Energy for Sustainable Development 40 (2017) 126–138

Contents lists available at ScienceDirect

Energy for Sustainable Development

An ecosystem services perspective for classifying and valuing the environmental impacts of geothermal power projects

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ARTICLE INFO

Article history:
Received 7 December 2016
Revised 18 July 2017
Accepted 19 July 2017
Available online 2 August 2017

Keywords:
Decision-making
Valuation
Geothermal energy
Environmental impacts
Ecosystem services

ABSTRACT

An ecosystem services perspective can provide a useful means of understanding, in human well-being terms, the type, scale and value of environmental impacts deriving from the deployment of renewable energy technologies. This paper provides the first thematic review of the ecosystem service impacts commonly associated with developing geothermal areas for power projects. In this study, the typical ecosystem service impacts of geothermal power projects are classified using the Common International Classification of Ecosystem Services (CICES) typology. Next, in order to develop a guide for future practitioners, an analysis is conducted of the most suitable valuation methods for the respective ecosystem service impacts. A pluralist approach is advised to aide decision-making, involving the use of monetary and non-monetary information. A number of non-market valuation studies may be required to estimate the total economic value of affected geothermal ecosystems, likely including the contingent valuation and travel cost methods. The more intangible ecosystem services associated with geothermal areas, such as artistic inspiration and landscape aesthetics, are best valued using non-monetary approaches, including deliberative methods. Finally, in recognition of the importance of having a strong physical basis underpinning non-market valuation techniques, this paper critically assesses the merits of the most appropriate data sources for future environmental economists working in a geothermal context. A literature review reveals that neither Environmental Impact Assessments (EIA) nor Life Cycle Analysis (LCA) studies in a geothermal context have embedded an ecosystem service perspective into their processes. EIA are closest to fulfilling the needs of environmental economists, encompassing the majority of ecosystem service impacts, yet further methodological progress is recommended to ensure that all project stakeholders are given voice and arbitrage in the data-gathering process.

Introduction

Renewable energy transition and increasing significance of geothermal energy

Growing global energy demand and sustainable energy development

The use of energy is essential to the maintenance and advancement of human well-being, ensuring the functionality of economic activities, governments, hospitals and emergency services, public transport, agricultural systems and communication networks. It is expected that population growth and economic expansion could lead to growth in global energy demand of 37% by 2040 (IEA, 2014). In meeting such demand, continued reliance on the use of fossil fuels would lead to the exacerbation of many environmental problems that already undermine human well-being, including greenhouse gas emissions and climate change impacts, air and water pollution, acid rain, and the destruction of forest ecosystems.

The energy sector can play a crucial role in mitigating global climate change, principally by fulfilling a transition from the use of carbon-intensive fossil fuels to the greater deployment of renewable energy alternatives. The European Union's target for 27% of member state energy generation to be from renewable sources by 2030 reflects the importance of sustainable energy development, a concept involving “the provision of adequate energy services at affordable cost in a secure and environmentally benign manner, in conformity with social and economic development needs” (IAEA/IEA, 2001). Implicit in this definition is recognition that sustainable energy development, as an objective, is tied to the pursuit of human well-being, since its delivery must satisfy socio-economic needs whilst avoiding environmental harms. However, the deployment of renewable energy technologies frequently leads to environmental and social impacts with negative consequences for human well-being. Biomass use in some countries has led to

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http://dx.doi.org/10.1016/j.esd.2017.07.007
0973-0826/

desertification, biodiversity loss, and diminished areas of arable land (Hastik et al., 2015). The erection of wind turbines has sometimes presented blights to scenic amenity (Leung and Yang, 2012). When considering the merits of new renewable energy projects, decision-makers frequently have to consider complex trade-offs which weigh the meeting of socio-economic needs against the virtues of nature preservation.

Geothermal energy development

Utilisation of geothermal energy dates back to Palaeolithic times, when hot springs were first used for bathing. In more recent times, geothermal energy has been used widely for electricity generation, as well as direct uses such as in district heating, space heating, industrial and agricultural processes, swimming pools, and spas. Worldwide, a total of 12.6 gigawatts (GW) of geothermal power capacity had been installed by 2014 (BP, 2015). The United States has the largest installed capacity (3.5 GW, 28% of world total), followed by the Philippines (1.9 GW, 15%), Indonesia (1.4 GW, 11%) and New Zealand (1.0 GW, 8%) (BP, 2015). Although as a share of global power generation, geothermal energy represents just 0.3%, it grew in scale by 6.4% in 2014 and provides a significant proportion of total electricity generation in certain countries, such as Kenya (32%), Iceland (30%), El Salvador (25%), and New Zealand (17%) (BP, 2015). Furthermore, the Intergovernmental Panel on Climate Change estimates that geothermal energy could satisfy 5% of global heating demand by 2050 (IPCC, 2012).

