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# The Rationales for Technology-Specific Renewable Energy Support: Conceptual Arguments and their Relevance for Germany[*]

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## Abstract

In order to achieve cost-effective RES-E deployment it is often argued that technology-neutral support schemes for renewables are indispensable. Against this background, RES-E support policies making widely use of technology differentiation in remuneration settings, e.g. across the EU, are frequently criticized from a theoretical point of view. However, in this paper we provide a systematic critique of the technology neutrality concept as a foundation for designing policy support schemes in the RES-E technology field. Specifically, the main objective of the paper is to scrutinize the arguments for technology-neutrality, and discuss three conceptual arguments for why technology-specific support schemes could in fact help minimize the societal costs of reaching future RES-E targets. We also briefly address different political economy concerns, which could constrain the choice of cost-effective policy support schemes, and that have to be taken into account for economic policy advice. For empirical illustration of the key arguments we refer to the case of German RES-E support.

**Keywords:** Renewable energy technologies; technology-specific support; market failures; Germany.

**JEL classification:** O38, Q42, Q48, Q55

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# 1 Introduction

An increased use of renewable energy sources is considered necessary for a transition towards a carbon-free and sustainable society, and many countries have introduced policy schemes (e.g., feed-in tariffs, certificate schemes, tendering procedures etc.) supporting the deployment of renewable energy technologies such as wind power and solar photovoltaics (PV). However, while there is still a controversial debate among economists on the general need for such policies (Fankhauser et al., 2010; Fischer and Preonas, 2010; Lehmann and Gawel, 2013; Söderholm and Klaassen, 2007), particularly, there exist different views on how the specific policy schemes, if ever implemented, should be designed in practice. In this paper we address the issue of whether the granted remuneration for renewables for electricity – i.e., a certain price premium per kWh – should be differentiated on the basis of inter- or intra-technology differences, or if it instead should be technology-neutral.[1]

Many support schemes for electric power generated from renewable energy sources (RES-E) in Europe grant technology-specific support. The German scheme mandated by the Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz*, EEG) is a prominent example (see Table 1). The German tariff levels are differentiated based on the energy sources employed, the specific technology, capacity and location of a plant as well as, for biomass, the substrates used in a plant. In addition, the dynamic tariff adjustment rules (degression rates, so-called "breathing caps" etc.) as well as the basic tariff scheme (fixed tariffs vs. premium tariffs, administratively set tariffs vs. tenders) vary with technologies.

However, this approach of technology-specific RES-E support has been criticized, primarily since it is argued to make the attainment of RES-E deployment targets unnecessarily costly (e.g., Frontier Economics, 2012; Frontier Economics, 2014; Frontier Economics and r2b, 2013; Fürsch et al., 2010; Jägemann, 2014; Jägemann et al., 2013). Lauber (2004) notes that in the European Union (EU), quota-based renewable certificate schemes have often been favored by DG Competition. These schemes have been considered as an ideal case of technology-neutral support[2], and have therefore been perceived to better promote a cost-effective deployment of RES-E compared to technology-specific feed-in tariff schemes. Over the years the European Commission has continued to express support for the use of technology-neutral support schemes; it however also acknowledges that in view of the different stage of technological development of renewable energy technologies, technology-specific schemes may also be motivated (e.g., European Commission, 2013a, b, c, 2014).

Technically the link between technology-neutrality and cost-effectiveness lies in the notion that a given RES-E deployment target can only be achieved at minimum costs if the net marginal costs across all relevant RES-E technologies are equalized. The net marginal cost in

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[1] In practice, the implementation of technology-specific RES-E support may be based on differentiation across technologies as well as within a given technology (e.g., the latter with respect to size, geographical location, fuel use etc.). This paper primarily addresses the former, although we also recognize that various versions of some renewable energy technology may have reached different levels of technological maturity (e.g., onshore versus offshore wind power).

[2] Even though the practice in the United Kingdom, where in fact technology-specific bands have been implemented for the quota system, tells otherwise (Helm, 2010).

turn equals the marginal cost of RES-E generation *minus* the marginal value of RES-E; in other words, it can be interpreted as the extra remuneration (e.g., per kWh) needed to incentivize investment. If this cost-effectiveness criterion is not met, the support scheme in place cannot ensure that the least costly RES-E technologies in a given allocation period are deployed first. For instance, Jägemann (2014) employs an electricity optimization model to show that the German feed-in tariff schemes for wind power and solar PV impose substantial excess costs for complying with the country's RES 2020 target; this is in part due to the comparatively generous production support to offshore wind power and solar PV compared to onshore wind power referring to different market cost levels . Thus, the remuneration levels for PV and offshore-wind often reach double the size of that granted to onshore wind power (see Table 1).

A number of previous studies have already questioned the rationale for relying on technology-neutral RES-E support schemes (e.g., Sandén and Azar, 2005; Azar and Sandén, 2011; Jacobsson and Bergek, 2011), typically emphasizing the role for this type of support in promoting technological development. Different technologies, the argument goes, tend to face unique and multi-dimensional growth processes, e.g., in terms of bottlenecks, learning processes, the dynamics of the capital goods industries etc. This thus necessitates the use of differentiated policies; with technology-neutral support there is a risk that market actors will devote too little attention to RES-E technologies that are currently relatively expensive but yet holding a great potential for improved cost performances in the future.

Yet another argument for the reliance on technology-specific RES-E support has been that such policy schemes may decrease final consumer prices despite the presence of excess generation costs, this since price discrimination across technologies with different marginal costs may help to reap producer rents (see, e.g., del Rio and Cerdá, 2014; Held et al., 2014; Resch et al., 2014). Generally, the design of the RES-E support schemes could therefore also be based on motives beyond cost-effectiveness, i.e., distributional concerns and other political economy considerations.

