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Cost-effectiveness and Incidence of Renewable Energy Promotion in Germany

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Abstract

Over the last decade Germany has boosted renewable energy in power production by means of massive subsidies. The flip side are very high electricity prices which raises concerns that the transition cost towards a renewable energy system will be mainly borne by poor households. In this paper, we combine computable general equilibrium and microsimulation analysis to investigate the cost-effectiveness and incidence of Germany's renewable energy promotion. We find that the regressive effects of renewable energy promotion could be ameliorated by alternative subsidy financing mechanisms which achieve the same level of electricity generation from renewable energy sources.

Keywords: Renewable energy policy, feed-in tariffs, CGE, microsimulation

JEL classification: Q42, H23, C63

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1 Introduction

Germany has been a forerunner in the promotion of renewable energy over the last decade with the outspoken objective to achieve a share of renewable energy in gross power production of 35% by 2020 and of 80% by 2050. The central legislation in Germany's renewable energy policy is the Renewable Energy Sources Act – the so-called Erneuerbare-Energien-Gesetz (EEG; see BMWi (2014)). The core element of the EEG are technology-specific feed-in tariffs (FITs) that guarantee purchases of green power at fixed prices over longer periods. The FITs are combined with the system operators' obligation to provide connection to the grid and to warrant priority feed-in of electricity from renewable energy sources over electricity from conventional energy sources. The difference between FITs and the (lower) electricity market price is borne by the electricity consumers via the EEG reallocation charge (RAC). For reasons of international competitiveness, highly electricity-intensive industries are paying a reduced RAC. Over the last ten years the share of renewable energy in Germany's gross power production has increased from around 11% in 2006 to ca. 32% in 2015 – with rapid expansions especially in wind power, photovoltaic, and biomass. The flip side of the massive expansion of renewable power is the drastic increase of subsidy payments. From 2006 to 2014, the total subsidies almost quadrupled from 5.8 to roughly 21.5 billion Euros. As a consequence, the EEG surcharge on households' electric bills meanwhile amounted to more than 6 Euro cent/kWh, which is roughly a quarter of the average household electricity price in Germany (Bundesnetzagentur, 2015). The high cost burden has provoked an intense public debate on the cost-effectiveness and incidence of Germany's renewable energy policy. For assessing cost-effectiveness the key question is whether the subsidy scheme could be changed to achieve the same share of renewable power production at lower cost. With incidence the issue is how costs are spread across different households. In this paper we provide quantitative evidence on both the cost-effectiveness and incidence of Germany's renewable energy policy. We investigate how the cost-effectiveness of renewable energy promotion could be improved by switching to uniform as compared to differentiated FITs. Regarding cost incidence, we examine how the abolition of exemptions for electricity-intensive industries or a more fundamental shift towards value-added financing of green subsidies affect the burden across households. Clearly, in a broader economic perspective the efficiency and incidence of policy design are intertwined and potentially subject to trade-offs. For our quantitative assessment we use a numerical framework which combines a computable general equilibrium (CGE) model with a microsimulation (MS) model. The advantage of the CGE-MS combination is that we can analyse implications for economy-wide cost-effectiveness of policy reforms while at the same time provide a very detailed perspective on household incidence. The integrated modelling framework does not only

feature a rich representation of household heterogeneity but accounts for important inter-sectoral linkages and price-dependent market feedbacks across the whole economy. Another special feature of our modelling framework – owing to the requirements of technology-specific policy regulations in the electricity sector – is the bottom-up representation of discrete power generation technologies within the top-down CGE model following the seminal contributions by Böhringer (1998) and Böhringer and Rutherford (2008).

We find that phasing out the exemptions from the RAC on electricity prices for electricity intensive sectors would increase the cost-effectiveness of the EEG. Yet, replacing the RAC by increasing the value-added tax (VAT) on consumption goods would increase cost-effectiveness even further. The VAT financing would also attenuate the adverse incidence on the poorest households which are particularly hurt under the current policy design. Making FIT uniform across subsidised renewable technologies neither improves on cost-effectiveness nor on the regressive impacts of renewable energy promotion as long as the distortive RAC is in place.

So far, economic analyses of Germany’s renewable energy promotion largely focused on the implications of the EEG in the context of EU-wide climate policies. Taking CO₂ emission reduction as the major objective of renewable energy promotion, the EEG has been particularly criticised on the grounds of missing climate effectiveness. As a matter of fact, CO₂ emissions from the power sector and other energy-intensive industries in Germany and the rest of the EU are capped through an EU-wide emissions trading system – the so-called EU ETS. Massive subsidies to renewable power production will simply reallocate emissions across these EU-ETS sectors while the overall compliance cost to the EU-wide emission cap will rise due to costly CO₂ emission abatement from excessive expansion of renewable energies and too little abatement from other (cheaper) mitigation opportunities such as fuel switching from coal to gas or energy efficiency improvements (Böhringer et al., 2009; Frondel et al., 2010). Beyond inducing excess cost in climate policy, the EEG generates potentially undesired shifts in cost incidence across regions, industries, and technologies. The EEG lowers the demand pressure on the supply of emission certificates, which depresses the price for CO₂ emission allowances. Cross-region and cross-industry carbon ‘leakage’ then benefits countries that are importers of emission certificates (industries that purchase emission allowances) and hurts regions that are exporters of emission certificates (industries that sell emission allowances); likewise the most CO₂-intensive power technologies such as lignite-fired power plants gain a cost advantage at the expense of non-renewable technologies with lower CO₂ intensity such as gas power plants (Böhringer and Rosendahl, 2010). A more narrow cost-effectiveness perspective on the EEG – which is also adopted in the current paper – does not question renewable energy targets against the background of overlapping counterproductive regulation with the EU ETS. The major point for discussion is rather the re-design of renewable promotion

