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Abstract in Dutch

Wat zijn de additionele kosten van een aparte 20% doelstelling voor hernieuwbare energie als deel van het Europese klimaatbeleid voor 2020? In dit paper gebruiken de auteurs het algemeen evenwichtsmodel WorldScan om deze vraag te beantwoorden. WorldScan is daarvoor met een bottom-up module voor de elektriciteitssector uitgebreid. Dit maakt het mogelijk om schattingen van de kosten en van het potentieel voor hernieuwbare energie uit bottom-up studies te gebruiken om het model te kalibreren. In de centrale modelvariant zijn de kosten van EU-klimaatbeleid met als doelstelling verhoging van het aandeel hernieuwbare energie 6% hoger dan die van een beleid zonder deze doelstelling. Vanwege de grote onzekerheid over het aanbod van hernieuwbare energie wordt een uitvoerige gevoeligheidsanalyse gedaan ten opzichte van het niveau en de stijging van de aanbodcurves van windenergie en biomassa. In deze gevoeligheidsanalyse variëren de additionele kosten van nul (wanneer het doel niet bindend is) tot 23% (wanneer we het initiële kostennadeel en de stijging van de kosten voor hernieuwbare energie verdubbelen ten opzichte van de centrale modelvariant).

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Supply of Renewable Energy Sources and the Cost of EU Climate Policy

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February 2010

Abstract

What are the excess costs of a separate 20 % target for renewable energy as a part of the EU climate policy for 2020? We answer this question using a computable general equilibrium model, WorldScan, which has been extended with a bottom-up module of the electricity sector. The model set-up makes it possible to directly use available estimates of costs and capacity potentials for renewable energy sources for calibration. In our base case simulation, the costs of EU climate policy with the renewables target are 6 % higher than those of a policy without this target. As information on the supply of renewable energy is scarce and uncertain, we perform an extensive sensitivity analysis with respect to the level and steepness of the supply curves for wind energy and biomass. In the range we explore, the excess costs vary from zero (when the target is not binding) to 23 % (when the cost progression and the initial cost disadvantage for renewables are doubled).

Keywords: EU climate policy, renewable energy, computable general equilibrium model
JEL Code: Q42, Q54, D58

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1 Introduction

In its climate policy strategy, the European Union has formulated greenhouse gas (GHG) reduction targets that are among the most ambitious worldwide. As an outcome of the European Council Spring Summit 2007, the EU committed itself to a 20 % emission reduction in 2020, compared to 1990 levels, and even to a conditional 30 % reduction objective, "provided that other developed countries commit themselves to comparable emission reductions" (EU Council, 2007). Climate policy has never been seen as an isolated policy area in the EU, though. It always comes in tandem with other energy policy considerations and targets. The 2007 GHG reduction goals explicitly go under the heading of "An integrated climate and energy policy" (EU Council, 2007, p. 11). The most prominent energy policy target is a share of 20 % renewable energy in total EU energy consumption.

The purpose of this paper is a quantitative assessment of the interaction between the renewable energy target and the EU climate policy. For this purpose, we use the computable general equilibrium (CGE) model "WorldScan". Lead by theoretical reasoning, we may tend to the conclusion that the interference of an additional target will cause excess costs of climate policy. The assessment of whether they are of a relevant size, however, can only be carried out using a quantitative model. Only if we have identified a plausible cost range can we go on asking whether the goals that are presented to justify the target for renewable energy are attainable by other means at lower costs.

The core instrument of EU climate policy is the Emissions Trading Scheme (ETS), currently the most comprehensive emissions cap-and-trade system, which may pave the way for coordinated, worldwide climate actions (Ellerman and Buchner, 2007). Even if the ETS covers no more than roughly half of all GHG emissions in the EU, it is set up in the spirit of least-cost abatement. Within the ETS, a uniform emission price is established, which serves as a standard for the marginal costs of each potential abatement measure. A target for renewable energy interferes with this least-cost idea by exempting this particular group of abatement options from the common benchmark price. What is the motivation behind the special treatment of renewable energy?

In the "20 20 by 2020" formulation of the EU policy (EC, 2008a), the target for renewable energy has made its way to the first page, as one of the "two key targets", together with GHG reduction.[1] Apart from its contribution to climate policy (through lower GHG emissions per unit of energy), the main motive is energy supply security. The EU wants to be less dependent on the import of oil and gas, and better shielded against the volatility and increase of international energy prices (EC, 2008a, p. 3).[2] Other possible positive consequences of renewable energy that have been mentioned as arguments in favour of the target are the creation of jobs due to above-average labour intensity of renewable energy, the fuelling of technological progress, pushing the EU to technological leadership and competitive advantage in this field, and the fostering of regional development in rural and isolated areas (EC 2008b, p. 2).

These reasons given for renewable energy promotion illustrate an important difference between political and economic thinking. Politicians tend to start from a given policy measure and collect positive aspects of it. Each of these aspects has the potential to gain support from one of various interest groups, which in the end must ensure a majority for the policy measure in question. Positive connotation is of particular importance. In the context of renewable energy, promoting security of supply and initiating technological progress sounds much more positive than merely reducing GHG emissions. Economists, in contrast, disregard such connotations. They start from the stated goals and look for the instruments best suited to achieve them. Their ambition is to devise a single, separate instrument per goal, and, consequently, they tend to be sceptical about multi-purpose instruments. The target for renewable energy is a case in point.

In this paper, we use the computable general equilibrium (CGE) model "WorldScan" for assessing the excess costs of the renewables energy target.[3] The energy/climate version of WorldScan has been applied to analyse a broad range of EU climate policy options (see e.g. Boeters et al., 2007; Wobst et al., 2007). Until now, no special fo-

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[1] Other EU energy policy targets, which we do not focus upon here, are a 10 % target for biofuels in transport, a 20 % reduction in overall energy use and a 20 % increase in energy efficiency.

[2] The final negotiations for the proposal for a EU directive on renewable energy (EC 2008b) took place at the time of the 2008/09 gas conflict between Russia and Ukraine.

[3] We do not try to quantify possible benefits of renewable energy, however. Supply security, in particular, is a question more of political risk assessment than of economic costs.

cus has been put on renewable energy sources, however. For the present study, we have extended WorldScan by a bottom-up module for the electricity sector, which makes it possible to explicitly consider different electricity generation technologies. In calibrating this electricity module, supply functions for renewable energy are the core element. These supply functions and their empirical foundation are discussed extensively in the body of this paper.

Given a particular specification of the supply functions, we can answer the questions: "What would the EU climate policy cost with and without a separate target for renewable energy?" and "What are the excess costs of the target?" In our central case simulation, which is as close to the institutional details of the actual EU climate policy as the model allows, the excess costs of the target for renewable energy turn out to be approximatley 6 % of the costs the EU policy would produce without such a target.

The data on the supply curves for different renewable energy sources are subject to high uncertainty. Therefore, a considerable part of the paper is devoted to an extensive sensitivity analysis, both with regard to the costs of the first additional unit of renewable energy and the steepness of the curves. This sensitivity analysis shows that excess costs of the target for renewable energy are not a universal result. We are able to identify constellations in which a target for renewable energy actually reduces the costs of climate policy. Explaining the driving forces behind this qualitative switch is much more difficult, however, than showing that it exists. The coexistence of subsidies for renewable energy, pre-existing taxes on fossil fuels and the ETS-non-ETS split generates a complicated environment where economic intuition may fail. Interacting "second best" effects are at work,[4] which can be reconstructed in explaining a particular result, but are difficult to predict when designing a climate policy regime.

The set-up of the rest of the paper is as follows. In Section 2, we graphically illustrate the basic economic argument. In Section 3, we present the model with a special focus on the calibration of the electricity module. Section 4 summarises the scenarios and Section 5 shows the results of the base case and the sensitivity analysis.

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[4] The "second best" theory has been introduced by Lipsey and Lancaster (1956). In second-best situations simple blueprints for optimal tax design (e.g. "implement a uniform emission price") fail because of the interaction with other distortions in the economy.

Section 6 concludes. In the appendix, we present two simple, analytical models that isolate second-best effects contributing to the complications in the model.

2 The basic economic argument

Let us start by representing climate policy in a simple, stylised model. If we have a pre-existing cap on emissions, an additional target for renewable energy sources ("renewables" for short) is useless at best, but likely to cause excess costs. This is illustrated in Figure 1. The total abatement target, A, can be reached either by installing renewables ("REN", from right to left), or by reducing the use of fossil energy through demand reduction, fuel switching or higher energy efficiency ("FOS", from left to right). Marginal costs both for the REN and FOS options are increasing, and total abatement costs are minimised (shaded area) by equalising them. An additional target on renewables (REN_1) is either not binding (if it is to the right of REN_0) or it produces excess costs (heavily bounded triangle) by crowding out cheaper FOS abatement options by more expensive REN ones.[5]

In a concrete policy assessment, we are not only interested in whether excess costs exist, but also in their magnitude. Are they quantitatively so important that they can change the overall evaluation of the policy measure in question? Figure 1 shows that the size of the triangle is determined by the *difference* between the costs of renewables and the costs of the other options for emission reduction, which are crowded out. High excess costs of a target for renewables may result not only from a (locally) steep supply curve for renewables themselves, but also from a steep supply curve for other options. Only if both supply curves are flat will excess costs be low. This makes clear that, for a quantitative assessment, we need a model that captures both sides reasonably well: the renewables as well as the rest. We explain our model choice in the following section.

In Figure 1 it is assumed that there is no further distortion than the renewables target. In the evaluation of the actual EU policy, however, we will encounter several of such interacting distortions: pre-existing taxes on fossil fuels, pre-existing subsidies

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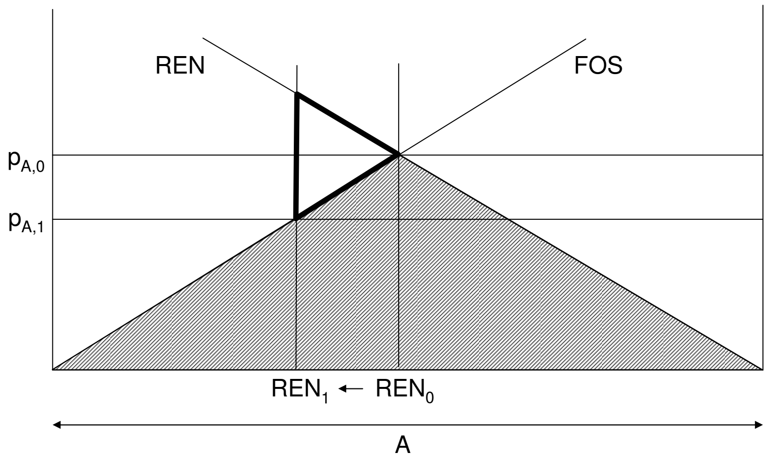
[5] At the same time the emission price drops from $p_{A,0}$ to $p_{A,1}$. This is an example of a situation where the level of the emission price is *not* a suitable indicator of the overall costs.