In this paper we provide a systematic critique of the technology neutrality concept as a foundation for designing policy support schemes in the RES-E technology field. The starting point of the analysis is the notion that the standard cost-effectiveness argument for a technology-neutral RES-E support rests on at least two important assumptions:

- Efficient competition between RES-E generation technologies on the basis of *present* generation costs
- A focus on *private* generation costs, assuming that external costs do not exist or that these are perfectly internalized by other public policies

Both assumptions thus relate to a relatively simple concept of *static* cost-effectiveness. Against this observation, we discuss three conceptual arguments for why technology-specific support schemes could in fact help minimize the costs of reaching future RES-E targets: (a) technology market failures, (b) obstacles to long-term risk taking (both arguments take a *dynamic* perspective of technological development considering also *future* generation costs), and (c) generation externalities (considering *social* costs) We also briefly address different political economy concerns, which could constrain the choice of cost-effective policy support schemes, e.g., due to the need to maintain legitimacy for the policy and/or satisfy the interests of different stakeholder groups.

**Table 1: Examples of technology differentiation in Germany under the 2014 Renewable Energy Sources Act.**

| **Object of differentiation** | **Base of differentiation** | **Specification in the 2014 German Renewable Energy Sources Act (Examples)** |
|---|---|---|
| Tariff level (Art. 40-54 EEG 2014) | Energy source | • Geothermal: 25.20 Cent/kWh<br>• Solar: 9.23-13.15 Cent/kWh<br>• Biomass: 5.85-23.73 Cent/kWh<br>• Landfill gas: 5.83-8.42 Cent/kWh<br>• Sewage gas: 5.83-6.69 Cent/kWh<br>• Wind onshore: 4.95-8.90 Cent/kWh<br>• Wind offshore: 3.90-19.40 Cent/kWh<br>• Mine gas: 3.80-6.74 Cent/kWh<br>• Hydropower: 3.50-12.52 Cent/kWh |
| | Plant technology | • Higher support for solar energy plants mounted on buildings (9.23-13.15 Cent/kWh) than for ground-based plants (9.23 Cent/KWh)<br>• Premium for flexible biogas generation<br>• No support for hydropower plants with insurmountable dams |
| | Plant capacity | • Stepwise decrease of tariff with increasing plant capacity for hydropower, mining, landfill, sewage gas, biomass, solar<br>• Example hydropower:<br>≤ 500 kW: 12.52 Cent/kWh<br>≤ 2 MW: 8.25 Cent/kWh<br>≤ 5 MW: 6.32 Cent/kWh<br>≤ 10 MW: 5.54 Cent/kWh<br>≤ 20 MW: 5.34 Cent/kWh<br>≤ 50 MW: 4.28 Cent/kWh<br>> 50 MW: 3.50 Cent/kWh |
| | Plant location | • Support for wind onshore increases with decreasing wind yield (reference yield model)<br>• Support for wind offshore increases with increasing distance to shore and depth of sea<br>• No support for wind offshore in protected areas |
| | Substrate (for biomass) | • Biogas from fermented manure: 23.73 Cent/kWh<br>• Biogas from fermented biological waste: 13.38-15.26 Cent/kWh<br>• Biomass according to Biomass Ordinance: 5.85-13.66 Cent/kWh<br>• Additional pre-qualification criteria apply for each type of substrate |
| Tariff degression rate (Art. 26-31 EEG 2014) | Energy source | • Solar: 6.2 % p.a.<br>• Geothermal: 5.0 % p.a. (starting 2018)<br>• Biomass: 2.0 % p.a.<br>• Wind onshore: 1.6 % p.a.<br>• Mining, landfill, sewage gas: 1.5 % p.a.<br>• Hydropower: 0.5 % p.a.<br>• Wind offshore: 0.5 Cent/kWh/a in 2018, 1.0 Cent/kWh/a in 2020, 0.5 Cent/kWh/a starting from 2021 |
| Breathing cap (reduction/increase of tariff if annual deployment target is exceeded/not reached) (Art. 3 EEG 2014) | Energy source | • Not defined for wind offshore, geothermal, mining, landfill and sewage gas, hydropower<br>• Wind onshore: 2,400-2,600 MW/a<br>• Solar energy: 2,400-2,600 MW/a (in addition total cap of 52,000 MW installed)<br>• Biomass: 100 MW/a<br>• In addition, adjustment rates for tariffs applying if caps are not met vary with energy sources |
| Basic tariff scheme (Art. 37, Art. 55 EEG 2014) | Energy source/plant technology | • Tenders for ground-based solar power plants<br>• Administratively set tariffs for other energy sources and technologies |
| | Plant size | • Premium tariff mandatory for plants larger than 100 kW<br>• Smaller plants can opt for fixed tariff |

In order to empirically illustrate the relevance of our main arguments for practical policy-making, the paper refers to the case of the German Renewable Energy Sources Act (EEG), where appropriate. However, neither our conceptual analysis nor the discussion of the case study do suggest that the ways in which the *existing* technology-specific RES-E support schemes are designed, e.g., in Germany, do promote a cost-effective deployment of technologies. Rather, we make the point that technology-specific RES-E support is not by definition violating the social cost minimization criterion, but its impact depends on sundry cost conditions, and that economic rationales in favor of technology-specific support should play a certain role for real-world policy making.

In the remainder of this paper we argue that a rationale for technology-specific RES-E support is likely to emerge once one (or both) of the above assumptions is (are) relaxed (see section 2). Moreover, and as noted above, an additional assumption underlying the quest for technology neutrality could be the ignorance of different political economy constraints, e.g., distributional concerns. The consequences of relaxing also this assumption are briefly discussed in section 3. Finally, section 4 concludes the paper.

