Geothermics 66 (2017) 151–155

Contents lists available at ScienceDirect

Geothermics

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

Calculations of environmental benefits from using geothermal energy must include the rebound effect

R.S. Atlason[a,*], R. Unnthorsson[b]

[a] University of Southern Denmark, Department of Technology and Innovation, Campusvej 55, 5000 Odense, Denmark
[b] University of Iceland, Department of Industrial Engineering, Mechanical Engineering and Computer Science, Centre for Productivity, Performance and Processes, Hjardarhagi 6, 107 Reykjavik, Iceland

ARTICLE INFO

Article history:
Received 29 August 2016
Received in revised form 5 December 2016
Accepted 7 December 2016

Keywords:
Rebound effect
Greenhouse gas
Geothermal utilization
Sustainability

ABSTRACT

When considering the environmental benefits from converting to renewable energy sources, the rebound effect is often omitted. In this study, the aim is to investigate greenhouse gas emission reduction inclusive of the rebound effect. We use Iceland as a case study where alternative consumption and energy production patterns are simulated using data from countries with similar environmental conditions but do not use geothermal or hydropower to the same extent as Iceland. Because of the rapid shift towards renewable energy and exclusion of external energy provision, the country is considered suitable for such a study. It was found that real emission reductions are most likely overestimated by previous calculations. Results show that between 1969 and 2014 greenhouse gas emission savings are likely to be between 164 and 361 million tonnes of CO_2 equivalents. Between 1994 and 2014 savings are likely to be between the range of 76 and 142 million tonnes of CO_2 equivalent. This study sheds a stronger light on the real observed environmental benefits when changes in consumption pattern are included in calculations stating greenhouse gas emission reductions.

1. Introduction

It is widely known that humans need to convert from reliance on fossil fuel energy sources, to renewable and environmentally friendly sources. The diverse negative environmental effects from human reliance on fossil fuels are appearing in multiple forms, such as in rising global temperatures, sea levels and negative human effects (IPCC, 2015). It has also been shown that easy and inexpensive access to energy has positive effects on global economies, leading to increased living standards, extended average lifetimes among other positive factors (Poizot and Dolhem, 2011). Nations therefore seek to reduce negative environmental effects while maximizing economic benefits from energy production. Some countries have managed to divert the energy product from being fossil fuel based to renewable energy based. The Norwegian nation for instance produces most of its electricity for domestic consumption using hydropower (Gabrielsen and Grue, 2012). Multiple studies have demonstrated in some form environmental benefits from using geothermal energy. Such studies often take the form of Life Cycle Assessments (LCA), where the energy system is studied in isolation (Martín-Gamboa et al., 2015). While LCA studies can provide a sharp image of the potential environmental impact of systems, they do not provide information about the emission savings of the systems under study. Doing so, the practitioner of the assessment would need to speculate how societies would behave if the system in question was absent. The difference between the two scenarios would only then allow for estimation of emission savings. Conducting such analysis is however not the goal of LCA's, and therefore not a common practice. For geothermal fields, various other environmental issues are often more evident and in need of more consideration. Reinjection of fluids may for example create a local environmental problem which are usually given more attention than regional or global issues (Şimşek et al., 2005). It has explicitly been stated that surface disturbances, physical effects of fluid withdrawal, heat effects and discharge of chemicals are the most notable environmental impacts from geothermal resource use (Kristmannsdóttir and Ármannsson, 2003; Ármannsson and Kristmannsdóttir, 1992). One must however note that the effects mentioned before, are all on a local or a regional scale. It can therefore be seen that researchers of geothermal utilization may not be all that interested in global effects of the utilization, or believe that environmental issues on a global scale are of little significance. It has numerously been demonstrated, partially through LCA's, that geothermal energy utilization contributes to a decreased amount

* Corresponding author.
E-mail addresses: resa@iti.sdu.dk (R.S. Atlason), runson@hi.is (R. Unnthorsson).

http://dx.doi.org/10.1016/j.geothermics.2016.12.002
0375-6505/

of emitted greenhouse gases. The amount of greenhouse gas emission savings is however something that researchers have not paid attention to. This can further be seen in a recent paper which outlines which research areas are of most importance to the authors. All research suggestions by that particular paper are on utilization and geology of geothermal systems (Axelsson, 2010). In the present paper, an overlooked research perspective is taken, where a more realistic approach is taken on calculations of greenhouse gas emission savings from geothermal utilization than previously has been done. To do so, Iceland is used as a case study.

The Icelandic nation relies almost solely on hydro and geothermal energy if the transport sector is excluded (Moore and Simmons, 2013). However, by converting to renewable energy sources, nations may be prone to change their consumption patterns. This is because from the newly gained knowledge that the energy consumed has less effects on the environment and is less expensive than energy previously consumed. This is known as the rebound effect (Berkhout et al., 2000). It has previously been estimated that the rebound effect is not so significant but is sensitive to the sector affected (Berkhout et al., 2000).

