Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE
Energieforschung

Schlussbericht

Mitwirkung IEA Annex Task 42 „Heat Pumps in Smart Grids“

© XY 2016

Lucerne University of
Applied Sciences and Arts

HOCHSCHULE
LUZERN

Engineering and Architecture
FH Zentralschweiz

Datum: 5. Dezember 2016
Ort: Bern

Auftraggeberin:
Bundesamt für Energie BFE
Sektion Energieforschung
CH-3003 Bern
www.bfe.admin.ch

Auftragnehmer/in:
Hochschule Luzern – Technik und Architektur
CC Thermische Energiesysteme & Verfahrenstechnik
Forschungsgruppe Thermische Energiespeicher
Technikumstrasse 21
CH-6048 Horw
www. hslu.ch

Autor/in:
Damian Gwerder, Hochschule Luzern, damian.gwerder.01@hslu.ch
Philipp Schütz, Hochschule Luzern, philipp.schuetz@hslu.ch

BFE-Bereichsleitung: M. Pulfer, martin.pulfer@bfe.admin.ch
BFE-Programmleitung: S. Renz, renz.btr@swissonline.ch
BFE-Vertragsnummer: SI/501084-01

Für den Inhalt und die Schlussfolgerungen sind ausschliesslich die Autoren dieses Berichts verantwortlich.

Bundesamt für Energie BFE
Mühlestrasse 4, CH-3063 Ittigen; Postadresse: CH-3003 Bern
Tel. +41 58 462 56 11 · Fax +41 58 463 25 00 · contact@bfe.admin.ch · www.bfe.admin.ch

Zusammenfassung

Die Internationale Energie Agentur (IEA) untersucht in Rahmenprogrammen zukünftige Lösungen für die sichere, bezahlbare und umweltverträgliche Versorgung mit Energie. In Ihrem IEA Annex Task 42 untersuchen Vertreter aus mehr als 10 Mitgliedstaaten die Möglichkeiten zur besseren Integration von Wärmepumpen in Smart Grids, sowie deren Einsatz zum Ausgleich von Verbrauch und der Produktion von Energie im elektrischen Netz. In diesem Bericht werden die Arbeiten der Hochschule Luzern im Rahmen dieses Projektes gemeinsam mit passenden Resultaten aus dem BFE-geförderten Projekt «Optimale Kombination von Wärmepumpe und Speicher» präsentiert.

Résumé

L'Agence internationale de l'énergie (AIE) examine dans les programmes-cadres des solutions futures pour l'approvisionnement énergétique sûr, abordable et écologique. Dans l'Annexe 42 de l'AIE, les représentants de plus de 10 États membres évaluent les procédures d'intégration optimale des pompes à chaleur dans les Smart Grids ainsi que leur exploitation pour équilibrer la demande et l'offre d'énergie dans le réseau électrique. Dans ce rapport les travaux de recherche de l'Haute école de Lucerne – sont présentés ensemble avec les résultats appropriés d'un projet financé par l'OFEN («Combinaison optimale de pompes à chaleur et entrepôts thermiques»).

Summary

The international energy agency (IEA) facilitates research on future, safe, affordable and clean energy supply. In the IEA Annex Task 42, representatives of 14 member countries investigate procedures for optimum integration of heat pumps in smart grids as well as their exploitation to balance electricity demand and supply in a network. In this report, the contribution of the Swiss representative – Lucerne University of Applied Sciences and Arts – to this project along with results of a SFOE-funded project running in parallel (“Optimum combination of heat pumps an thermal storages”) are reported.

Anhang

Anhang

VORGABEN

Bis Seite 6 darf die Berichtsform nicht verändert, sondern nur vervollständigt werden. Es dürfen – ausser auf Seite 2 – **keine Firmen-Logos** eingebettet werden.

Ab Seite 7 kann der Jahresbericht inhaltlich frei gestaltet werden.

Die zur Verfügung gestellten Absatzformate können durch Drücken der Tastenkombination Alt + Ctrl + Shift + s angezeigt werden.

Inhaltsverzeichnis

Abkürzungsverzeichnis

IEA	International Energy Agency
SFOE	Swiss Federal Office of Energy

1. Introduction

In the IEA Annex Task 42 ‘Heat pumps in smart energy grids’ [1] of the IEA heat pump program, the potential of smart operation of heat pumps to facilitate an optimum balance within smart grids shall be explored. The key questions in this IEA Annex Task are very similar to the guiding questions addressed by Lucerne University of Applied Sciences and Arts in the SFOE funded project «Development of an optimised combination of heat pump and thermal storage» (grant SI/500978-01), where the potential of heat pump based residential heating system for the provision of flexibility to the smart grid exploiting thermal storages are investigated. Therefore, Lucerne University of Applied Sciences and Arts joined the IEA Annex task to represent Switzerland and to stimulate the mutual development activities and maximise the progress in the individual project.

In this document, the contribution of the Swiss partner to the IEA Annex Tasks is reproduced. This report is organised as follows: After a short overview of the aims of the project in section 2, the contributions of Lucerne University of Applied Sciences and Arts is reviewed in section 3 and reproduced in the annexes. The final combined report of the IEA Annex Task 42 ‘Heat pumps in smart energy grids’ will be published by the coordinator Business Development Holland in April 2017 and distributed to all partners and the SFOE.

2. IEA Annex 42 ´Heat pumps in smart energy grids’ for sustainable cities

The International E nergy A gency (IEA) i s an aut onomous or ganization with 29 m ember s tates (including S witzerland). Aim of this organisation is facilitate research on future solutions for a safe, affordable and clean energy supply via a framework program. In this program, IEA Annex 42 "Heat pumps in smart grids" investigates how heat pumps can be integrated into smart grids, how they can be exploited to balance between energy demand and supply as a regulator.

2.1. Members of IEA Annex Task 42

The following organisations participate in the IEA Annex Task 42:

Organisation	Country
Électricité de France EDF - R&D	France
Alliander (DSO)	Netherlands
Lucerne University of Applied Sciences and Arts – School for Engineering and Architectures	Switzerland
Danish Technology Institute	Denmark
Electric Power Research Institute (EPRI)	U.S.A.
Oak Ridge National Laboratory (ORNL)	U.S.A.
Department for Energy and Climate Change (DECC)	U.K.
Delta-ee	U.K.
Fraunhofer ISE	Germany
TU Graz	Austria
Austrian Institute of technology (AIT)	Austria
Korea Institute of Energy Research (KIER)	South-Korea
TNO Innovation	Netherlands
Business Development Holland	Netherlands

Table 1: Members of the Annex Task ‚Heat Pumps in Smart Grids‘

2.2. Overview of Tasks

Annex Tasks are organised in five individual tasks (confer Figure 1). For each of member country (organisation) a task report is compiled describing the peculiarities of the individual country. In meetings, these country specific reports are compared and discussed to identify common features as well as particularities. The IEA Annex Task 42 consists of the following five tasks:

- Task 1: Market overview — *National differences, energy house keeping*
- Task 2: System aspect and opportunities — *Configuration and options, what do we use where and when*
- Task 3: Modelling and technology — *Required technical R&D, software models*
- Task 4: System technology — *Overview projects, standard implementation modelling*
- Task 5: Communications — *Communication model, overview tools*

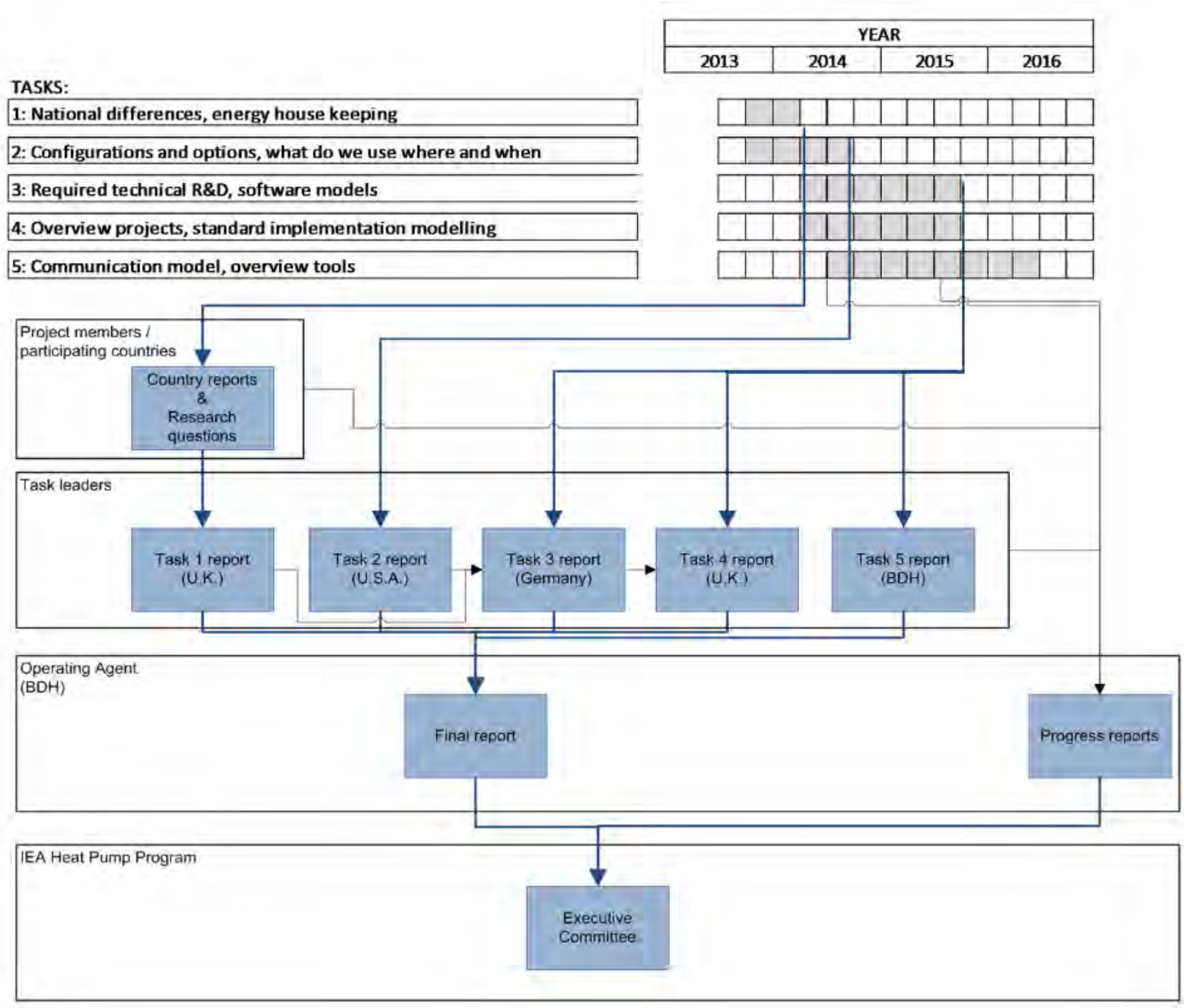


Figure 1: Structure of the IEA Annex Task 42 [1]