policy to make compliance with exogenous renewable targets less costly. In the absence of technology-specific market failures such as differential knowledge spillover or adoption externalities, economic efficiency suggests expansion of renewable power in a manner that marginal costs of green production across technologies are equalised. In practise, however, FITs as stipulated in the EEG vary depending on the technology. For instance, electricity generated from solar power gets remunerated with a much higher price than electricity generated from wind power. As a result, too much solar power is being produced and the expansion target for renewable energy is not implemented at least cost. A reform concept proposed by various expert commissions (Statistisches Bundesamt, 2011; Monopolkommission, 2013) is to select renewable power plants eligible for funding through a tendering procedure; an alternative mechanism would be to switch to tradable green certificates, a market-based regulatory system that is already in place in various other EU countries such as Belgium, Sweden, or Poland. Due to the sharp increase in the RAC over the last ten years, the distributional impacts of the EEG have gained more and more attention. According to a survey by the German Network Agency, German private consumers rank third in Europe in terms of electricity prices (Bundesnetzagentur and Bundeskartellamt, 2014). Average electricity prices for a three-person household have risen from 18.01 Cent/KWh in 2006 by more than 50% to 29.16 Cent/KWh in 2015 with the subsidies to renewable energy as the main cost driver. Since demand for electricity is very inelastic, one would assume that low-income households are burdened to a relatively higher degree than high-income households, yielding regressive effects of the German transition towards renewable energy.¹ The regressive effects on the expenditure side may be further strengthened when accounting who is likely to gain from the renewable energy subsidies on the income side: Payments emerging from the EEG's provisions accrue to owners of rooftop photovoltaic installations or shareholders in wind parks – these beneficiaries tend to belong to a more affluent segment of society. Neuhoff et al. (2013) use household micro data to explore the distributional implications of the EEG. Their analysis confirms that poorer households are more heavily affected and propose three options for alleviation: lump-sum transfers, a reduction of electricity taxes, or additional subsidies to improve energy efficiency. Grösche and Schröder (2013) show that the redistributive effects of the German FIT system persist for alternative inequality indices. Existing literature on the distributional effects of renewable promotion policies focuses largely on the expenditure (spending) side, i.e., how consumers are affected by policy-induced price changes given the way they spend their income. These studies tend to base the incidence analysis on exogenous price

¹Note that the fact that electricity-intensive manufacturing companies have to pay only a reduced EEG RAC so as to remain competitive leads to an even greater cost burden for residual electricity consumers.

changes or use simple input–output models to gauge the direct and indirect impacts of policy intervention. Such analyses remain, however, an incomplete attempt with respect to assessing the full distributional impacts as they (i) suppress behavioural responses of consumers, (ii) assume away the role for price-dependent market interactions, and (iii) do not take into account how (various components of) consumer income may be affected. To our best knowledge of the existing literature, our paper is the first that combines an economy-wide efficiency perspective with a detailed incidence analysis of the German EEG. A comprehensive and coherent impact assessment is warranted through the combination of computable general equilibrium analysis with microsimulation analysis.

The remainder of this paper is organised as follows. In Section 2, we describe the numerical framework underlying our quantitative analysis. In Section 3, we lay out the policy scenarios. In Section 4 we present and discuss our simulation results. In Section 5, we conclude.

2 Numerical framework

To assess the cost-effectiveness and incidence of Germany’s renewable promotion strategy, we couple a CGE model calibrated to German national input–output accounts with a MS model of German household income and expenditure. In the following, we describe the CGE and MS components of our modelling framework separately and also lay out the specific data requirements.

2.1 Computable general equilibrium (CGE) model

2.1.1 Model summary

Our CGE model features a standard static small-open economy representation of the German economy. The CGE approach accommodates counterfactual ex-ante comparisons, assessing the outcomes of changes in policy design against a business-as-usual reference without the EEG in place. CGE models are rooted in general equilibrium theory combining assumptions on the optimising behaviour of economic agents with the analysis of equilibrium conditions: producers employ primary factors and intermediate inputs at least cost subject to technological constraints; consumers with given preferences maximise their well-being subject to budget constraints. The CGE approach provides a comprehensive microeconomic representation of price-responsive market interactions and income-expenditure circles. CGE analysis quantifies the changes in key macroeconomic indicators (e.g. gross domestic product) as well as sector-specific economic activities (e.g. output, export, import) as compared to a business-as-usual situation. CGE analysis does not only deliver positive information on policy-induced changes in key economic

indicators at the macroeconomic level, at the sector level and at the household level; CGE analysis also allows for normative rankings of alternative policy options to achieve some given policy target such as the promotion of renewable energy.

Below we provide a non-technical description of key model features. A detailed algebraic exposition of the economic logic is provided in previous publications such as Böhringer et al. (2005) or Böhringer and Rutherford (2008).

PRODUCTION TECHNOLOGIES AND FIRM BEHAVIOUR. Industries produce gross output (Y) using primary inputs labour (L) and capital (K) and intermediate inputs of energy (E) and materials (M). Intermediate inputs are composed of a domestically produced variety and imports.

We employ nested constant-elasticity-of-substitution (CES) cost functions to characterise price-responsive trade-offs across inputs in production. Fig. 1 provides a diagrammatic representation of the nesting structure where we refer to inputs with their input prices.² The elasticities of substitution that govern how easy on commodity can be replaced by another in the production process are denoted with σ . In the bottom-level nest, labour and capital are combined in a value-added nest. Value-added is then combined with energy in a CES nest that represents a value-added–energy composite. In the top-level nest, a composite of intermediate material inputs trades off against the value-added–energy composite at a constant-elasticity-of-substitution. The composites of energy and material in itself are again CES aggregates of various energy or material inputs. All industries except for fuel resource extraction and electricity generation are characterised by constant-returns-to-scale production functions.

In the production of fossil fuels, all inputs, except for the sector-specific fossil fuel resource, are aggregated in fixed proportions. This aggregate trades off with the sector-specific fossil fuel resource at a constant elasticity of substitution.

Given the paramount importance of the electricity sector with respect to the promotion of renewable power generation the standard top-down representation of power production through a CES production (cost) function is replaced by a bottom-up activity analysis characterisation where several discrete generation technologies produce electricity by combining technology-specific capital with inputs of labour, fuel, and materials. Electricity from different technologies is treated as a homogeneous good. Power generation technologies respond to changes in electricity prices according to technology-specific supply elasticities (see Rutherford (2002) for details on the calibration technique). In addition, lower and upper bounds on production capacities can provide explicit limits to the decline and the expansion of technologies.

²For example, the Armington price for intermediate input i is denoted PA_i .

