change mitigation, carbon leakage and competitiveness: an application to the European Union. International Journal of Global Warming 1, 405-417.

Bennear, L.S., Stavins, R.N., 2007. Second-Best Theory and the Use of Multiple Policy Instruments. Environmental and Resource Economics 37, 111-129.

Bernard, A., Vielle, M., 2009. Assessment of European Union transition scenarios with a special focus on the issue of carbon leakage. Energy Economics 31, S274-S284.

Bjørner, T.B., Mackenhauer, J., 2013. Spillover from private energy research. Resource and Energy Economics 35, 171-190.

Bläsi, A., Requate, T., 2007. Subsidies for Wind Power: Surfing down the Learning Curve?, CAU Economic Working Paper. Christian-Albrechts-Universität Kiel, Kiel.

Bläsi, A., Requate, T., 2010. Feed-in-Tariffs for Electricity from Renewable Energy Resources to Move Down the Learning Curve? Public Finance and Management 10.

Boeters, S., Koornneef, J., 2011. Supply of Renewable Energy Sources and the Cost of EU Climate Policy. Energy Economics 33, 1024-1034.

Bohi, D.R., Toman, M.A., 1996. Economics of Energy Security. Kluwer, Norwell, MA.

Böhringer, C., Löschel, A., Moslener, U., Rutherford, T.F., 2009a. EU climate policy up to 2020: An economic impact assessment. Energy Economics 31, S295-S305.

Böhringer, C., Rosendahl, K.E., 2010. Green Promotes the Dirtiest: On the Interaction between Black and Green Quotas in Energy Markets. Journal of Regulatory Economics 37, 316-325.

Böhringer, C., Rosendahl, K.E., 2011. Greening Electricity More Than Necessary: On the Cost Implications of Overlapping Regulation in EU Climate Policy. Schmollers Jahrbuch 131, 469-492.

Böhringer, C., Rutherford, T.F., Tol, R.S.J., 2009b. The EU 20/20/2020 targets: An overview of the EMF22 assessment. Energy Economics 31, 268-273.

Borenstein, S., 2012. The Private and Public Economics of Renewable Electricity Generation. Journal of Economic Perspectives 26, 67-92.

Bosetti, V., Gerlagh, R., Schleicher, S., 2009. Modelling Sustainable Development: Transitions to a Sustainable Future. Edward Elgar, Cheltenham.

Braun, F.G., Schmidt-Ehmcke, J., Zloczysti, P., 2010. Innovative Activity in Wind and Solar Technology: Empirical Evidence on Knowledge Spillovers Using Patent Data, Discussion Paper. Deutsches Institut für Wirtschaftsforschung (DIW), Berlin.

Cambridge Econometrics, 2014. E3ME Technical Manual, Version 6.0. Cambridge Econometrics, Cambridge, UK.

Canton, J., Johannesson Lindén, A., 2010. Support schemes for renewable electricity in the EU, Economic Papers. European Commission, Brussels.

Capros, P., Mantzos, L., Papandreou, V., Tasios, N., 2008. Model-based Analysis of the 2008 EU Policy Package on Climate Change and Renewables. Report to the European Commission - DG ENV.

Capros, P., Mantzos, L., Parousos, L., Tasios, N., Klaassen, G., van Ierland, T., 2011. Analysis o fthe EU policy package on climate change and renewables. Energy Policy 39, 1476-1485.

Creutzig, F., Goldschmidt, J.C., Lehmann, P., Schmid, E., von Blücher, F., Breyer, C., Fernandez, B., Jakob, M., Knopf, B., Lohrey, S., Susca, T., Wiegandt, K., 2013. Catching two European birds with one renewable stone: Mitigating climate change and Eurozone crisis by an energy transition Working Paper prepared for the 2013 Dahrendorf Symposium, Berlin.

Dagoumas, A., Barker, T., 2010. Pathways to a low-carbon economy for the UK with the macro-econometric E3MG model. Energy Policy 38, 3067-3077.

Dechezlepretre, A., Martin, R., Mohnen, M., 2013. Knowledge spillovers from clean and dirty technologies: A patent citation analysis, Discussion Paper, downloadable at http://www.diw.de/documents/dokumentenarchiv/17/diw_01.c.434965.de/martin_ams_jan2014.pdf.

