Energy Strategy Reviews 20 (2018) 6–19

Contents lists available at ScienceDirect

Energy Strategy Reviews

journal homepage: www.ees.elsevier.com/esr

# Analysis of the power-to-heat potential in the European energy system

Hasan Ümitcan Yilmaz [a,*], Dogan Keles [a], Alessandro Chiodi [b], Rupert Hartel [a], Martina Mikulić [c]

[a] Karlsruhe Institute of Technology, Chair of Energy Economics, Hertzstraße 16, D-76187 Karlsruhe Germany
[b] E4SMA Srl, Via Livorno, 60 10144 Torino Italy
[c] Energy Institute Hrvoje Pozar, Savska cesta 163, 10000 Zagreb Croatia

A R T I C L E  I N F O

*Article history:*
Received 18 July 2017
Received in revised form
1 December 2017
Accepted 18 December 2017

*Keywords:*
Power-to-heat
PtH potential in Europe
PtH business models
Excess electricity
District heat demand

A B S T R A C T

The European power system is currently experiencing new challenges due to growing shares of intermittent renewable energy sources. Compared to other flexibility options, power-to-heat (PtH) technologies have a high level of maturity. The goal is, therefore, to analyse the potential for PtH in the European energy system and possible business models that enable the exploitation of these potentials. A literature review on the European and country-level potential for PtH is carried out revealing a wide range of these potentials. An own approach assesses the potential in district heating for selected European countries. PtH potential makes up a remarkable share of the peak electrical load, but varies due to the inhomogeneous nature of the investigated national energy systems and different weather conditions.



## 1. Introduction

The European power system is currently experiencing new challenges due to growing shares of intermittent renewable energy sources, mainly wind and photovoltaic. Technical stability of the system is affected not only by the intermittent nature of renewable sources, but also by current regulations in this field. The intermittent renewable energy sources (RES) in general have nearly zero marginal costs and priority dispatch, meaning that they can feed in electricity to the grid whenever they produce. Thus, the renewable feed-in is not necessarily correlated with the electricity demand. Furthermore, in some parts of the electricity network, such as in Northern Germany, the produced renewable electricity exceeds the capacity of the network to transport this electricity to demand sinks. Hence, some of the electricity production from RES has to be curtailed. It is expected that regional curtailment of RES electricity will increase due to further RES expansion [1,2]. The RES expansion may also lead to excess electricity in future which means that RES electricity production will exceed the total demand in national energy markets in some hours of the year [3,4]. For these and other reasons, renewable electricity production will challenge the stability of the power system and new concepts for RES electricity use, especially in the transport and heat sector, are necessary [5,6]. Besides, the stability of the system can only be guaranteed if adequate amounts of flexibility can be provided.

There are different ways of providing flexibility to the power system. Conventional sources of flexibility are related to flexible generation assets such as gas turbines or hydro power plants. Apart from gas turbines and power plants fuelled by natural gas, power plants fuelled by coal or fuel oil can provide a certain amount of flexibility as well [7]. Storage and demand side technologies can also provide flexibility to the energy system. Some of them are in the mature phase of development, while some of them are not yet commercially justified for wider deployment. In that sense the following technologies can be stated as possible flexibility options: electric batteries, compressed air energy storage, flywheels, superconducting magnetic energy storage, supercapacitors, fuel cells. Beside supply side options, there are also favourable demand side options providing flexibility. Table 1 summarizes the techno-economic characteristics of important demand side flexibilities.

PtH technologies, such as electric boilers and heat pumps coupled with storage tanks, which are scalable from small to large

* Corresponding author.
*E-mail address:* hasan.yilmaz@kit.edu (H.Ü. Yilmaz).

https://doi.org/10.1016/j.esr.2017.12.009

**Table 1**
Overview of the main demand side flexibility options, including PtH (own elaboration based on [8–13]).

| Technology | Power | Technology maturity | Investment cost in €/kWe | Efficiency |
|---|---|---|---|---|
| DSM in industry | N/A | High | N/A (Low) | 95%–100% |
| DSM in households and services | N/A | Low | 300–370/installation (meter, gateway and installation) | 95%–100% |
| EVs | ~6.5 kW/vehicle | High (BAT)<br>Low (FLEX) | min 15000 (vehicle) | 93% |
| PtG | 01–10 MW | Low | 1000–6000 | 66%–69% (electrolyser)<br>79.4% (methanation) |
| PtH small boiler | 3–9 kW | High | 196–248 (boiler) | >99% |
| PtH/C small HP | 5–25 kW | High | 530–2560 (HP) | 3–5.5 (COP) |
| PtH large boiler DH | 1–90 MW | High | 88–180 | >99% (boiler) 50–90% (storage) |
| PtH/C large HP DH | 0.5–15 MW | High | 527 (ASHP) – 1321 (GSHP) | 1.7–3.8 (COP) 50–90% (storage) |