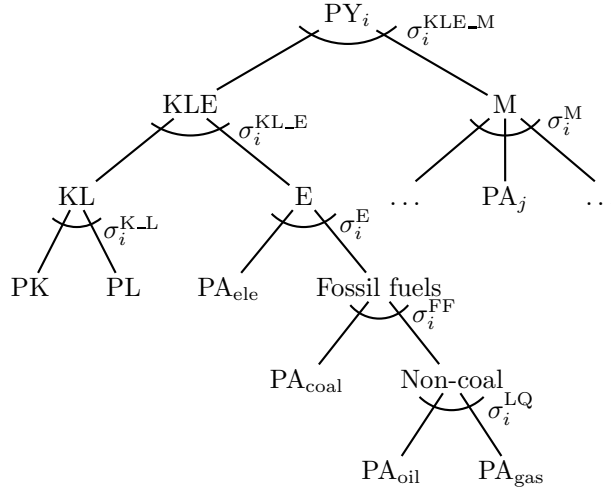


Figure 1: Cost function in production

Fossil fuel resources and generation capacity to power technologies are treated as specific capital in fixed supply, whereas capital otherwise is assumed to be perfectly mobile across sectors; likewise labour can move freely across sectors. Firms operate in perfectly competitive markets and maximise their profits by selling their products at a price equal to marginal costs.

PREFERENCES AND HOUSEHOLD BEHAVIOUR. Final consumption demand is determined by a representative agent who maximises welfare subject to a budget constraint with fixed savings which determines investment demand. The representative household receives income from net factor earnings and government transfers. The disposable income is then spent across consumption categories at given prices subject to CES preferences where the different consumption categories are traded off at a constant elasticity of substitution. Each consumption category consists of goods produced by industrial sectors.

GOVERNMENT. The government collects taxes to finance transfers and the provision of a public good. The public good is produced with commodities purchased at market prices. Across all policy simulations the level of public good provision is kept constant in order to assure a meaningful cost-effectiveness analysis without the need to trade off private consumption and government (public) consumption. By default, the equal-yield public good provision is warranted through lump-sum transfers between the government and households.

INTERNATIONAL TRADE. In international trade, Germany is treated as small relative to the world market. That is, we assume that changes in German import and export volumes have no effect on its terms of trade. Domestic and foreign products are distinguished by the Armington assump-

tion of product heterogeneity (Armington, 1969). On the import side, domestic goods and imported goods of the same variety are combined to a so-called Armington composite that enters intermediate and final demands. On the export side, goods destined for domestic and international markets are treated as imperfect substitutes, produced subject to a constant elasticity of transformation. We impose a constant trade balance with respect to the rest of the world, accounting for an exogenously specified net trade surplus which is warranted through an endogenous real exchange rate.

2.1.2 Data

As is customary in applied general equilibrium analysis, benchmark quantities and prices – together with exogenous elasticities – are used to calibrate the model. They determine the free parameters of the functional forms that capture production technologies and consumer preferences.

We use the input–output table of the German federal statistical office for the year 2006 as the central data source for model calibration. The choice of 2006 as the base-year for model calibration is motivated by the fact that renewable energy subsidies under the EEG started to become quite substantial from 2006 onward. The first quadrant of the input–output table reports intermediate inputs for each sector. The second quadrant provides information on final demand components private and public consumption, investment, inventory changes and exports. Factor payments to labour and capital (combined with profits in the row ‘operating surplus’) are included in the third quadrant which also reports the inflows of foreign goods and services to each production sector. Output by production sector is linked to consumption by private households in terms of consumption expenditure categories through the Z-matrix (in German: the so-called ‘Konsumverflechtungstabelle’). The electricity sector is decomposed into discrete power generation technologies according to technology-specific production shares provided by AG Energiebilanzen e.V. (2016) and input cost shares provided by Wissel et al. (2008).

Elasticities of substitution for the input structure sketched in Figure 1 are chosen in accordance to empirical estimates by Koesler and Schymura (2012) and Steinbuks and Narayanan (2015). The elasticities of substitution in fossil fuel sectors are calibrated to match exogenous estimates of fossil-fuel supply elasticities (Graham et al., 1999; Krichene, 2002). The price elasticities of electricity supply by technologies are calibrated to match the changes in power generation shares across technologies following the massive subsidies to renewables over the period between 2006 and 2014 (see scenario DIFFRACX in Section 3).

Table 1 provides an overview of sectors, consumption categories and power generation technologies that are explicitly represented in our CGE model.

Table 1: Overview of sectors, consumption categories, and power generation technologies

Set	Elements
Sectors ($i \in I$)	
<i>Fossil fuel supply</i>	Crude oil (cru), Coal mining(coal), Natural gas (gas)
<i>Electricity</i>	Electric power generation (epg), Transmission & distribution (ele)
<i>Production sectors</i>	Manufacturing (man), Energy-intensive sectors (ein), Agriculture and food (agr), Other mining (min), Services (ser), Transport (trp), Refined oil products (oil)
Consumption categories ($c \in C$)	Food, Housing, Electricity, Heating, Transport, Education and leisure, Other non-durable goods and services, Durables
Electricity generation technologies ($et \in ET$)	Hydro, Gas, Nuclear, Solar, Wind, Biomass

2.2 Microsimulation (MS) model

The core of the microsimulation model is the well established Almost Ideal Demand System (AIDS) proposed by Deaton and Muellbauer (1980). The micro data ‘Einkommens- und Verbrauchsstichprobe’ (EVS) is used to compute the parameters from the AIDS which are used to simulate demand responses of households. As is the case for the representative household in the CGE model, each household in the MS model is represented by their fixed factor endowments from which they receive income, their fixed savings decision, and their spending of disposable income across consumption categories of the model.