## 2 Three Cost-Effectiveness Reasons for Technology-Specific RES-E Support

In this section we identify and discuss three general arguments for why the use of technology-specific support policies may, if properly designed, help achieve long-term RES-E targets at minimum cost to society. These rationales include: (a) different types of technology market failures impairing future progress in RES-E technologies; (b) capital market failures and other obstacles to long-term risk-taking; and (c) the presence of (non-internalized) external costs from RES-E generation. The relevance of these arguments for the German case is outlined in section 2.4.

### 2.1 Technology Market Failures Impairing Improvements in Future Cost Performance

The development of RES-E technologies may be impaired by the presence of technology market failures, thus implying that private investors face too weak incentives to undertake the investments needed to bring down the costs of these technologies. The economics literature has in particular stressed the risk for the under-provision of R&D as a public good; private companies will typically be able to appropriate only a fraction of the total rate-of-return on their R&D investment since substantial benefits will also accrue to other companies (e.g., through reverse engineering or staff movements between companies). This may motivate the use of public subsidies to private R&D (e.g., Gillingham et al., 2008).

However, technological breakthroughs following past R&D investment are followed by often long processes of incremental improvements along a fairly well-defined trajectory. This will in turn affect future innovations (the re-development of a technology) through different learning processes. Experiences of the production and use of a technology often lead to the encountering of new problems and the discovery of new opportunities, thus raising the rate-of-return on additional R&D (e.g., Huenteler et al., 2012; Rosenberg, 1982). Increased RES-E generation today may therefore help to bring down generation costs in the future due to processes characterized by both learning-by-doing (i.e., tacit knowledge acquired through manufacturing) and learning-by-using (i.e., improvements in the technology as a result of feedback from user experiences).

Also the benefits from these learning processes will often be difficult to appropriate in full for single investors, and a number of factors support the argument that these spillovers could be particularly prevalent in the energy sector (e.g., Neuhoff, 2005). For instance, in the energy sector the end product is homogenous and companies primarily compete on the basis of costs; there is therefore little room for product differentiation and thus an absence of customers with varied preferences who are willing to purchase the product even at a higher price (Kalkuhl et al., 2012). Moreover, the scope for patenting new innovations could be relatively limited (e.g., compared to the pharmaceutical sector), in part since RES-E technologies consist of a large number of components that require expertise from several companies to be improved.

Given the need for introducing RES-E support due to the presence of learning spillovers, the important point to make here is that the granted support (i.e., the price premium) needs to be technology-specific as long as the RES technologies are heterogeneous in terms of: (a) the sizes of the respective learning effects; and (b) the extent to which the knowledge generated from learning cannot be appropriated by the companies that contribute to it.

Previous studies suggest that both of these two conditions hold empirically. First, in a recent survey of previous estimates of RES-E learning rates, i.e., measures of the percentage rate declines in generation costs following a doubling of cumulative capacities or production levels, Rubin et al. (2015) find significant differences across technologies. For instance, the learning rates are generally lower for onshore wind power and hydropower compared to solar PV. Second, the empirical evidence on learning spillovers from RES-E technologies is more limited, but it also points towards a need for technology differentiation. Noailly and Shestalova (2013) provide an assessment of knowledge spillovers by relying on patent citation count data. They conclude that knowledge spillovers from solar PV and wind power are generally more prevalent compared to those emanating from the fossil-fuel technologies, but they also differ across RES-E technologies (e.g., being more profound for wind power compared to solar PV). Examining the case of Germany, Cantner et al. (2016) show in addition that the characteristics of inventor networks vary with RES-E technologies and are, in consequence, affected differently by various types of policy instruments.

Even though it should be clear that these empirical assessments are associated with a fair amount of uncertainties,[3] there is little to suggest that the degree of learning market failures is uniform across the various RES-E technologies. The observed variations are likely due to different technological maturity levels, and could emerge as a result of differences in the complexity of the relevant actor networks as well as the role of users in the technology development process. For instance, the technological progress of wind power has largely been

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[3] Many learning studies are not able to adequately separate endogenous learning effects from both exogenous technological change and economies of scale (e.g., Nordhaus, 2014; Söderholm and Sundqvist, 2007). For instance, in the solar PV field significant technological progress has resulted from investments made outside the RES-E sector, such as in the semiconductor industry (e.g., Nemet, 2006).

driven by turbine manufacturers and the existence of strong home markets, while equipment suppliers and manufacturers that produce their own equipment have dominated solar PV development (e.g., Huenteler et al., 2012).

When introducing support schemes in a specific country, one must also take into account that RES-E technology development takes place on a global scale with significant international learning spillovers. For a single country this raises the question about in which technologies it has a comparative advantage, and to what extent the domestic economy can appropriate the learning benefits emanating from the implementation of RES-E support schemes. Peters et al. (2012) study solar PV development, and conclude that the international learning spillovers from solar PV production support schemes have tended to be more prevalent than the corresponding spillovers from public R&D. In addition, as noted above, some RES-E technologies (e.g., wind power) tend to be more dependent on a home market than others, e.g., making possible important interactions between basic knowledge generation and learning-by-using etc. Still, while these considerations may render difficult choices and trade-offs in the design of domestic policies, neither of these should suggest a strong emphasis on technology-neutral RES-E support.

Our discussion so far in this sub-section suggests that ignoring the often technology-specific learning effects will lead to underinvestment in the RES-E technologies with great long-term potentials for cost reductions. It is also important, though, to recognize that this effect may be reinforced by the presence of path dependencies and technology lock-in. Path dependencies will in part arise since the knowledge accumulation processes are sector-specific (Acemoglu et al., 2012). In simple terms this will imply that if current investments in technology-specific human and physical capital are biased towards technologies with limited potentials for future cost reductions, this could lower the pay-off of directing future development activities towards other more promising technologies that cannot make any use of this capital. Such path dependencies may in turn be reinforced by the institutional frameworks (i.e. legal rules, codes of conduct etc.) that co-evolve with the technologies, thus further increasing the costs of exploring alternative technological trajectories (Prado and Trebilcock, 2009).