3. Contributions of Lucerne University of Applied Sciences and Arts

Lucerne University contributes to the IEA Annex Task 42 ‚Heat Pumps in Smart Grids‘ in the following topics:

IEA Annex 42 Task	Beitrag Hochschule Luzern
Task # 1: Market overview	**Task # 1 Report:** **“Market Overview Switzerland”** - Overview of the Swiss Energy Sector - Analysis of the Swiss housing stock & heating market - Analysis of the Swiss domestic heat pump market - List of smart heat pump projects in Switzerland - Analysis of smart ready products
Task # 2 System aspect and opportunities	**Task # 2 Report:** **“System Aspects and Opportunities – Switzerland”** - Overview of Residential Heat Pump Systems used in Switzerland - Motivation and Objectives for Smart Grid Interaction - Define Typical (or Prototypical) HP Case Scenarios for use in Task 3 Analyses
Task # 3 Modelling and technology	**Task #3 Report**
Task # 4 System technology and applications	**Task #4 Report**
Task # 5 Communications	Participation and representation of Switzerland in the IEA group meetings as well on conferences inside and outside the IEA Task 42 framework.

Table 2: Overview of the contributions of Lucerne University of Applied Sciences and Arts within the IEA Annex 42 framework.

3.1. Task 1 report

The complete country specific report on the market overview is added in attachment A1.

3.2. Task 2 report

An overview of the residential heat pump sector, a review of the motivation for broader integration of heat pumps in Smart Grids and a sets of four typical scenarios for heat pump integration are given in the country report for task 2, which is reproduced in attachment A2.

3.3. Task 3 report

The report on task 3 – simulation and modelling technology – is currently under compilation and will be submitted to the SFOE together with the final report of the complete IEA task as soon as completed.

As a summary of the achieved results, two articles written in the framework of the IEA project are attached in attachment A3 – A5.

3.4. Task 4 report

The complete report on system technologies and applications is reproduced in attachment A6.

3.5. Task 5 - communication

In the following, a short list of official contributions of Lucerne University of Applied Sciences to advertise the results of the IEA Annex 42 Task in the industrial and scientific community is given in the following sections.

Besides the conferences/meetings mentioned subsequently, Lucerne University of Applied Sciences and Arts also participated in the semiannual meetings of the IEA Annex Task and actively participated in the respective reporting activities.

3.5.1. Representation of Switzerland within IEA Annex Task 42

Lucerne University of Applied Sciences and Arts participated in the following meetings of the IEA Annex Task:

Meeting	Location	Host	Date
IEA Annex Introduction Organisation CC TEVT	Horw – Switzerland	Lucerne University of Applied Sciences and Arts	18.03.2014
Kick off IEA Annex 42	Montreal – Canada		12.05.- 14.05.2014
Task 1	Freiburg – Germany	Fraunhofer ISE	10.10.2014
Task 2	London – United Kingdom	Department for Energy &Climate Change	18.06.2015 19.06.2015
Task 2 & 3	Vienna – Austria	Austrian Institute of technology (AIT)	03.12.2015
Task 2 & 3	Horw - Switzerland	Lucerne University of Applied Sciences and Arts	23.06.2016
Symposium	Utrecht – Nederland	BGH	26.10.- 27.10.2016

Table 3: Meetings within the framework of IEA Annex Task 42

3.5.2. Representations activities outside IEA Annex Task 42

The results of this project were presented to a general audience in the framework of the following meetings and conferences:

Meeting/Conference	Host	Date
21. Wärmepumpentagung	SFOE - Burgdorf	17.06.2015
Workshop: Intelligente Wärmepumpen mit PV-Eigenverbrauch und/oder Netzdienstleistungen	Institut für Solartechnik (SPF) – Rapperswil	13.06.2016
International Renewable Energy Storage Conference (IRES)	Eurosolar - Düsseldorf	15.03 - 17.03.2016
Workshop: Solarenergie und Wärmepumpen – Fokus: Photovoltaik + Wärmepumpe	Institut für Solartechnik (SPF) – Rapperswil	16.11.2016
SCCER storage - conference	Lucerne University of Applied Sciences and Arts – Horw	24.10.2016
Swiss Symposium of Thermal Energy Storage (SSTES)	Lucerne University of Applied Sciences and Arts – Horw	20.01.2017
Heat Pump Conference	IEA - Rotterdam	15 – 18.5.2017

Table 4: Conference contributions of the IEA Annex project results and representation of Switzerland outside the Annex Task Meetings

References

[1] “IEA SHC Task 42: Heat pump in smart energy grids,” *International Energy Agency*. [Online]. Available: http://www.annex42.nl/. [Accessed: 01-Dec-2016].

A Attachment

A1 Task Report 1: Country Report

IEA HPP Annex 42: Heat Pumps in Smart Grids

Task 1: Market Overview

Switzerland

October 2014

Report compiled by:

Lucerne University of Applied Sciences and Arts

Lucerne University of Applied Sciences and Arts

HOCHSCHULE LUZERN

Contents

Table of figures

List of tables

List of abbreviations

BFE	Bundesamt für Energie (Federal Office of Energy)
CCPP	Combined cycle power plants
ElCom	Federal Electricity Commission
ERA	Energy reference area
EU	European Union
GDP	Gross domestic product
ICT	Information and communication technology
KEV	Kostendeckende Einspeisevergütung (cost-covering feed-in tariffs)
MoU	Memorandum of Understanding
MuKEN	Mustervorschriften der Kantone im Energiebereich (model rule for all Canton in the field of energy)
ORC	Organic Rankine Cycle
UVEK	Eidgenössisches Department für Umwelt, Verkehr, Energie und Kommunikation (Federal Department of the Environment, Transport, Energy and Communications)
EBF	Energiebezugsfläche (energy-related surface)

1. Overview of the Swiss Energy Sector

1.1. Overview of main challenges in Switzerland

According to the 2013 overall energy statistics from the BFE, Switzerland consumes 1.165 million tera Joules (TJ) of energy from primary sources (gross consumption). The most important energy sources are crude oil or petroleum products 43.3 %, nuclear fuel 23.3 %, hydropower 12.2 %, and gas 11.1 %, as well as garbage and industrial waste 5 %. This results in a dependence on imported sources of nearly 80 %. The conversion of primary energy into secondary energy carriers is associated with losses of about 25 %, so that the final consumption is 0.91 million TJ. Switzerland's main secondary energy carriers are 33.5 % fuels (diesel, petrol and aviation fuels), 23.8 % electricity, 18.8 % heating oil and 13.5 % gas [1].

With a primary energy dependence on foreign sources of around 78%, Switzerland covers only one-fifth of its consumption from domestic energy sources. This 22 % is shared between hydropower, energy wood, waste and industrial waste as well as other renewable energies (solar, wind, biogas, bio-propellants, and environmental heat). The use of hydro power, with around 54.5 % of the domestic share represents by far the most important energy source in the Switzerland. The other renewable energy sources account for a share of around 7 %. The energy consumption is almost half as high as the world average per unit of GDP and is distributed about one-third each between transport, households, and industry and services [1].

The electricity production in Switzerland is carried out 36.4 % in nuclear power plants and around 3.9 % in conventional thermal power plants. So now to generate electricity, Switzerland is approximately 41 % dependent on imports of energy sources (uranium, oil, and gas). About 58 % of electricity production comes from the use of hydropower, about 1.5 % from the use of new renewable energy sources (biomass, solar, wind and treatment of waste) [1].

Energy perspectives have been the basis of all Switzerland's energy policy choices. Since the creation of the total energy concept in the mid-1970s, these perspectives are periodically updated. The Federal Council decided on 21 February 2007, on the basis of "Energy 2035", to support its energy strategy on the four pillars of energy efficiency, renewable energies, large power plants and an active foreign energy policy. As a result of the accident in the Fukushima nuclear power facility, the Federal Council commissioned the UVEK on 23 March 2011 to update the "Energy 2035" from the year 2007 on the basis of three power supply variations. On 25 May 2011 the Federal Council decided to abandon new nuclear power plants and confirmed the turnaround in energy policy. The contents of this turning point are: a reduction of the consumption of fossil energy (oil, gas, and petrol), no nuclear power and stabilization of power consumption. By 2050, Switzerland seeks to be a 2000-watt and a 1-1.5 ton CO_2 society. In comparison, today each and every Swiss annually consumes 6400 watts of power and produces around 6 tonnes of CO2.