Figure 1: Excess costs of a target on renewable energy



for renewables and the split between ETS and non-ETS. These distortions lead to considerable complications in the interpretation of the welfare effects. In the appendix we discuss two of the relevant distortions in a simple analytical model. They are presented in a form analogous to Figure 1.

3 The model

From an applied modelling perspective, the difficult point is that alternative measures of emission reduction (i.e. measures other than using renewables) comprise a rather diverse collection. Emission reduction can be achieved by more efficient use of fossil fuels, by fuel switching (from coal to gas), various emission control measures for non-CO_2 gases (see e.g. Lucas et al., 2007), but also by demand reduction (less heating, less driving), and a general change in the production structure of the economy.

Different types of models have their specific strengths and weaknesses in capturing particular subsets of these emission reduction options, and there is no model that captures all of them equally well. Technology-oriented engineering models ("bottom-up") are particularly well tailored to depict the interaction and complementarity of particular technology options. Economic general equilibrium models have their strengths when it comes to demand shifts and reshuffling of the whole production structure (IPCC, 2001, Sec. 7.6.3).

This "bottom-up / top-down" cleavage has been narrowed down considerably – but not fully closed – by a whole family of "hybrid" models (see Hourcade et al., 2006, for an overview). Most of the hybrid models can clearly be traced back to originate from one of the camps. Either they are bottom-up models with a relatively simple macroeconomic extension (e.g. MARKAL-Macro, Messner and Schrattenholzer, 2000), or they are general equilibrium models with some restricted bottom-up modules (e.g. MIT-EPPA, Paltsev et al., 2005). They share, even if to a lesser degree, the strengths and weaknesses of their respective camp of origin.

WorldScan, the model we use in this study, belongs to the second group. Traditionally it has been a pure top-down model working exclusively with aggregate production functions. For this study, we have extended WorldScan with a bottom-up module of the electricity sector, which represents a number of alternative electricity generation technologies by marginal cost curves (see Section 3.2).

3.1 General structure of WorldScan

WorldScan is a multi-region, multi-sector, recursively dynamic computable general equilibrium model based on the GTAP7 data set (Badri and Walmsley, 2008) with base year 2004. The model is described in detail in Lejour et al. (2006). Here we give only a brief sketch of the general model features and focus on the bottom-up representation of the electricity sector, which is an extension prepared particularly for this study.

The aggregation of regions and sectors can be flexibly adjusted in WorldScan. We use a version with 18 regions and 18 sectors, listed in Tables 1 and 2. Regional disaggregation is relatively fine within Europe, but coarse outside. Likewise, we focus on the energy-related sectors, whereas other sectors are captured in a more aggregated manner.

WorldScan is set up to analyse deviations from a baseline ("business as usual") path. In general, this path is not generated by WorldScan itself, but taken over from

Table 1: Regions in WorldScan

France	Bulgaria and Romania
Germany	USA
Italy	Other OECD
Spain	Brazil
Netherlands	China
United Kingdom	India
Rest of EU 15	Other SE Asia
Poland	Former Soviet Union
Rest of EU 25	Rest of the World

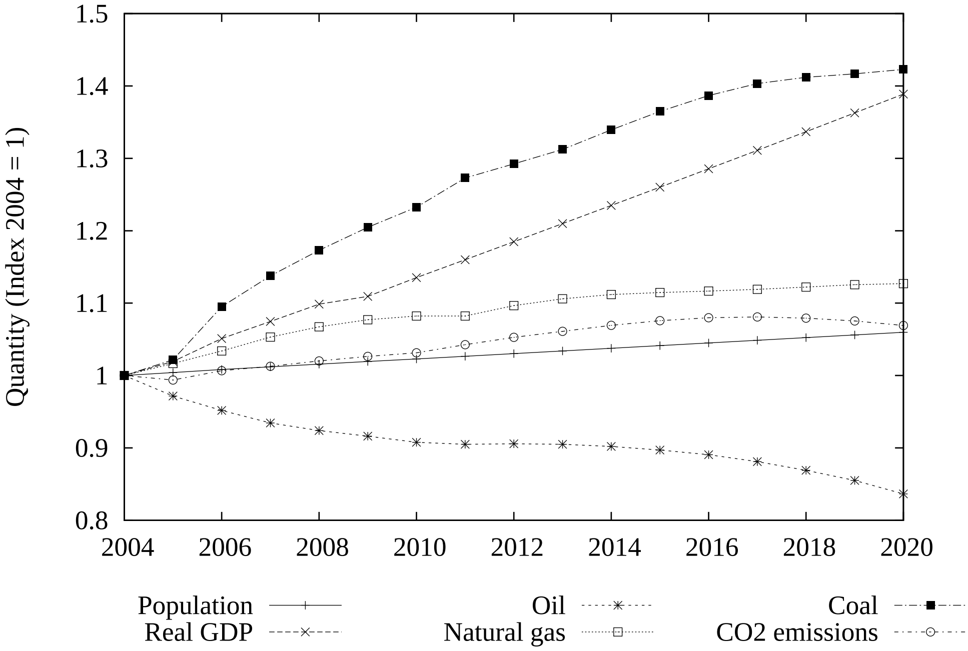
Table 2: Sectors in WorldScan

Cereals	Electricity
Oilseeds	Energy intensive sectors
Sugar crops	Vegetable oils
Other agriculture	Food processing
Minerals	Other consumer goods
Oil	Capital goods and durables
Coal	Road and rail transport
Petroleum and coal products	Other transport
Natural gas	Other services

other models or scenario studies. For our present purposes, we use the Environmental Outlook 2008 scenario generated with the TIMER model of the Netherlands Environmental Assessment Agency (OECD, 2008) as our baseline.

Basic inputs for the baseline calibration are time series for population and GDP by region, energy use by region and energy carrier, and world fossil fuel prices by energy carrier. Population is an exogenous input to the model. The other time series are reproduced by adjusting the corresponding model parameters. GDP is

Figure 2: Baseline assumptions for EU: quantities



targeted by total factor productivity (differentiated by sector), energy quantities are targeted by autonomous energy efficiency, and fuel prices are targeted by the amount of natural resources available as input to fossil fuel production.

Figure 2 shows important baseline quantities for the EU. In the use of fossil fuels, there is a significant shift from oil to coal. Total CO_2 emissions are only slightly increasing.[6] Figure 3 shows the underlying fuel prices (relative to the EU consumption price index). We see that the shift from oil to coal is induced by a considerable increase in the relative oil price. The overall increase of the fossil fuel price level is one important reason for fossil fuel use and CO_2 emission growing less than GDP (Figure 2).[7]

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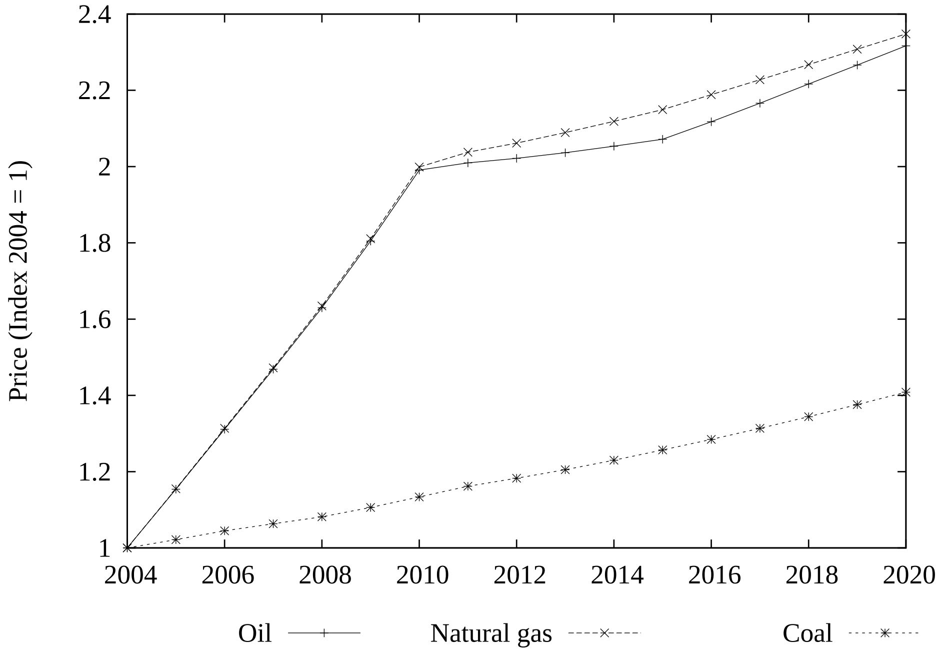
[6] The baseline was constructed before the credit crisis in 2008, and the recession of 2008/09 is not included. Given our focus on the long-term effects in 2020, we do not consider this a serious defect. For the consequences of baseline adjustment due to the credit crisis for climate policy, see Böhringer et al. (2009a).

[7] The oil price peaks of 2007/08 do not appear in Figure 3. We were not able to reproduce such drastic short-term fluctuations in our general equilibrium model and, given our long-term focus, decided to smoothen the price path until 2010.

Figure 3: Baseline assumptions for EU: fossil fuel prices



3.2 Bottom-up representation of the electricity sector

Modelling renewables as separate electricity generation technologies, we enter the area of "bottom-up" complements to general equilibrium models. The standard approach in CGE modelling is to base the model on the sectoral structure of the input-output table of national accounts. To a certain extent, different technologies within the electricity sector are represented by the input coefficients the fossil fuels (coal-, gas- and oil-based electricity plants).

