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Sustainability assessment of renewable power and heat generation technologies

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HIGHLIGHTS

- We used choice experiment to estimate the weights of criteria for the sustainability assessment of RES technologies.
- The most important attributes of RES technologies according to experts are land demand and social impacts.
- Concentrated solar power (CSP), hydropower and geothermal power plants are advantageous technologies for power generation.
- Geothermal district heating, pellet-based non-grid heating and solar thermal heating are favourable in case of heat supply.

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ABSTRACT

Rationalisation of consumption, more efficient energy usage and a new energy structure are needed to be achieved in order to shift the structure of energy system towards sustainability. The required energy system is among others characterised by intensive utilisation of renewable energy sources (RES). RES technologies have their own advantages and disadvantages. Nevertheless, for the strategic planning there is a great demand for the comparison of RES technologies. Furthermore, there are additional functions of RES utilisation expected beyond climate change mitigation, e.g. increment of employment, economic growth and rural development. The aim of the study was to reveal the most beneficial RES technologies with special respect to sustainability. Ten technologies of power generation and seven technologies of heat supply were examined in a multi-criteria sustainability assessment frame of seven attributes which were evaluated based on a choice experiment (CE) survey. According to experts the most important characteristics of RES utilisation technologies are land demand and social impacts i.e. increase in employment and local income generation. Concentrated solar power (CSP), hydropower and geothermal power plants are favourable technologies for power generation, while geothermal district heating, pellet-based non-grid heating and solar thermal heating can offer significant advantages in case of heat supply.

1. Introduction

It gives rise to concerns that regarding the ecological problems we have crossed or at least we have come close to that border where the space for the long-run survival of the human civilisation is doubtful (Meadows et al., 2004). Amongst these ecological problems one of the most significant phenomena is the climate change (Rockstrom et al., 2009) which is mainly resulted by energetic processes (Haas et al., 2011).

The current energetic system is unsustainable due to the increasing energy demand triggered by population expansion and economic growth, as well as short- and long-term uncertainty in connection with the availability of resources. Rationalisation of consumption, more efficient energy usage and a new energy structure are needed to be achieved in the same time. More intensive utilisation of renewable energy sources (RES) is an important aspect in order to shift the structure of energy system towards sustainability.

Utilisation of RES is still far from its potential at global scale. Although the main reason is for this, is that due to market failures (external effects as well as monopoly and monopsony on the production side) RES in general are characterised by higher costs than the current energy mix; however, some other barriers also exist. These include informational and awareness barriers (deficit of

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human resources, public and institutional awareness); socio-cultural barriers (conflict between RES utilisation and social values, landscape for instance); institutional and policy barriers (energy system regulation issues and inefficient financial support) (Moomaw et al., 2011).

None of the RES are solely beneficial for the environment (Kosenius and Ollikainen, 2013). The most important harmful impacts on the environment are emissions to atmosphere, biodiversity loss, effects on soil and water resources, thermal and noise pollution, effects on landscape (Cherubini and Stromman, 2011; de Almeida et al., 2005; Josimovic and Pucar, 2010; Kristmannsdottir and Armannsson, 2003; McBride et al., 2011; Phillips, 2010; Tsoutsos et al., 2005). In order to avoid of the negative ecological impacts is a continuous challenge for the R+D+I regarding RES technologies.

We have assumed every renewable energy technology to be sustainable; however, these technologies have their own well-known advantages and disadvantages. Naturally, utilisation of RES needs to meet local conditions; including available resources, such as labour supply, knowledge and infrastructure. Nevertheless, for the strategic planning on global, national and regional level, there is a great demand for the comparison of possible utilisation technologies of RES.

Simultaneously with ecological crisis, there are other crucial challenges in the world. Developmental goals may vary by regions. The core problems in developed countries are mainly social tensions, unemployment and economic stagnation. Increased utilisation of RES would play an essential role in solving of these problems. Expected functions of RES utilisation beyond climate change mitigation are increment of employment, economic growth and rural development, among other functions (Bergmann et al., 2006; Elghali et al., 2007; Grunwald and Rösch, 2011; Madlener and Stagl, 2005; Menegaki, 2008; Menegaki, 2012).

Preference of policies, technologies and projects bearing higher sustainability performance should be built in supporting systems according to the recommendation of European Union energy strategies. Sensitive subsidy practice is aimed in terms of multi-objective development policy. Sustainability assessment of RES utilisation technologies is able to support establishment and ex ante (preliminary) valuation of strategies, operative programs and macro-scaled supporting systems (e.g. feed-in-tariffs of RES power) (EC, 2007a, 2007b).