The electric power sector exhibits several characteristics, which are likely to generate path dependencies. Investments in this sector are large-scale, long-term and exhibit increasing returns from technology adoption (Neuhoff, 2005). The sector is also highly regulated, implying that existing technological patterns tend to be embedded into – and enforced by – a complex set of institutions. The empirical relevance of these effects is also likely to differ across various RES technologies. Investments in new RES-E capacity are capital-intensive, and as the investment costs of existing technologies are sunk this capacity will compete with new capacity purely on the basis of their variable costs.

The greater the difference between the total cost of a new plant and the variable cost of the existing plant, the greater the incentive for better and more intense use of existing capacity, i.e., through higher capacity utilization, life time extensions, and incremental capacity additions (e.g., Söderholm, 2001). Some new RES-E technologies may be more aligned with existing institutions than others, thus lowering the cost of new plants. In addition, for some technologies increases in RES-E generation within existing technologies, e.g., co-firing with biomass in combined heat and power plants, are easier than for others. Thus, a strong reliance on technology-neutral support schemes in favor of initially low-cost technologies may create inefficient lock-in effects in the long run.

## 2.2 Capital Market Failures and other Obstacles to Long-term Risk-taking

Another important factor potentially affecting the design of RES-E support schemes relates to the uncertainties and risks facing both firms and governments, as well as the limited ability of the capital market to address the issue of long-term risk-taking. For potential RES-E investors the uncertainties relate to, for instance, the extent of the technological learning benefits, the future development of energy prices, and the trajectories of climate and energy policies.

In theory the private investors should be able to hedge against the resulting risks, and would then be indifferent between RES-E investments with different risk profiles as long as the expected return on investment is equal. However, in practice capital and insurance markets are unlikely to ensure such outcomes, e.g., due to moral hazard problems. The capital markets often face difficulties in providing risk management instruments for the immature RES-E technologies, in part due to a lack of historical data to assess risk (Neuhoff, 2005).[4] Moreover, since RES-E projects are often small-scale, transaction costs for risk management and financing arrangements may be disproportionally high.

The main implication of these capital market failures is that private investors will discount uncertain future income streams more strongly than public investors. This type of myopic investment behavior may also result from other factors, such as the fact that firm managers tend to be appointed only for shorter periods. Moreover, Stein (1989) argues that due to agency problems within firms, private decision-making may be inefficient with a bias towards short-term payoffs, thus resulting in myopic behavior also in the presence of efficient capital markets.[5]

This is in turn likely to affect different technologies to varying degrees; overall there will be a bias away from the relatively capital-intensive RES-E technologies such as wind power while favoring the currently cost-effective technologies with short payback periods (Neuhoff and De Vries, 2004). The risk profiles for different RES-E technologies may also differ due to technological complexity. Technologies incorporating a large amount of technical components or depending on a larger variety of inputs for plant production (e.g., diverse rare earth metals for solar PV) or power generation (e.g., different biomass feedstock) are likely subject to higher multiplicative risks.

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[4] In some developing countries there may even be a genuine lack of financial institutions that would allow savings from traditional sectors to be used to finance investments in new sectors and immature technologies.

[5] The way in which the patent system is structured in most countries may even create a bias towards the development of close-to-commercial technologies. The reason is that while patents award innovators a certain period of market exclusivity (e.g., 20 years), the effective term may be considerably shorter since some firms choose to file patents at the time of discovery rather than at first sale. This implies that the patent system will tend to provide meager incentives for firms to engage in R&D focusing on technologies that have a long time between invention and commercialization (Budish et al., 2015).

There may be several ways of addressing these types of capital market failures and firm inefficiencies directly. Yet the feasibility of many policy options may be limited. For instance, in principle the risks facing RES-E generators could be eliminated through the use of long-term contracts between final consumers and the owners of the producing plants, but in liberalized electricity markets such practices are prevented due to regulations aiming at fostering retail competition (Neuhoff and De Vries, 2004). In the presence of such constraints, RES-E support schemes may turn out to be a feasible, though only second- or third-best option. The important point to make here is that if such schemes are implemented to address these problems, the support levels should ideally be technology-specific due to the heterogeneous risk profiles for different RES technologies.

Of course, the regulators who decide to design and implement RES-E schemes will also have to address considerable uncertainties about future market developments etc., and the design of efficient technology-specific support schemes is likely to be particularly demanding in terms of information. In the light of the future risks and uncertainties regulators should therefore in general avoid supporting “single winners”, and instead provide support for several emerging RES-E technologies (that are not perfect substitutes) to reduce uncertainties (e.g., Aalbers et al., 2013; Azar and Sandén, 2011). However, this should not be seen as an argument against technology differentiation; it rather tends to highlight an additional reason for the preferential treatment of specific technologies.

Specifically, a few RES-E technologies, often referred to as backstop technologies, may play a particularly important role in bringing down the cost of complying with ambitious long-term climate mitigation targets. A true backstop technology is available in more or less unlimited quantities at some given (sometimes relatively high) cost (Nordhaus, 1973). For this reason a backstop technology may help to put a cap on the cost of reaching strict emission reduction targets, i.e., given the uncertainties about future climate damages it represents an insurance against high costs (Fischer et al., 2012). Some RES-E technologies are more likely to exhibit important backstop characteristics than other. For instance, compared to biomass the scarcity constraints are likely to be less prevalent in the case of solar PV. The flow of solar energy to earth is abundant, and solar panels can be placed on roofs. Support schemes that can bring down the cost of, for instance, solar PV can therefore have an added insurance value compared to biomass energy.

