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# Comparing different support schemes for renewable electricity in the scope of an energy systems analysis

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## HIGHLIGHTS

- Explicit modelling approaches for renewable support schemes are developed.
- The German feed-in tariff system is contrasted with alternative support schemes.
- Renewable generation is more cost efficient under technology–neutral systems.
- Technology–neutral schemes tend to entail higher costs for electricity consumers.
- Energy system models provide a valuable contribution to policy evaluation.

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## ABSTRACT

The present analysis illustrates how energy system models can play an important role in the long-term evaluation of support schemes for renewable electricity. Methodological approaches for the explicit representation of such instruments are presented both for price-based and quantity-based systems. In the subsequent scenario comparison, the current German feed-in tariffs (FIT) are contrasted with several alternative support mechanisms. With the current scheme, renewable generation is increased to almost 46% of gross electricity consumption in 2020 and 54% in 2030 associated with a rise in the surcharge on consumer electricity prices of 40% between 2011 and 2020. By switching to a technology–neutral certificate system which promotes only the most cost-efficient generation and adheres to the political targets renewable generation costs could be lowered by more than €200 billion between 2013 and 2030. At the same time, it has to be kept in mind that technology–neutral systems tend to cause a higher cost burden for electricity consumers. The greatest cost reduction can be achieved under a technology-specific quantity-based system with a decrease in cumulated FIT differential costs of €68 billion and of €416 billion in total energy system costs between 2013 and 2030 compared to the current system.


## 1. Introduction

Enhancing the use of renewable energy sources is considered as one of the major strategies in the combat against climate change. For the European Union, an ambitious goal of raising the share of renewable energies in gross final energy consumption to at least 20% until 2020 has been established. In this context, the electricity sector plays an essential role. According to the National Renewable Energy Action Plans, the contribution of renewables to total electricity generation should rise to 37% by 2020. In order to reach this goal, by now some type of support schemes for renewable electricity has been implemented in every EU member state, with a clear domination of price-based mechanisms like feed-in tariffs (FIT) or premiums over quantity-based schemes, like tradable green certificate (TGC) systems or tendering procedures [1]. In Germany, fixed tariffs for renewable electricity have been applied since 1991 and especially the revised and expanded FIT scheme from 2000 has been highly successful in promoting renewable electricity generation raising its share in gross final electricity consumption from 6% in 2000 to 23% in 2012. However, with the growing importance of renewable energies, criticism of the instrument is also increasing due to its insufficient cost efficiency and market integration of renewable electricity.

A large variety of studies has evaluated and contrasted different support systems for renewable electricity from a theoretical and empirical point of view (cf. for example [2–8]). In general,

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assessment criteria like cost efficiency, distributional impacts, technology promotion, market integration of renewables, distribution of risk, transaction costs, etc. are applied in such analyses. Energy system models provide an appropriate quantitative framework for the evaluation of the long-term implications of support schemes for renewable electricity taking into account all interactions and repercussions within the energy system. Yet, so far the effects of such support schemes have in most cases only been taken into account in an indirect and inflexible way by exogenously setting the expected minimum amounts of electricity produced from different types of renewable energies without making reference to the characteristics of a specific support system (for the case of Germany cf. for example [9,10]). This, however, clearly reduces the flexibility of the model, as generally no changes in the electricity generation from renewable sources will occur when the scenario assumptions are altered and the effects on electricity prices are often not accounted for. Some first attempts have been made in recent years to incorporate renewable electricity generation in the optimisation approach and to explicitly represent specific support instruments (cf. the Green-X model [11], the PERSEUS-RES-E model [12], and the simulation model in [13]). With the exception of the PERSEUS-RES-E model, these approaches have the disadvantage that renewable electricity generation is analysed in an isolated manner, i.e. electricity prices are set exogenously such that no interactions with conventional power generation are considered and the effects on the demand side are neglected. Apart from that, the support systems for renewable electricity are generally modelled in a very simplified and abstract manner without keeping in mind the often complex structure of the real-world application of such instruments.