The aim of the study was to reveal the most beneficial RES utilisation technologies with special respect to sustainability by using a sustainability assessment frame. Ten technologies of power generation and seven technologies of heat supply were examined in a sustainability assessment frame of seven attributes which were evaluated by choice experiment (CE) survey.

The content of this present article is organised according to the following sections: in Section 2 methods and data sources are presented, Section 2.1 introduces attributes of sustainability assessment; Section 2.2 presents the survey, while in Section 2.3 the methodological frame of technology assessment is described. Section 3 contains our results: in Section 3.1 estimation model of (CE) survey is shown, while in Section 3.2 results of the technology assessment are presented. Section 4 contains our conclusions and policy implications.

2. Materials and methods

Methods of sustainability assessment are mainly corresponding to the field of environmental and ecological economics. According to Gasparatos and Scolobig, 2012, tools for sustainability assessment can be divided into three groups; monetary, biophysical and indicator tools. Methods for sustainability assessment can be interpreted on different temporal focus (retrospective/prospective), coverage areas (product, program, policy) and level of integrity of nature-society systems (Ness et al., 2007).

The anthropocentric approach in monetary valuation (monetarisation) results biased undervaluation of the ecosystems, while ecocentricity of the biophysical tools makes political decision-making difficult. Biophysical assessments interpreted in physical dimension (e.g. material requirement, ecological footprint, emissions etc.) still exceed the economic context. Problems in connection with the evaluation of different aspects of sustainability have emerged in both cases. Decision makers are supported by indicator-based methods in order to make the tracking of trends on several subsystems easier to reach higher quality (Singh et al., 2012). Since sustainability is a complex and multidisciplinary problem, it is worth considering the application of indicator-based tools (Frame and O'Connor, 2011).

Multi-criteria analysis/assessments (MCA) are appropriate methods of sustainability assessment. This includes direct analysis of the impact matrix and compensatory or non-compensatory approaches (Antunes et al., 2010). Direct analysis is a description without aggregation and comparison of the different aspects, thus conclusion regarding sustainability performance is difficult. Compensatory techniques make the compensation of weak performance from one sustainability aspect possible. For instance, proper economic circumstances of an investment are able to obscure its negative environmental impacts in the evaluation.

Expert evaluation based direct analyses (del Rio and Burguillo, 2009; Evans et al., 2009, 2010; Giampietro et al., 2006; Stamford and Azapagic, 2012), non-compensatory (Ghafghazi et al., 2010; Madlener and Stagl, 2005; Tsoutsos et al., 2009) and compensatory (Chatzimouraddis and Pilavachi, 2009; Renn, 2003; San Cristobal, 2011; Shen et al., 2010) methods of MCA are widely used in the field of general and RES specified energy management.

Based on the literature, three criteria of a suitable sustainability assessment frame were realised. These include complexity, ability for the generation of relative ranking; and weighting. Complexity is a need for the coverage of all aspects of the sustainable utilisation of examined object; with special regard to ecological, social and economic subsystems. Relative ranking presents detailed information about the sustainability performance, namely, that differences between the options are clearly provided for the decision-maker.

Weighting of the attributes i.e. description of criteria with a different importance in the analysis is a significant methodological challenge in MCA studies. Statement of these weights is either integrated into the model (e.g. AHP, ELECTRE) or defined in a separated process. In our study the latter is applied. If weights are not introduced, equally important aspects of RES utilisation are assumed, which lead to incorrect assessment.

Method of our sustainability assessment is non-compensatory MCA with CE based weighting. MCA meets all the criteria of a sustainability assessment presented above, if correct attributes of the utilisation are built in. The choice experiment method (CE) was used for weighting purposes regarding its suitability for valuating the changes in welfare compared to other stated preference methods (Roche et al., 2010). It belongs to the family of conjoint analysis methods and has been widely used in market (Chark and Muthukrishnan, 2013; Kallas et al., 2012), and transportation research (Hensher, 2010; Train and Wilson, 2008). In the last decade, this approach has also become popular in environmental and resource economics because it allows realistic trade-off situations to be modeled, while reducing some of the risk of social desirability bias (Hoyos, 2010).

CE methodology is based on Lancaster's characteristics theory of value and the McFadden's random utility theory (Bennett and Blamey, 2001). In order to link actual choices with the theoretical construct utility, the random utility framework is used. According