2.2.1 Model summary

The AIDS assumes an expenditure function $e(\vec{p}, u)$ which is homogeneous of degree one in prices³ and from which the following system of budget share can be obtained after applying Shephard’s lemma:

$$\theta_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i \log \frac{m}{P}, \quad (1)$$

³The estimated parameters follow the standard constraints for homogeneity $\sum_i \alpha_i = 1$ and $\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = \sum_i \beta_i = 0$.

where θ_i , p_i , m denote expenditure shares, commodity prices and total expenditures. P is a price index given by

$$\log P = \alpha_0 + \sum_i \alpha_i \log p_i + \frac{1}{2} \sum_{i,j} \gamma_{i,j} \log p_i \log p_j, \quad (2)$$

In our empirical specification, the parameters $\gamma_{i,j}$ and β_i are specific for each of seven household groups. The groups discern between households of different size and age. Moreover, α_i is allowed to change across dwelling and demographic characteristics (see Blundell et al., 1993). The system is then estimated employing the Seemingly Unrelated Regression (Zellner, 1962). The estimated parameters related to price and income changes are statistically significant and displayed in the Appendix in Table 12.⁴ Regarding the aggregation categories used in the demand system, we create the commodity groups as described in Table 11.⁵ Changes in commodity prices and income simulated by the CGE model are passed to the AIDS system through the terms p_i and m . The equilibrium prices are used to estimate P as defined in equation (2). These values are then used to compute our metric of equivalent variation (EV) which in analogy to Creedy and Sleeman (2006), is derived as follows:

$$\frac{EV}{\bar{m}} = \left(\frac{\bar{P}}{\bar{m}} \right) \exp \left[\prod_i \left(\frac{\bar{p}_i}{p_i} \right)^{\beta_i} \log \left(\frac{m}{P} \right) \right] - 1, \quad (3)$$

where \bar{p}_i and \bar{m} are the reference price levels and total expenditure. Moreover, we use Atkinson's index (Atkinson, 1970) to quantify the trade-off between efficiency and equity (e.g., mean equivalent income and its distribution across households) which is defined as follows:

$$\text{Social Welfare} = \underbrace{\frac{\sum_h (Y_{\text{no-policy},h} + EV_h) \sqrt{\text{hsize}_h}}{\sum_h \text{hsize}_h}}_{\text{Mean equivalent income (MEI)}} \times (1 - A\epsilon), \quad (4)$$

where $Y_{\text{no-policy}}$ is total household expenditure in the no-policy situation (in our case the base-year equilibrium), hsize is household size, and $A\epsilon$ is Atkinson's inequality index at a given level of the inequality aversion parameter ϵ (see e.g. King, 1983).

2.2.2 Data

The AIDS is estimated using the “survey of income and expenditure (EVS)” for Germany which provides information on expenditure across different

⁴For the econometric estimation, we follow standard practise by approximating price index P by using the Stone index.

⁵We also estimated own price and income elasticities for these commodities. They are statistical significant and consistent with economic theory. The estimates are available upon request for interested readers.

commodities, income, and other socioeconomic variables. The survey is carried out every five years. We use the waves 1993, 1998, 2003, 2008 and 2013 for the econometric estimation and only the wave 2008 (closest to 2006, the year the input-output table for the CGE model refers to) for the microsimulation exercise. Regarding prices, we use Lewbel (1989)'s methodology to obtain household specific prices by combining the micro data and prices reported by the German Statistical Office. Table 10 in the Appendix provides mean and standard deviation of the variables used in the estimation.

2.3 Linkage of CGE and MS models

The coupling approach follows the decomposition method by Rutherford and Tarr (2008). It uses the CGE model which represents households by one single representative household in order to evaluate impacts of given policies on market prices for consumer goods and production factors. The MS model then takes these prices as given and calculates first household income and then household consumption at the given prices. The representative household in the CGE model is then recalibrated such that it reproduces aggregate consumption according to the MS model at present prices. This creates new imbalances in the markets for the consumption goods. By repeatedly resolving the top-down model and reevaluating the MS model at new market prices the two models converge the solution of the overall model.

In order to achieve a tight link between the CGE model and the MS model, we need the aggregate incomes and consumption demands of households in the MS model to agree with the corresponding numbers in the CGE model. The survey data used in the MS model comes with statistical weights that indicate how many of Germany's households one household in the survey represents. This lets us determine aggregate consumption and income from survey data but this will not agree with national accounts in the Z-matrix. To achieve the required match, we scaled up households' total expenditures from the survey to match total household expenditure according to national accounts. In order to cleanly implement the AIDS, it is imperative that we leave expenditure shares as they are in the survey. Thus, differences in national household expenditures on a commodity basis have to be compensated in the CGE model. We shifted the residual demands to government consumption to achieve this.

On the income side, we scaled capital and labour income in the MS model by factors uniform across all households. Lacking information about savings from the survey, we distribute saving decisions among households in proportion to their capital income. The residual between expenditure, savings, and factor income was then allocated to government transfers.

3 Scenarios

The reference scenario for our economic impact assessment is established by the design of Germany’s renewable promotion policy as mandated under the EEG: (i) there are FITs that vary substantially across renewable technologies, and (ii) the difference between the electricity market price and the technology-specific FITs is financed by a RAC across electricity consumers with electricity-intensive industries paying only a fraction of the nominal RAC.⁶

In our simulation analysis we investigate how the cost magnitude and cost distribution of renewable promotion policy change as we change the EEG prescriptions along two dimensions. The first dimension refers to the cost-effectiveness of renewable subsidies. Instead of providing differentiated FITs,⁷ one could postulate uniform subsidies in order to equalise marginal cost of renewable expansion across technologies. The second dimension reflects concerns on distributional impacts of the RAC: To avoid discrimination across electricity consumers, one would at least postulate electricity-intensive sectors to pay the full RAC; alternatively, one might abolish the RAC and switch to a financing of the renewable energy subsidies by broader based value-added taxation.

We distinguish renewable promotion policy scenarios with respect to tariff design (differentiated (labelled DIFF-) versus uniform (labelled UNI-) and the financing of subsidy payments (reallocation charge with exemptions (labelled -RACX), RAC without exemptions (labelled -RAC), or VA tax (labelled -VAT)). In total, we obtain six scenarios with acronyms as provided in Table 2. Note that scenario DIFFRACX most closely reflects the current design the EEG and represents the reference against which we try to find improvements.

Table 2: Scenario overview

	differentiated RAC	uniform RAC	VA tax
uniform FIT	UNIRACX	UNIRAC	DIFFVAT
differentiated FIT	DIFFRACX	DIFFRAC	UNIVAT

Across all renewable promotion scenarios, we keep the electricity generation from renewable energy sources at the level of scenario DIFFRACX to accommodate a coherent cost-effectiveness analysis of alternative policy designs. The economic impacts of renewable promotion are measured against

⁶The EEG allows firms that use more than 1 GWh of electric power per annum and spend more on electricity than 14 percent of their value-added to apply for reduced rates. Annual electricity demand beyond 1 GWh is then charged a lower RAC with further reductions for demand beyond 10 GWh and 100 GWh.

