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EXPANSE methodology for evaluating the economic potential of renewable energy from an energy mix perspective

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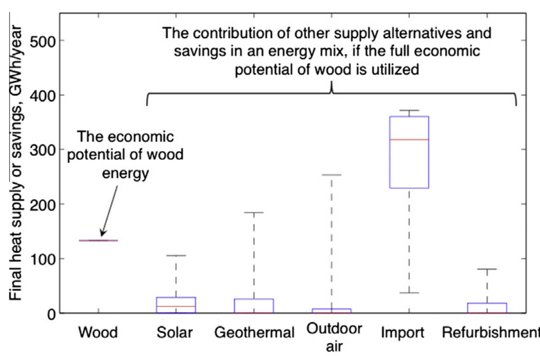
HIGHLIGHTS

- EXPANSE methodology for evaluating the economic potential of renewable energy.
- It estimates how this potential depends on its embedding in the whole energy mix.
- Economic potential of renewables can be as high as their exploitable potential.
- Full economic potential of all renewables cannot be deployed simultaneously.

GRAPHICAL ABSTRACT



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ABSTRACT

Several methodologies exist for evaluating the economic potential of renewable energy sources. These methodologies either cannot capture how this economic potential depends on its embedding in the whole energy mix, or provide a single cost-optimal energy mix, which is not flexible enough for building consensus among the relevant stakeholders. This article addresses these two limitations and introduces a novel methodology EXPANSE (EXploration of PAtterns in Near-optimal energy ScEnarios) for evaluating the economic potential of renewable energy sources from an energy mix perspective. This methodology is based on generation of cost-optimal and multiple near-optimal energy mixes. These mixes show the maximum, technically feasible, cost-effective potential of a renewable energy source under consideration and how this potential depends on the other supply alternatives and energy savings in an energy mix. The methodology is illustrated with the example of the renewable energy use for heat supply in a Swiss region. The example shows that even a particular renewable energy source is costlier than the currently deployed alternatives such as oil, its economic potential in an energy mix can be as high as its full exploitable (theoretical) potential, when some deviation is allowed from the cost-optimal energy mix. However, the full economic potential of all renewable energy sources cannot be utilized simultaneously. The full deployment of the economic potential of one renewable energy source decreases the economic potential of others. EXPANSE provides basis for analyzing such interlinkages.

1. Introduction

Increased deployment of renewable energy is among the key energy policy goals in many countries, especially in Europe. Researchers dedicate extensive efforts to understanding and providing crisp estimates of the potentials of renewable energy sources (RES), such as biomass, solar, geothermal, outdoor air (in air–water heat pumps), wind, hydro, and wave energy. In

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particular, as shown in [1], tremendous expertise has accumulated about the estimation of the technical potential, which shows the energy amount that can be harvested by energy conversion systems at a certain geographical location. Various techniques are used for further maximizing this technical potential by optimization of the design and control of these conversion systems [2]. Final, exploitable potential that can be realistically harvested is then estimated by reducing the technical potential due to the additional legislative, environmental, social and economic constraints [1,3,4].

Often, the economic potential of a particular RES is evaluated as the part of the technical potential that has lower costs per produced energy unit than a predefined cost level [5,6]. This level is assumed as the costs of a competitive, locally deployed alternative, such as oil, natural gas, etc. Such estimation of the economic potential of RES, by comparing its costs to one alternative, is, however, problematic. It is widely accepted that the future energy system—whether based solely on RES [7] or not—requires a mix of several energy supply alternatives as well as demand reduction measures [8,9]. From this energy mix perspective, it becomes misleading to compare the costs of the particular RES with only one competitive alternative. As there are many interlinked energy supply options and the supply mix is coupled to demand, it is essential to find ways to compare the costs of the analyzed RES with the costs of the multiple, rather than one, supply alternatives that form the feasible energy mixes.