With the Energy Strategy 2050 and the gradual phasing out of nuclear energy, gas will play an even more important role in Switzerland to ensure the energy supply. Since hardly any mineable domestic deposits are present, the demand of about 30 TWh per year is 100 % covered by imports. For this purpose there are long-term supply contracts with partners in the EU. Switzerland purchases by far the largest part (about 67 %) of its gas from countries within the EU and Norway [2].

The Swiss electricity grid is facing major challenges. The bulk of the Swiss transmission lines were created about 50 years ago. The network will need to be partially renewed. In addition, its transport capacity is limited because the lines were originally designed for much smaller amounts of current. The substance conservation and optimum utilization of existing capacity is intended to be pursued as a priority, for example by means of smart grid and congestion management. New lines should be built only where it is necessary for the security of supply. The investment requirements of the next 10 years amount to around 3.2 billion Swiss francs [2].

Switzerland is not a current island. The supply system has historically grown by close connections with foreign countries. Therefore, security of power supply is possible only in conjunction with the European network. Switzerland's participation in the trans-European network, the construction of high-performance power grid, the design of energy infrastructure and participation in the market coupling initiatives are therefore of central importance. It is equally important that Switzerland can exercise its influence in international bodies. This is an important aspect in bilateral negotiations with the EU.

1.2. Swiss electricity generation

- **Swiss electricity generation, by fuel type (incl. renewables & import/export balance if available), historic trend and outlook:**

  Due to the topological conditions, hydropower has always played an important role in Swiss electricity production. At the beginning of the seventies the Swiss also started to generate electricity in nuclear power plants. Today, nuclear energy is with 38.1 % the second most important primary energy source for the generation of electricity. To set the goal of achieving the phase-out of nuclear energy by 2050, it is therefore necessary to realize about 40 % of today's electricity production by other conversion processes.

  With imports of 36.2 billion kWh and exports of 38.6 billion kWh a trade surplus of 2.4 billion kWh resulted in 2013. The proceeds from the current exports amounted to CHF 2,386 million (6.22 Rp. / kWh). For electricity imports 2,059 million Swiss francs (5.71 Rp. / kWh) were spent. Switzerland's positive foreign trade balance in 2013 fell by 42.4 % to 327 million Swiss francs (2012: Francs 771 million) [3].

HOCHSCHULE LUZERN

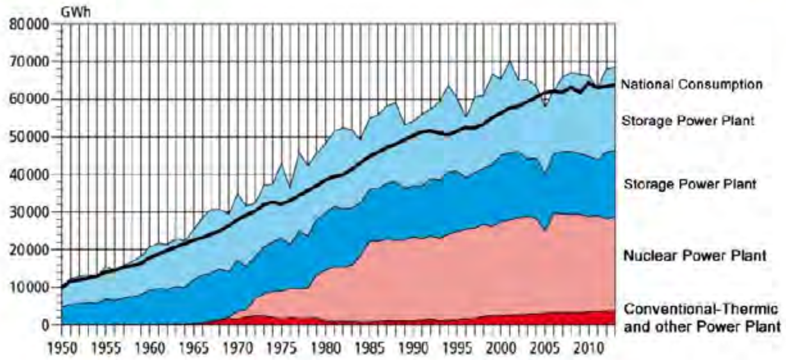


Figure 1.1: Electricity production by power plant (1950 – 2013) [3].

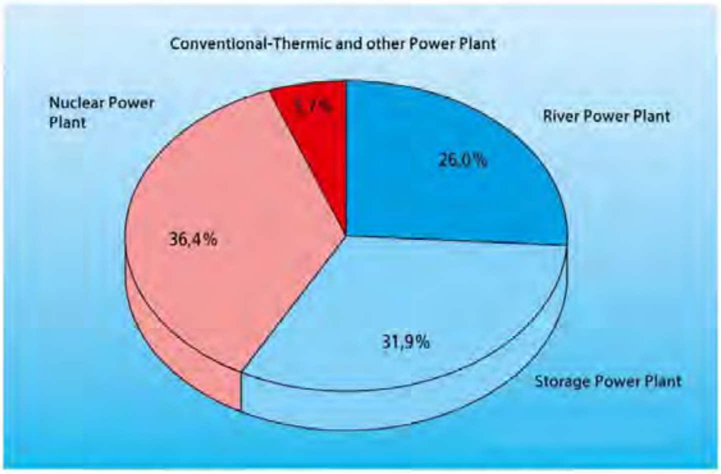


Figure 1.2: Electricity production by power plant in 2010 [3].

- **Historic development and outlook of renewable generation capacities, production and market share:**

The development of renewable electricity production runs quite differently in the various fields of technology since 1990. At the dominant hydropower plants, the influence of hydrological conditions is clearly visible.

In recent years a marked increase in other technologies for renewable electricity production is observed. In solar electricity (photovoltaics) it was only in the late eighties and in wind energy, even until the mid-nineties, that the annual production of 1 million kWh was exceeded. Apart from hydropower, electricity production from renewable waste components has experienced the absolute strongest increase since 1990.

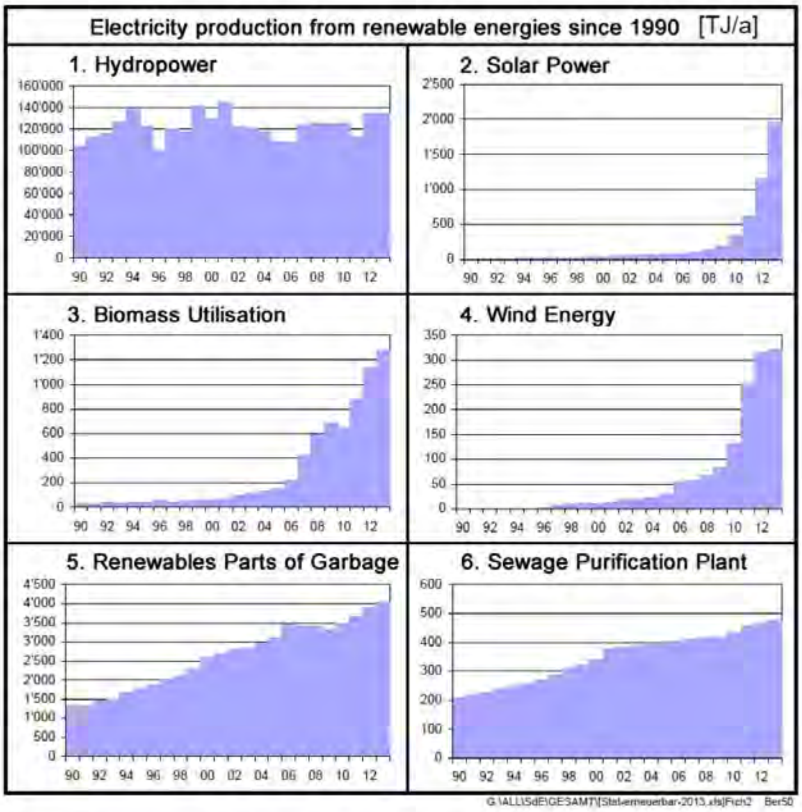


Figure 1.3: Development of electricity production from renewable energies since 1990 [4].

In order to estimate the future development of the energy situation in Switzerland, three electricity supply scenarios for the Federal Council were created [4]:

- *Scenario 1: "Going on as up to now"*

  Autonomous trends of the past will be observed and updated according to the current market conditions. Further on, they will be reinforced by the energy policy instruments, which are either already in force at the present time, or planned.

- *Scenario 2: “Policy measures”*

  The adopted measures drawn up by the Federal Council on 18 April 2012 will have been analysed, giving special consideration to their legislative basis (e.g. provisions for building standards, CO_2 emission limits for new vehicles).

- *Scenario 3: “New energy policy”*

  The targeted policy variant, "New energy policy", examines how to achieve the target of reducing energy-related CO_2 emissions in Switzerland to around 1.5 tonnes per head by 2050.

In the "New Energy Policy" scenario it is important to recognize that the annual consumption of electricity decreases from the year 2020. There is an increase of consumption until 2020, due to the expansion of pumped storage plants. The nuclear power plants all together should be turned off by the year 2035. The resulting gap in available energy or electricity is initially closed primarily through the development of renewable energy systems and combined cycle power plants. From the year 2035, renewable energy systems will be continuously expanded and therefore replace the combined cycle power plants.

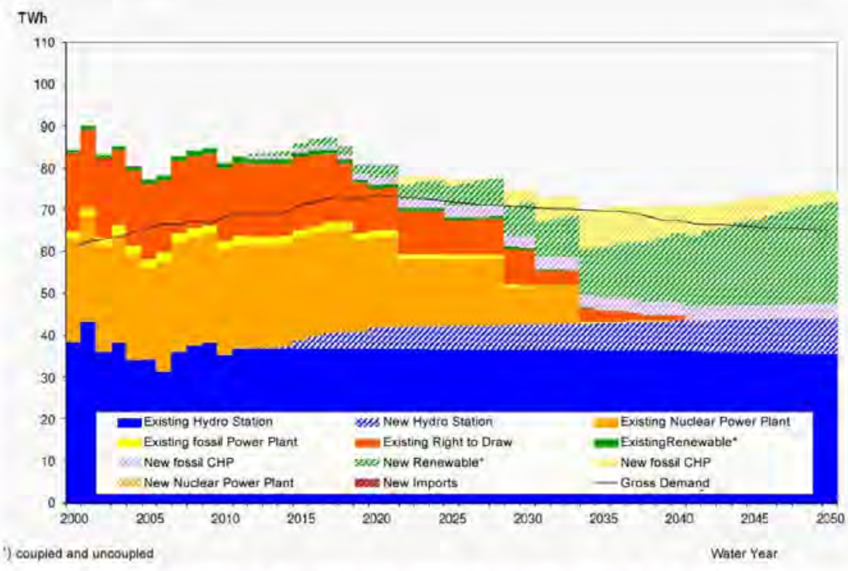


Figure 1.4: Development of the electricity supply by power plants up to 2050 in the “New energy policy” scenario [5].