⁷In 2014 the average FITs amounted to roughly 34 Euro cents per kWh for photovoltaics, 20 Euro cents per kWh for biofuels, and 13 Euro cents per kWh for wind power.

a no-policy scenario which we take as the 2006 base-year equilibrium before the massive penetration of renewable energy into the power system started.

In the our scenario analysis, we abstain from any other policy regulations – such as the EU ETS – but focus in our assessment on the impacts of renewable energy promotion.

4 Results

We start the discussion of simulation results with electricity market effects. Changes in electricity prices induced by alternative policy design constitute a driver of economic impacts at the sector level – in particular for electricity-intensive industries. We then assess the cost-effectiveness of policy reforms from the perspective of a representative agent neglecting any details and concerns on cost distribution. The incidence of renewable energy promotion policies across different households is discussed in Section 4.4.

If not mentioned otherwise, all results are reported in percentage change from the no-policy benchmark.

4.1 Electricity market effects

Table 3 shows the effects of policies on electricity generation. The producer price of electricity for conventional power sources corresponds to the market rate for electricity generation, while the renewable power sources wind, biomass, and photovoltaics (PV) receive FIT payments that are higher than that. Overall power generation changes little between the different scenarios that finance the FIT with a RAC. Only if the FIT is financed by a value-added tax, does electricity generation increase due to a demand side effect from lower consumer prices. Consumer prices of electricity vary considerably in scenarios in which RAC has exemptions (UNIRACX and DIFFRACX). The average RAC rate that different electricity consumers pay are given in the fourth section of Table 3. The total volume of RAC payments necessary for reaching the targeted renewable energy sources (RES) generation in electricity generation is given in the last row and increases somewhat for scenarios in which the FIT is uniform.⁸

4.2 Industry-specific effects

The exemptions to the RAC have been made in order to preserve international competitiveness of electricity-intensive industries. Our results indeed indicate that abolishing the exemptions would indeed hurt those industries (see Table 4): They produce less and export less under scenarios DIFFRAC

⁸Fischer (2010) shows that promotion of renewable energy sources in electricity generation can have ambiguous effects on electricity prices and that the effects depend on the price elasticities of supply across technologies.

Table 3: Impacts on electricity production

	diffRACX	uniRACX	diffRAC	uniRAC	diffVAT	uniVAT
Producer price of electricity [EUR per MWh]						
Market rate	42.3	41.8	42.6	42.0	50.7	50.6
Wind	128.0	214.5	127.9	214.4	131.2	220.0
Biomass	201.0	214.5	200.9	214.4	206.1	220.0
PV	336.0	214.5	335.8	214.4	344.5	220.0
Generation [TWh]						
Conventional	502.3	499.0	501.7	498.3	553.5	552.9
Wind	56.5	61.9	56.5	61.9	56.3	61.8
Biomass	42.7	43.8	42.7	43.8	42.5	43.5
PV	35.5	29.1	35.5	29.1	35.3	28.8
Other RES	23.3	23.3	23.4	23.3	24.0	23.9
Consumer price of electricity [EUR per MWh]						
Coal mining	107.5	107.7	153.6	157.4	106.2	106.1
Gas	129.2	131.1	153.6	157.4	106.2	106.1
EIS	136.7	139.2	153.6	157.4	106.2	106.1
Other mining	127.1	128.8	153.6	157.4	106.2	106.1
Other industries	156.7	160.7	153.6	157.4	106.2	106.1
Households	160.0	164.3	153.6	157.4	106.2	106.1
Average RAC [EUR per MWh]						
Coal mining	14	15	59	64		
Gas	35	38	59	64		
EIS	43	46	59	64		
Other mining	33	36	59	64		
Other industries	63	68	59	64		
Households	66	71	59	64		
RAC payments [Billion EUR]						
National	22.0	23.3	22.0	23.2		

and UNIRAC than under scenarios DIFFRACX and UNIRACX. But it is the scenarios that finance the FIT through an increase in value-added taxes that would constitute the biggest boon for the electricity-intensive industries. Their output in these scenarios shrinks only by little, if at all, and their exports even increase compared to the no-policy scenario. Sectors react to changes in electricity prices by adjusting their electricity intensity⁹ (see fourth part of Table 4). This results in lower electricity intensities in scenarios that finance the FIT through a RAC. If the FIT is financed through a value-added tax, electricity intensities tend to increase compared to the no-policy case.

Table 4: Impacts on industries (% change from no-policy).

	diffRACX	uniRACX	diffRAC	uniRAC	diffVAT	uniVAT
Output						
Coal mining	-15.48	-16.27	-19.71	-20.77	-2.97	-3.06
Natural gas	-5.48	-5.77	-6.56	-6.92	-0.53	-0.48
EIN	-6.23	-6.72	-10.47	-11.18	0.59	0.59
Other mining	-6.15	-6.66	-12.19	-13.03	0.80	0.80
Electricity	0.33	-0.31	0.31	-0.34	10.50	10.39
Other industries	-6.15	-6.66	-12.19	-13.03	0.80	0.80
Imports						
Coal mining	-31.95	-33.38	-29.31	-30.59	-6.92	-7.16
EIN	-1.66	-1.77	-2.05	-2.17	-0.08	-0.08
Other mining	-4.34	-4.65	-5.99	-6.38	0.17	0.18
Electricity	-53.94	-56.46	-53.27	-55.76	-3.62	-4.23
Other industries	-0.53	-0.59	-0.93	-1.01	0.23	0.24
Exports						
Coal mining	2.49	2.58	-10.02	-10.83	0.74	0.78
EIN	-7.82	-8.45	-13.36	-14.26	0.82	0.83
Other mining	-7.42	-8.08	-16.41	-17.53	1.25	1.25
Electricity	69.02	72.80	67.55	71.17	22.30	22.66
Other industries	-0.34	-0.34	0.58	0.63	-0.34	-0.35
Electricity intensity of output						
Coal mining	-3.87	-4.09	-5.02	-5.31	-0.71	-0.73
Natural gas	-1.89	-1.99	-2.25	-2.36	-0.19	-0.18
EIN	-11.10	-11.94	-16.27	-17.31	1.42	1.47
Other mining	-7.40	-8.03	-15.55	-16.54	1.32	1.38
Other industries	-4.55	-5.93	-4.23	-5.59	10.65	10.15

