Geothermal resource dynamics and implications for energy system planning

Nathalie Spittler1,[[1]](#footnote-1)\*, Ehsan Shafiei1,2, Brynhildur Davidsdottir1, Egill Juliusson3

1 *﻿School of Engineering & Natural Sciences, Environment & Natural Resources, University of Iceland, Reykjavik, Iceland*

2 Environmental Policy Centre, Finnish Environment Institute (SYKE), Helsinki, Finland

3 *Landsvirkjun, Reykjavik, Iceland*

## Overview

Geothermal power production grew by 16% between 2010 and 2015 [1]. Geothermal resources are renewable, have relatively low emission rates and production is unrelated weather conditions making them suitable to provide base load electricity and independent of changes in climatic conditions. Due to those characteristics further expansion of geothermal resources is expected [1,2]. However, geothermal resources, unlike other renewable resources, can be (almost) depleted if they are utilized excessively beyond their regeneration rate for electricity production [3,4]. Once a geothermal resource has been used excessively and utilized close to depletion, in some cases, geothermal regeneration can take up to a century [5]. The production capacity of a geothermal plant depends on the available geothermal energy resource in the reservoir, which is influenced by the extraction of it through actual resource utilization for electricity production. The connection between the geothermal resource utilization and changes in the resource’s availability depends on the characteristics of the reservoir such as for example reservoir temperature and pressure [6]. If the geothermal resource at a plant site is utilized beyond its sustainable harvesting rate, the capacity of the plant decreases over time. In general, the geothermal capacity losses can be compensated up to a certain level by drilling additional wells [5]. Because of these characteristics, it has been argued that the geothermal resource can be studied as a stock and flow system [7]. So far, geothermal resources have been modelled and investigated for individual reservoirs or plants, focusing on the implications of utilization mainly on pressure and temperature losses but also to some extent on future electrical capacity. So far, they have not investigated the effect of geothermal resource dynamics in the context of energy system modelling. Hence the model introduced captures the dynamics of geothermal resources occurring during its utilization for electricity production on a system’s level (i.e. national level), incorporating an economic structure, which will make it possible to connect it to an energy system’s model such as the UniSyD\_IS model [8–10]. The model discussed captures the dynamics related to geothermal resource utilization for electricity production as described in the introduction.

## Methods

The model consists of three main sectors: “geothermal resource dynamics”, “geothermal plant construction”, and “geothermal economics”.

The System Dynamics approach has several advantages and has been used to develop the model because of the following reasons [11]:

(i) System dynamics is suitable for modelling feedback loops between different variables. This aspect is particularly relevant in this study for addressing the feedback between resource utilization, power plant capacities and economics of geothermal system.

(ii) System dynamics makes structural differences between stock and flow structures. This aspect is important considering that like other energy resources also geothermal resources can be seen as stocks.

(iii) System dynamics is suitable for addressing material as well as information delays in systems. There are some delays in the system associated with electricity system capacities, resource availabilities and electricity cost.

In order to test the model structure, it has been applied to Iceland. Four main scenarios are simulated and compared based on the level of resource utilization, which can either be high or low, and whether the geothermal resource dynamics are incorporated or not. Sensitivity analysis is performed with respect to well capital cost and geothermal natural recharging rates.

## Results

Results show that including geothermal resource dynamics into the model structure makes it possible to estimate capacity installation cost as well as production cost per unit more accurately. In some scenarios, which include the resource dynamics the unit cost of electricity production is 16% higher than if resource dynamics are not considered. With regards to assessing future resource availability, including the feedback between resource dynamics, the economic and plant construction sector, allows for an improved planning of the distribution of resource utilization between fields. Through sensitivity analysis carried out for the case study it was shown that despite uncertainties regarding the natural recharge, average unit production costs fall less significantly with a decrease in the maximum recharge coefficient than they grow with an increase in the maximum recharge coefficient in the same order.

## Conclusions

Applying a System Dynamics approach is useful, as it is able to represent the stock-like dynamics of the geothermal resource and feedbacks between various system components. By capturing those, it became possible to investigate the impact of electricity production on the geothermal resource and the changes in cost of electricity production as captured by unit production cost. This implies that excluding geothermal resource dynamics from energy system models, results in higher emphasis on utilization of geothermal resources than perhaps is warranted.

Incorporating the current model into a national energy system model would allow us to assess the prospects of geothermal power and its competitiveness with other resources, in the short- and specifically long-term, under different demand scenarios. As the consequences of excessive geothermal resource utilization for electricity production can occur with a delay, it is especially relevant to understand how certain supply choices affect the system in the long-term. Therefore, it is planned to connect the presented model to the Icelandic national energy system model, to assess the implications of including geothermal resource dynamics for energy system development.

## References

[1] Sigfússon B, Uihlein A. 2015 JRC Geothermal Energy Status Report. 2015. doi:10.2790/959587.

[2] Bruckner T, Bashmakov AI, Mulugetta Y, Chum H, De la Vega Navarro A, Edmonds J, et al. Energy Systems. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, et al., editors. Clim. Chang. 2014 Mitig. Clim. Chang. Contrib. Work. Gr. III to Fifth Assess. Rep. Intergov. Panel Clim. Chang., Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2014, p. 511–98.

[3] Dayan GM, Ambunya M. Geothermal Energy-Making It Renewable and Sustainable. Fourtieth Work Geotherm Reserv Eng Stanford Univ Stanford, California, January 26-28, 2015 2015:1–8.

[4] Axelsson G, Stefansson V. Sustainable Management of Geothermal Resources. Int Geotherm Conf Reykjavík 2003:40–8.

[5] Juliusson E, Horne RN, Sweeney J, Hart M, Rich J, Sandler J. Optimal Extraction of Geothermal Resources. Geotherm Resour Counc Trans 2011;35:1457–66. doi:10.1002/yd.430.

[6] Rybach L. Geothermal Sustainability Assessment Framework. Proc. Eur. Geotherm. Congr. 2007, Unterhaching, Germany: 2007.

[7] Júlíusson E, Axelsson G. Stock models for geothermal resources. Geothermics 2018;72:249–57. doi:10.1016/j.geothermics.2017.11.006.

[8] Shafiei E, Davidsdottir B, Fazeli R, Leaver J, Stefansson H. Macroeconomic effects of fiscal incentives to promote electric vehicles in Iceland : Implications for government and consumer costs 2018;114:431–43. doi:10.1016/j.enpol.2017.12.034.

[9] Shafiei E, Leaver J, Davidsdottir B. Cost-effectiveness analysis of inducing green vehicles to achieve deep reductions in greenhouse gas emissions in New Zealand. J Clean Prod 2017;150:339–51. doi:10.1016/j.jclepro.2017.03.032.

[10] Shafiei E, Davidsdottir B, Leaver J, Stefansson H, Asgeirsson EI. Economic Impact of Adaptation to Climate Change in Iceland ’ s Energy Supply Sector 2015:0–4.

[11] Sterman JD. Business Dynamics: Systems Thinking and Modeling for a Complex World. 2000. doi:10.1057/palgrave.jors.2601336.

1. \* Corresponding author. University of Iceland, Sæmundargata 2, 101 Reykjavik, Iceland.

   E-mail addresses: nas14@hi.is (N. Spittler), Ehsan.shafiei@env.fi, ehsan.shafi@gmail.com (E. Shafiei), bdavids@hi.is (B. Davidsdottir), Egill.Juliusson@landsvirkjun.is (E. Juliusson) [↑](#footnote-ref-1)