Renewable energy, in contrast, is not characterised by a particular input. Here, technologies must be introduced as separate economic activities. In technical terms, the addition of new activities to CGE models is a straightforward exercise (Böhringer, 1998), but the determination of the production split between the individual technologies in the counterfactual simulations remains a challenge. Simply placing several technologies with constant returns to scale into a competitive framework would result in an implausible corner solution: exclusive use of the least expensive technology. In the literature, several mechanisms have been proposed that produce a smooth shift between technologies: (a) Output levels are governed by technology-specific physical capital, which is a Leontief input to production. The capital quantity is determined by an investment function that is sensitive to technology-specific returns to capital (Böhringer and Löschel, 2006). (b) Output levels are governed by technology-specific knowledge, which is a substitutable input and whose quantity follows a logistic learning function (McFarland et al., 2004). (c) Output levels are governed by user- and technology-specific stochastic excess costs, which results in a (logit) discrete-choice function (Schumacher and Sands, 2007).

Each of these approaches induces its own follow-up question. How to specify the investment function (a), the learning function (b) or the stochastic costs (c)? In many cases, modellers resort to ad-hoc assumptions at this point because it is extremely difficult to find appropriate data. We opted for a different approach, which is less subtle in the mechanism applied, but as parsimonious as possible in the data requirements for calibration. Electricity generation technologies are represented by simple, linearly increasing supply functions and calibrated using existing estimates of cost ranges and potentials. The technology split is determined by equalising marginal costs across technologies.[8]

WorldScan captures five concrete electricity technologies: (1) fossil electricity with a flat supply curve and coal, gas and oil as imperfectly substitutable inputs, (2) wind (onshore and offshore) and solar energy, (3) biomass, (4) nuclear energy and (5) conventional hydropower. Wind and biomass have increasing supply functions, whose calibration is described in the next section. Nuclear and hydropower are calibrated to the Environmental Outlook baseline (OECD, 2008), but do not endogenously react in our climate policy scenarios. Figure 4 shows the quantities of the five technologies along the baseline path.

As individual electricity technologies are not represented in the input-output tables, the values in the aggregate electricity sector must be split up among them. We do this with three simple assumptions: (1) Marginal costs (after taxes and subsidies) are equal across technologies. (2) Fossil fuels are used as inputs in fossil electricity generation, but not for the other electricity technologies. (3) All other inputs (capital, labour, intermediate goods and services) are used in proportion to

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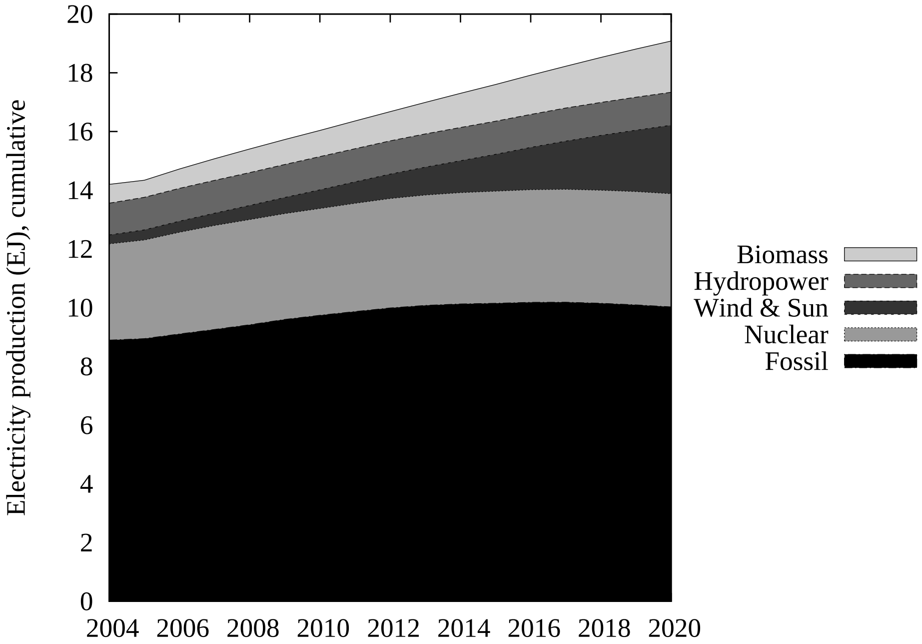
[8] We see the main advantage of our approach in its simplicity, not necessarily in its realism. When we discuss the supply of renewables, we can talk directly about costs and potentials, and need not translate these into model parameters whose interpretation requires considerable effort.

Figure 4: EU electricity production in the baseline



the aggregate shares. As we are mostly interested in aggregate costs, not in sectoral effects, we do not engage in a detailed study of the input structure of different electricity technologies as done, for example, in Lehmann et al. (1998).

3.3 Calibration

Central to the calibration of the electricity module are the supply functions for renewables. Three questions must be answered here: (1) which renewable sources to include, (2) what cost range and (3) what quantity potential to assume.[9] We discuss these questions in turn.

Even though we engage in a bottom-up representation of the electricity sector, WorldScan is not designed to cover the full range of detailed electricity generation technologies. Instead, we have a stylised representation of some principal options.

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[9] If we had not restricted ourselves in the first place to linear supply functions, the choice of the functional form would add to this. Given the data at hand, we found this too ambitious a goal for the present version of the model. Our reading of Figure 6.4 in EEA (2009) is that linear supply curves can be defended.

Which of them will determine the quantitative reactions, so that we can concentrate our calibration effort on them? Resch et al. (2008) estimate that in 2020 30 % of renewable electricity in the EU-27 will be generated by biomass, 30 % by wind, 25 % by hydro and 15 % by solar, tidal and wave energy. We conclude from this that it is most important to adequately model supply of wind and biomass. Hydro energy can only be extended at very high costs, which means that not much action is taking place here. The contribution of the other options is small, so that leaving them out of the picture will not significantly change the simulation results.[10]

As to the cost range of renewables, we use data from EC (2008c, p. 4). The minimum and maximum costs of electricity from fossil fuels, wind and biomass are reproduced in Table 3. WorldScan has only an aggregated fossil electricity technology, so we need to express costs in relation to a representative fossil fuel mix. We take the average EU fuel mix in the base year 2004 (60 % coal, 32 % gas, 8 % oil) and multiply the shares with the midpoint of the range of the least expensive technology per carrier (e.g. 12.5 €/GJe for coal). This gives an average price of electricity from fossil energy in the base year of 15.5 €/GJe. The cost multipliers for renewables with respect to this average fossil price are given in the right-hand column of Table 3. In the GTAP data set, which provides the input-output information for WorldScan, the average EU electricity cost (total amount of electricity divided by total input costs) is higher: 20 €/GJe. We assume that everything that might be responsible for the discrepancy affects renewables in proportion and therefore apply the multipliers of Table 3 to the GTAP costs.

With the cost range given, the steepness of the supply curves is determined by the potential capacity. Finding appropriate capacities for wind and biomass to be used for our model has turned out to be a major challenge. The range of published capacity estimates is extremely wide, with part of the variation caused by diverging definitions. “Technical potentials”, where only the restrictions of technological knowledge are applied, can be very high, whereas “economic potentials”, where cost competitiveness considerations are taken into account, are much lower (see Doukas et al., 2007, or Resch et al., 2008, for a discussion of different definitions). Both types of potentials pose problems when integrated into a model such as WorldScan.

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[10] We do not model endogenous supply of nuclear energy because we consider this mostly a political decision depending on the risk assessment of nuclear accidents and nuclear waste disposal.

Table 3: Cost range of power generation technologies

Technology	Cost range in €(2005)/GJe	Relative to fossil average
Open cycle gas turbine	18 ÷ 21	
Combined cycle gas turbine	14 ÷ 17	
Internal combustion diesel engine	28 ÷ 35	
Combined cycle oil-fired turbine	26 ÷ 29	
Pulverised coal combustion	11 ÷ 14	
Circulating Fluidised Bed Combustion	12 ÷ 15	
Integrated gasification combined cycle	12 ÷ 15	
Solid biomass	22 ÷ 54	1.43 ÷ 3.50
Biogas	15 ÷ 60	0.99 ÷ 3.86
On-shore wind farm	21 ÷ 31	1.35 ÷ 1.97
Off-shore wind farm	24 ÷ 39	1.52 ÷ 2.51

Technical potentials normally lack the restrictions that the technologies face before market forces come into play, such as various space restrictions for wind energy or the priority of food production in the case of biomass. Economic potentials, on the other hand, are the outcome of cost comparisons; we want this mechanism to be working in our model rather than imposing its outcome. We therefore rely on technical potentials from the literature, but choose those at the lower end of the range.

For wind, onshore and offshore installations must be distinguished. For onshore wind, we take the overall technical potential for Europe from Hoogwijk (2004, p. 133, Table III) and apply the regional split of EEA (2009, p. 48, Table 6.8). For offshore wind, we use the constrained potential of EEA (2009, p. 34) and the regional split of Figure 3.5 (EEA, 2009, p. 21).[11] For biomass, we use the overall European potential of Hoogwijk (2004, p. 104, Table III, Scenario A2), apply a conversion efficiency of 40 % (Hoogwijk, 2004, p. 101, Table II), and perform the breakdown within the

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[11] Onshore wind: 4.0 PWh/y (14.4 EJ/y), offshore wind: 2.8 PWh/y (10.0 EJ/y), regional shares of offshore wind have been approximately recovered from the figure.

Table 4: Potential for wind and biomass in the EU

EU region	Wind (EJe/y)	Biomass (EJe/y)
France	2.7	1.4
Germany	2.1	1.2
Italy	0.8	1.1
Spain	1.2	1.1
Netherlands	1.2	0.5
United Kingdom	3.6	0.6
Rest of EU 15	8.3	1.5
Poland	1.5	0.4
Rest of EU 25	2.3	0.5
Bulgaria and Romania	0.8	0.6
EU 27	24.4	8.8

EU in proportion with agricultural production. The resulting potentials (associated with maximum costs from Table 3) are given in Table 4.

Constructing supply curves for renewables in this way is loaded with uncertainties, both for cost ranges and potentials. Apart from the different definitions discussed above, this is a consequence of the fact that both costs and potentials depend on uncertain technological developments. The further we extend the model horizon, the larger the uncertainty range. As the steepness of the supply curves for renewables is a core driver of the results in Section 5, we engage in an extensive sensitivity analysis that focuses on this point. We vary the steepness of the curve from half to double the value that results from the base case data in Tables 3 and 4. We leave it unspecified, though, whether variations in steepness are due to changes in cost or potential.