Two types of methodologies have been so far used to analyze the economic potential of RES from an energy mix perspective. Using the first type, researchers construct the desired, feasible energy mixes from a technological perspective, as done in [10–12]. The economic or socio-economic costs are then used as the assessment criteria only. Usually, the costs of the constructed RES-based mix are compared to those of the reference mix (for example, current situation). If the costs of the desired RES-based mix are within the acceptable range, as compared to the reference mix, then the RES-based mix is considered economically feasible. Using the second type of methodologies, the economic potential of RES is evaluated by solving an optimization task and identifying the energy mix with the lowest costs, as done in [3,4,13]. Additional constraints may be added on greenhouse gas emissions, minimal deployment of RES, etc. [14]. The methodologies of this type capture well the links between the costs of the multiple supply alternatives in an energy mix. Yet, they provide only one energy mix as an output of one set of input parameters. Therefore, they have two major drawbacks considering the complexity of the real-world applications. First, real-world decisions about the future energy system involve stakeholder discussions. Constructive discussions can hardly evolve on a basis of a single cost-optimal energy mix, which might be rejected due to a lack of stakeholder consensus. Thus, there is generally a need to pose several alternatives for discussion [15]. Second, this single, cost-optimal energy mix may not be the best, when unmodeled objectives such as landscape quality or others are taken into account, often through discussion as well [16–18]. After all, when it comes to implementation, such a complex system, as the real-world energy system, can hardly be engineered to a single desired state [19].

Motivated by the limitations of the current methodologies, this article suggests a third type of methodology—EXPANSE (EXploration of PAtterns in Near-optimal energy ScEnarios)—for evaluating the economic potential of RES from an energy mix perspective. EXPANSE has the rationale of the modeling-to-generate-alternatives techniques [16,17], which have been recently successfully adopted for energy analysis [18,20]. EXPANSE is based on the cost-optimization of energy mixes, but the output of the analysis is not limited to a single optimal energy mix. Instead, the domain of feasible energy mixes, that are near-optimal (or optimal), is systematically explored. This exploration results in a number of maximally different near-optimal mixes. In this way, two core improvements of the evaluation of the economic potential of RES are achieved. First, EXPANSE allows for understanding how the economic potential of a particular RES depends on its combination with other supply alternatives. Second, consideration of multiple energy mixes, rather than a single one, provides the necessary flexibility for building consensus among the relevant stakeholders. Besides that, approaches of this type are argued to accommodate the uncertainties in costs [18].

Section 2 of this article introduces the EXPANSE methodology in general. Section 3 presents and discusses an example of evaluating the economic RES potential for heat supply in a Swiss region. Section 4 draws the general conclusions.

2. General methodology

In line with the other authors [1,3–6], EXPANSE adopts these definitions of RES potentials (Fig. 1):

- *Theoretical potential*—the theoretically extractable amount of energy at a certain geographical location. For example, in the case of solar thermal units, the theoretical potential depends on the solar irradiation and its fluctuations at the analyzed location.
- *Technical potential*—the energy amount that can be harvested by a currently technically feasible energy conversion system, including the storage and supply infrastructure. For example, the technical potential is the amount of heat that could be produced in the technically feasible installations of these solar thermal units; that is, this potential depends on the suitable area of roofs and the efficiencies of energy conversion, heat storage and supply.
- *Exploitable potential*—the part of the technical potential that meets the environmental, legislative and social constraints. For example, the technical potential of solar heat may be reduced, according to the existing legislation, by excluding the heritage-protected buildings.
- *Economic potential*—the part of the exploitable potential that is cost-effective in the whole energy mix. For example, the amount of heat produced in those solar thermal units that are cost-competitive compared to the multiple other available energy supply alternatives.

The EXPANSE methodology consists of two steps. First, the exploitable potential of every RES under consideration is estimated. The methods and tools are not described in this article as a comprehensive overview can be found in [1]. Second, a number of technically feasible, cost-effective energy mixes are analyzed in order to estimate the economic potential of these RES. This analysis of the energy mixes is in principle very similar to the standard approach of cost optimization, as used by [3,4,13]. The difference is that instead of analyzing one, cost-optimal energy mix, a number of near-optimal mixes (as well as the optimal one) are systematically sampled and analyzed. In this way, costs are not considered as the sole objective for constructing energy mixes, but rather as a cost-effectiveness constraint [18,20].

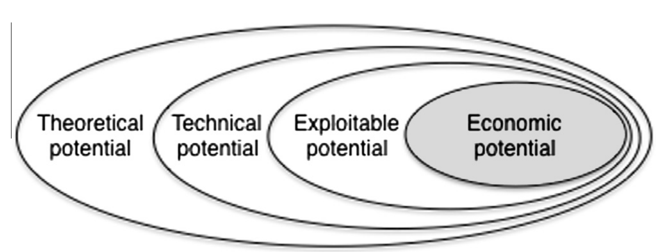

Fig. 1. Used definitions of RES potentials.