Total available generation capacity:

The entire volume of net electricity production in 2013 amounted to 238'248 TJ (equivalent to 66'180 GWh). From this domestic production 142'867 TJ (60.0 %) were from renewable sources. The vast majority comes of the use of hydropower. The contribution of solar energy, biomass, biogas, wind and waste usage amounts to 8'083 TJ, or about 3.4 % of total electricity production [4].

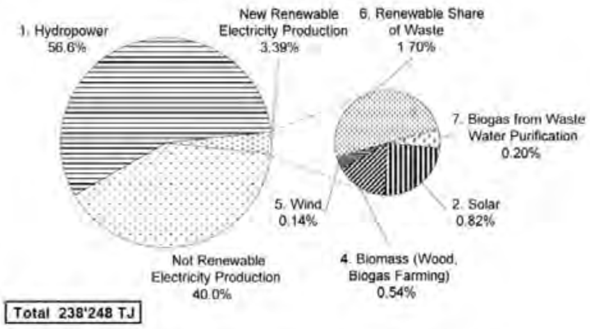


Figure 1.5: Swiss overall electricity production by technologies in 2013 [4].

How is peak demand met?

In Switzerland, peak loads are balanced predominately by the use of pumped storage power plants. 31.9 % of total electricity production comes from pumped storage power plants. In addition, Switzerland is a transit country for electricity and depending on the needs and excesses of electricity demands; Switzerland is constantly trading electricity with its adjacent neighbour countries.

Figure 1.6: Importation and exportation of electricity in 2013 (TWh) [3].

1.3. Swiss Energy Demand

- **Final energy demand in the domestic heating sector (& cooling sector where appropriate) divided by fuel type [12]:**

In 2012, 69.7 % of the final energy consumption of Swiss households was used for space heating. Therefore the auxiliary energy consumption for the operation of facilities and heat distribution is not included.

Between 2000 and 2012, the total heated living space in Switzerland was expanded to 80.5 million m^2 ERA (energy reference area) (+ 20.9 %), representing a growth rate of 1.6 %. This does not take into account newly built areas for second and holiday homes.

With an increase of 46.5 million m^2 ERA (+ 68.8 %) the area heated by natural gas has seen the most growth in the period 2000-2012. In 2012, a quarter of the area was approximately heated with natural gas (24.5 %). The area heated by electric heat pumps has also expanded strongly (+ 38.6 million m^2 ERA; + 269 %). Solar thermal plants have seen a strong percentage growth too, with + 258 % however (vs. + 0.8 million m^2 ERA. 2,000) they are still on a very low absolute level of around 1.1 million m^2 ERA.

The area heated with fuel oil is declining: compared to 2000, it has decreased about 18.8 million m^2 (- 8.0 %). However, oil still remains the main source of energy to provide space heating. In 2012, almost half of total Swiss household space was still heated with fuel oil (46.2 %).

The average heating demand per m^2 ERA between 2000 and 2012 has decreased by 14.7 % to 332.2 MJ/m^2 and year. The average efficiency of heating systems has been increased by 6.1 % to 85.6 % in this period. The strongest growth in efficiency gains shows up in the heating systems powered by electric heat pumps and gas central heating (condensing systems).

	2000	2006	2007	2008	2009	2010	2011	2012	Δ '00 – '12
Heating Oil	109.3	108.5	93.0	99.9	95.6	105.3	78.8	86.9	-20.5%
Natural Gas	28.0	34.9	31.6	36.1	36.0	41.7	33.0	38.8	+38.9%
Ohmic Heating	10.4	11.1	10.1	11.0	10.7	11.7	9.4	10.1	-2.3%
Wood	15.5	16.7	15.2	16.7	16.6	18.6	15.1	17.0	+9.7%
Coal	0.4	0.4	0.3	0.4	0.4	0.4	0.3	0.3	-1.8%
District Heating	4.4	5.5	5.1	5.9	5.9	7.0	5.6	6.5	+46.9%
electric Heatpump	1.5	2.5	2.4	3.0	3.2	3.9	3.3	4.0	+166.9%
Ambient Heat	2.8	4.8	4.8	6.0	6.5	8.0	6.9	8.4	+203.6%
Solar	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	+229.0%
Total	172.2	184.8	162.7	179.2	175.1	196.9	152.6	172.4	+0.1%
Total weather-adjusted	191.8	189.2	188.6	188.1	187.3	186.2	184.9	183.4	-4.4%

Table 1.1: Residential energy end-use, by fuel type (2000-2012) [12].

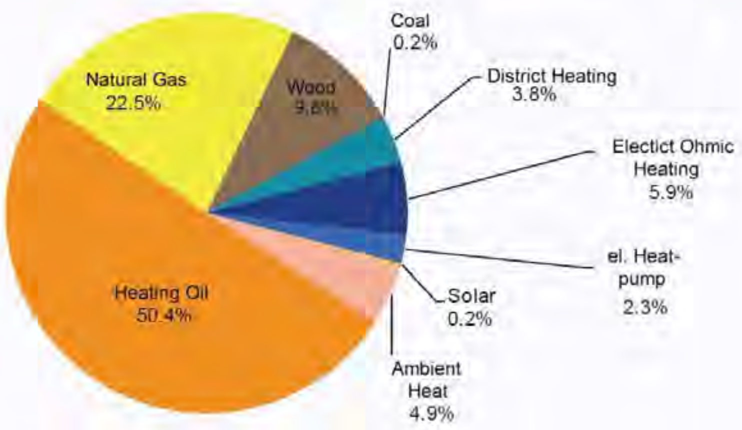


Figure 1.7: Residential energy end-use, by fuel type (2012) [12].

Typical heating / cooling / electricity demand in households [12]:

The total energy consumption in private households increased in the years from 2000 to 2012 by 5 PJ (+ 2.1 % according to energy statistics + 10.9 PJ; + 4.5 %). According to the model calculations the growth is mainly due to the increase of the energy consumption of other electrical appliances (+ 3.4 PJ; + 77.8 %), the most significant increase is the consumption for washing and drying laundry (+1.2 PJ; + 47.3 %). The energy consumption for other uses has changed by less than 1 PJ in the considered period.

In 2012, two thirds of Swiss household energy consumption was accounted for by space heating (69.7 %). The production of hot water also had great importance for the sector's consumption (2012: 12.9 %). In contrast to space heating, hot water consumption barely reacts to the weather conditions.

Other domestic uses account for comparatively small amounts of energy. The share of the sector consumption was low: cooking including dishwashing 3.9%; other electrical appliances 3.2 %; cooling and freezing 2.8 %; illumination 2.2 %; entertainment 2.1 %; washing and drying 1.6%; and air conditioning, ventilation and building services 1.7%. However, these uses exclusively require energy of high quality (electricity).

	2000	2006	2007	2008	2009	2010	2011	2012	Δ '00 – '12
Room Heating	172.2	184.8	162.7	179.2	175.1	196.9	152.6	172.4	+0.1%
Space Heating Installed	170.5	183.1	161.0	177.4	173.4	195.1	151.0	170.8	+0.2%
Mobile heating	1.7	1.7	1.7	1.7	1.7	1.8	1.6	1.6	-4.7%
Hot Water	32.3	31.9	31.7	31.9	31.9	32.2	31.5	31.8	-1.6%
Building Services (HVACR)	3.6	4.0	3.7	4.0	4.0	4.4	3.8	4.2	+16.4%
Heating Auxiliary Energy	2.4	2.7	2.3	2.6	2.5	2.9	2.2	2.5	+5.6%
Air Conditioning	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.0	+30.7%
others Buidling Services	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.7	+51.7%
Entertainment, ICT	5.3	5.4	5.5	5.6	5.7	5.6	5.4	5.2	-2.1%
Cooking / Dishwashing	8.9	9.1	9.1	9.2	9.3	9.4	9.5	9.6	+7.7%
Illumination	5.7	6.3	6.2	6.2	6.0	5.9	5.6	5.5	-5.1%
Washing & Drying	2.6	3.4	3.6	3.7	3.7	3.8	3.9	3.9	+47.3%
Cooling & Freezing	7.1	7.1	7.1	7.1	7.1	7.1	7.0	6.9	-3.2%
other Electrical Appliances	4.4	6.1	6.3	6.5	6.8	7.1	7.4	7.8	+77.8%
Total Final Energy Cons.	242.3	258.2	235.9	253.4	249.7	272.4	226.6	247.3	+2.1%

Table 1.2: Energy consumption in private households by purpose (2000 - 2012) [12]

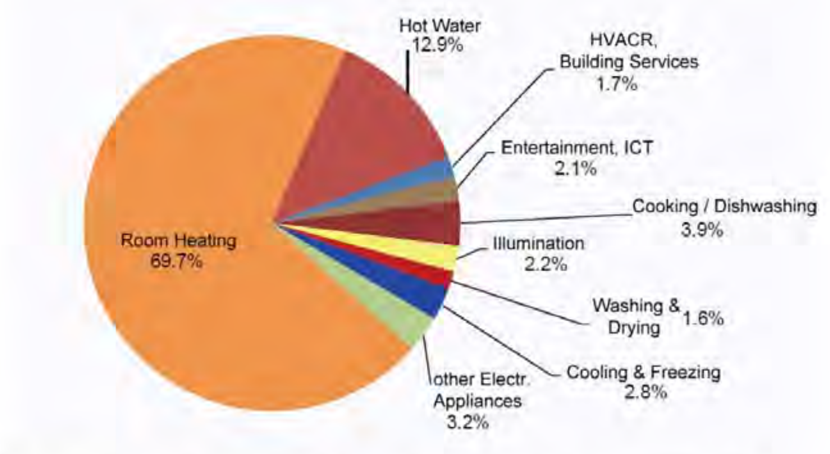


Figure 1.8: Energy consumption in private households by purpose (2012) [12].