In order to arrive at a modelling approach with high practical relevance, the analysis at hand uses the German FIT system as a case study and outlines a methodological approach with which instruments for the promotion of renewable electricity generation can be explicitly integrated into an energy system model such that all features influencing the competitiveness of renewable technologies are accounted for in a realistic and detailed manner and the effects both on the generation side and the demand side are determined endogenously. Germany has been a pioneer in renewable electricity policy and the FIT system has served as a model for several other European countries. Since the basic features of the FIT systems in use across Europe are relatively comparable, the methodological approach can easily be transferred to another national setting. The description of the methodology in Chapter 2 is followed by a comparative scenario analysis for Germany in Chapter 3 contrasting the current FIT system with alternative both price-based and quantity-based support schemes in terms of renewable electricity generation, costs of the support system, effects on the demand side and total energy system cost. This allows to contrast the performance of different support systems for renewable electricity in terms of important evaluation criteria such as cost efficiency of generation, distributional impacts on electricity consumers as well a technology promotion in a quantitative manner. To structure the analysis, a number of specific research questions have also been established: (1) How does the German electricity system develop under the current support scheme for renewable electricity? (2) What are the implications of a technology–neutral support scheme for technology choice and costs? and (3) Might Germany benefit from a quantity-based support mechanism where target adherence is guaranteed?

## 2. Model and methodological approach

### 2.1. The TIMES-D model

For the quantitative analyses the energy system model TIMES-D is employed. TIMES-D is based on the model generator TIMES, which has been developed in the scope of the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA). It is a multi-periodic bottom-up energy system model that follows a partial equilibrium approach for representing, optimising and analysing energy systems on local, regional, national or global scales. TIMES employs linear optimisation techniques that depict the energy system as a network of processes (e.g. different types of power plants, heating systems, transport technologies, etc.) and commodities (e.g. energy carriers, emissions, materials, etc.), the so-called reference energy system. It usually minimises, in a dynamic manner under perfect foresight, the total energy system costs required to meet the exogenously set sectoral energy service demands subject to additional constraints, as, for example, a cap on total GHG emissions. This detailed, process-oriented model allows for the evaluation of technical adjustment processes and the associated costs within the energy system in the case of changes in the exogenously set model assumptions, e.g. in the political framework or the energy prices. For further information on the TIMES model generator see [14].

The application used for the analysis at hand, the TIMES-D model, represents the whole energy system of Germany from primary energy production and imports through all conversion steps up to the level of useful energy or energy service demands (like, for example, space heating, lighting, refrigeration, passenger kilometres, steel production, etc.). Demand sectors considered are the industry, service/commercial (including agriculture), residential and transport sector, which are further disaggregated. The German model contains more than 380 end-use technologies (e.g. boilers, electrical appliances, production technologies like blast furnaces or kilns in industry, transport technologies like cars or trucks, etc.), which provide the various energy service demands, encompassing several vintage classes and represented by techno-economic parameters such as the utilisation factor, energy efficiency, lifetime, capital costs, operating and maintenance costs, etc. In this analysis, the partial equilibrium approach of TIMES is chosen, i.e. own-price elasticities are assigned to the exogenous projections of the various demand commodities for energy services. The supply side of the model covers energy conversion processes, like petroleum refining, coal processing, heat and electricity generation, etc. It includes over 120 conversion technologies for central electricity and district heat generation based on fossil (coal, lignite, oil, gas), nuclear and renewable (hydro, wind, solar, biomass, geothermal) resources and three different voltage levels of electricity (high voltage, medium voltage, low voltage). The technological and economic data for supply side technologies comprises the availability factor, capacity factor, efficiency, technical lifetime, specific capital costs, etc. Moreover, exchange processes with neighbouring countries are taken into account with the help of cost potential curves and assumptions are laid down concerning primary energy prices, resource availability, the potentials of renewable energy sources, etc. In addition to the energy flows, energy and process related emissions of greenhouse gases as well as other air pollutants are accounted for in the model. Fig. 1 shows a simplified reference energy system of TIMES-D.

TIMES-D has a temporal disaggregation level with 32 time-slices per year (4 on the seasonal, 2 on the weekly and 4 on the daily level). Statistical data on the hourly load profile of different types of electricity end-uses as well as the hourly generation patterns of fluctuating renewable technologies are aggregated to this temporal resolution of the model. In order to reflect the electric peak load adequately with this limited temporal disaggregation, the required capacity reserve margin is set higher than the usual values used by electric utilities such that it also covers the difference between the actual peak demand and the demand in the peak time-slice in the model. Moreover, for each type of power plant the share of its installed capacity contributing to the peak equation is