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ENVIRONMENTAL TRADE-OFFS OF (DE)CENTRALIZED RENEWABLE ELECTRICITY SYSTEMS

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Overview

Renewable energies are key to reduce CO2 emissions and other environmental impacts of fossil-fueled electricity generation. However, renewable power systems can also cause negative environmental effects. In this paper, we analyze the potential environmental trade-offs associated with different spatio-technical (de)centralization options for a renewable electricity system. For this purpose, we first review the potential environmental life cycle impacts of key technologies for renewable electricity systems. Subsequently, we develop a framework identifying which factors determine actual environmental effects of renewable electricity systems. We apply the framework to four basic spatio-technical (de)centralization options for the future Germany electricity system. Our analysis shows that all (de)centralization options are associated with potential environmental trade-offs. We find that the degree of (de)centralization is a relevant factor determining these trade-offs. For instance, the two more centralized options considered have lower environmental impacts related to PV, whereas the two more decentralized options have lower environmental impacts related to grid infrastructure. However, we also find that the trade-offs depend on the specific way (de)centralization is pursued. For instance, only in one of the two considered more decentralized development options, there is a potential environmental trade-off between higher impacts related to battery storage and lower impacts related to offshore wind power. In addition, our analysis reveals that besides the (de)centralization aspect also further factors like the institutional and stakeholder management in place shape potential environmental trade-offs. Still, policy makers should acknowledge the identified potential environmental trade-offs and their influencing factors when making policies favoring certain spatio-technical (de)centralization options.

Method

We first review the potential environmental life cycle impacts of key technologies for renewable electricity systems from the literature. Subsequently, we develop a framework identifying which factors determine actual environmental effects of renewable electricity systems. We apply the framework to the case of the future German electricity system by reviewing four possible spatio-technical (de)centralization options which we derive reviewing ten quantitative modeling studies. We consider an “offshore wind option” and an “import option” as rather centralized development options and a “distributed onshore wind option” and a “PV option” as rather decentralized development options. We identify and discuss environmental-trade-offs of these (de)centralization options along our framework.

Results

Our analysis shows that all (de)centralization options for a fully renewable electricity system are associated with potential environmental trade-offs. We find that the degree of (de)centralization is a relevant factor determining these trade-offs. For instance, both centralization options examined are rather associated with lower potential environmental effects related to PV occurring especially during the raw material sourcing and manufacturing stage as well as during the decommissioning and end-of-life stage, while both decentralization options examined are associated with lower potential environmental effects from grid infrastructure occurring especially during the installation and operation stage. However, our analysis also yields that the occurrence of environmental trade-offs also depends on how spatio-technical (de)centralization is achieved. For instance, environmental trade-offs between potential environmental effects related to battery storage and potential environmental effects related to offshore wind power are found only for one of the two centralizing options considered as well as only for one of the two decentralizing options considered. Thus, the question of whether electricity system development options are more centralized or decentralized is not sufficient to comprehensively deduce their potential environmental trade-offs. Instead, the specific spatio-technical characteristics of centralization and decentralization development options (i.e., their specific technology portfolios and spatial allocations) also need to be considered.

In addition, our analysis reveals that actual environmental effects and trade-offs of electricity system development options depend also on other aspects than their spatio-technical (de)centralization. These aspects include the total electricity demand, local siting decisions, applied product life cycle management measures for the energy infrastructure components (e.g., on-site measures), and the institutional and stakeholder management (e.g., procedural participation opportunities). Moreover, a societal valuation of potential environmental impacts is required for a decision-oriented environmental trade-off assessment of different (de)centralization options. It also should be noted that, in addition to environmental trade-offs, there are, of course, also further criteria (e.g., system costs, security of supply aspects, and equity considerations) that need to be considered for a comprehensive evaluation of different electricity system (de)centralization options.

Conclusions

Various policy implications emerge from or findings. First, policy makers should be aware of the identified potential environmental trade-offs of different centralizing and decentralizing electricity system development options.

In a theoretical first-best world, however, policy makers would not have to decide on the right degree of (de)centralization at all – even when there are environmental trade-offs involved. Rather, the first-best approach would be to price in all potential environmental effects (as well as all other technology costs and benefits). The socially optimal degree of (de)centralization would then arise endogenously. The political decision-makers could thus be agnostic about (de)centralization questions.

In practice, however, it will be impossible to accurately price in all factors due to regulatory constraints, such as only domestic regulatory jurisdiction, issues of political feasibility, and imperfect information of the regulator. In this case, influencing the (de)centralization of a renewable electricity system through policy interventions may be a second-best approach. Depending on the desired outcome, political interventions could include, for instance, regionalized site provision obligations for wind turbines, a general PV duty for all rooftops, or differentiations of subsidy levels for different renewable technologies. No-regret and possibly also low-regret measures that can avoid potential environmental trade-offs should be identified and implemented. Possible starting points for this may include environmental supply chain management regulations for the manufacturing stage and environmental on-site management regulations for the operation stage. However, it is important to keep in mind that the promotion of specific (de)centralization options will probably still remain ambivalent and involve trade-offs. In this case, policy decisions will inevitably require political valuations and prioritizations of different potential environmental effects (and further non-environmental effects).

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