1.4. Swiss Energy Infrastructure

- **Electricity networks – current status & outlook [1]:**

Figure 1.9 shows the current prevailing bottlenecks in the Swiss high-voltage grid. According to the review of the multi-year plan by the Federal Electricity Commission (ElCom), there is a need for investment in the renewal and expansion of the Swiss transmission system over the next 10 years in the amount of around 3.2 billion Swiss francs. Based on recent estimates from Swiss Grid, an investment requirement of around 6 billion francs can be expected. By 2030, or 2050 there will be additional investment required in network infrastructure. New construction or expansion of pumped storage power plants (Nant-de-Drance, Linth Limmern, Lago Bianco, KWO plus, etc.) also places new demands on the network infrastructure.

However, it is not enough to simply strengthen transport capacity. Switzerland is facing additional new technical challenges such as a quickly growing number of decentralized power plants feeding electricity from renewable sources into the grid. Accordingly, appropriate backup capacity must be provided. It is also necessary - particularly due to the realignment of the energy strategy - to redesign the interplay between the band energy and peak current. Information and communication technologies should therefore be used to expand the networks to become intelligent, so-called "smart grids". From the perspective of security of energy supply, “smart grids” are extremely important.

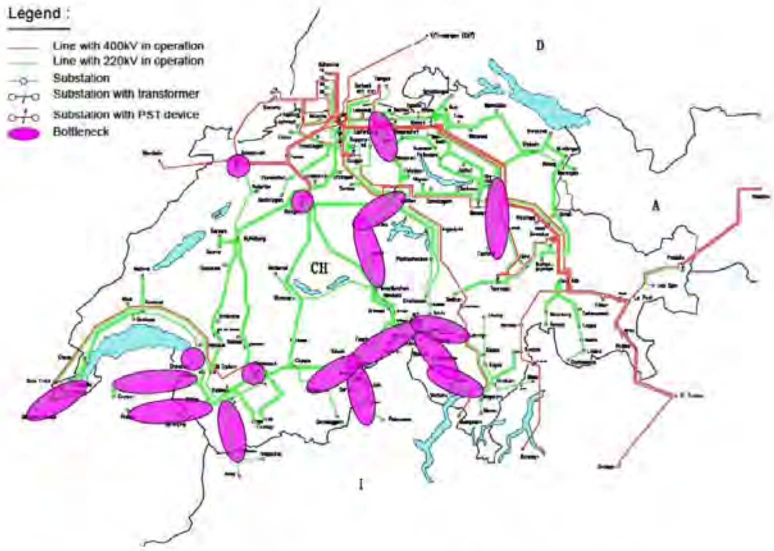


Figure 1.9: Bottlenecks in the Swiss high-voltage grid in 2010 [1].

Gas network + heat network - current extent and future outlook:

With a share of 13 % in energy consumption natural gas is an important energy source in Switzerland, even if it is under-used in comparison to the European average [1]. With the implementation of Energy Strategy 2050 and the gradual phasing out of nuclear energy, gas will play an even more important role to ensure the energy supply.

The backbone of the Swiss gas infrastructure is the 1974 commissioned north-south transit line (transit gas, marked in orange on the map of figure 1.10) heading from Wall Bach (AG) to Griespass (VS). Over approximately three-quarters of the country's consumption is imported through this transit line, while the remainder is imported on various cross-border connection points on the regional high-pressure networks. The capacity of the Swiss high-pressure gas transport network is sufficient for the foreseeable future. The transport capacity of transit gas line was doubled between 1998 and 2003 from 9 to 18 billion cubic meters per year, which is five times the current Swiss annual gas consumption. The national network and the supply lines to the Swiss border are dimensioned so that they could cope with a possible increase in consumption by gas combined cycle power plants (CCPP). Currently, no extensions of the high-pressure gas network are planned.

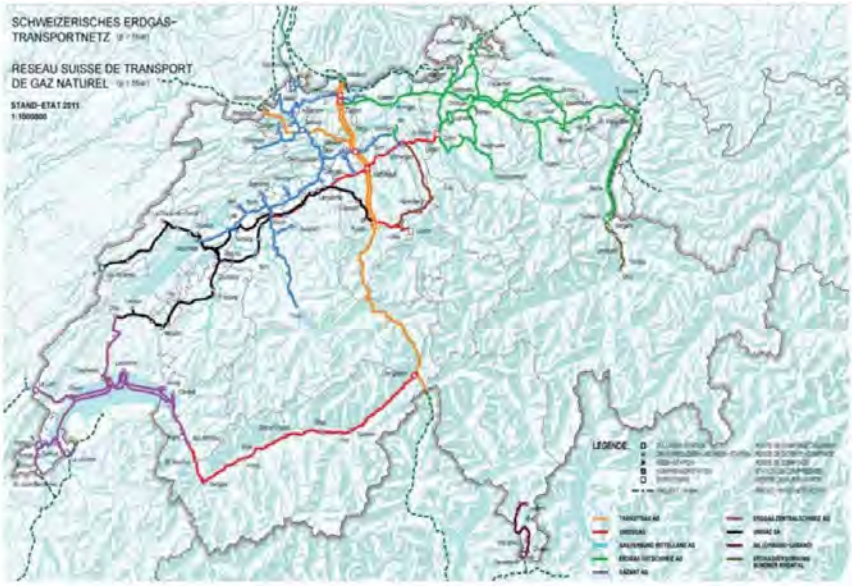


Figure 1.10: Swiss high pressure gas grid [1].

1.5. Swiss Energy Policy

- **Major policies affecting the electricity sector, including renewable energy/CO_2 reduction targets:**

After the radioactive accident in Fukushima, the existing energy outlook for 2035 came under critical scrutiny and has been adapted to macroeconomic

(GDP and population) and energy industry conditions. The Federal Council decided in May 2011 that the existing nuclear power plants will not be replaced at the end of their life. On the basis of this decision, the three scenarios: "Business as usual", "Federal actions", and "New energy policy" were created. These were briefly described in chapter 1.2. The Energy Strategy 2050 will be implemented in stages. According to the Swiss Federal Council decision of 25 May 2011, the energy strategy for 2050 is aiming towards the medium to long-term objectives of the "New energy policy". This is not being put into action in Switzerland alone, but is connected to a concerted international energy policy.

According to the order of the Federal Council to the UVEK (Federal Department of the Environment, Transport, Energy and Communications) of 18 April 2012, a first package of measures until 2020 was drawn up, which focuses on the "Federal actions" scenario.

"Business as usual"	"Federal actions"	"New energy policy"
Private Household, Buildings		Strategic overall aim CO_2 emission of 1 – 1,5 t per head until 2050 Limited sustainable biomass potential Derived strategic Requirements Efficiency ahead of renewable Electricity efficiency is essential Electro mobility is necessary Small changes in the amount of traffic Bio mass mainly in transport of goods and CCPP plants
Moderate updating of MuKEN Building program 200 Mio Fr. Promotion renewable energies and building program Moderate update for standards	Aggravation of MuKEN Replacement of resistance heater Building program 300 Mio Fr. from 2014 600 Mio Fr. from 2015 SIA 380/4 obligatory in all multifamily houses and residential buildings	
Industry and service		
Competitive tender 16 – 27 Mio. Fr./a Voluntary commitment	Competitive tender 100 Mio. Fr./a Bonus for efficiency and CO_2 tax Optimization of operation Promotion ORC-unit	
Traffic		
EU Emission limits (130 or 95 g CO_2/km) achieve until 2030 Improvement of the efficiency of the transport design	Aggravated values for emission limits (130 or 95 g CO_2/km until 2020, 35 g CO_2/km until 2050) Traffic organisation	

Table 1.3: Assumption for the scenarios "Business as usual", "Federal actions", "New energy policy" [5].

- **Major policies affecting the heating sector, including building regulations and renewable energy/CO_2 reduction targets:**

Building program and cantonal programs: The building program supports in all of Switzerland improving the insulation of buildings. In most cantons, the transition to renewable energy heating systems such as heat pumps, solar or wood energy plants is encouraged. The cantonal energy offices advise on these cantonal support measures. The federal government itself has no direct funding for such projects. However, it supports the cantonal funding on contributions under the building program initiated in 2010. In addition to the support provided by the federal government and the cantons, there are a number of other funding opportunities through communities, energy suppliers and banks.

- **Heat pump related incentives/policies etc.:**

There are no additional specific heat pump incentives apart from the upper mentioned building program.

Research and development of heat pumps and heat pump related projects are funded by the Swiss Federal Office of Energy SFOE within a program specifically dedicated to heat pump related topics.

1.6. Energy Prices, Tariffs & Structures

- **Electricity prices, including price structure (generation costs, network charges, taxes & levies) [6]:**

The price of electricity is made up of four components: network usage charges, energy prices, taxes and benefits to the community as well as cost-covering remuneration KEV. For households and businesses, the percentage of network usage charges on electricity price is highest - in 2010 it made up around 50 % of the electricity price. For industry, the cost of network usage is set at more than one-third of the electricity price. The components of taxes and benefits as well as KEV contribute to a lesser extent (total 10 % to 15 % of households) in the total electricity tariffs. The smallest difference between the individual types of consumers is in the price of the actual energy.

The current prices for Swiss households are slightly below the average of those in the EU. However, the electricity prices for industry are slightly above the EU average.