Demsetz, H., 1969. Information and Efficiency: Another Viewpoint. Journal of Law and Economics 12, 1-22.

Edenhofer, O., Hirth, L., Knopf, B., Pahle, M., Schlömer, S., Schmid, E., Ueckerdt, F., 2013a. On the economics of renewable energy sources. Energy Economics 40, S12-S23.

Edenhofer, O., Knopf, B., Luderer, G., 2013b. Reaping the benefits of renewables in a nonoptimal world. Proceedings of the National Academy of Sciences 110, 11666-11667.

Edenhofer, O., Seyboth, K., Creutzig, F., Schlömer, S., 2013c. On the Sustainability of Renewable Energy Sources. Annual Review of Environment and Resources 38, 16.11-16.32.

Ellis, J., 2010. The Effects of Fossil-Fuel Subsidy Reform: A review of modelling and empirical studies, Untold billions: fossil-fuel subsidies, their impacts and the path to reform. International Institute for Sustainable Development (IISD), Winnipeg.

Engle, R., Granger, C., 1987. Cointegration and error correction: representation, estimation and testing. Econometrica 55, 251-276.

Epstein, P.R., Buonocore, J., J., Eckerle, K., Hendryx, M., Stout, B.M.I., Heinberg, R., Clapp, R.W., May, B., Reinhart, N.L., Ahern, M.M., Doshi, S.K., Glustrom, L., 2011. Full cost accounting for the life cycle of coal. Annals of the New York Academy of Sciences 1219, 73-98.

European Commission, 2008. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: 20 20 by 2020 - Europe's climate change opportunity.

European Commission, 2009. Directive 2009/29/EC, amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community. European Commission, Brussels.

European Commission, 2010a. Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage, COM(2010) 265 final. European Commission, Brussels.

European Commission, 2010b. EU energy trends to 2030 – Update 2009. European Commission, Brussels.

European Commission, 2011a. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Energy Roadmap 2050. European Commission, Brussels.

European Commission, 2011b. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions:A Roadmap for moving to a competitive low carbon economy in 2050. European Commission, Brussels.

European Commission, 2012. The 2012 Ageing Report – Economic and budgetary projections for the 27 EU Member States (2010-2060). European Commission, Brussels.

European Commission, 2013a. EU energy, transport and GHG emissions – Trends to 2050 – Reference scenario 2013. European Commission, Brussels.

European Commission, 2013b. Green Paper: A 2030 framework for climate and energy policies. European Commission, Brussels.

European Commission, 2014. Commission Staff Working Document: Impact Assessment accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "A policy framework for climate and energy in the period from 2020 up to 2030". European Commission, Brussels.

European Communities, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, World Bank, 2009. System of National Accounts 2008, New York.

European Council, 2014. European Council (23 and 24 October 2014) – Conclusions. EUCO 169/14. European Council, Brussels.

EWI, IE, RWI, 2004. Gesamtwirtschaftliche, sektorale und ökologische Auswirkungen des Erneuerbare Energien Gesetzes (EEG) - Gutachten im Auftrag des Bundesministeriums für Wirtschaft und Arbeit

