Energy Economics 40 (2013) S12–S23

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

On the economics of renewable energy sources

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ARTICLE INFO

Available online 21 September 2013

JEL classification:
Q21
Q28
Q42
Q54
Q55
D47

Keywords:
Energy
Mitigation
Integrated assessment modeling
Variable renewables
Electricity market design
Renewable policy

ABSTRACT

With the global expansion of renewable energy (RE) technologies, the provision of optimal RE policy packages becomes an important task. We review pivotal aspects regarding the economics of renewables that are relevant to the design of an optimal RE policy, many of which are to date unresolved. We do so from three interrelated perspectives that a meaningful public policy framework for inquiry must take into account. First, we explore different social objectives justifying the deployment of RE technologies and review model-based estimates of the economic potential of RE technologies, i.e. their socially optimal deployment level. Second, we address pivotal market failures that arise in the course of implementing the economic potential of RE sources in decentralized markets. Third, we discuss multiple policy instruments curing these market failures. Our framework reveals the requirements for an assessment of the relevant options for real-world decision makers in the field of RE policies. This review makes it clear that there are remaining white areas on the knowledge map concerning consistent and socially optimal RE policies.

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1. Introduction and motivation

The use of renewable energy (RE) sources has grown rapidly in recent years. Approximately half of the electricity-generating capacity installed globally between 2008 and 2009 draws on RE sources (IPCC, 2011). Although RE supplied 16.7% of final global energy consumption in 2010 – split evenly between traditional biomass and modern RE – fossil fuels still provided the lion's share at 80.6%, with the final 2.7% being generated by nuclear power (REN21, 2012). Yet, for all sectors of the energy-system a large variety of technically viable RE solutions have been developed that are theoretically capable of substituting fossil-fuel-based technologies. Recent assessments indicate that the technical potential of RE sources, i.e. the amount of RE output obtainable through the full implementation of demonstrated technologies or practices, is substantially higher than global energy demand (IPCC, 2011). The technical potential therefore does not limit the accelerated use of RE sources; however, it is a poor indicator for the net social benefits of the deployment of RE technologies. The metric is hence not capable of guiding the policy-maker with regard to the design of an optimal RE policy, which becomes ever more urgent as renewables leave the status of a niche market in many countries.

In order to assess the future role of RE, a richer analytical framework is needed. A subset of the technical potential that addresses the policy-relevant questions of technology choice, location and timing is the economic potential of RE sources. It constitutes the socially optimal benchmark deployment level of RE technologies when all corresponding social costs and benefits, including negative externalities and cobenefits, are taken into account (Moomaw et al., 2011). By definition, the economic potential is not only a function of techno-economic assumptions, e.g. expectations on technology learning, but also hinges crucially on the prioritization of underlying and potentially competing public policy objectives. In order to determine the global economic potential of RE sources, the starting point is to choose a particular weighting of public policy objectives based on value judgments, i.e. a social welfare function, used for the evaluation of climate and energy policies. Climate change mitigation, energy security, green jobs, green growth, reduced local environmental damages and poverty reduction are potential public policy objectives highlighted by decision makers that can, in principle, justify the deployment of RE technologies as a means to an end. In

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http://dx.doi.org/10.1016/j.eneco.2013.09.015

economic language, the economic potential is referred to as the welfare-optimal deployment level.

The decentralized market solution generated by decentralized agents like firms, consumers and investors that do not take into account relevant multiple externalities of their actions, e.g. climate damages, technological spillovers, and security standards, cannot be expected to yield the welfare-optimal quantity of RE deployment. That is, in the presence of market failures (arising when externalities of decentralized actions impede the fulfillment of multiple public policy objectives) the market potential of RE sources attains a lower level of welfare than the economic potential (Fig. 1). Such a setting, with multiple externalities, requires a careful analysis of the multiple policy instruments curing these market failures. A meaningful public policy framework for inquiry must take into account the interrelated triplet of (i) multiple public policy objectives, (ii) multiple externalities, i.e. market failures, and (iii) multiple policy instruments (Edenhofer et al., in press).

For designing an optimal RE policy (one that steers the market solution towards the welfare-optimal benchmark), the policymaker requires knowledge of the welfare-optimal deployment level, the nature, dynamics and causality of system effects that cause multiple market failures, as well as those of policy instruments intended to incentivize agents on the market towards the welfare-optimal benchmark. Besides that many of these aspects are to date unresolved, available literature treats the different aspects inherent to the economics of renewables in a rather disjunctive manner. The economic potential is subject to analysis in the integrated assessment community by means of complex, numerical integrated assessment models (IAMs). Externalities, market failures and policy instruments are generally investigated using empirical methods and analytical models within a different community. The fragmented literature and the lack of a consistent framework prevent a concise assessment of the different policy options. Therefore, our aim is to bring these perspectives together.

