Renewable and Sustainable Energy Reviews 64 (2016) 279–288

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Geothermal heat pumps and the vagaries of subterranean geology: Energy independence at a household level as a real world experiment

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ARTICLE INFO

Article history:
Received 23 December 2014
Received in revised form
15 February 2016
Accepted 15 June 2016

Keywords:
Geothermal heat
Engineering
Energy independence
Experimental learning
Sustainability

ABSTRACT

Geothermal heating is often perceived as an almost ideal sustainable energy source and as one that provides its users with a means of potentially heating their homes independently from established energy suppliers. However, our research in Germany also shows that the implementation of geothermal energy technology has triggered uncertainties regarding environmental impacts and its general technical feasibility also beyond the household level. Unlike traditional heating systems, geothermal technology forms a tightly coupled relationship with the complex environmental system of subsurface. Our analyses show that decentralized renewable energy sources are not “ready-made” but need to be adapted to the specific situation. Questions often emerge in situ when new facilities are installed or are already in use. The paper discusses some of the strategies actors have developed in the course of interactions between nature, culture, and technology to enable them to cope experimentally with unforeseen risks. We suggest that the way geothermal energy use is organized can serve as a typical example of coping with uncertainties in ongoing energy transitions.

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1. Introduction

In the realm of energy research the transformation from fossil fuel based energy production to renewable energies has focused mainly on wind, solar, biomass and, to a lesser extent, hydropower. Geothermal heat, the heat stored in the depths of the Earth, has perhaps received the least attention of the potential sources of renewable energy. This lack of attention may have to do with the fact that, for a long time, tapping geothermal energy has been limited to extracting energy from hot springs located near tectonic plate boundaries. However, by the end of the 20th century the use of so-called shallow geothermal heat had also become well established in several countries. Generally speaking geothermal (ground-source) heat pumps extract energy from groundwater and humid subsurface to provide space heating, cooling, and domestic hot water for buildings. Diverse technologies have been

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http://dx.doi.org/10.1016/j.rser.2016.06.013
1364-0321/

developed reaching from open systems using extraction and injection wells to closed systems using for example borehole heat exchangers, direct expansion heat pumps with horizontal collectors or foundation piles [1,2,11,20,41]. The use of low enthalpy geothermal energy for these purposes is of particular interest because a large proportion of fossil resources are wasted in processes where the actual temperatures needed range from 40 °C to 60 °C [3].

As a result of growing political attempts since the late 1990s to foster a transition towards more sustainable energy systems (in Germany and Denmark, but also in Spain and many other areas, especially North America) the sociotechnical regime of heating and cooling has become destabilized, thus providing an opportunity for several niche technologies to enter the market. The technologies used for geothermal heating and cooling have since emerged from the incubatory stage it went through during the 1980s and has made an entrance onto the market [2,4–8].

Shallow geothermal energy is a ubiquitous and environmentally friendly renewable energy resource delivering heat throughout the year [8,43]. Geothermal energy is thus understood by its proponents and many of the users as an infinite and stable source of energy that promises its users a certain independence from energy imports (mainly oil and gas) and political conflict related with fossil resources [45,46]. Nevertheless, unlike oil or gas based heating systems, geothermal heat pumps operate on the basis of potentially fluctuating flows of heat and water, thus requiring new ways of coping with unavoidable uncertainty. Although less fluctuating than wind and sun geothermal flows are invisible for the user and any possible vagaries of subterranean geology remain a matter of the mercy of natural processes. Given that hydrogeological conditions in each location are heterogeneous and are not readily accessible to close inspection, each geothermal installation has to cope with unforeseen issues that often emerge in situ while new facilities are either being installed or while they are in use. Furthermore, although the costs of heat pumps along with their ducts and electrical installations have fallen over the last few decades, home owners additionally need to cover the cost of drilling wells. These drilling costs can suddenly increase if the drilling process is hampered by unforeseen geological conditions. In addition, after a few years wells may deliver less heat due to naturally changing hydrogeological conditions, or the soil may cool down because the levels of heating required have been underestimated.