4 Scenarios

Our point of departure are the scenarios that have been formulated in the European group of Round 22 of the Energy Modeling Forum (see Böhringer et al., 2009b). These are

- "UNIFORM": EU reduction target (-20 % GHG emissions compared to 1990 in 2020) implemented through a single emission price, which is uniform across regions and sectors.
- "UNIFORM + RET": The same as UNIFORM, but with a 20 % share of renewable energy in gross final consumption as an additional target ("RET" for "renewable energy target").
- "ETS": EU reduction target (-20 % in 2020) implemented in the form of the segmentation implied by the current European Emission Trading System (ETS), i.e. separate targets for ETS and for the non-ETS sector in each of the EU member countries.
- "ETS + RET": The same as ETS, but with a 20 % share of renewable energy in gross final consumption as an additional target.

In the base case, we combine these scenarios with the supply curves for wind energy and biomass according to the calibration in Section 3.3. For wind, there is an initial subsidy of 26 % and the slope of the curve implies a 1.0 €/GJ rise in the marginal price with each extension of capacity by 1 EJ/year. For biomass, the slope of the curve is 6.6 €/GJ per EJ/year.[12] These slopes are only applied to *additional* units of renewables, because this is what the price and quantity potential ranges (Section 3.3) are about. For the renewables already existing in the baseline we assume constant costs at the level of the first additional unit (horizontal part of the supply curves in Figure 5).

Figure 5 shows the variations of the base case that we use in the sensitivity analysis. We start with the curve "base case" and the calibration point. The vertical difference between the supply curve and the calibration point represents the

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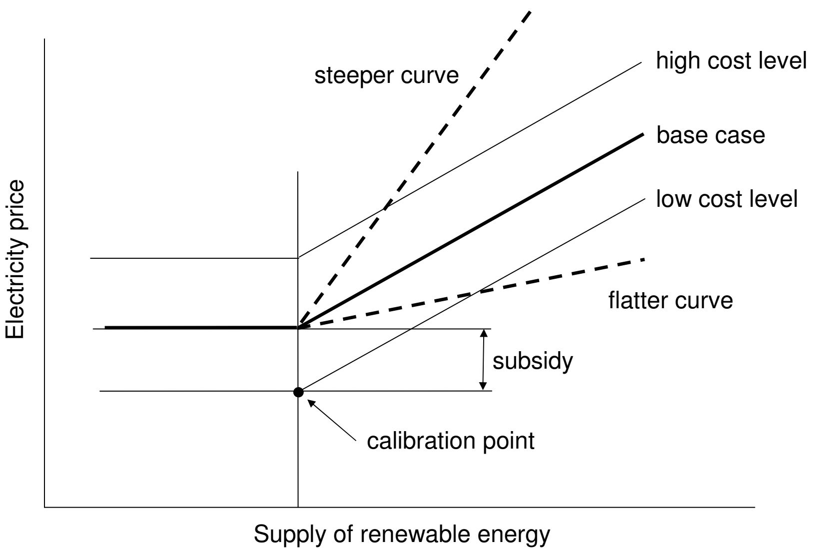
[12] We disregard the small cost discrepancy between biomass and fossil electricity in Table 3 and do not apply an initial subsidy here.

Figure 5: Supply curves in the sensitivity analysis



subsidy that must be paid to the marginal unit of renewable electricity for it to be competitive at user costs. This case is explored in Section 5.1.

In Section 5.2 we focus on the steepness of the supply curves. What are the consequences if the curve still passes through the same point above the calibration point, but additional units of renewable energy are more expensive ("steeper curve") or less expensive ("flatter curve") than in the base case?[13]

In Section 5.3, we look at the consequences of a parallel movement of the supply curve for wind.[14] As we keep facing the constraint that the marginal unit of wind energy must be competitive, a parallel movement of the supply curve must be compensated by an adjustment of the initial subsidy. We explore two cases: higher cost of wind, so that the subsidy must be doubled ("high cost level"), and lower cost of wind, so that no initial subsidy is necessary ("low cost level").

Finally, in Section 5.4, we consider a combined case with the base-case subsidy for renewables already present in the baseline, but no subsidy for additional units.

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[13] We assume that the steepness of the wind and biomass supply curves changes in proportion.

[14] We focus on wind here, because there is no cost discrepancy for biomass in the base case.

This gives a supply function with a step (from “low cost level” to “base case”) at the calibration point.

5 Results

5.1 Base case calibration of renewables supply

We start with a look at the four core scenarios from Section 4 (“UNIFORM”, “UNIFORM + RET”, “ETS” and “ETS + RET”) with the renewables supply curves calibrated as in the base case of Section 3.3 (this case is indicated by a vertical line in the figures to follow).

Figure 6 shows the emission prices in the different scenarios. The uniform emission price is at approximately € 17 per ton CO_2. The segmentation into ETS and non-ETS with the respective reduction targets of 2008 drives the emission prices apart: € 11 within ETS, € 44 outside ETS.[15] Given this starting point, what are the consequences of introducing a target for renewables in addition to the generic CO_2-reduction policy?

In the UNIFORM + RET scenario, the emission price does not change at all, because the renewables target is not binding. This can be seen in Figure 7. In the baseline, the renewables share is at 14.5 % in 2020. In the UNIFORM scenario, it increases to 20.1 % as a result of the emission price and the induced increase in the cost of fossil electricity. In the ETS + RET scenario, in contrast, the endogenous share of renewables remains below the target, at 19.0 %. This difference between the scenarios is a consequence of the allocation of emission rights between ETS and non-ETS, which results in a lower emission price in ETS than in UNIFORM and, consequently, in less ETS emission reduction than with a uniform emission price. Introducing the target in ETS actually changes the energy mix. The difference between endogenous share and target is small, however.

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[15] The non-ETS emission price reported here is the emission-weighted average of all country-specific non-ETS prices. The spread within non-ETS is even larger than between ETS and non-ETS, with very low non-ETS prices in the Central European countries. As the efficiency of the ETS-non-ETS split is not the focus on the paper, we do not discuss it further.

Figure 6: Emission prices (EU, 2020, base case cost level)

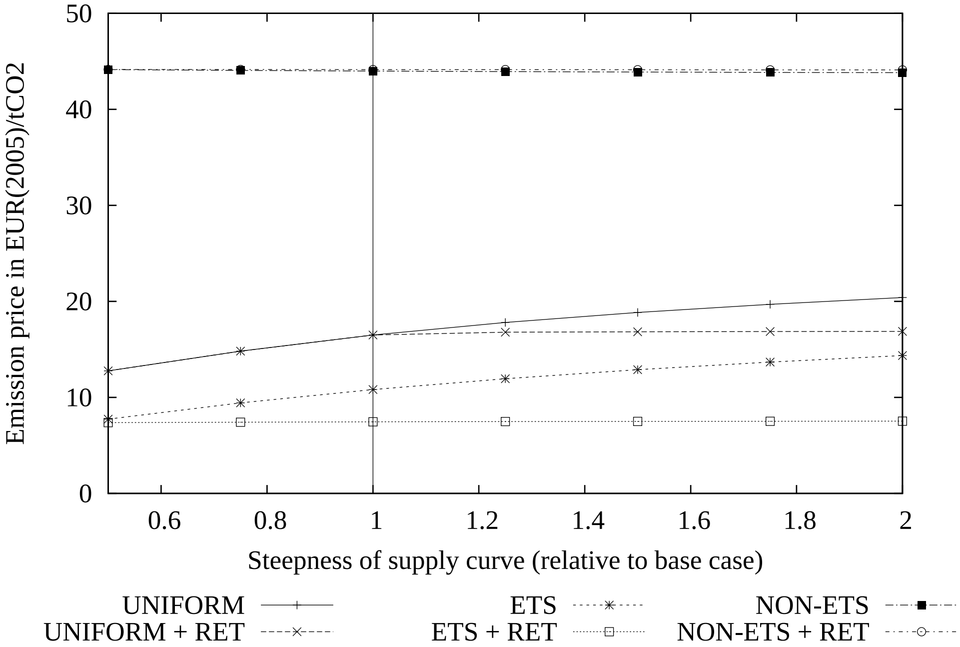
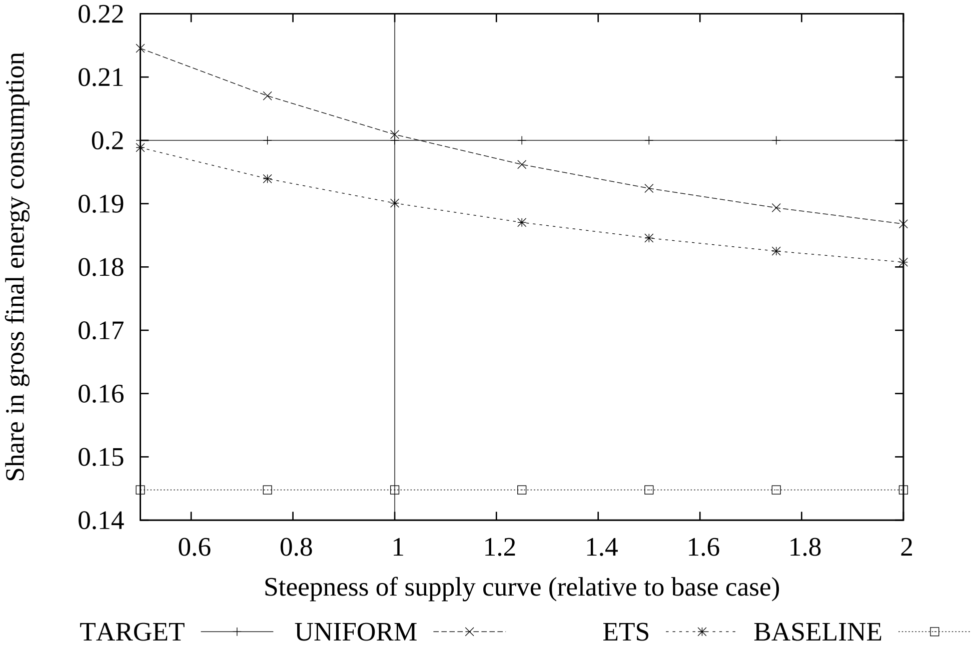


Figure 7: Renewables share (EU, 2020, base case cost level)



The consequences of introducing the renewables target in the ETS + RET scenario are concentrated on the ETS sector. The ETS price drops from € 11 to € 7. At a given reduction target for ETS as a whole, more reduction is achieved by renewable electricity, so that the emission price, which reflects the marginal costs of all other options, must fall. The non-ETS price is hardly affected at all, because we do not consider renewables outside electricity production. In non-ETS, neither the reduction targets nor the reduction options change, so that the only effect on the non-ETS price is through an overall change in economic activity, which is indirect and small.