## 2.3 Heterogeneity of External Costs and Benefits of RES-E Generation

A cost-effectiveness assessment of RES-E technologies must also take into account the fact that the direct (market) costs of these technologies will not necessarily include a number of external costs and benefits. This may be due to the presence of different types of externalities that have not been properly internalized by means of other policies and regulations. In this sub-section we comment on three different types of RES-E externalities: (a) the external environmental costs and benefits; (b) the costs of electric power system integration; and (c) the external costs in terms of safeguarding energy security. In all three cases we are likely to experience differences in costs across the various RES-E technologies, thus suggesting that any non-internalized costs could be addressed through the use of support schemes that differentiate the support level on the basis of these differences. Although such schemes will only be a second-best means to address any remaining externalities, there is nevertheless little support for the adoption of a completely technology-neutral policy approach in these cases.

*First*, RES-E deployment may generate environmental costs but also benefits in terms of, for instance, the avoided pollution from plants being replaced by increased RES-E generation, and both costs and benefits tend to be heterogeneous across RES-E technologies. The external costs of RES-E generation can be site-specific (e.g., habitat losses, water and air pollution etc.) and/or distance-related, i.e., dependent on the distances to human settlements (e.g., noise emissions, air pollution, aesthetical changes to landscapes etc.) (e.g., Abbasi and Abbasi, 2000). Although it may be difficult to determine the extent to which these cost are already internalized, important differences in external costs are likely to exist. For instance, in their empirical survey of the external environmental costs of power generation Söderholm and Sundqvist (2006) conclude that in general these costs tend to be higher for biomass generation than for both wind power and solar PV. Their review also identifies substantial variances in external cost estimates for each of the RES-E technologies (e.g., due to different geographical contexts).

Furthermore, previous studies have pointed out that important differences across RES-E technologies also exist in terms of avoided air pollution, thus also questioning the commonly used assumption that the marginal generation source displaced equals the average generation mix in the electricity system. One recent example is Novan (2015) who concludes that in the Texas electricity market an increase in wind power will offset more carbon dioxide emissions than a corresponding increase in solar PV generation (see also Kaffine et al., 2013).[6] Obviously, the first-best policy response is to target these externalities directly (e.g., by emissions taxes and standards or land use planning). However, if such approach is not feasible in practice, RES-E support schemes could represent a decent second-best approach. This unfeasibility might be the case due to, e.g., practical limits of tackling a high number of complex environmental externalities associated with RES-E generation in a first-best way at the same time, spatial constraints of legislations to deal with regional spill-over effects or overall distributional concerns with respect to internalization policies. In this case, the heterogeneity in the externalities to be addressed can only be accounted for sufficiently by a corresponding degree of technology differentiation.

*Second*, there are also the costs associated with system integration, and the fact that market values of renewable energy sources differ depending on timing (i.e., when they are available). These costs may include: (a) balancing costs, i.e., the marginal costs of coping with deviations from day-ahead generation schedules due to forecast errors for intermittent RES-E generation; (b) grid-related costs, i.e., the marginal costs of transmission constraints and losses due to the location of RES-E generation in the electricity grid; and (c) profile costs, i.e., the marginal

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[6] The timing and location of RES-E generation and the pre-existing mix of other energy sources will also affect what generation is displaced, and thus which environmental impacts are avoided. For instance, due to its intermittent nature wind power will sometimes tend to replace hydropower, which can easily be regulated to address different loads. Bioenergy in contrast can more easily be seen to replace fossil fuels, e.g., through co-firing in combined heat and power plants.

cost of output adjustments and overall reduced use of conventional (e.g., thermal) electric power plants due to the timing of intermittent RES-E generation (Hirth et al., 2015).

These system integration costs are clearly of a greater magnitude for intermittent RES-E generation (Joskow, 2011) but in many cases the existing regulatory framework may fail to internalize these costs properly. In Germany, this holds true because payments to RES-E generation are only weakly linked to wholesale prices (e.g., fixed feed-in tariffs and sliding premium tariffs are used instead of fixed premium tariffs).[7] Moreover, the German electricity market fails to send proper investment and generation signals, inter alia, due to the design and timing of contracts traded, the absence of locational price signals etc. (Löschel et al., 2013). While the first-best response would be the reduction of these distortions, this may not be feasible due to politico-economic constraints and/or administrative hurdles. For example, the implementation of price zones would potentially lead to higher power prices in Southern Germany and is correspondingly likely to fail due to opposition from the *Länder* Bayern or Baden-Württemberg (Monopolkommission, 2015, p. 107). In this case, technology-specific RES-E support schemes may help promote a system-friendly RES-E portfolio and reduce integration costs.

*Third* and finally, the literature on domestic energy security has identified a number of potential economic externalities arising from the level of fossil fuel (e.g., oil and natural gas) imports (e.g. Bohi and Toman, 1996). This type of externality may involve a direct and an indirect effect. The former involves the exercise of market power of, most notably, oil and natural gas exporters, while the latter refers to how fossil fuel imports may affect the macroeconomy through their impacts on inflation and the trade balance. It is worth underscoring that these economic externalities are concerned with *economic costs* and not with physical availability per se. In the presence of such energy security externalities, society is overall better off paying a premium on the price of fuels imported from dominant exporters.

Similar to the case of environmental externalities, the first-best policy typically works by “getting the prices right”, i.e., with a correct price on imported fuels, firms and consumers will switch to other energy resources that are not associated with the same energy security externalities. However, quantifying the energy security externalities associated with oil or natural gas use could be more fraught with difficulties than environmental externalities (Gillingham and Sweeney, 2010). For this reason direct support for RES-E technologies may also here represent a decent second-best policy.