(BMWA). Energiewirtschaftliches Institut an der Universität zu Köln (EWI), Institut für Energetik & Umwelt gGmbH (IE), Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI), Köln, Leipzig, Essen.
Fischer, C., 2008. Emissions Pricing, Spillovers, and Public Investment in Environmentally Friendly Technologies. Energy Economics 30, 487-502.
Fischer, C., Newell, R.G., 2008. Environmental and Technology Policies for Climate Change Mitigation. Journal of Environmental Economics and Management 55, 142-162.
Frondel, M., Ritter, N., Schmidt, C.M., 2008. Germany's solar cell promotion: Dark clouds on the horizon. Energy Policy 36, 4198-4204.
Frondel, M., Ritter, N., Schmidt, C.M., Vance, C., 2010. Economic impacts from the promotion of renewable energy technologies: The German experience. Energy Policy 38, 4048-4056.
Garrone, P., Piscitello, L., Wang, Y., 2010. Innovation Dynamics in the Renewable Energy Sector: The Role of Cross-Country Spillovers, USAEE Working Paper.
Gawel, E., Strunz, S., Lehmann, P., 2014. A public choice view on the climate and energy policy mix in the EU — How do the emissions trading scheme and support for renewable energies interact? Energy Policy 64, 175-182.
Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy 31, 1257-1274.
Gillingham, K., Sweeney, J.L., 2010. Market Failure and the Structure of Externalities, in: Moselle, B., Schmalensee, R., Padilla, A.J. (Eds.), Harnessing Renewable Energy in Electric Power Systems: Theory, Practice, Policy. Johns Hopkins University Press, Washington, D.C.
Goldthau, A., Sovacool, B.K., 2012. The uniqueness of the energy security, justice, and governance problem. Energy Policy 41, 232-240.
Grübler, A., Nakicenovic, N., Victor, D.G., 1999. Dynamics of energy technologies and global change. Energy Policy 27, 247-280.
Hansen, J.D., Jensen, C., Madsen, E.S., 2003. The establishment of the Danish windmill industry - was it worthwhile? Review of World Economics 139, 324-347.
Hendry, D., Pagan, A., Sargan, J., 1984. Dynamic specification, in: Griliches, Z., Intriligator, M.D. (Eds.), Handbook of Econometrics, Volume II. North Holland, Amsterdam.
Hertel, T., 1999. Global Trade Analysis: Modeling and Applications. Cambridge University Press, Cambridge, UK.
Heyes, A., Heyes, C., 2000. An empirical analysis of the nuclear liability act (1970) in Canada. Resource and Energy Economics 22, 91-101.
Hillebrand, B., Buttermann, H.G., Behringer, J.M., Bleuel, M., 2006. The expansion of renewable energies and employment effects in Germany. Energy Policy 34, 3484-3494.
IEA, 2000. Experience Curves for Technology Policy. International Energy Agency (IEA), Paris.
IEA, 2010. World Energy Outlook. International Energy Agency (IEA), Paris.
IEA, 2012. World Energy Outlook. international Energy Agency (IEA), Paris.
IEA/OPEC/OECD/World Bank, 2010. Analysis of the scope of energy subsidies and suggestions for the G-20 initiative. International Energy Agency (IEA), Organization for Petroleum Exporting Countries (OPEC), Organisation for Economic Co-operation and Development (OECD), World Bank, Toronto.
IPCC, 2011. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, UK and New York, USA.
IPCC, 2014. Summary for Policymakers, in: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.C. (Eds.), Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA.
Irwin, D.A., Klenow, P.J., 1994. Learning-by-doing spillovers in the semiconductor industry. Journal of Political Economy 102, 1200-1227.
Jaffe, A.B., Newell, R.G., Stavins, R.N., 2005. A Tale of Two Market Failures: Technology and Environmental Policy. Ecological Economics 54, 164-174.
Jägemann, C., Fürsch, M., Hagspiel, S., Nagl, S., 2013. Decarbonizing Europe's power sector by 2050 — Analyzing the economic implications of alternative decarbonization pathways. Energy Economics 40, 622-636.
Jansen, H., Klaassen, G., 2000. Economic Impacts of the 1997 EU Energy Tax: Simulations with Three EU-Wide Models. Environmental and Resource Economics 15, 179-197.