ASHP: air source heat pumps, BAT: Battery, COP: coefficient of performance, DH: district heating, DSM: demand side management, EV: electric vehicle, FLEX: flexibility, GSHP: ground source heat pumps, HP: heat pump, PtG: power-to-gas, PtH/C: power-to-heat/cool.

sizes, might be promising options for delivering flexibility and coupling the energy sectors. Particularly, electric boilers have comparatively low investment expenditures and consequently are able to operate profitably with only a few full load hours, which is important for making use of excess electricity. On the other hand, heat pumps have the advantages of converting power more efficiently and allowing both heating and cooling. In addition to these, due to their short response times PtH technologies are suitable for the provision of ancillary services. However, due to economic profitablity, the deployment levels are still lower than in the case of competing heating technologies, such as gas boilers.

The required flexibility in the electricity system combined with decarbonisation objectives in heating sector serves as the basis for analysing the potential of flexible PtH in Europe in this paper. PtH technologies provide simultaneous benefits to both heating and electricity sector and may facilitate further integration of renewable sources into the energy system. However, PtH applications can be considered as a resource that has not yet been effectively pursued within energy policy. Furthermore, there are non-technological barriers such as historically evolved consumer behaviours or political decisions. The potential for PtH as well as the barriers for technology diffusion have not been sufficiently analysed yet. Some studies cover only national markets or focus on the current potential in Europe (see Section 3).

The goal of this paper is therefore to analyse the future economic potential for PtH technologies within the European energy system. Thereby, the focus is set on technologies providing flexibility to the energy system. To understand how the technical potential can be exploited, mechanisms and regulations necessary to incentivize PtH and related business models are investigated and introduced. The potential for PtH is studied in both ways, based on a broad literature analysis and an own quantitative approach determining the potential in district heating networks, one of the most commercially promising areas for PtH. For these purposes, the paper is structured as follows.

Section 2 presents existing business cases and pilot projects on PtH in different European countries and summarizes the policy recommendations that can incentivize these business cases. It focuses on the utilization of PtH technologies in decentralized installations as wells as on the applications and services offered in wholesale markets, such as providing reserve power.

Section 3 allows insights to be drawn on the evolution of PtH technologies from now to 2030 in the light of the current status and expected evolutions in entire Europe and some selected member states. A broad review of literature and existing studies deliver indications and figures about PtH potentials in Europe and selected countries, such as Austria, Denmark, France, Germany, Italy and the Netherlands.

Section 4 compromises a quantitative-based approach for the estimation of PtH potentials in the above-mentioned countries. While existing studies present figures and numbers on PtH in general, the authors did not find any study concentrating on potential estimation for applications in district heating networks. These applications have drawn special interest, as they can not only commercialize the use of excess or low-cost electricity for heating and cooling, but also gain extra profits from providing reserve power for the electricity system.

Section 5 delivers a brief summary, draws conclusions from the business models as well as from the potential analyses. It especially proposes solutions and policy recommendations to support the uptake of PtH technologies that have the ability to support system stability and decarbonise the heat sector.

## 2. Exemplary business models and challenges for PtH deployment

In general, when talking about business models[1] for PtH technologies, there are two different categories: business models for large-scale units and business models for small-scale units (e.g. for households). Business models for large-scale units could be based on gaining the benefits from network services, which can be provided for system operators. For small-scale units, business models should enable direct benefits through adequate price tariffs and regulations (e.g. hourly billing).

Three general concepts of business models to market the flexibility of PtH in the current wholesale market setting are distinguished: marketing via the spot market (especially using the flexibility for balancing fluctuations in RES supply to the spot market and exploiting low and negative prices), marketing flexible capacity via the control reserve market and usage for network services. In addition to that, the generated heat can be marketed in several ways - depending on the PtH installation itself and its surrounding heat consumers. The heat could either satisfy the heating and hot water demand of buildings, i.e. the heat is fed-in into a local or district heating network, or satisfy industrial heat demands.

In order to analyse aforementioned business cases several existing projects are investigated:

- Projects based on business model of marketing via the German reserve power market, e.g. by Enerstorage [14] or TWL (Technische Werke Ludwigshafen) [15];

[1] In the following we use the term business model as a conceptual term explaining on which markets the capacity of a PtH technology can be traded and which service this technology can provide. We distinguish here from some textbook definitions that are close to the term "business plan". Hence, we do not provide a concrete business plan, but show some initial concepts and real world applications how PtH technologies can be commercialized in the future energy system.