The effect has been estimated to be between 0% and 30% depending on sector. This means that up to 30% of the energy savings gained because of increased efficiency can be offset because of increased energy consumption (Greening et al., 2000; Sorrell et al., 2007). Therefore, the rebound effects need to be considered when attempting to visualize the perceived environmental and economic benefits of moving from finite to renewable energy sources. In a recent publication from the Icelandic National Energy Authority (NEA) (NEA, 2015), an attempt was made to demonstrate the benefits in environmental and economic terms from converting from fossil fuel energy in the late 1960s to geothermal and hydropower. The publication by the NEA is acknowledged by the authors to be a good starting point for visualizing the benefits of converting to renewable energy, but eventually lacks any consideration for the rebound effect. The NEA assumes that the same consumption pattern would have prevailed even if geothermal energy would not be utilized in Iceland. This means that Iceland would have consumed little less than 7 million tonnes of coal in 2014 (if coal would be the primary source of energy). Such consumption of coal would be approximately the same as in Columbia and the Icelandic nation would have spent a staggering 500 million US dollars (1515 USD per capita) in 2014 alone to purchase the European coal (EIA, 2016a,b). It can be seen that such assumptions are out of proportions and can be improved. In previous studies by the Icelandic National Energy Authority attempts have been made to calculate the financial savings of the Icelandic society of using renewable energy instead of fossil fuels (Haraldsson et al., 2010). Such attempts have however failed to include the rebound effect and the fact that consumption patterns change with different market situations.

The hypothesis of this paper is that the rebound effect for the Icelandic society is relatively large. This is because the nation has built an infrastructure heavily reliant on geothermal energy. For example, more than 120 thermal swimming pools have been built around the country since the geothermal utilization began (Ragnarsson et al., 2003). Thermal energy used for district heating is furthermore treated as a disposable product, disposed to the sewer system after use, in some cases used for street heating. Because of the cheap, abundant energy, heavy industries have settled within the country, benefiting from the renewable energy sources (Benediktsson and Karlsdóttir, 2011). Allowing heavy industries to access the domestic energy can be considered a way of exportation. Products, such as aluminum are processed within the country prior to being transported overseas. It is therefore of little debate, that if the Icelandic society would not have easy access to geothermal or hydropower, the consumption pattern of the Icelandic society would be to a large extent different.

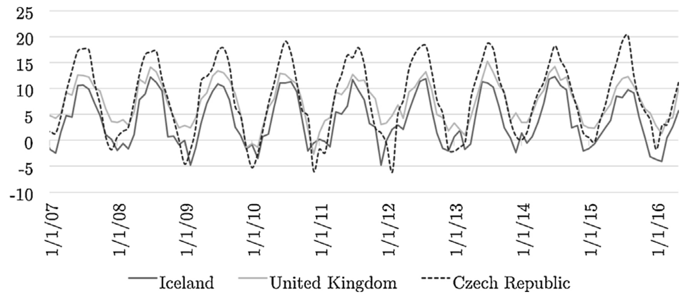

Fig. 1. Average monthly temperatures (measured in degrees Celsius) in the countries examined in this paper (Wolfram|Alpha, 2016).

- It is the objective of this paper to estimate the greenhouse gas emission savings of the Icelandic nation from converting to renewable energy, considering the rebound effect.

2. Methods

To estimate the energy consumption patterns and subsequent greenhouse gas emissions of the Icelandic nation had it not converted to geothermal energy, consumption patterns of nations living in a similar climate were examined. In this case, the United Kingdom (UK) and Czech Republic were chosen as reference nations as temperature fluctuations are similar as in Iceland so energy consumption for heating and cooling are estimated to be similar. Fig. 1 demonstrates the similarity in temperature fluctuations between all three nations. We then analyze the consumption patterns of the chosen nations and the methods of energy production. We assume that nations in a similar climate can to some extent represent the consumption pattern of the Icelandic nation if it had not began exploration and utilization of geothermal energy. The aggregated emission savings (ES) can mathematically be represented as:

$$ES = \sum_{i=q}^{d} a_i \sum_{j=p}^{n} b_{ij} k_j - \sum_{i=q}^{d} c_i \frac{I_p}{I_{ref}} \sum_{j=p}^{n} d_{ij} k_j \tag{1}$$

where a_i is the energy consumption for given year i for the country studied, in this case Iceland. Let b_{ij} denote the portion of the energy mix from a given resource j for a year i, for example hydro or coal and k_j the CO_2 equivalent per energy unit from that given resource j. On the right side of the equation, the reference consumption pattern is included. c_i is the energy consumption from a reference nation for a given year i. I_p is the size of the Icelandic population for the year i and I_{ref} is the size of the reference nation for the same year. d_{ij} is the portion consumed of given resource j for year i and k_j is the emission factor for resource j.

In this study we estimate the CO_2 savings between 1969 and 2014. Nineteen sixty nine marks the year when the first geothermal power plant in Iceland, a two MW station named Bjarnaflag, was put into operation (Atlason et al., 2015). The development of the energy grid mix is then adopted from the above countries when calculating the potential consumption and emissions in Iceland if geothermal energy would not be used. This means that several scenarios are to be developed, based on consumption patterns and emissions from the energy grid mix of the countries used in this study.

For comparison, emission factors from different energy producing systems are gathered from the Intergovernmental Panel on Climate Change (IPCC). In this study, the following emission factors are used, note that numbers in brackets are grams of CO_2 equivalents per kilowatt hour (gCO_2eq/kWh): Coal (820), Gas – combined cycle (490), Geothermal (38), hydropower (24), nuclear (12) (Schlömer et al., 2014). The numbers detailed above are used except when more detailed numbers are provided from official