Jensen, S.G., Skytte, K., 2003. Simultaneous attainment of energy goals by means of green certificates and emission permits. Energy Policy 31, 63-71.
Johansson, T.B., Nakicenovic, N., Patwardhan, A., Gomez-Echeverri, L., 2012. Global Energy Assessment. Cambridge University Press, Cambridge, UK and New York, USA.
Junginger, M., Faaij, A., Turkenburg, W., 2005. Global experience curves for wind farms. Energy Policy 33, 133-150.
Kalkuhl, M., Edenhofer, O., Lessmann, K., 2012. Learning or Lock-in: Optimal Technology Policies to Support Mitigation. Resource and Energy Economics 34, 1-23.
Kalkuhl, M., Edenhofer, O., Lessmann, K., 2013. Renewable energy subsidies: Second-best policy or fatal aberration for mitigation? Resource and Energy Economics 35, 217-234.
Kerr, R.A., 2010. Do We Have the Energy For the Next Transition? Science 329, 780-781.
Knopf, B., Chen, Y.-H.H., De Cian, E., Förster, H., Kanudia, A., Karkatsouli, I., Keppo, I., Koljonen, T., Schumacher, K., van Vuuren, D., 2013. Beyond 2020 - Strategies and costs for transforming the European energy system. Climate Change Economics 4, 1340001.
Knopf, B., Geden, O., 2014. A warning from the IPCC: the EU 2030's climate target cannot be based on science alone, Energypost.
Kretschmer, B., Narita, D., Peterson, S., 2009. The economic effects of the EU biofuel target. Energy Economics 31, S285-S294.
Kverndokk, S., Rosendahl, K.E., 2007. Climate policies and learning by doing: Impacts and timing of technology subsidies. Resource and Energy Economics 29, 58-82.
Lee, K., Pesaran, M., Pierse, R., 1990. Aggregation Bias in Labour Demand Equations for the UK Economy, in: Barker, T., Pesaran, M. (Eds.), Disaggregation in Econometric Modelling. Routledge.
Lee, S.C., Pollitt, H., Ueta, K., 2012. A model- based econometric assessment of Japanese environmental tax reform. The Scientific World Journal Article ID 835917.
Lehmann, P., 2012. Justifying a Policy Mix for Pollution Control: A Review of Economic Literature. Journal of Economic Surveys 26, 71-97.
Lehmann, P., 2013. Supplementing an emissions tax by a feed-in tariff for renewable electricity to address learning spillovers. Energy Policy 61, 635-641.
Lehmann, P., Creutzig, F., Ehlers, M.-H., Friedrichsen, N., Heuson, C., Hirth, L., Pietzcker, R., 2012. Carbon Lock-Out: Advancing Renewable Energy Policy in Europe. Energies 5, 323-354.
Lehmann, P., Gawel, E., 2013. Why should support schemes for renewable electricity complement the EU emissions trading scheme? Energy Policy 52, 597-607.
Lehmann, P., Strunz, S., Gawel, E., Korte, K., 2014. EU-Energiepolitik nach dem Jahr 2020 - Vorteile eines Ziel- und Instrumentenmixes. GAIA 23, 60-61.
Lehr, U., Nitsch, J., Kratzat, M., Lutz, C., Edler, D., 2008. Renewable energy and employment in Germany. Energy Policy 36, 108-117.
Lester, R.K., McCabe, M.J., 1993. The effect of industrial structure on learning by doing in nuclear power plant operation. RAND Journal of Economics 115, 418-438.
Markussen, P., Svendsen, G.T., 2005. Industry lobbying and the political economy of GHG trade in the European union. Energy Policy 33, 245-255.
Matthes, F.C., 2010. Greenhouse gas emissions trading and complementary policies. Developing a smart mix for ambitious climate policies. Öko-Institut e.V., Berlin.
McCollum, D.L., Krey, V., Riahi, K., 2011. An integrated approach to energy sustainability. Nature Climate Change 1, 428-429.
Mercure, J.-F., 2012. FTT:Power A global model of the power sector with induced technological change and natural resource depletion. Energy Policy 48, 799-811.
Mercure, J.-F., Salas, P., 2012. An assessment of global energy resource economic potentials. Energy 46, 322-336.
Mercure, J.-F., Salas, P., 2013. On the global economic potentials and marginal costs of non-renewable resources and the price of energy commodities. Energy Policy 63, 469-483.
Mercure, J.-F., Salas, P., Foley, A., Chewpreecha, U., Pollitt, H., Holden, P.B., Edwards, N.R., 2013. The dynamics of technology diffusion and the impacts of climate policy instruments in the decarbonisation of the global electricity sector, Preprint available on ArXiv. Retrieved from http://arxiv.org/abs/1309.7626.
Messner, S., Strubegger, M., 1995. User's Guide for MESSAGE III, Working Paper. International Institute of Applied System Analysis (IIASA), Laxenburg.
Möst, D., Fichtner, W., 2010. Renewable energy sources in European energy supply and interactions with emission trading. Energy Policy 38, 2998-2910.
Neij, L., 1999. Cost dynamics of wind power. Energy 24, 375-389.
Neuhoff, K., 2005. Large-scale deployment of renewables for electricity generation. Oxford Review of Economic Policy 21, 88-110.