Usually considered to be a renewable energy source, the development of geothermal power is nevertheless associated with significant and multi-dimensional sustainability implications. Shortall et al. (2015a) carried out a thematic review of the most important sustainability issues of concern in relation to geothermal power projects, listing multiple environmental and social effects, including air and water quality impacts, noise emissions, soil erosion and land degradation, deforestation, loss of biodiversity and impacts to recreational and cultural amenity. As geothermal power is expected to grow in significance in the coming decades, particularly hydrothermal fields harnessed for electricity generation, it is important that these energy resources are utilised in a sustainable manner, with due consideration given to all well-being impacts related to their development.

Analysing the environmental impacts of renewable energy technologies – the ecosystem services perspective

Ecosystem services are the functions of the environment that support, either directly or indirectly, human well-being (Costanza et al., 1997; Daily, 1997; MEA, 2005; Haines-Young and Potschin, 2010). Understanding the links between the processes and functionality of ecosystems and their ultimate contribution to human well-being is of critical importance to a wide-range of decision-making contexts (De Groot et al., 2002; Wallace, 2007; Fisher et al., 2009). Due to the public goods characteristics of ecosystem services, they are typically not assigned their full value in land-use decision-making (Loomis et al., 2000; Boyd and Banzhaf, 2007; Fisher et al., 2009; Simpson, 2014).

A recent study by Hastik et al. (2015) used the CICES framework to provide a detailed thematic review of the ecosystem service impacts associated with biomass production, hydro power, wind power, and solar photovoltaics. The paper considerably advanced the literature base with regards to identifying and comparing the potential ecosystem services impacts and land management trade-offs associated with harnessing these renewable energy technologies. However, although the authors briefly discussed the impacts of geothermal power, this paper's first aim is to provide a detailed thematic classification of ecosystem service impacts in a geothermal energy context. Such a study is long overdue in view of the distinct land-management complexities associated with harnessing such resources (Thayer, 1981; Shortall et al., 2015a). Not only are geothermal areas unique in terms of their geophysical, geomorphological and biological characteristics, all stages of the fuel cycle are located at the production site, increasing the likelihood that a multitude of ecosystem services may have to be sacrificed, both during the construction phase and subsequent operation of plant infrastructure and transmission lines.

Valuing ecosystem services impacts

The debate concerning the use of monetary or non-monetary sources of information to value ecosystem service impacts has been heated in recent years, and includes three disparate schools of thought. On the one hand, arguments have abounded for the use of monetary valuation on the grounds that this approach leads to the increased likelihood of protecting highly valued resources, both through knowledge accumulation concerning the economic value of their sacrifice and integration into cost-benefit analysis (Myers, 1997; Atkinson and Mourato, 2008; Koundouri et al., 2009; De Groot et al., 2010; Dixon et al., 2013). On the other, critics have asserted that economic valuations of ecosystem service impacts lead neither to the conservation of resources (Heal, 2000; Simpson, 2014) nor constitute a necessary or sufficient means for decision-makers to make coherent and consistent choices about the environment (Vatn and Bromley, 1994). The third view – adopted in this paper – is more pluralist, maintaining that coherence in cost-benefit analysis can be maintained through the use of monetary data, provided that appropriate complementary, non-monetary sources of information are also used in decision-making processes (Fisher et al., 2009; Wegner and Pascual, 2011).

To date, only one study has attempted to estimate the economic value of preserving a geothermal area intact, the contingent valuation assessment by Thayer (1981). Given the absence of valuation studies in a geothermal context, a second aim of this paper is to extend the thematic classification of ecosystem service impacts relating to geothermal power projects, applying a set of general criteria to determine whether monetary or non-monetary information is best suited for the valuation of respective ecosystem service impacts. Where monetary information is deemed appropriate, the paper outlines the most appropriate non-market economic valuation techniques to be used in future valuation studies. In so doing, a methodological guide is developed as a form of practical starting-point for future valuation studies.

Assessing impacts to ecosystem service impacts

A strong physical basis is critical to the success of non-market valuation techniques and their ultimate usefulness in decision-making (Cook et al., 2016). In a geothermal context, no studies have sought to evaluate the optimal approach for identifying, in a scientific manner, the degree of qualitative change to ecosystem services, with a view to communicating such information in non-market valuation techniques. Therefore, this paper's third aim is to discuss the two main techniques – LCA and EIA – that could be used to qualitatively assess the ecosystem service impacts of developing hydrothermal fields. All reviewed studies are recent assessments specific to the context of geothermal power.

Paper structure

The organization of this article is as follows. The Ecosystem service impacts and classification frameworks for geothermal power projects section begins by providing an overview of the ecosystem services concept, broad environmental characteristics of undeveloped hydrothermal fields, and classifies the ecosystem service impacts typically associated with their development. The Valuing ecosystem service impacts from geothermal power projects section constructs a framework for valuing these impacts, discussing the various monetary and non-monetary techniques available, and then evaluating their applicability specific to a geothermal energy context. The Discussion section discusses (a) the respective advantages and disadvantages of relying on either LCA or EIA for practitioners seeking to fathom the change in provisioned quantity and/or quality of ecosystem services in a