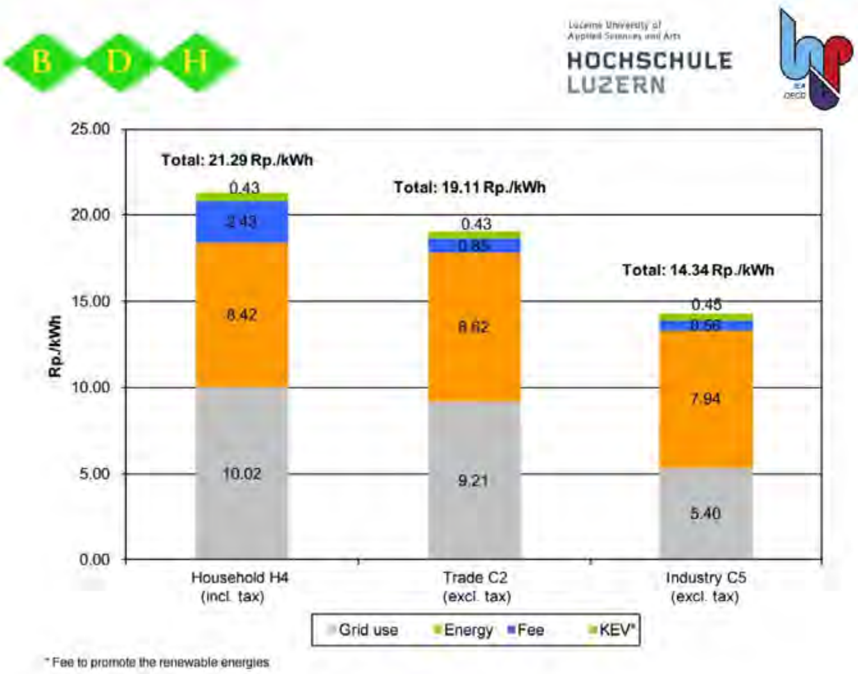


Figure 1.11: Composition of electricity prices in 2010 [6].

Gas prices / prices of other competing heating technologies:

Basically, a cost comparison between different heating systems is possible only in specific individual cases, because there are many factors playing a role. It would be wrong to make a comparison based only on the pure energy price per kWh, because energy costs usually make less than half of the total cost. Therefore a complete comparison must also include the acquisition cost, the costs of premises, maintenance, servicing and inspections.

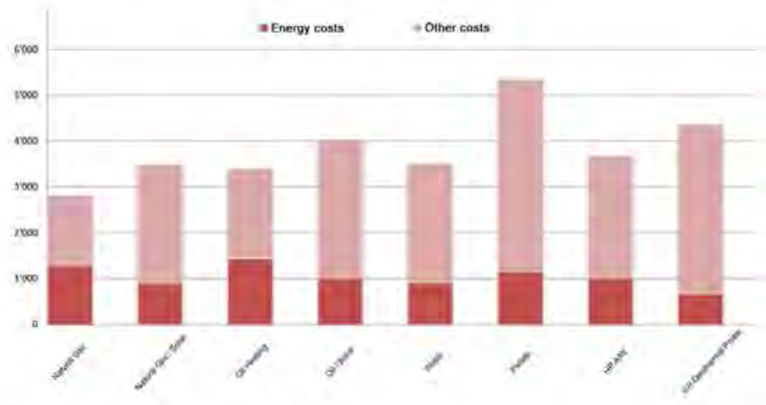


Figure 1.12: Total comparison of different heating systems [8].

What types of tariffs are available?

In Switzerland there are a high and a low tariff. The high tariff takes effect during the day from around 07.00 am until 09.00 pm. The rest of the day is low tariff.

There is also segmentation into three categories of energy users. The first group consists of households and community usage; the second and third groups are for trade, business and industry users, separated by the quantity of their energy use. The effect is to offer a lower price to companies that have a high demand for energy.

2. Analysis of the Swiss housing stock & heating market

2.1 Overview of main challenges in the Swiss market

A big challenge is to show operators and users how much energy their appliances consume and how much energy, and consequently how much money, they can save. The Federal Department of Energy (BFE, Bundesamt für Energie) has created the Energy Swiss platform to inform consumers about energy matters and respond to questions.

Further, the Federal Department of Energy is intended to promote the use of renewable resources, for example with financial support such as the "cost-covering remuneration for feed-in to the electricity grid" (KEV, kostendeckende Einspeisevergütung), which is used to promote renewable energy. Other tools to promote the use of renewable energy sources are regulations such as the "Model Regulation of the Canton in the Energy Sector" (MuKEn, Mustervorschriften der Kantone im Energiebereich), which regulate the amount of non-renewable energy sources.

A new law allows the use of direct electric heating in the building of new housing only in special cases. However, the replacement of around 800,000 warm water storage systems with direct electric heating systems is another challenge. At the moment, the search for the most economical and ecologically friendly solution is ongoing [17].

In new buildings and renovated older buildings insulation is very good as a result of MuKEn regulations, which reduce energy loss to a minimum. So there is no reason to build houses with a greater level of insulation. Now the focus is on energy generation and distribution. The targets are: to promote the use of renewable energy; to increase the efficiency of energy conversion; and to reduce the irreversibilities. Current heating systems are controlled by the daily household demands. However, because of the heat inertia inherent in buildings, the temperature and climate in houses doesn't necessarily correspond to the weather conditions. To improve the situation and increase efficiency a predictive control system can be installed, which calculates a forward-looking load profile. With the newly gained information the system is able to set up and maintain the optimal temperature in the building. Given this information on the predicted energy requirements, the energy supplier can respond and the energy can be generated at the time when it is economically best, as well as maintaining the highest possible efficiency. At all times the energy supply system tries to use as much electricity from renewable energy sources as is possible. Even the discharge of heat and cold energy will be adapted to the external loads.

2.2. Swiss Housing Stock Characteristics

- **Type of dwelling and building ownership:**

Switzerland's building stock consists of approximately 1.7 million dwellings [2].

At the end of 2011, 36.8 % of Swiss households live in apartments. Since 1970, the apartment ownership rate has steadily risen and the number of apartments in buildings has increased. However, households who own the building in which their apartment is located still make up the majority of owner-occupied apartments.

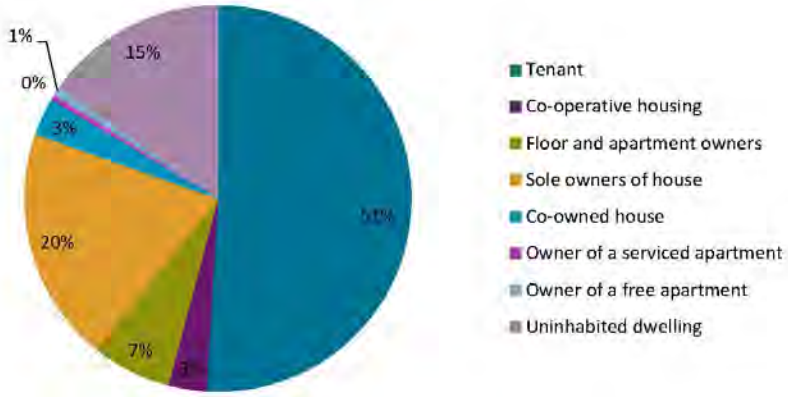


Figure 2.1: Swiss dwelling stock by resident types 2012. Data are from [13].

The dominant residential building in Switzerland is the family house. The majority of the buildings with residential use are used only for residential purposes with no other functions. Three-fifths of these purely residential buildings are in urban areas. Single-family homes account for more than half (57 %) of all residential buildings. In rural areas the proportion of single family homes is slightly higher (59 %) than in urban areas (57 %). Multi-family houses represent a quarter of all residential buildings (26 %), and slightly more than two-thirds (67 %) of all multi-family houses are located in urban areas [10].

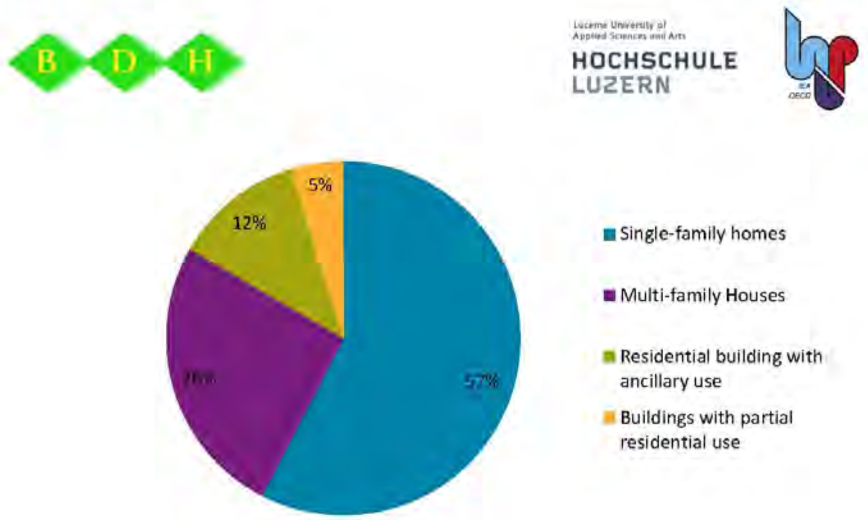


Figure 2.2: Swiss dwelling stock 2012 by class. Translated pictures from [10], page 18.

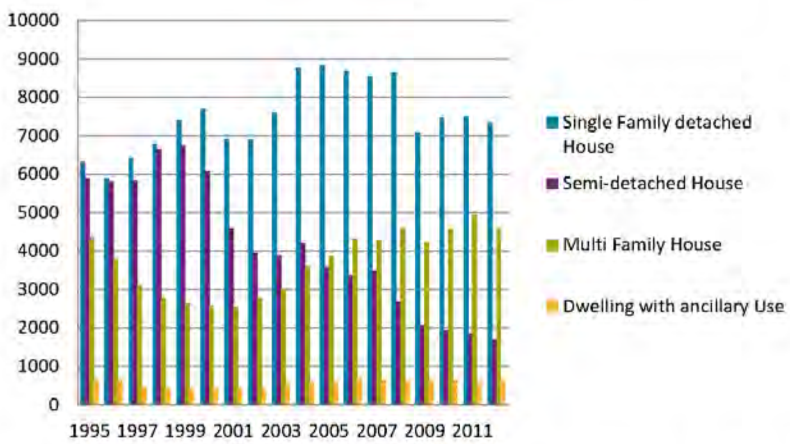


Figure 2.3: Newly built homes by type and age. Translated pictures from [10], page11.