4.3 Cost-effectiveness

While sector performance is an important indicator to the economic impact assessment of policy changes, it provides just a partial perspective. The more general (equilibrium) view investigates the economic implications across households for ranking policy scenarios. Households are affected on

⁹Electricity intensity is the electricity consumption per € of output.

the income side through changes in wage and capital earnings (reflecting policy-induced shift in the marginal productivity of primary factors) and on the expenditure side through change in price for consumption goods. Table 5 provides an overview of policy-induced changes in consumer prices and factor remuneration. It can be seen that if the FIT is financed by a RAC, consumer prices for electricity go up considerably while other prices slightly drop. If the FIT is financed by a uniform value-added tax, this tax tends to increase consumer prices almost uniformly, while the FIT depresses consumer electricity prices somewhat compared to the no-policy case. On the income side, average rents on capital resources and technology specific factors increase (especially so for scenarios where the FIT is financed through a VAT) while wages decrease for scenarios with a RAC and increase (but less so) for scenarios that finance the FIT through a value-added tax.

Table 5: Impacts on consumer and factor prices (% change from no-policy)

	diffRACX	uniRACX	diffRAC	uniRAC	diffVAT	uniVAT
Consumption goods						
Food	0.06	0.06	-0.03	-0.04	1.86	1.96
Education and leisure	-0.30	-0.32	-0.46	-0.50	1.90	2.00
Electricity	46.68	50.64	40.85	44.27	-0.83	-0.83
Heating	-1.21	-1.26	-1.09	-1.13	1.69	1.81
Other housing	-0.36	-0.39	-0.53	-0.57	1.90	2.01
Transportation	-0.19	-0.21	-0.33	-0.35	1.90	2.01
Other goods and services	-0.30	-0.32	-0.46	-0.49	1.90	2.01
Durable goods	-0.15	-0.17	-0.27	-0.29	1.90	2.01
Income factors						
Wages	-0.82	-0.91	-0.95	-1.05	0.26	0.25
Capital rents	-0.61	-0.62	-0.80	-0.82	-0.19	-0.16
Resource rents	-14.55	-15.27	-16.40	-17.21	-1.83	-1.77
Technology rents	72.42	83.29	72.70	83.57	102.23	114.68
Average rents	0.45	0.60	0.26	0.40	1.41	1.63

The overall effect on the representative German households in terms of equivalent income (EI)¹⁰ can be found in the fourth column of Table 6. This measure indicates that the German population bears the lowest cost of renewable energy promotion for the case that a uniform FIT is financed through a value-added tax – thus scenario UNIVAT turns out to be the most cost-effective design across our policy variants for promoting renewable energy in power production. As expected, abolishing exemptions in the current RAC is increasing cost-effectiveness of renewable energy promotion. But making FIT uniform across promoted technologies unexpectedly decreases

¹⁰Equivalent income denotes the amount of money that households would need to afford a scenario's utility level of consumption at prices of the no-policy scenario.

Table 6: Inequality and social welfare changes estimated with expression (4) and the inequality aversion parameter $\epsilon = 1.2$.

	AI	Δ AI (%)	EI	Δ EI (%)	SW	Δ SW (%)
diffRACX	0.109	1.251	1231.715	-1.601	1097.599	-1.749
uniRACX	0.109	1.469	1231.176	-1.644	1096.829	-1.818
diffRAC	0.109	1.238	1233.005	-1.498	1098.765	-1.645
uniRAC	0.109	1.454	1232.566	-1.533	1098.088	-1.706
diffVAT	0.107	-0.440	1246.378	-0.430	1112.932	-0.377
uniVAT	0.107	-0.339	1247.109	-0.371	1113.448	-0.331

Atkinson Index (AI), Equivalent income (EI), Social Welfare (SW)

cost-effectiveness as long as tariffs are financed by a RAC. While promoting RES for electricity generation with FITs is most efficient if the tariffs are uniform across technologies, it also entails a decrease in the market rate for electricity generation and an increase in the volume of FIT payments (see first and last rows in Table 3) compared to the differentiated FIT. Because the FIT is financed using a distortionary mark-up on consumer prices of electricity, this entails additional efficiency costs. It can be observed that while electricity generation contracts slightly, net exports of electric power increase and thus domestic electricity consumption decreases. From the perspective of the representative households' welfare, the more expensive electricity does more harm than the rents earned in electricity generation do good.

The cost-effectiveness analysis so far has been based on a mean EI metric for the representative household taking a Benthamite perspective which neglects the distribution of costs across household types with different income levels. Modifying mean EI by the Atkinson index yields a social welfare function that values gains in EI by poor households higher than it does gains in EI of rich households depending on the assumed degree of inequality aversion. The first column of Table 6 gives the Atkinson index for an inequality aversion parameter $\epsilon = 1.2$ ¹¹ and column six displays the resulting change in social welfare (SW) vis-à-vis the no-policy scenario. Note that social welfare and EI have similar relative changes (see columns four and six of Table 6) and (incidentally) their ranking for the analysed scenarios is the same. This is due to the fact that the Atkinson index only changes by small amounts between the scenarios that use a RAC for financing the promotion of RES. If the FIT is financed through a VAT, the Atkinson index actually improves against the no-policy scenario, which makes the most cost-effective scenario UNIVAT also most desirable from a distributional perspective.

¹¹Creedy and Sleeman (2006) use $\epsilon = 0.2$ and $\epsilon = 1.2$. Our choice of ϵ seems to be a reasonable upper bound for the inequality aversion parameter, even though Pirttilä and Uusitalo (2010) suggest that under certain circumstances, even higher values of ϵ may apply.

4.4 Cost incidence across households

Our combined CGE-MS model puts us in the comfortable situation of having welfare functions for each household included in the MS model. Thus we can not only evaluate the Atkinson index to account for inequality aversion, but we can analyse how different household types are affected by alternative policy options. Table 7 displays the estimated mean EV relative to total expenditure across expenditure quartiles. Comparison of the first and fourth quartile indicates that when the FIT is financed through a RAC, poor households suffer disproportionately more. For scenarios that finance the FIT through an increase in VAT, the situation for the poorest quartile actually improves compared to the no-policy scenario, which is in line with the decrease in the Atkinson index discussed above.