We now turn to the welfare consequences, shown in Figure 8. Welfare is given as Hicksian equivalent variation, i.e. the income change (at baseline prices) that would leave the representative household at the same consumption level as the respective version of climate policy. Welfare costs of climate policy are lowest in the scenario UNIFORM.[16] Adding a target for renewables (UNIFORM + RET) produces no excess costs, because the target is not binding. The costs of the actual emission trading system (ETS) are approximately 30 % higher than those of UNIFORM. Finally, in the scenario ETS + RET the implementation of the renewables target produces further excess costs, and the total costs of climate policy add up to 0.40 % of aggregate consumption in the baseline.

Expressed in absolute numbers, i.e. multiplied by the baseline EU national income of € 16.8 trillion (real value in prices of 2005), this gives welfare costs of 63 billion Euro in 2020 for ETS, and € 67 billion for ETS + RET. The excess costs of the renewables target, € 4 billion, are not particularly high, which again is a consequence of the fact that the endogenous share of renewables in ETS is already close to the target. To put the welfare effect of the target in perspective, we compare it with a partial cost calculation.[17] The renewables target induces 0.70 EJe of additional renewable electricity on top of the endogenous level in ETS, divided into 0.63 EJe of wind and 0.07 EJe of biomass. The average excess costs (compared to

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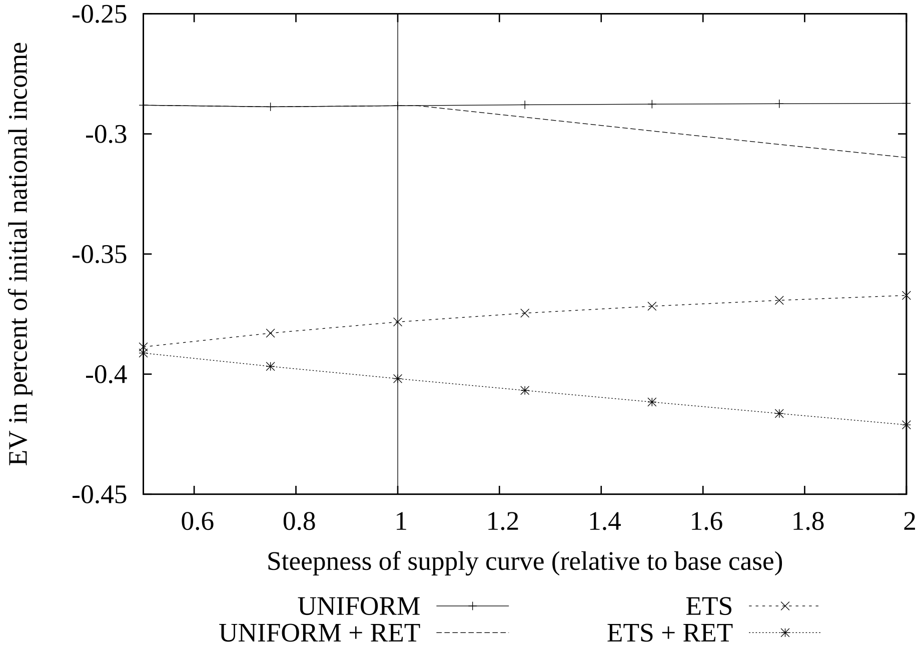
[16] This is what one might have expected when applying first-best principles of environmental regulation. However, below, we will encounter cases where UNIFORM is not the scenario with the lowest welfare costs.

[17] This partial calculation is not independent of the actual model runs, though. Quantity and price differences are taken from the scenario results.

Figure 8: Welfare costs (EU, 2020, base case cost level)



the fossil mix replaced) are 8.6 €/GJ for wind and 0.4 €/GJ for biomass, which, multiplied with the quantities, amounts to € 5.4 billion. This is somewhat higher, but in the same range as the welfare effects expressed in equivalent variation.[18]

5.2 Varying steepness of the renewables supply curves

Until now, we have focused on the points on the vertical lines in Figures 6 to 8. These lines mark the base case with supply curves for renewables as described in Section 3.3. To the left, we have less steep supply curves, to the right steeper ones. The steepness varies from half to double the base case value. All supply curves pass through the same quantity-price combination in the baseline ("calibration point" in Figure 5).

Steeper supply curves reduce the renewables share (Figure 7) both in the UNIFORM and ETS scenarios, because renewables become comparatively less attractive as abatement options. This is reflected in the emission price, which is increasing in

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[18] See Appendix A.3 for an interpretation of the difference between partial and general equilibrium costs.

the steepness of the supply functions (Figure 6). With the ETS-non-ETS split in place, the effects are segment specific. The non-ETS price hardly reacts to the costs of renewables at all, whereas the ETS price increases. When the renewables target is binding (UNIFORM + RET to the right of the separation from UNIFORM, and ETS + RET), emission prices are virtually flat. This is because the amount of renewables is fixed by the target, and the cost of the other options does not change (apart from very small general equilibrium effects).

The effect of the steepness of the supply curves on the excess costs of the renewables target (Figure 8) is more difficult to explain. Surprisingly, generic climate policy (UNIFORM and ETS) does not become more expensive with steeper supply curves. In UNIFORM, the costs are virtually constant, and in ETS, they are even decreasing. The key to this effect is in the pre-existing subsidy for wind. By subsidising wind, the government forces more of this energy source into the climate policy solution than would have been efficient. Higher costs of wind counteract this effect and can lead to a welfare gain. The bad thing about a steeper supply curve is that each marginal unit becomes more expensive. The good thing about it is that less wind enters into the solution, with less subsidy to be paid and less excess costs to be borne by the economy. At a high subsidy level, the second effect may dominate. Appendix A.2 shows this in a simple analytical model.

The excess costs of introducing a renewables target (UNIFORM + RET vs. UNIFORM and ETS + RET vs. ETS in Fig. 8) are, as expected, increasing in the steepness of the supply curves. This results from the combination of two effects. First, each individual unit of renewables becomes more expensive. Second, the renewables target becomes more ambitious, because the gap between the endogenous renewables share (Figure 7) and the target is the larger the steeper the supply curves. As we have already seen in the base case, the renewables target is not binding in the UNIFORM scenario when supply curves are flat, so that excess costs are zero.

5.3 Variation in the cost level of wind

Some of the effects that appeared in Section 5.2 can be highlighted by introducing an additional dimension to the sensitivity analysis: the cost level of the initial unit of additional wind. We assume that the cost difference with fossil electricity is compensated by a pre-existing subsidy, so that the baseline quantity of wind is competitive. A high (low) cost difference thus corresponds to a high (low) pre-existing subsidy.[19]

In Section 5.2, we have looked at the consequences of a variation in the steepness of the supply curve, while keeping the producer costs of the first additional unit of wind constant. In our base case calibration, these costs are 35 % higher than those of fossil electricity. We now introduce two variants. In the first, we eliminate the cost difference, so that the pre-existing subsidy disappears as well. In the second variant, we double the cost disadvantage of wind to 70 %, with a correspondingly higher subsidy.

The scenario outcomes for the emission prices (Figure 6) and the endogenous renewables shares (Figure 7) are hardly affected by these variations. This is because the user prices (producer prices less subsidy) are, apart from small general equilibrium feedback, the same in all variants. The main effects are in the total resources necessary to produce electricity and in the size of the subsidy payments.[20] These effects show in the welfare changes, which are given in Figures 9 (low cost level with no initial subsidy) and 11 (higher cost level).

As one would expect, with lower producer costs of renewables (no subsidy), the general cost level of climate policy is lower than in the base case (Figure 9 compared to 8). Contrary to the base case, welfare costs are now unambiguously increasing in the steepness of the supply curves. However, a new counterintuitive effect occurs: the renewables target is welfare enhancing (if binding). The reason is that pre-existing taxes on fossil fuels constitute an excess burden on reducing CO_2 by means of using less of these fuels. The subsidy for wind (in the base case) acts as a countervailing excess burden on reducing CO_2 by renewables. In the low cost scenario, renewables are a cheaper option in terms of social costs, but because of the pre-existing taxes, this is not transmitted to producers and consumers via price signals. In this setting, an additional renewables target acts as a correction of pre-existing inefficiencies and increases welfare (in relation to a climate policy without renewables target).

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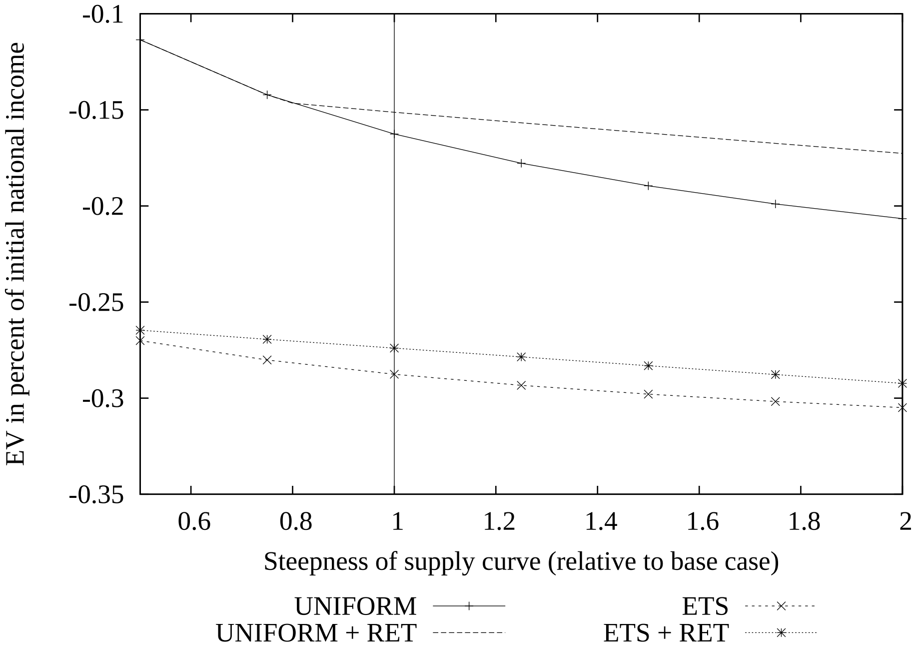
[19] We focus on wind in this section, because only for wind is there a pre-existing subsidy in the base case calibration.