Age of the building stock

Slightly less than half (44 %) of all homes in Switzerland were built before 1961 and thus they are relatively old. The proportion of over 50 year-old single-family homes is just 36 %, so therefore other categories of buildings have higher proportions of old buildings. Buildings that were built in the last 30 years (after 1980) account for a third (34 %) of the total building stock. 41 % of single-family homes have been built since 1980 (higher than the average) whereas multi-family houses at 30 % and other building categories (17 %) are less likely to have been built since 1980. Thus there are more recently-built single-family houses while buildings for mixed use or multiple families are generally older [10].

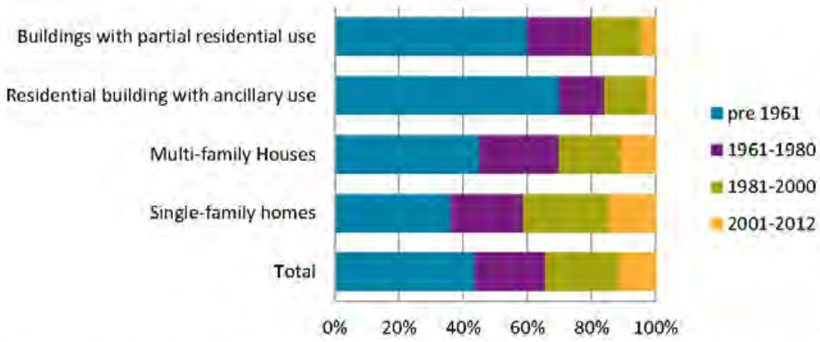


Figure 2.4: Swiss dwelling stock 2012 by age. Translated pictures from [10], page 19.

- **Heat demand**:

  As mentioned previously, the energy demand for dwellings is dominated by space heating followed by the operation of facilities and hot water.

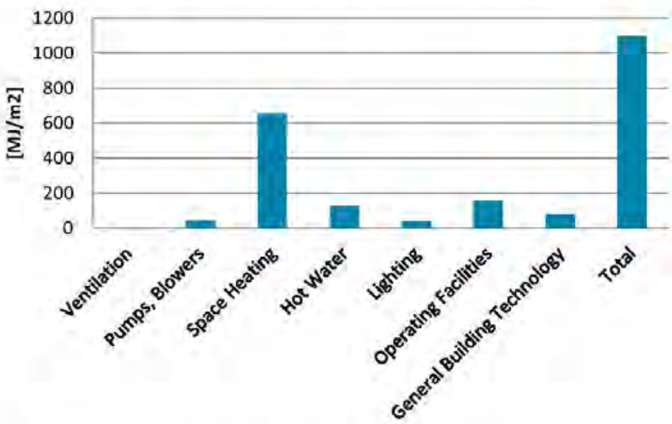


Figure 2.5: Energy demand for a single family house 2012. Translated pictures from [10].

- **Heating system type and fuel type:**

The vast majority (87 %) of all buildings, whether multi-family or single-family houses, use a central heating system. In some Swiss cities, for example in Basel, the central heating systems are replaced by district heating networks. Generally, in urban areas central heating is the dominant system, while in rural areas there are a greater percentage of more traditional systems such as the single oven and floor heating. One in every ten buildings in Switzerland heat supply is by single oven- or floor heating [10].

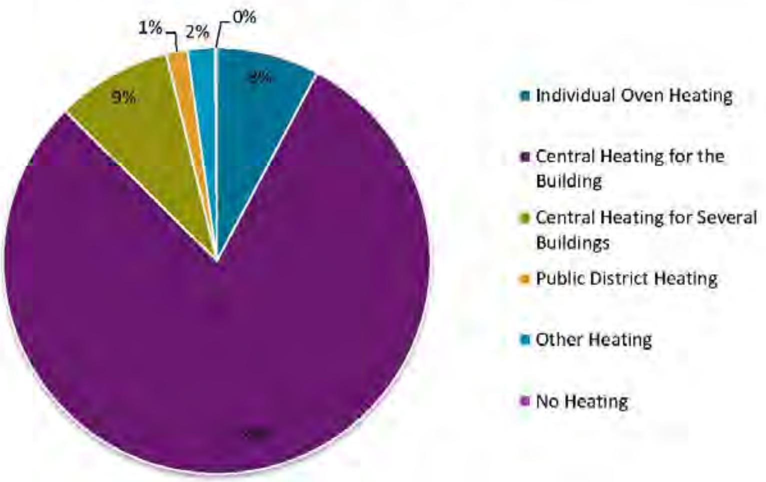


Figure 2.6: Heating systems of Swiss housing stock 2012. Translated pictures from [10].

Building stock by fuel type for space heating

Heating oil is by far the most important energy source for Swiss residential heating, with almost half of the buildings heated with oil. 15 % of buildings have gas heating and about one tenth are heated with wood (12 %) or electricity (10 %). In the buildings heated with the traditional single oven wood is used most often as fuel. Only a fifth of these buildings are also heated with electricity and 16 % have additional heating using fuel oil. In both urban and rural areas, heating oil is the most used energy source (52 % and 47 % respectively). In the urban areas gas (22 %) and electricity (8 %) are the main fuel sources used in addition to the heating oil. In the rural areas mainly wood (22 %) and electricity (13 %) are used alongside heating oil. The stock of buildings with a heat pump has doubled since the beginning of the 21st century [10].

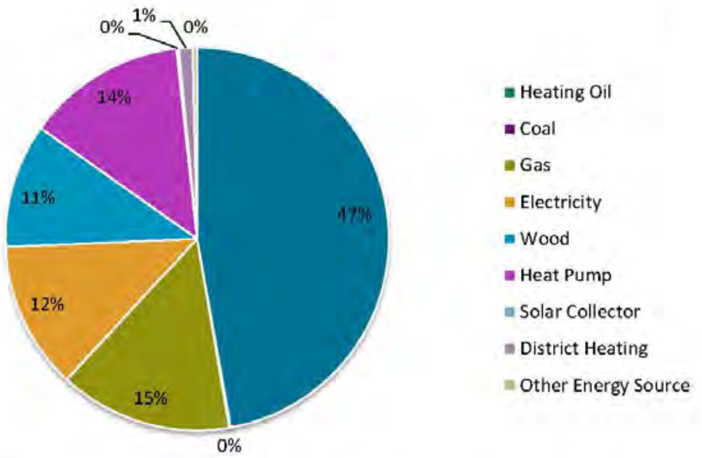


Figure 2.7: Energy source for space heating in a single-family house 2012. Translated pictures from [10].

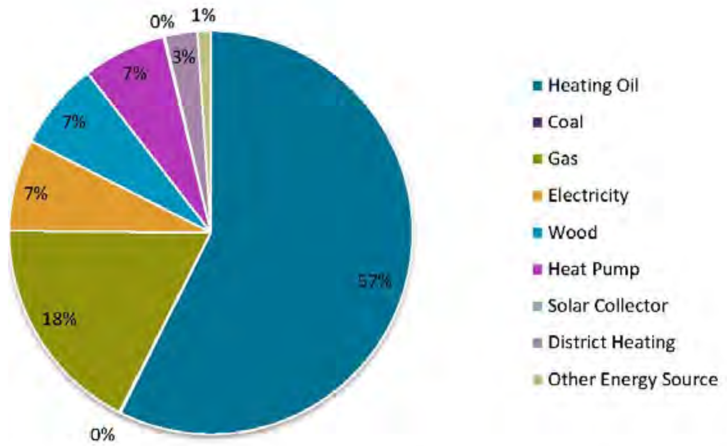


Figure 2.8: Energy source for space heating in a multi-family house 2012. Translated pictures from [10].

Building stock by energy type for hot water heating

Currently the two most important sources of energy for domestic hot water heating are electricity and fuel oil. While in single-family houses electricity is the dominant energy source for water heating, oil is preferred in multi-family homes. Water heating using a heat pump is in place in Switzerland, but hasn't been established yet as a popular alternative.

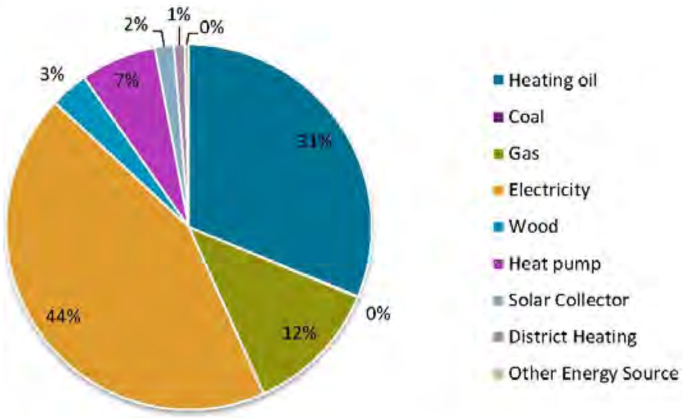


Figure 2.9: Energy source for hot water heating in a single-family house 2012. Translated pictures from [10].