Table 7: Equivalent variation estimates in % of total expenditure

	1st quartile	2nd quartile	3rd quartile	4th quartile
diffRACX	-1.87	-1.81	-1.56	-1.15
uniRACX	-1.97	-1.87	-1.58	-1.13
diffRAC	-1.76	-1.70	-1.46	-1.05
uniRAC	-1.85	-1.76	-1.47	-1.02
diffVAT	0.02	-0.43	-0.63	-0.44
uniVAT	0.06	-0.38	-0.56	-0.35

In order to assess how different policy scenarios affect vulnerable households with different income sources, Table 8 shows average EV for households where the household head does not have a job¹² (column 2) or is a blue-collar worker (column 3). The fact that wage income fares worse than capital and resource rents under the policy scenarios causes employed working age households to lose the highest share of their income. On the expenditure side, tenants and occupants of old dwellings may be more vulnerable to increases in energy costs because the buildings they occupy tend to be less energy efficient (see e.g. Rehdanz, 2007). The results in columns four and five suggest that tenants are indeed vulnerable to the policies analysed here. But the fact that the decrease in electricity prices in scenarios DIFFVAT and UNIVAT brings less relief to these two types than to other households suggests that income effects are at least as important for them as are expenditure effects.¹³

¹²This includes disabled, retired, and unemployed householders.

¹³We also estimate mean EV across households with different composition. In addition, we compute the relative frequency of households with the largest and smallest welfare losses. The results are displayed in Table 9 in the Appendix.

Table 8: Monthly equivalent variation for vulnerable households (€)

	Jobless	Blue-collar Workers	Tenants	Occupants of old dwellings
diffRACX	-20.64	-38.73	-30.54	-24.30
uniRACX	-21.08	-41.22	-32.36	-22.53
diffRAC	-19.14	-36.37	-28.60	-22.47
uniRAC	-19.47	-38.69	-30.27	-20.52
diffVAT	15.42	-17.27	-17.58	-21.77
uniVAT	17.37	-17.88	-18.09	-18.86

5 Conclusions

We have coupled a microsimulation model that employs the Almost Ideal Demand System (AIDS) for representing household demand with a computable general equilibrium (CGE) model to investigate the cost-effectiveness and incidence of renewable energy promotion policies in Germany.

Our simulation analysis indicates substantial scope for improving on the cost-effectiveness of Germany’s policy regulation. While phasing out exemptions from the reallocation charge (RAC) would reduce the economy-wide costs of the German EEG by around 5 percent, replacing the RAC by increased value-added taxes would cut the EEG’s efficiency cost by more than two thirds. Making the FIT uniform across promoted technologies, surprisingly, does not have the expected beneficial effects in the context of a RAC. This is due to increasing inefficiency of rising RAC rates under such scenarios.

From a distributional perspective, replacing the RAC by higher value-added taxes also turns out to be attractive since the poorest households benefit. The Atkinson index (a measure of social welfare that includes inequality across the nation) also points to a VAT based subsidy financing as the most favourable policy design among those investigated in this paper.

Our analysis looks at the efficiency cost of introducing targets for electricity generation from renewable energy sources (RES) at given world market prices for fossil fuels without accounting for potential benefits from such promotion of RES. Our counterfactual scenarios keep the power generation by RES constant in order to warrant a coherent cost-effectiveness comparison. Our analysis cannot, however, judge if it is worthwhile to have a RES target for the national power sector in the first place. The economic compliance cost to such targets must be balanced against potential economic benefits arising from increased energy security or spillover effects from technology innovation.

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A Additional results

Table 9: Monthly welfare losses and portion of household with larger and smaller losses (ranked equivalent variation)

	Mean EV (€)	Largest losses (%)	Smallest losses(%)
Scenario: diffRACX			
Single +65	-15.65	5.66	37.06
Single no children	-20.24	21.36	22.36
Single with children	-20.13	9.81	14.34
2 adults +65 no children	-20.55	16.66	15.52
2 adults no children	-29.39	47.00	10.61
2 adults one child	-27.46	38.83	8.86
2 adults two children	-25.31	34.29	9.99
Scenario: uniRACX			
Single +65	-15.96	5.40	36.88
Single no children	-21.20	22.49	21.75
Single with children	-21.34	9.99	13.14
2 adults +65 no children	-20.70	15.57	17.27
2 adults no children	-30.60	46.89	11.26
2 adults one child	-28.72	39.02	9.23
2 adults two children	-26.03	34.08	10.32
Scenario: diffRAC			
Single +65	-14.49	5.59	37.83
Single no children	-18.79	21.56	23.48
Single with children	-18.61	9.62	16.00
2 adults +65 no children	-18.98	16.14	16.22
2 adults no children	-27.35	47.12	10.99
2 adults one child	-25.58	39.06	9.27
2 adults two children	-23.44	34.13	10.20

Continued on next page

Table 9: (continued) Monthly welfare losses

	Mean EV (€)	Largest losses (%)	Smallest losses(%)
Scenario: UniRAC			
Single +65	-14.72	5.33	37.90
Single no children	-19.66	22.59	22.73
Single with children	-19.72	10.18	14.71
2 adults +65 no children	-19.01	15.00	17.93
2 adults no children	-28.42	47.09	11.60
2 adults one child	-26.71	39.06	9.60
2 adults two children	-24.03	33.92	10.44
Scenario: diffVAT			
Single +65	13.19	0.37	75.70
Single no children	-9.04	34.51	9.14
Single with children	0.32	3.79	6.38
2 adults +65 no children	15.09	0.33	87.61
2 adults no children	-14.86	42.14	10.51
2 adults one child	-10.47	28.76	2.55
2 adults two children	-8.63	18.38	1.86
Scenario: UniVAT			
Single +65	14.77	0.37	73.68
Single no children	-8.99	35.22	8.86
Single with children	0.56	3.98	5.27
2 adults +65 no children	17.34	0.22	87.75
2 adults no children	-14.64	41.94	11.07
2 adults one child	-10.27	29.01	2.66
2 adults two children	-7.90	18.10	2.26