[20] WorldScan has no separate government sector, all tax revenues and subsidy payments affect the budget of the representative household in a lump-sum fashion.

Figure 9: Welfare costs (EU, 2020, low cost level)



This interpretation of the results can be confirmed by running an auxiliary scenario, in which first all existing taxes on energy are abolished and then a uniform carbon price is introduced. The price will be much higher than in the scenarios with pre-existing taxes (because cutting energy taxes has an expanding effect), but the result will nevertheless be closer to the efficient choice of abatement options.[21] We have run such a scenario in the low cost case, and the endogenous renewables share turned out to be higher than 20 % in UNIFORM and for low and medium steepness values in ETS. With the energy taxes in place, we are below 20 %, which generates the potential for welfare improvements through a renewables target. In Appendix A.1, we present a simple analytical model that isolates this case.

If we impose a binding renewables target in the model version *without* taxes, the welfare effects become intuitive again. To maintain comparability with the other model variants, we impose a renewables target that becomes binding at the base case steepness of the wind supply function in the UNIFORM scenario (25.4 %). Figure

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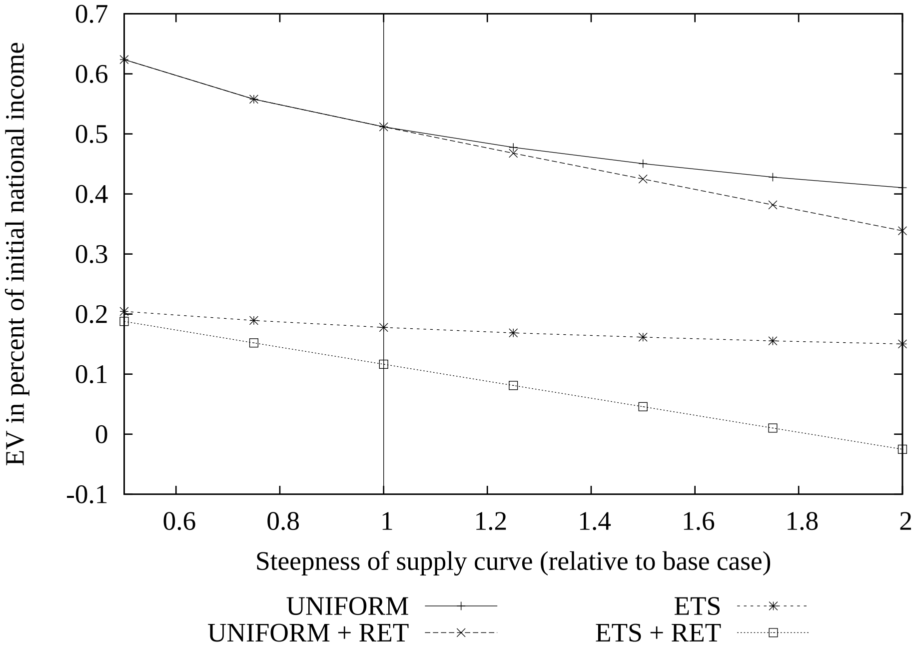
[21] Still we cannot expect to have achieved a first-best solution, because other distorting taxes in the model remain.

Figure 10: Welfare costs (EU, 2020, no pre-existing energy taxes)



10 shows the resulting welfare effects. Now the renewables target produces excess costs once it becomes binding.[22]

Figure 11 shows the welfare effects in the case where the cost disadvantage of wind energy is doubled, so that a higher subsidy is needed to make the marginal unit of wind energy competitive. Reassuringly, the effects confirm our analysis of the other model variants. The welfare costs of the scenarios without renewables target are again (as is ETS in Fig. 8) decreasing in the steepness of the renewables supply curves, and even more so, because the savings in subsidy payments are the higher the higher the level of the subsidy. The excess costs of the renewables target are higher as well, which is the mirror image of the case without subsidies.

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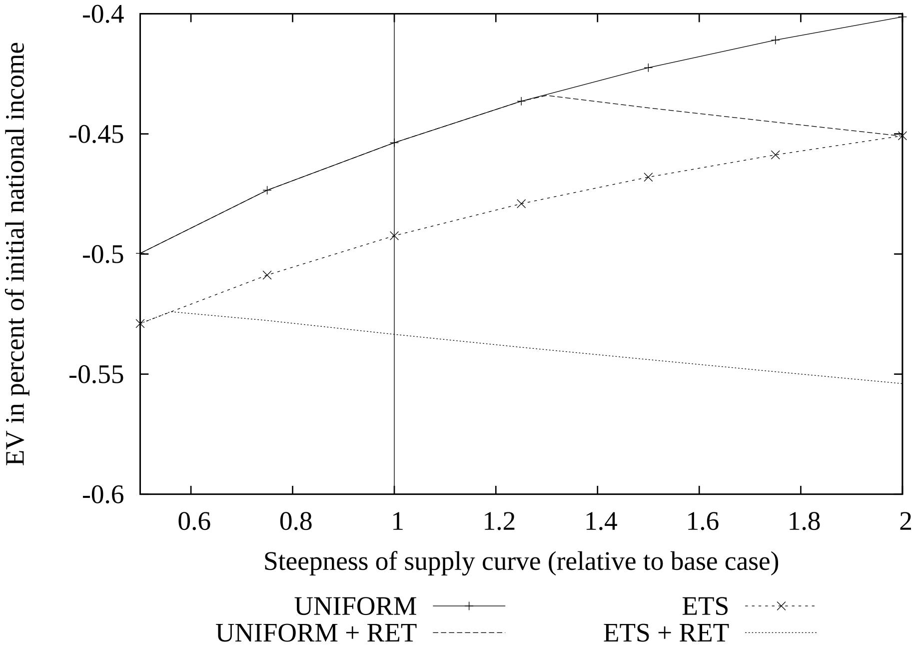
[22] The general level of welfare effects in Figure 10 is positive, which means that the distortions through pre-existing energy taxes are higher than the costs of climate policy. This deserves a closer look, but is outside the focus of the present paper.

Figure 11: Welfare costs (EU, 2020, high cost level)

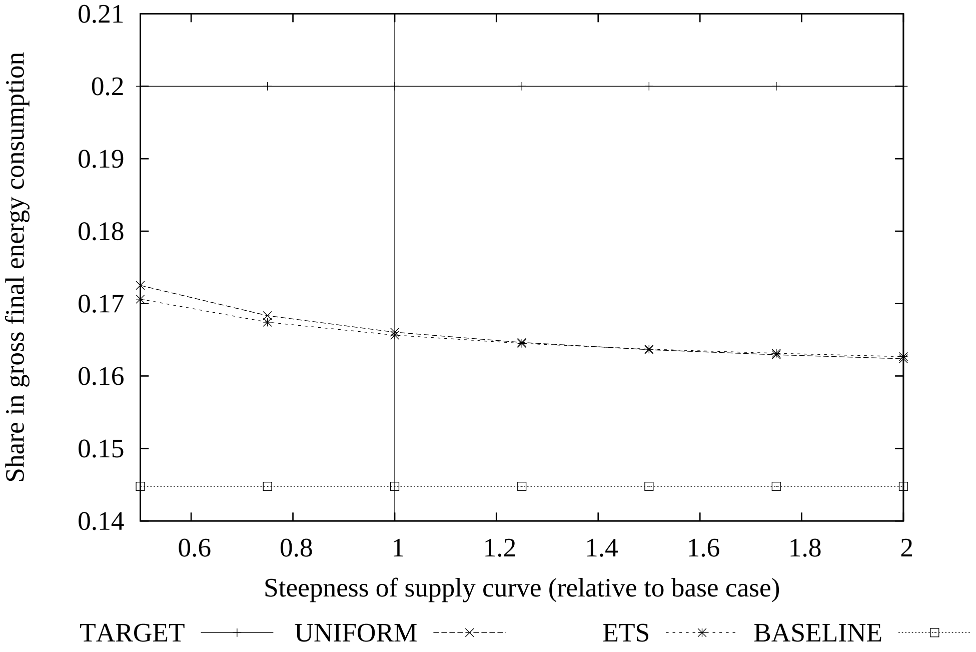


5.4 No subsidy for additional units of wind

Until now, we have assumed that any subsidy needed to make the marginal unit of wind competitive is also applied to additional units. A subsidy for wind was part of the baseline set-up, as were pre-existing taxes on fossil fuels. However, subsidies for wind are most probably the result of some sort of renewables-promotion policy. Even if we cannot remove the subsidies from the initial situation (because this would make it impossible to reproduce the exogenous baseline), we can treat any subsidy for *additional* units of wind as part of the counterfactual policy. This is what we do in this section, generating a supply function with a step at the calibration point (see Section 4).