O'Sullivan, M., Edler, D., Bickel, P., Lehr, U., Peter, F., Sakowski, F., 2013. Bruttobeschäftigung durch erneuerbare Energien in Deutschland im Jahr 2012 - Eine erste Abschätzung. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Berlin.
Oates, W.E., Portney, P.R., 2003. The Political Economy of Environmental Policy, in: Mäler, K.-G., Vincent, J.R. (Eds.), Handbook of Environmental Economics, pp. 325-354.
OECD, 2011. Inventory of estimated budgetary support and tax expenditures for fossil fuels. Organisation for Economic Cooperation and Development (OECD), Paris.
Olson, M., 1965. The Logic of Collective Action. Harvard University Press, Cambridge, MA.
Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R., D'haeseleer, W., 2005. Distributed generation: definition, benefits and issues. Energy Policy 33, 787-798.
Pethig, R., Wittlich, C., 2009. Interaction of Carbon Reduction and Green Energy Promotion in a Small Fossil-Fuel Importing Economy, CESIfo Working Paper, Munich.
Pollitt, H., Park, S., Lee, S., Ueta, K., 2014. An economic and environmental assessment of future electricity generation mixes in Japan – an assessment using the E3MG macro-economic model. Energy Policy 67, 243-254.
Popp, D., Newell, R.G., 2012. Where does energy R&D come from? examining crowding out from energy R&D. Energy Economics 34, 980-991.
Rivers, N., 2013. Renewable energy and unemployment: A general equilibrium analysis. Resource and Energy Economics 35, 467-485.
Rudolph, S., 2009. How the German Patient Followed the Doctor's Orders: Political Economy Lessons from Implementing Market-Based Instruments in Germany, in: Lye, L.-H., Milne, J.E., Ashiabor, H., Kreiser, L., Deketelaere, K. (Eds.), Critical Issues in Environmental Taxation - International and Comparative Perspectives Volume VII. Oxford University Press, Oxford, pp. 587-606.
Seebregts, A.J., Goldstein, G.A., Smekens, K., 2001. Energy/Environmental Modeling with the MARKAL Family of Models. Operations Research Proceedings 2001/2002, 75-82.
Siler-Evans, K., Azevedo, I.L., Morgan, M.G., Apt, J., 2013. Regional variations in the health, environmental, and climate benefits of wind and solar generation. Proceedings of the National Academy of Sciences 110, 11768-11773.
Skodvin, T., Gullberg, A., Aakre, S., 2010. Target-group influence and political feasibility: the case of climate policy design in Europe. Journal of European Public Policy 17, 854-873.
Stone, R., 1951. Functions and Criteria of a System of Social Accounting. Review of Income and Wealth 1, 1-74.
Tol, R.S.J., 2012. A cost-benefit analysis of the EU 20/20/2020 package. Energy Policy 49, 288-295.
Trend Research/Leuphana, 2013. Definition und Marktanalyse von Bürgerenergie in Deutschland. Trend Research/Leuphana University, Bremen/Lüneburg.
Ulph, A., Ulph, D., 2010. Optimal Climate Change Policies When Governments Cannot Commit, Discussion Paper. Department of Economics, University of St. Andrews, St. Andrews, UK.
Unruh, G.C., 2000. Understanding Carbon Lock-in. Energy Policy 28, 817-830.
Unteutsch, M., Lindenberger, D., 2014. Promotion of Electricity from Renewable Energy in Europe Post 2020—The Economic Benefits of Cooperation. Zeitschrift für Energiewirtschaft 38, 47-64.
van Benthem, A., Gillingham, K., Sweeney, J.L., 2008. Learning-by-Doing and the Optimal Solar Policy in California. The Energy Journal 29, 131-152.
Wei, M., Patadia, S., Kammen, D.M., 2010. Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US? Energy Policy 38, 919-931.
Zimmerman, M.B., 1982. Learning Effects and the Commercialization of New Energy Technologies: The Case of Nuclear Power. The Bell Journal of Economics 13, 297-310.