B Supplementary statistics

Table 10: Summary statistics, rounded to the depicted number of digits

Individualized consumer prices	Mean	Std. Dev.
food	82.900	19.074
housing	76.579	27.04
electricity	75.697	19.67
heating	24.513	10.424
transport	52.318	17.991
education	79.516	17.819
others	68.452	13.281
durables	50.066	17.188
Household economic variables		
Budget share for food	0.18	0.07
Budget share for housing	0.27	0.09
Budget share for electricity	0.03	0.01

Table 10: (continued) Summary statistics

Budget share for heating	0.04	0.03
Budget share for transport	0.06	0.03
Budget share for education	0.08	0.07
Budget share for others	0.25	0.09
Budget share for durables	0.10	0.11
Total expenditure	9627.25	5002.45

Dwelling and households characteristics

Central heating (dummy)	0.73	0.44
District heating (dummy)	0.17	0.38
Built before 1948 (dummy)	0.18	0.39
Building date 1949 - 1990 (dummy)	0.53	0.50
Living space in m ²	99.52	40.64
Tenant (dummy)	0.49	0.50
Below 20k inhabitants (dummy)	0.11	0.32
20k-100k inhabitants (dummy)	0.20	0.40
Jobless households (dummy)	0.29	0.46
Workers (dummy)	0.13	0.33
Heating degree days	258.89	130.51
Number of observations	128,254	

Table 11: Goods categories and classification of individual consumption by purpose (COICOP) codes

Main category	Subcategories	COICOP classification
Food	Food, alcohol, tobacco	01, 02
Housing	Rent, imputed rent, water, trash, and other housing costs	041 - 044
Electricity	Electricity	0451
Heating	Solid fuels, liquid fuels, district heating, natural gas	0452 - 0455
Transport	Private and public transportation	07(only 0722 and 073)
Education	Education, recreation and culture	09 (only 093-096), 10
Durable goods	Furniture, tools and domestic appliances	051-056, 091-092
Other goods	Clothing, health, communications, restaurants and hotels, other goods	03, 06, 08, 11, 12

See <http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=5>

Table 12: Almost Ideal Demand System as specified in Equation (1), estimated as a seemingly unrelated regression, estimates rounded to 3 digits.

	Dependent variable: budget share for ...						
	food	housing	electricity	heating	transport	education	durables
log(p_food)	0.028 (0.002)	-0.030 (0.001)	-0.002 (0.001)	-0.009 (0.001)	-0.006 (0.001)	-0.026 (0.002)	0.015 (0.001)
log(p_housing)	-0.030 (0.001)	0.031 (0.002)	-0.004 (0.000)	-0.002 (0.001)	-0.012 (0.001)	-0.000 (0.002)	0.006 (0.001)
log(p_electricity)	-0.002 (0.001)	-0.004 (0.000)	0.015 (0.001)	-0.003 (0.000)	-0.004 (0.000)	-0.006 (0.001)	-0.000 (0.000)
log(p_heating)	-0.009 (0.001)	-0.002 (0.001)	-0.003 (0.000)	0.010 (0.001)	-0.004 (0.001)	-0.001 (0.001)	0.003 (0.001)
log(p_transport)	-0.006 (0.001)	-0.012 (0.001)	-0.004 (0.000)	-0.004 (0.001)	0.025 (0.001)	0.001 (0.001)	-0.007 (0.001)
log(p_education)	-0.026 (0.002)	-0.000 (0.002)	-0.006 (0.001)	-0.001 (0.001)	0.001 (0.001)	0.044 (0.002)	-0.017 (0.001)
log(p_durables)	0.015 (0.001)	0.006 (0.001)	-0.000 (0.000)	0.003 (0.001)	-0.007 (0.001)	-0.017 (0.001)	0.003 (0.002)
log(M/P)	-0.025 (0.000)	-0.107 (0.001)	-0.009 (0.000)	-0.013 (0.000)	-0.012 (0.000)	0.002 (0.001)	0.113 (0.001)
Central heating	-0.018 (0.001)	0.009 (0.001)	-0.005 (0.000)	0.009 (0.000)	-0.002 (0.000)	0.010 (0.001)	-0.007 (0.001)
District heating	-0.016 (0.001)	0.007 (0.001)	-0.007 (0.000)	0.012 (0.000)	-0.006 (0.000)	0.011 (0.001)	-0.006 (0.001)
Building: 1948	-0.006 (0.001)	-0.053 (0.001)	0.002 (0.000)	0.006 (0.000)	0.002 (0.000)	-0.017 (0.001)	0.049 (0.001)
Building:1949-1990	-0.010 (0.000)	-0.037 (0.001)	0.001 (0.000)	0.004 (0.000)	0.001 (0.000)	-0.020 (0.000)	0.044 (0.001)
Dwelling size	-0.000 (0.000)	0.001 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Tenant	0.007 (0.000)	-0.011 (0.001)	-0.002 (0.000)	-0.002 (0.000)	0.000* (0.000)	0.004 (0.000)	-0.001 (0.001)
Below 20k inh	-0.013 (0.001)	-0.019 (0.001)	-0.002 (0.000)	-0.004 (0.000)	0.000 (0.000)	0.020 (0.001)	0.006 (0.001)
20k-100k inh	-0.015 (0.001)	-0.012 (0.001)	-0.002 (0.000)	-0.006 (0.000)	-0.003 (0.000)	0.028 (0.001)	0.002 (0.001)
Jobless	0.018 (0.001)	0.013 (0.001)	0.003 (0.000)	0.005 (0.000)	-0.010 (0.000)	-0.006 (0.001)	0.000 (0.001)
Workers	0.018 (0.000)	0.005 (0.000)	0.002 (0.000)	0.003 (0.000)	0.002 (0.000)	-0.009 (0.000)	0.011 (0.000)
HDD	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)
constant	0.367 (0.002)	0.652 (0.003)	0.070 (0.001)	0.106 (0.001)	0.136 (0.001)	0.078 (0.003)	-0.405 (0.004)
R-squared	0.275	0.443	0.222	0.139	0.137	0.171	0.214
N	128,254						

Household specific parameters for prices and expenditure are available upon request