Even though all RES-E technologies help reduce the dependence on imported fossil fuels, their impacts on overall energy security may not necessarily be homogeneous. One reason is that some RES-E generation will create new import dependencies, e.g., import of wood pellets in the case of biomass-fired generation. Although in such cases the distortion created by a technology-neutral scheme may perhaps be minor in the context of a single country, it may well become more profound in the case where technology-neutral schemes are integrated

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[7] For instance, if the generation of solar PV increases in southern Germany, this will lower the wholesale price of electricity in the relevant hours. This price fall should induce RES-E developers to choose better locations, i.e., with higher local prices. However, a contract price that is independent of the spot price suppresses efficient signals, in turn raising the cost of power generation.

across countries (e.g., Söderholm, 2008). The whole point of integrating different domestic support schemes is to permit a cost-effective location of RES-E generation, and thus enable increased electricity trade.

Different countries are also likely to have different perceptions of the significance of the respective (energy security and environmental) externalities, thus implying different views on how much to support different RES-E technologies. This also implies that an EU-wide technology-neutral market approach will not be cost-effective (Strunz et al., 2015b). Since market valuation of externalities is lacking a political assessment is needed instead to cover regional preferences that may also be heterogeneous across both technologies and countries.

## 2.4 Relevance of Theoretical Arguments for RES-E Policy-Making – The Case of Germany

So far, we pointed out that there are economic rationales for having technology differentiation for RES-E policies in general, and that the empirical evidence suggests that these rationales are relevant. Moreover, respective policy patterns can be witnessed e.g. across EU member states, especially in Germany. However, the question arises whether the outlined arguments in favor of differentiation in fact do play any role for practical policy-making. Again, for illustration purposes, we refer to the German case. Whether the described economic rationales are also important for practical policy-making is discussed by a short review the official legislative reasoning of the German EEG.

*Addressing technology market failures.* The official justification for the first version of the EEG, which entered into force in 2000, identified “a structural discrimination of new technologies” (Bundestag, 1999, p. 7, own translation) as a decisive reason for why the competition between RES-E and conventional energy technologies tends to be distorted. The EEG explicitly aimed to create demand for a range of renewable energy sources and technologies; the rationale was that individual technologies should be enabled to benefit from economies of scale, which would not take effect as long as the number of production units remained low (Bundestag, 1999, pp. 7f.). Technologies were distinguished according to their innovative potential, but also the role they were expected to play in the future electricity system – this is particularly evident in the case of solar PV, where comparatively high feed-in tariff rates were justified on the basis that mass production should bring down the costs of the RES-E technology with the largest expected long-term potential (Bundestag, 1999, p. 9).

In addition, technology-specific digression rates for remuneration were established to follow technologies’ specific progression down the learning curve (Bundestag, 1999, p. 9; 2008a, pp. 51ff.). Later versions of the EEG followed the logic that support should be continuously aligned with technologies’ state of development, to set incentives for further innovations (Bundestag, 2008a, p. 37). EEG amendments in 2004, 2009 and 2012 even established bonuses for particularly innovative, but high-cost technology choices (e.g. petrothermal systems for geothermal power, or gas processing for biogas plants) (Bundestag, 2008a, pp. 56f.). In the EEG 2014, technology-specific expansion corridors are supposed to focus support on technologies comparatively close to competitiveness on the one hand (particularly onshore wind power and solar PV), but also technologies with a high remaining potential for innovation on the other (such as wind offshore) (Bundestag, 2014, pp. 89f.). Besides the aim of enabling economies of scale and reducing the long-term costs of a reliable and environmentally friendly electricity supply, official justifications of the EEG also emphasize that supporting specific, innovative technologies can contribute towards building competitive advantages in global technology markets and increasing employment (Bundestag, 2008a, p. 37; 2014, pp. 96f.).

*Addressing obstacles to long-term risk-taking*. During the initial period of the EEG investment security played a major role for the regulator, and RES-E operators were released from any kinds of market risks (e.g., Bundestag, 1999, p. 10). And even with the gradual introduction of the (optional) sliding feed-in premium in the EEG 2012 and 2014 – meant to promote the market and system integration of RES – price risks have remained low for investors because the premium balances out the difference between politically set reference prices and average market prices (e.g., Sensfuß and Ragwitz, 2011). While the EEG 2014 made direct marketing obligatory for all but small scale plants, it retained a fallback option with the explicit aim of reducing risks for plant operators (Bundestag, 2014, p. 91): under exceptional circumstances (e.g., insolvency of a direct marketing company) plant operators can count on transmission system operators (TSOs) to market their electricity at reduced feed-in tariff rates (Art. 38 EEG 2014). From 2017, the level of the sliding feed-in premium will be determined through competitive bidding for most RES technologies; still, limiting risks for bidders remains a goal of the tender design process, in order to facilitate participation by small actors with particular high risk aversion or risk-bearing costs (BMWi, 2015, p. 5).

*Addressing external costs of RES-E generation*. Regarding environmental externalities, the EEG's remunerations scheme repeatedly draws on technology-specific ecological impacts, e.g., for hydropower and biomass through additional ecological eligibility criteria or different tariffs.[8] In the case of hydropower, the EEG versions 2004, 2009 and 2012 included specific ecological criteria that projects had to meet in order to be eligible for support (Bundestag, 2008b, p. 19). With the EEG 2014, these criteria were lifted, and included in the revised Water Management Act ("Wasserhaushaltsgesetz") instead (Bundestag, 2014, p. 140). In the case of bioelectricity plants, sustainability certification for biofuels and bioliquids was adopted in 2009, to reflect concerns about the sustainability of imports (BioSt-NachV, 2009; Bundestag, 2008a, p. 30). The EEG 2012 excluded electricity produced from bioliquids and scrap wood from support altogether, because available energetic potentials were considered to be exhausted (BMU, 2011, pp. 85, 88; Bundesregierung, 2011, p. 15). Furthermore, the EEG 2012 differentiated bioelectricity tariff rates according to classes of biomass substrates, with higher remuneration available for selected substrates where comparatively high costs went hand in hand with ecologically favorable characteristics (the so-called "substrate tariff class II") (Bundestag, 2011b, p. 17). Moreover, a cap on the use of maize was introduced to reduce the loss of biodiversity due to an increased cultivation of monocultures. In order to improve the GHG balance of bioelectricity production, minimum requirements on slurry use or heat cogeneration were established, replacing earlier bonuses for these measures in the EEG 2009

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[8] The German Federal Government concedes that negative environmental impacts caused by wind turbines are sufficiently controllable by other jurisdictions (Bundestag, 2011a, p. 49).