In this paper, we review pivotal aspects of the economics of renewables that are relevant to the design of an optimal RE policy. We do so by adopting the three perspectives emerging from the public policy framework described above, leading to the following guiding research questions. Which public policy objectives can justify the deployment of RE technologies? What are current assessments of the economic potential of RE sources and how robust are they? Which pivotal market failures need to be addressed in the course of implementing the economic potential of RE in decentralized markets, and which kinds of policy interventions are adequate? The contribution of this paper is twofold. We discuss the available literature with regard to these research questions and identify knowledge gaps. At the same time, the analysis describes the requirements for an assessment of the relevant options for the expansion of RE technologies that real-world decision makers might have.

The paper is structured as follows. Section 2 discusses the multiple public policy objectives that can potentially justify the increased deployment of technologies drawing on RE sources. Section 3 explores and evaluates the available literature assessing the global economic potential of RE sources. It further provides a brief review on the economics of variability of RE sources. Section 4 then turns to the market perspective and reflects on the question of which pivotal market failures need to be addressed in order to fulfill the economic potential, i.e. the integration of RE technologies into the market, and by means of which policy instruments to achieve this. Finally, Section 5 summarizes and concludes.

2. Multiple public policy objectives for renewables

Asserting that the deployment of RE technologies is not an end in itself raises the question of which public policy objectives can potentially justify the increased deployment. In the past, the main argument for policy intervention intended to foster and develop RE sources is to avoid climate externalities of fossil fuel use. However, in recent years other policy objectives have become increasingly important in the public debate and it is frequently argued that the deployment of RE technologies is beneficial due to its associated cobenefits, i.e. physical positive side-effects (Edenhofer et al., in press). This section examines how RE can contribute to the achievement of public policy objectives other than climate change mitigation, including energy security, green jobs, green growth, reduction of local environmental damages, poverty reduction and other sustainability concerns.

In its broadest sense, *energy security* refers to the uninterrupted provision of vital energy services (GEA, 2012, p.27) or, in other words, robustness against sudden disruptions of energy supply (Arvizu et al., 2011, p.120). Important energy security concerns are hence the availability and distribution of resources and the variability and reliability of the energy supply (IPCC, 2011, p.47). This can be measured, for example, by reduced global interdependence via reduced import/export balances or increased diversity and resilience of the energy supply (GEA, 2012, p.6). For many industrialized countries the key energy security challenge is the dependence on imported fossil fuels, particularly oil. A sudden rise in oil prices may disrupt the economy of oil importers, for whom reduced oil imports may be beneficial. Yet, it seems that the potential for RE to reduce oil imports, of which the transport sector demands the largest share, is limited. In past scenario analyses RE solutions for the transport sector, e.g. biofuels or the electrification of the transport sector, have not played a dominant role (Arvizu et al., 2011, p.127ff). It should be noted, though, that biofuels and the electrification of the transport and heating sectors are not fully represented in current IAMs (cf. Table S2.1 in Luderer et al., in press). In the electricity and heating sector, RE have the potential to substitute coal and gas, but where there are large domestic resources, such as in the US, the substitution by RE has little impact on energy security. Therefore, the comparative advantage of RE lies in its environmental benefits rather than in its potential to increase energy security (Borenstein, 2012). An increasing share of variable and unpredictable RE in the electricity sector may even have an adverse effect on energy security if no appropriate measures to assure a constant and reliable supply are undertaken, which is particularly challenging in developing countries (Arvizu et al., 2011). McCollum et al. (2011, 2013) calculate that policy costs can be reduced if energy security and climate change mitigation are targeted simultaneously. However, energy security in this study is measured by an indicator that accounts for diversity in primary energy carriers and import dependence and the effect of increasing RE is solely to reduce imports and a larger diversity of energy carriers. It is unclear if the proposition that climate mitigation through an increased share of RE has

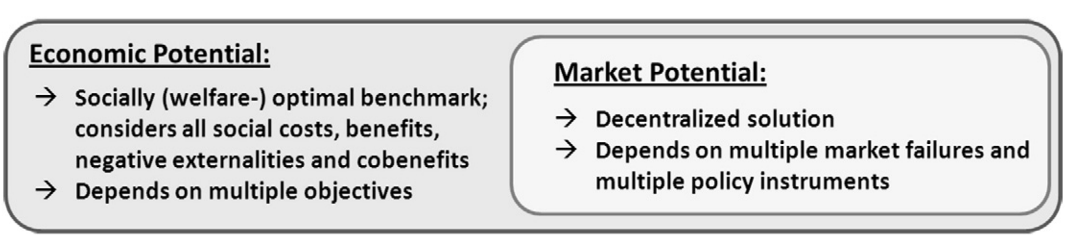

Fig. 1. The market potential of RE sources as a subset of the economic potential with respect to social costs and benefits, i.e. welfare. Own illustration, based on Verbruggen et al. (2011).

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