Removing the subsidy for additional units of wind has two effects, which work in opposite directions when it comes to the welfare costs of a renewables target. On the one hand, the cost level of renewables faced by private investors increases. This means that a generic climate policy (UNIFORM or ETS) produces a lower level of renewables than in the base case (see Figure 12). The gap between the endogenous renewables share, 16.6 %, and the target is now larger, so that imposing the target

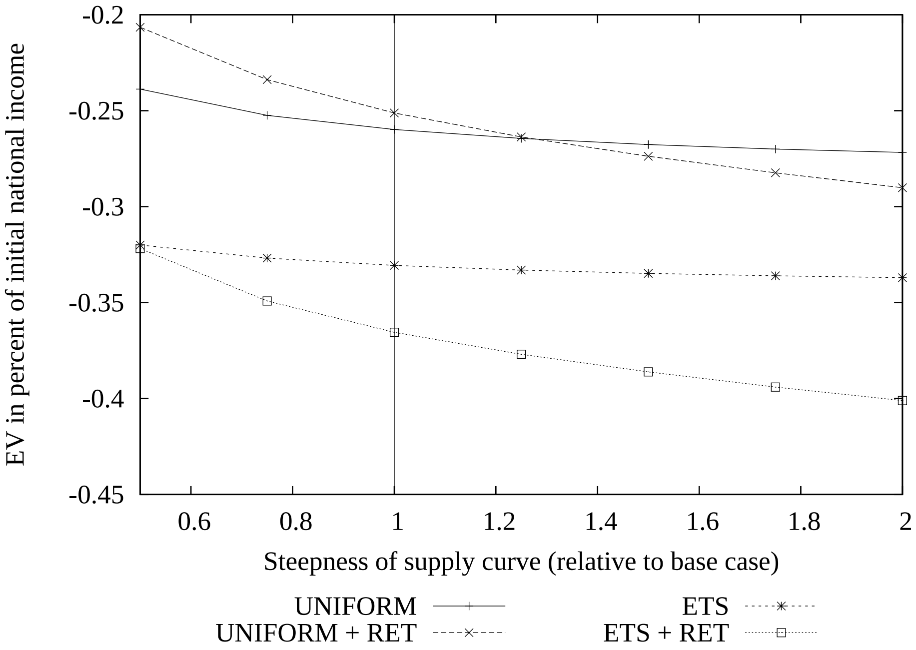
Figure 12: Renewables share (EU, 2020, restricted subsidy)



becomes more expensive. On the other hand, restricting the subsidy removes a distortion that led to an inefficient mix *within* renewables (more subsidised wind at the expense of biomass), which reduces costs. Which of these two effects is larger cannot be determined a priori.

Figure 13 shows the welfare effects in the scenario without a pre-existing subsidy for additional wind. Compared to the base case (Figure 8), welfare costs may be higher or lower, depending on climate policy institutions and the steepness of the supply curves. In the UNIFORM variant, we observe a similar phenomenon as earlier in the “high cost level” scenario: a renewables target may be welfare enhancing. This is made possible by the second-best effect caused by initial taxes on fossil fuels (see Appendix A.1). By eliminating the inefficiency caused by the subsidy for wind, we make additional renewables more attractive, and the conditions under which they outperform other options of emission reduction become less restrictive. This is particularly the case in the UNIFORM scenario, because the highest taxes are in non-ETS (taxes on transport fuels), and UNIFORM makes the re-allocation of abatement efforts between ETS and non-ETS possible.

Figure 13: Welfare costs (EU, 2020, restricted subsidy)



In the ETS scenario, the quantity effect of the subsidy for wind turns out to be dominating, so that the excess cost of the renewables target is roughly 50 % higher than in the base case (0.03 % of national income, € 5.8 billion). Again, we can compare this with a partial cost calculation, such as the one in Section 5.1. Now we have 2.37 EJe of renewable electricity induced by the target, divided into 1.23 EJe of wind and 1.14 EJe of biomass (i.e. a larger share of biomass, because additional wind is not subsidised any more). The average excess costs are 6.6 €/GJ for wind and 3.9 €/GJ for biomass, now more in line with one another than in the base case. This amounts to total partial costs of € 12.6 billion. The discrepancy with the welfare costs in general equilibrium is considerably larger than in the base case. This is analysed in more detail in Appendix A.3.

6 Conclusions

Including a 20 % target for renewable energy in the EU climate policy package increases the welfare costs by 6 %, which is 0.02 % of EU national income or approximately €4 billion (in constant prices of 2005) in 2020 (see Figure 8). This amount can be interpreted as the implicit cost of using the renewable energy target for other than climate policy goals, in particular as a contribution to energy supply security. If the EU had a uniform price for all CO_2 emissions, the target for renewables would not be binding, and hence produce no excess costs.

We have made use of the computable general equilibrium model WorldScan to generate these results. WorldScan has been extended by an electricity sector module where different electricity supply options are calibrated separately and the electricity mix is determined by equalising marginal supply costs across all options. As in any large, applied economic model, the results are subject to uncertainty with respect to both the model mechanisms and the underlying data. We focus on one particular dimension of this uncertainty: uncertainty with regard to the costs of renewable energy sources, captured in a variation of both the level and the steepness of the supply curves.

In the sensitivity analysis it becomes apparent that pre-existing taxes on fossil fuels, pre-existing subsidies for renewables and the split between ETS and non-ETS produce second-best effects that are not straightforward to interpret. The most important results from the sensitivity analysis are the following.

- The welfare costs of climate policy *without* a renewables target are decreasing in the steepness of the renewables supply function, except when the initial subsidy on renewables is very low.
- The welfare costs of climate policy *with* a renewables target are increasing in the steepness of the renewables supply function once the target becomes binding, irrespective of the subsidy level.
- The excess costs of the renewables target are increasing in the steepness of the renewables supply function.
- The excess costs of the renewables target are increasing in the level of the pre-existing subsidy for renewables. If this subsidy is very low, the renewables target may even be welfare-enhancing, due to the distortions generated by pre-existing taxes on fossil fuels.

- The highest excess costs in the sensitivity analysis are generated when both the initial cost disadvantage and the steepness of the supply curve are maximal. If both values are doubled with respect to the base case, policy excess costs increase to 31 %.
- A pre-existing subsidy for wind, which distorts the minimum-cost renewables mix, reduces the excess costs of the renewables target because, at the same time, it increases the endogenous renewables share.

While we scrutinise variations in the level and steepness of the renewables supply functions, other aspects of the model remain in the background. Some of them have a potentially significant impact on the costs of climate policy with or without a target for renewables as well. We close the paper with a list of factors that should be kept in mind when placing the results in the broader discussion of the pros and cons of a specific renewables policy.

- The cost curves for renewables we use are static, they do not include cost reduction through endogenous technological change. If there are significant learning-by-doing effects, high renewables shares in early periods would reduce the welfare costs of climate policy later on. This is not explicitly included in the model. However, one possible interpretation of flat supply curves in the sensitivity analysis is that they are a result of such endogenous technological change.
- We focus on two varieties of renewables: wind and biomass in electricity generation. These are quantitatively the most important options, but not the only ones. Sun and tidal/wave energy in the electricity sector as well as biofuels in transport and biomass for space heating are further potential contributors. We have them in the baseline, but they do not react in the policy counterfactuals, because we did not find suitable data for calibrating plausible supply functions. The effects of adding supply functions for these options would be similar to those of lowering the steepness of curves for existing options.
- We treat electricity from all sources as perfectly substitutable. This is legitimate for each point in time, but neglects the temporal aspect of electricity

supply. Wind (as well as sun) is an intermittent energy source, it is not always available, and its availability is not necessarily in line with energy demand (Heal, 2009). Again, this problem is to a certain degree taken care of by our sensitivity analysis. One possible interpretation of flatter/steeper supply curves is optimism/pessimism with respect to the cost development of electricity storage technologies.

- The baseline of WorldScan is taken over from the OECD Environmental Outlook and not generated by the model itself. This is common practice in CGE modelling, but may produce problems in the interpretation of the results. In particular, the baseline share of renewables (14.5 %) is not necessarily identical with the one that would have been generated by the model as an endogenous reaction based on the supply curves assumed. Given that the endogenous model reaction is restricted to wind and biomass supply, there is no simple way of closing the gap between calibration and simulation. A smaller share of renewables in the baseline would amplify all effects of the renewables target. For small changes in the baseline renewables share we expect changes in the results that are proportional to the difference between baseline share and target.

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Appendix

A.1 The role of pre-existing taxes on fossil fuels

There are two abatement options: reducing the use of fossil fuels and introducing renewables. Reduction of fossil fuels, a , comes with constant marginal cost,[23] $c_a = \alpha$, and linear total cost, $C_a = \alpha a$. In addition, option a leads to excess costs, caused by pre-existing taxes, γ.[24] Social costs of option a are therefore $c_a^s = \alpha + \gamma$. Introducing renewables, b, has increasing marginal cost, $c_b = \beta b$ and, correspondingly, quadratic total costs, $C_b = {}^1\!/_2 \beta b^2$. Implementing a reduction target A will generate an emission price α, at this price the supply of renewables is

$$b = \frac{\alpha}{\beta},$$

because private actors set the emission price equal to the marginal (private) abatement cost:

$$\alpha = \beta b. \tag{1}$$

The rest of the abatement is done by a at constant marginal costs of α.[25]

$$a = A - b = A - \frac{\alpha}{\beta}$$

The total social costs of abatement are then

$$C = C_a^s + C_b = (\alpha + \gamma)a + \frac{1}{2}\beta b^2.$$

As private and social costs of option a diverge, there are possible welfare gains from further regulation. A marginal increase of the renewables quantity is welfare enhancing.

$$\frac{dC}{db} = -(\alpha + \gamma)\frac{da}{db} + \beta b$$

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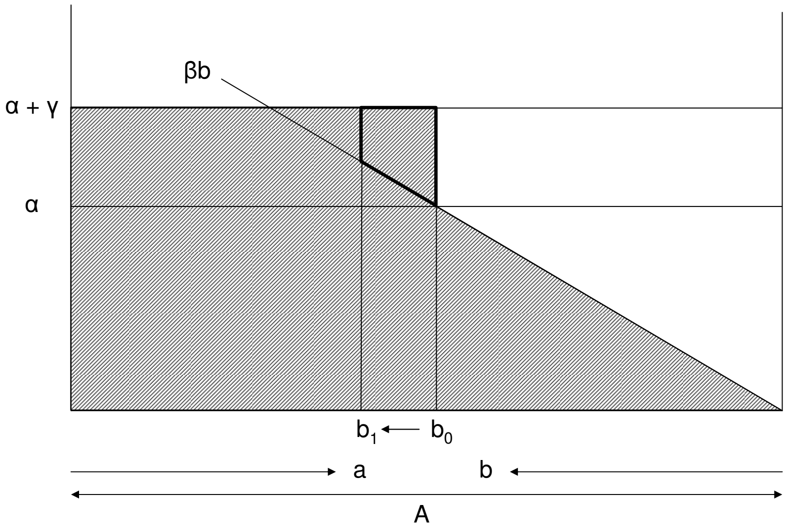
[23] The following generalises to the case where the marginal costs of a are increasing, but this complicates the calculations.

[24] This is an extreme simplification of the excess costs that result from taxation in general equilibrium. To model these costs accurately, a full general equilibrium model with utility function would be needed. This would destroy the simplicity of the example.