In addition to such uncertainties, the process of transferring this technology into broader societal contexts has raised novel questions about local ecological impacts such as the so-called neighborhood effects on groundwater temperature and how to deal with geological specificities [5,43]. Furthermore, it is far from clear what sociotechnical processes may be initiated by establishing geothermal heat facilities on a larger scale.

This leads to the *first* question we aim to answer, of how the transfer of a technology that forms a tightly coupled relationship with complex local environmental conditions from a niche into the existing technological regime takes place. We assume that specific recursive patterns of practice can offer opportunity for breaking down old structures and create novel arrangements and strategies that are needed in order to tailor the technology to specific contexts on the one hand and to further develop it on the other, so as to achieve a more sustainable form of energy provision [39]. This leads us to a *second* question on how human and non-human elements are dealt with in situations of newly faced uncertainties. The uptake of renewable energies and sustainable practices into the dominant technological regime has been discussed as part of transition theory [12,17,18]. One of the basic ideas is that innovative technologies and practices are developed in niches and then upscaled to the regime level where it might induce a regime shift. Within the concept of sustainability transitions the niche level is the place of trying things out, of developing new configurations of technologies (and practices) and of dealing with open questions [52,53]. Based on the idea of real world experimentation (see next section) we will add an aspect to this discourse in arguing that experimental strategies cannot be limited to the niche level but can also be observed in transferring a technology to the regime level.

Thirdly our analysis constitutes an attempt at better understanding: how is self-declared energy independence at the household level achieved? This is to say that in many cases house owners are well-aware that they are not self-sustaining on all levels in a closed system, but a heat pump in the basement gives them the feeling to be less dependent from “outside sources”. Many authors have already analyzed user's engagement with innovative energy technologies taking up the concept of prosumption [28,44]. This research focusses on the role of users in customizing pre-configured technologies to their specific situation and thus, the interplay of technology developers and users [27,28,47,48]. This correlates well with the classical notion of innofusion as coined by James Fleck. Fleck (1993) proposed an interactive model of technology development that aims to integrate user needs in “experimental” feedback loops [54]. We will contribute to these debates by shedding light on the interplay of governance mechanisms (notably administrative practices) and innovative technology users and the impact of these processes on technology design. In order to do this, we take into account the interplay between home owners' strategies for dealing with the technology, the role of the relevant statutory authorities, and the generation of site-specific knowledge in the face of largely unknown conditions beneath the earth's surface.

Given the enormous amount of potential energy stored underneath the Earth's crust, we would like to help adding knowledge in social science research by reconstructing and analyzing the specificities of implementing heat pumps for heating (and cooling) using sources from beneath people's own homes.

2. Ground source heat pumps as real world experiments

Geothermal technology differs markedly from other forms of heating: its dependence on the invisible geological conditions beneath a house is quite different from, say, the dependence of solar panels on sunshine [9]. This almost necessarily calls forth new practices and ways of coping with the unforeseen changes attributed to hydrogeological conditions. We thus follow an approach where actors and “activities” by technological devices in and above the Earth's subsurface are treated as part of a mobile collective where the boundaries are being negotiated (and renegotiated) during the process of assembling the collective [9,11,28]. Taking this idea a step further, we would like to link the notion of a collective to what has been termed real-world experiments [14–16] or sometimes collective experiments [13,21]. For Bruno Latour a “sharp distinction between scientific laboratories experimenting on theories and phenomena inside, and a political outside where non-experts were getting by with human values, opinions and passions, is simply evaporating before our eyes. We are now all embarked on the same collective experiments, mixing humans and non-humans together” [21:3]. The notion of experiment here can be used to show that the collectives' direction and composition is contested and the results presented are often not the ones expected (hypothesis falsified). To put it more bluntly, sudden, unexpected changes that make house owners but also responsible authorities and engineers aware of their own ignorance about the geological underground as well as the technology they are using can provide the impetus