(Bundesregierung, 2011, p. 15; Bundestag, 2011b, p. 31). In the EEG 2014, these measures were discontinued; instead, remuneration rates were subject to strong reductions, with the expectation that only projects using low competition, environmentally advantageous resources such as waste and residuals would remain profitable (Bundestag, 2014, p. 141). However, comparatively high cost-based remuneration remains for bio-degradable waste fermentation and small slurry installations.

External benefits of contributions to electric power system integration and safeguarding energy security were considered, e.g., in an extra support scheme for biogas plants (flexibility premium), which was introduced in the EEG 2012 (Bundesregierung, 2011, p. 10). This premium is meant to incentivize switching from a base load to a demand-oriented production mode, and to compensate for additional investments associated with the flexibilization of plants (Rohrig et al., 2011). The EEG 2012 also ushered in the transition from a fixed feed-in tariff to a sliding feed-in premium, where RES producers are exposed to electricity price signals to a limited degree, to improve the alignment of feed-in and demand (Bundesregierung, 2011, p. 8; Klobasa et al., 2013). This so-called “market premium scheme” included a technology-specific management premium which was meant to compensate additional costs of marketing electricity directly, instead of via TSOs. To incentivize better system compatibility of wind and solar PV plants, higher management premium rates were offered to plants which could be remote controlled (Bundestag, 2012, p. 1). In the EEG 2014, however, remote control capability was made a prerequisite for receiving the feed-in premium (see Art. 35 sentence 1 no. 2 in conjunction with Art. 36 (1) EEG 2014).

Again, these observations do not say much on whether the degree and complexity of the concrete differentiation outlined in Table 1 could ever be cost-effective. However, it demonstrates that our theoretical reasoning has been relevant for actual policy-making. In general, policy could benefit further by a more systematic empirical assessment of the different market failures outlined above. Our empirical understanding of these rationales need to be improved, not the least since their respective importance is likely to differ across countries and regions.

## 3 Political Economy Constraints to Technology-Neutral Support

While section 2 has provided a number of cost-effectiveness arguments for the introduction of technology-specific RES-E support, it is necessary to also discuss the political economy constraints that need to be addressed when designing RES-E support schemes in practice. These constraints arise since policy makers must maintain public support, and will therefore have to satisfy the interests of different stakeholder groups. Such considerations are likely to affect the degree of political feasibility of technology neutrality or differentiation of RES-E schemes, although overall, we argue, they might tend to endorse technology-specific support schemes. These constraints have to be taken into account when designing and suggesting economically rational policies from a theoretical point of view. Besides the mere feasibility issue, these constraints may also refer to some relevant and legitimate factors beyond cost-effectiveness (e.g., distributional effects).

### 3.1 Meeting the Interests of Electricity Consumers

An important interest group are electricity consumers, and it has been argued that technology-specific RES-E support schemes lead to lower wind fall profits and thus consumer prices compared to technology-neutral schemes, this since price discrimination across technologies with different costs will help reap producer rents (Bergek and Jacobsson, 2010; del Rio and Cerdá, 2014; Held et al., 2014; Hitaj et al., 2014; Resch et al., 2014).[9] From a political economy perspective, this redistribution of income from power generators to consumers may increase the public support for the RES-E policy in general. In principle, the windfall profit problem can also be addressed in the context of a technology-neutral scheme, not the least by taxing the excess rent (and redistribute the revenues to consumers). Such a tax could permit governments to capture a large share of the realized rents without greatly altering the extent or nature of RES-E generation. Still, it would be difficult to implement efficiently, and it would have negative impacts on *ex ante* investment incentives.

For the German case we find some evidence on the relevance of the windfall profit argument for policy-making. To avoid windfall profits and high economic cost that consumers would have to bear the level of the feed-in tariff declines step-wise with increasing plant capacity (considering economies of scale) for many RES-E technologies (Bundestag, 2008a, p. 50). Moreover, the level of the feed-in tariff varies with wind yield to avoid excessive support on wind-intensive sites (Bundestag, 1999, p. 9). Finally, the political motive of „affordable energy supply“ newly shows up in the EEG 2014 itself (see objectives in Art. 1: “ to reduce the costs to the economy not least by including long-term external effects”). In any case, distributional concerns show up in the general climate and energy concept of the government (BMWi/BMU, 2010) and in Art. 1 of the German Energy Act (EnWG), mandating affordable and low cost (“*preisgünstig*”) energy supply.

### 3.2 Meeting the Interests of RES-E Investors and Regions

There are also the interests of a heterogeneous set of different types of sub-national regions and investors. First, there are technology-specific interests groups of manufacturers and operators of RES-E plants which seeking to maximize their individual rents. Moreover, the promotion of RES-E deployment is sometimes viewed as a vehicle for regional growth and job creation, especially in local communities with a declining population trend. Although one may question the role of RES-E support as an efficient labor market policy tool (see also Ejdemo and Söderholm, 2015), it should be clear that at the regional and local levels policy makers and citizens may express concerns about the regional distribution of RES-E generation and the technology choices involved. Regional stakeholders will likely lobby for supporting RES-E technologies that: (a) can make use of the region’s physical, natural and human capital, e.g., biomass in rural areas; (b) generate limited local environmental external costs; and (c) show promising local employment impacts. These considerations will likely not match the technology mix resulting from RES-E support schemes aiming at domestic cost-effectiveness. In fact, technology-specific support facilitates the pinpoint distribution of rents

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[9] This does not suggest that there may not be windfall profits also in the case of technology-specific RES-E support schemes; some countries have introduced time-declining support levels to address such concerns (Hoppmann et al., 2014). The point is simply that the magnitude of the windfall profits will be more profound in the case of technology-neutral schemes.

to separate constituencies as it prevents competition between RES technologies and their interests groups (Aalbers et al., 2013; Helm, 2010; Strunz et al., 2015a).