[25] We assume that A is sufficiently high so that reduction by reducing fossil fuels is necessary: $A > \alpha/\beta$.

Figure 14: Renewables target with pre-existing taxes



Observing $da = -db$ and $\alpha = \beta b$ (equation 1), this gives

$$\frac{dC}{db} = -\gamma < 0.$$

This is illustrated in Figure 14. The shaded area comprises the total social cost of abatement, which result from equating line βb with α. Moving the amount of renewables from b_0 to b_1 reduces the cost by the area with the bold borderline.

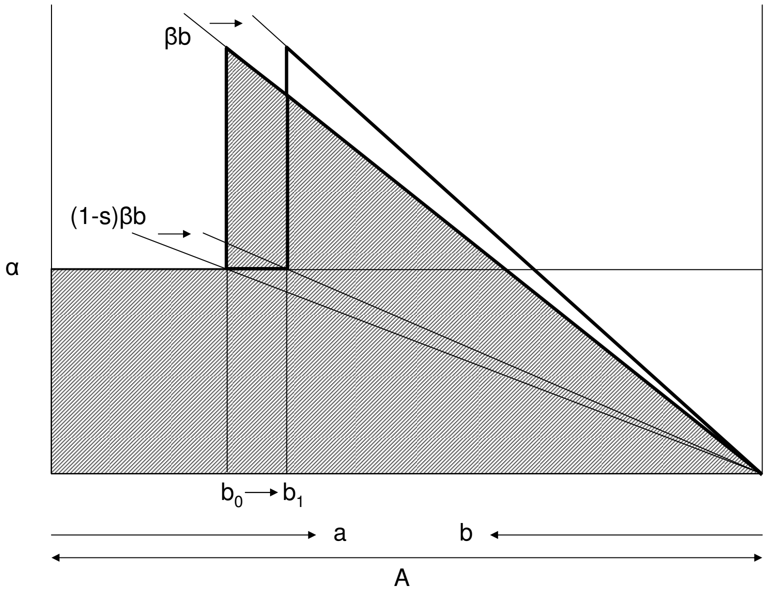
A.2 The role of a pre-existing subsidy for renewables

Consider once again the model of Appendix A.1. Now there are no excess costs for abatement option a, but an initial subsidy for renewables, s. Social marginal costs of renewables are still $c_b^s = \beta b$, but private costs are reduced to $c_b = (1 - s)\beta b$ by the subsidy.

Private abatement is governed by equalising private marginal abatement costs of both options:

$$\alpha = (1 - s)\beta b$$

Figure 15: Renewables supply with pre-existing subsidy



This results in a level of renewables that is higher than the optimal one:

$$b = \frac{\alpha}{\beta(1-s)} > \frac{\alpha}{\beta} = b^{\star}$$

Total social cost of abatement is

$$C = C_a + C_b^s = \alpha a + \frac{1}{2}\beta b^2$$

$$= \alpha\left(A - \frac{\alpha}{\beta(1-s)}\right) + \frac{1}{2}\beta\left(\frac{\alpha}{\beta(1-s)}\right)^2$$

$$= \alpha A - \frac{\alpha^2}{\beta(1-s)} + \frac{1}{2}\frac{\alpha^2}{\beta(1-s)^2}$$

The effect of a marginal increase in the steepness of the supply function for renewables, β, is

$$\frac{dC}{d\beta} = \frac{\alpha^2}{(1-s)\beta^2}\left(1 - \frac{1}{2(1-s)}\right)$$

This becomes negative (i.e. a welfare gain through a steeper supply curve) if $s > 0.5$.

The countervailing effects of a steeper supply curve are illustrated in Figure 15. With the original supply curve (βb), the subsidy brings the quantity b_0 into the solution. A steeper supply curve reduces this to b_1. This has two effects on the total social cost of abatement (the shaded area). On the one hand, the amount of renewables is reduced, which reduces the amount of subsidy to be paid and the amount of renewables that cause excess costs (the heavily bounded shaded area). On the other hand, each remaining unit of renewables has higher cost now (the heavily bounded triangle on top of the old supply curve). Which of these effects dominates depends on the parameter values. With a linear supply curve, the critical value of the subsidy (approximately the case of Figure 15), where the two effects precisely cancel out, is at $s = 0.5$.

A.3 Difference between partial and general equilibrium costs

The partial cost calculations in Sections 5.1 and 5.4 are an important benchmark for the plausibility of the range of the welfare costs in general equilibrium. However, they generate new interpretation challenges. How is it possible that partial costs more than double in the no-subsidy scenario (Section 5.4, relative to the scenario with subsidy in Section 5.1), but that the increase in welfare costs is much more moderate?

The relation between partial and general equilibrium costs is illustrated in Figures 16 and 17. Both figures contain the *marginal* costs of increasing the renewables share by one percentage point.[26] There are four curves in both Figures, two for each scenario (with and without pre-existing subsidy for additional wind energy). The curves labelled “partial” depict the partial costs as calculated in the main text: incremental quantities of renewables multiplied with their respective excess input costs compared to the fossil electricity mix. If we deduct the partial costs from the general equilibrium welfare effect, we obtain a residual “second-best” effect (labelled “sec. best” in the Figures). This second-best effect is negative (welfare losses are lower than partial costs), and it is decreasing (in absolute terms) in the level of the target. The fact that the resulting second-best costs are almost precisely the

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[26] These cost curves have been generated by running the model with gradually increasing targets and calculating the cost differences.

Figure 16: Partial and general equilibrium costs in the base case

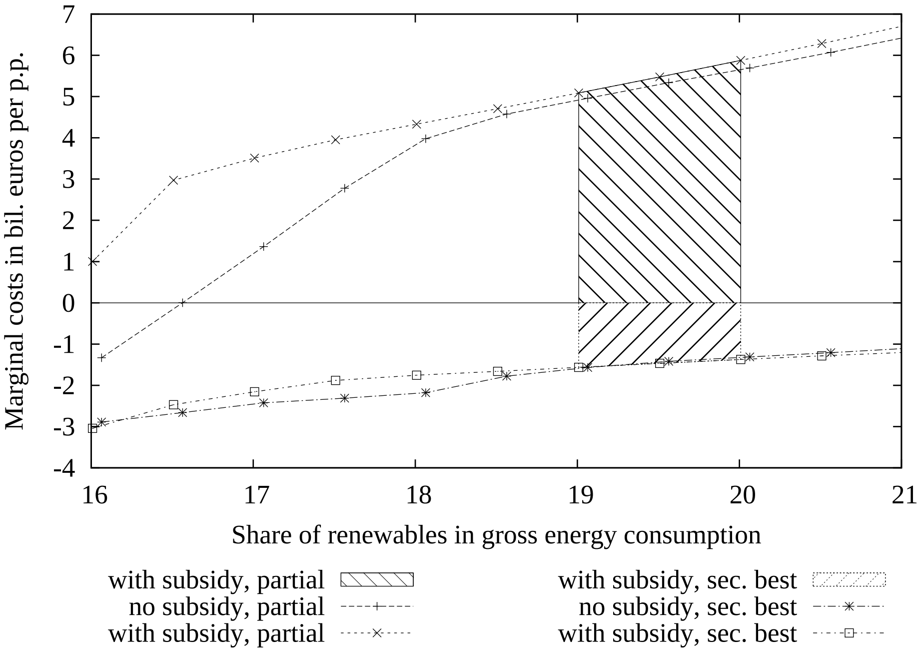
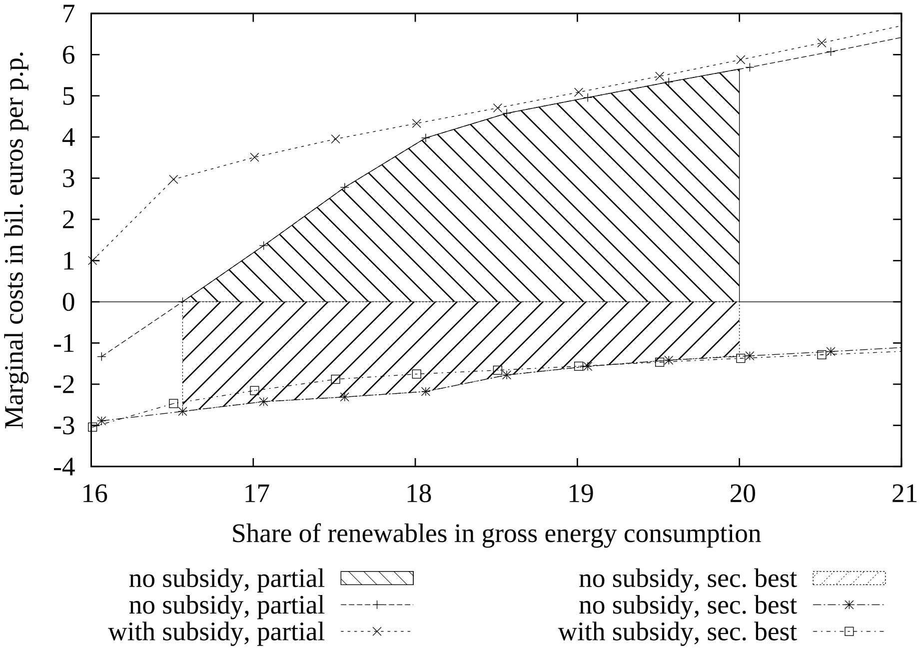


Figure 17: Partial and general equilibrium costs with no subsidy



same in both scenarios confirms that this is an actual model property, not simply an accounting residual.

If we take the integral over the marginal costs from the endogenous renewables share to the target, we obtain total excess costs. This is the shaded area in Figures 16 (for the scenario with subsidy) and 17 (for the scenario without). The area above the zero line (shaded downwards) counts as positive, the area below (shaded upwards) as negative. Figure 16 reproduces the cost calculations from Section 5.1. The partial cost area is €5.4 billion , the second-best area -2.4, resulting in a net welfare effect of €4 billion.

Figure 17 shows the situation of the partial cost calculation of Section 5.4. The partial cost area, €12.6 billion, is now more than twice as large as in Figure 16. However, the second-best area increases even more proportionally, because it is extended to lower levels of renewables, where second-best costs are higher (in absolute terms). Therefore the increase in welfare costs from Figure 16 to 17 is much smaller than the partial calculations suggest.