For the German case, there is clear empirical evidence, for example, that the technology-specific rates under the German EEG have been driven by interventions from business groups as well as from the subnational administrations of the German *Länder* (Hoppmann et al., 2014; Strunz et al., 2015a; Sühlsen and Hisschemöller, 2014; Vossler, 2014). When the 2014 amendment to the EEG was negotiated, Northern *Länder* opposed tight caps on onshore wind power expansion (the economic repercussions of which would primarily be borne by industries in Northern Germany), while Bavaria refused cutting biogas remunerations. These states' interests made their clear imprint on the final version of the law (Gawel, 2014; Gawel and Lehmann, 2014). In other words, some *Länder* tried to reap the regional benefits of RES deployment while free-riding on the RES subsidies paid for by all German electricity consumers (Gawel and Korte, 2015). In fact, the consideration of regional benefits is also laid down in the EEG itself as it is also justified by the promotion of green industry and regional development. For example, the the use of biomass for energy purposes is also seen as an additional perspective for domestic agriculture and forestry with untapped potential which creates jobs and thus strengthens regional economies (Bundestag, 2000).

Besides regional diversity there may also exist a demand for diversity with respect to investor types. This has been recognized at the national levels through a desire to encourage a wider diversity of investors to participate in renewable energy investment, including citizens, small-scale farmers, communities, small businesses and local governments (e.g., Couture et al., 2015). This can be achieved by keeping the barriers to entry low for certain kinds of market participants, while at the same time encouraging competition among larger project developers to secure low prices for consumers. Investor diversity arguments may also have repercussions for the appropriate choice between technology-specific and technology-neutral RES-E support schemes. For instance, tendering schemes have tended to favor large energy companies that are able to afford the associated administrative and transaction costs (Lucas et al., 2013), and may also create a bias towards certain types of RES-E technologies. Large wind power plants could crowd out small biogas projects if the two compete against one another.[10] Such considerations explain the capacity differentiation in the EEG as well as thresholds for choice between fixed FIT and market premium under EEG 2012. Moreover, the current EEG 2014 explicit mandates to maintain actor diversity with the gradual implementation of tenders (Art. 2(5) EEG 2014).

While government decision-makers typically cannot ignore the preferences and the power of important stakeholder groups, it should be clear that lobbying may lead to regulatory capture and economic inefficiencies. For this reason it becomes important to implement RES-E policies that minimize such rent-seeking activities in the first place. It is sometimes argued that technology-specific policies are more prone to regulatory capture by different political interest groups than technology-neutral ones (Aalbers et al., 2013; Helm, 2010; Lerner, 2009;

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[10] The desire to promote new and smaller investors can also be viewed as a way to mitigate the presence of market power in the electricity system. As such it can then also be motivated from an economic efficiency point of view.

SVR, 2014) Lobbyists may be more able to seek rents successfully in the case of differentiated support levels because their information advantages over regulators will be more profound. In the presence of firm-regulator information asymmetries, RES-E plant developers will have an incentive to given the impression that generation costs are high in order to maximize the likelihood of more generous support.

For these reasons, it has been argued, technology-neutral RES-E schemes may be less prone to interventions by political interest groups, in other words offering a "premium of simplicity" (Helm, 2010). A similar argument has been put forward by the so-called Monopolies Commission in Germany, an independent expert committee advising the German government and legislature in the areas of competition policy-making, competition law, and regulation (Monopolkommission, 2013). However, ultimately all types of policies may be eroded by the influence of political interest groups, even those which were meant to be technology-neutral in the first place (Strunz et al., 2015a). An apt example is carbon dioxide emissions trading in the EU where the alleged textbook simplicity in part vanished during the implementation process (e.g., Anger et al., 2008; Spash, 2010).[11]

To conclude, we argue that considering the political economy environment yields two important policy implications: First, RES-E schemes tend to be technology-specific in practice as they emerge from the complex interactions of political interest groups. That is, even if technology-neutral support was a cost-effective way to promote RES-E, it might be, for several reasons, a politically not preferable alternative. Second, the political economy environment will also impair the implementation of a possibly cost-effective, technology-specific RES-E scheme. That is, even if economic rationales for technology differentiation are relevant, they may not materialize in actually existing RES-E schemes.

## 4 Concluding Remarks

The central conclusion from this paper is that technology-specific RES-E support schemes may generate significant economic benefits, particularly if technology markets work imperfectly and in second-best settings with additional non-internalized market failures. The former becomes particularly important when RES-E technologies play a role in complying with long-term policy (e.g., climate) targets. This is not to say that technology-specific support schemes are by definition welfare-increasing; there will clearly be practical impediments to getting the technology-specific remuneration levels right. But in fact the same is true for technology-neutral approaches. Nevertheless, it becomes clear that technology-neutral schemes are neither by definition superior, and they hardly deserve to be treated as a benchmark in the analysis of cost-effective deployment of RES-E technologies. In the end this boils down to the notion that a RES-E target cannot be a desirable goal in itself; it must be logically derivable by analysis of more basic motives and of the relevant costs and constraints. Our point is that almost regardless of which these motives are, there is generally a stronger case to be made for technology differentiation compared to technology neutrality.

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[11] This insight is in fact confirmed by Helm (2010), who reports that due to lobbying efforts technology-specific bands were introduced for the originally technology-neutral concept of UK's renewable obligation certificates.

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