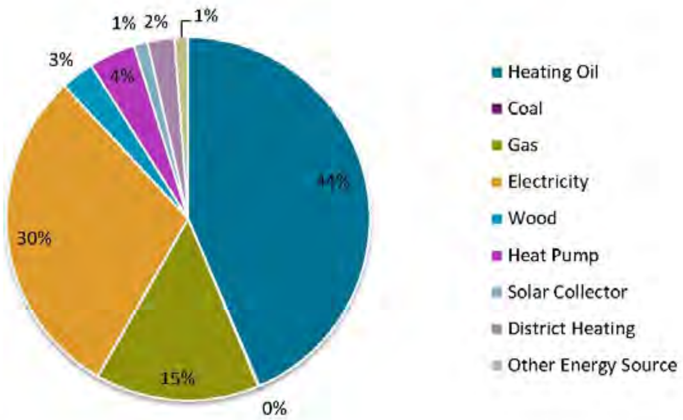


Figure 2.10: Energy source for hot water heating in a multi-family house 2012. Translated pictures from [10].

- **Use of storage tanks**:

  Many hot water heating systems in Switzerland use storage tanks because the unmodulated thermal energy producers switch on and off constantly. There are also a percentage of households using hot water storage tanks to store the excess thermal energy from log-wood heating systems, such as the single oven which is popular in rural areas.

  Hot water is also sometimes centrally produced, and then fed into a decentralized hot water system that supplies two or more draw-off points from the water heating system. This method of water heating is no longer permitted (MuKEn) and a new law allows decentralized water preparation with direct electric heating only in special cases.

  In new buildings legislation sets a maximum amount of 80 % of heating demand that can be covered with non-renewable energy. The central water purification system supplies all hot water draw-off points of a building or group of buildings. Thermal storage can be added as a separated storage system or integrated in the storage from the building's heating system, if it is a central heating system.

- **Heat distribution system:**

  Renovation of dwellings (field analysis)

  These data come from a field analysis of heat pump systems. In the refurbished buildings discussed, it is important to note that half of them were built after 1970 and 70 % more energy-relevant refurbishment measures were taken. In 25 % of the buildings a total renovation was made before the heat pump was installed.

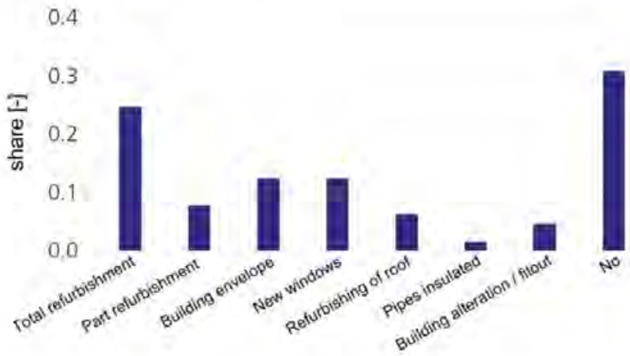


Figure 2.11: Type of renovation of the field analysis. Translated pictures from [9].

Heat distribution system (field analysis)

This field analysis shows that 92 % of new buildings use under-floor heating, in some cases supplemented by radiators. In renovated buildings the amount of floor heating is 53 % and far more radiators are used to heat the space [9].

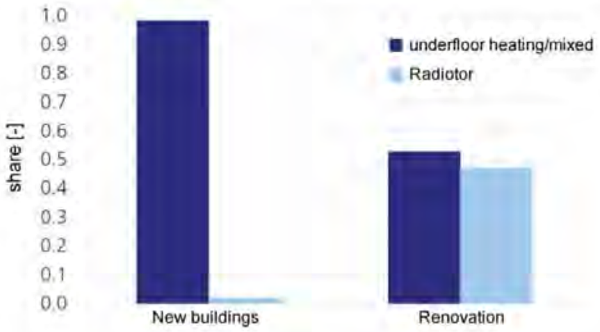


Figure 2.12: Distribution system of the field analysis. Translated pictures from [9].

2.3. Trends in the heating market

Heating systems types:

In Switzerland since 1995 the trend in heating systems in the market is clearly towards the heat pump. In contrast, the use of fuel oil has dropped and use of gas and wood has remained unchanged since 1995, while the choice of solely electric heating has fallen steadily since 1985. Figure 14 shows that the primary energy requirements will decrease throughout, since the biggest influence on energy demand is space heating.

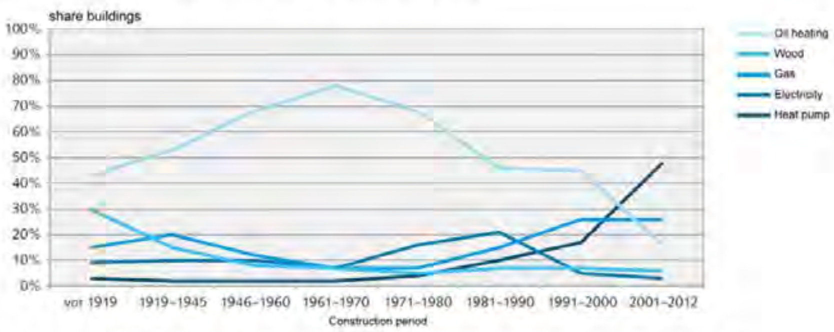


Figure 2.13: The five most important energy sources for heating by period of construction. Translated pictures from [10], page 21.

- **Fuel types:**

The proportion of space heating as an element of overall energy demand is decreased by improving efficiency. With a share of almost 53 % space heating is quantitatively the most important use. The size increase shows up in climate, ventilation and building services, hot water and other consumption.

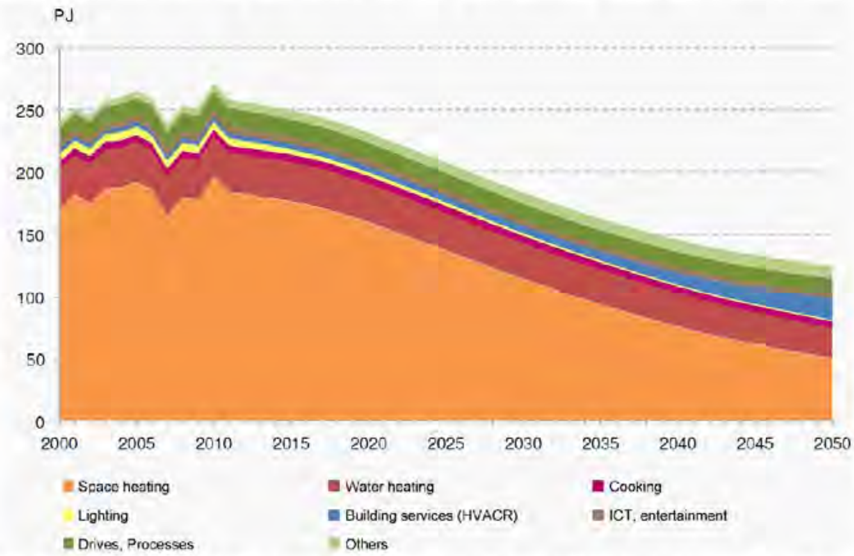


Figure 2.14: Scenario "new energy policy", private households: Final energy demand by purpose from 2000 - 2050 in PJ. Translated pictures from [4].

- **Heating structure of the living space**

In the future heating oil will be replaced by heat pumps and district heating to heat Swiss households.

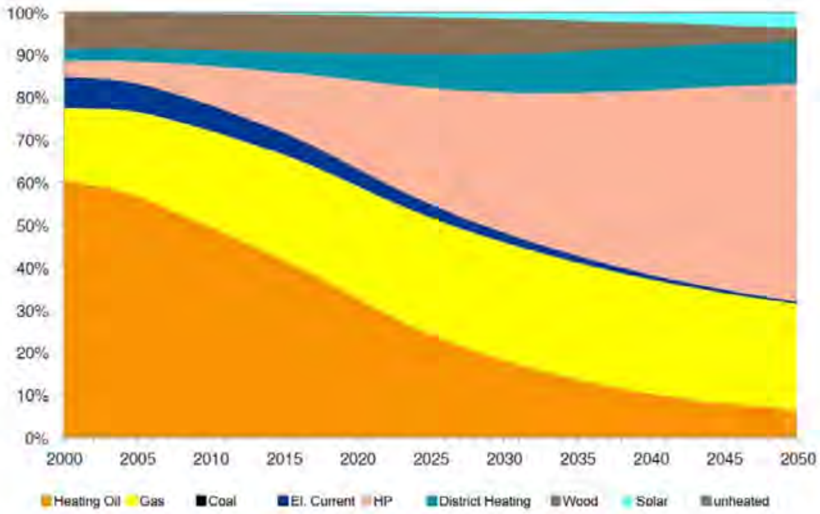


Figure 2.15: Scenario "new energy policy", private households: Heating structure of the area population 2000-2050 in %. Translated pictures from [4].

Starting in 2020 with new multi-family houses the passive house standard will be a specific heat requirement of about 10 watts per square meter EBF (energy-related surface), which will achieve an energy demand of 15 kWh per square meter each year. By 2025 all new multi- and single-family homes will comply with this standard. After 2025 the annual demand for new buildings will decrease to zero. In 2050 the specific energy demand will be around 6 watts per square meter for multi-family houses and also for single- or double-family homes.

	2000	2010	2020	2030	2035	2040	2050
New Building							
Single- and double-family home	57.6	32.3	17.1	8.7	8.5	8.3	8.1
Multi-family home/NWG	40.8	21.1	9.5	6.8	6.6	6.5	6.3
Renovation							
Single- and double-family home	60.3	48.4	27.3	13.0	12.7	12.5	12.1
Multi-family home/NWG	44.5	30.6	15.3	10.2	9.9	9.7	9.4

Table 2.1: Scenario "new energy policy", private households: development of specific heat capacity requirements for new buildings and renovations; in W / m^2 EBF. Translated pictures from [4].

Figure 2.15 and Figure 2.16 show the planned final Swiss energy consumption in PJ for space heating and hot water. For the generation of space heating it is expected that the primary source of energy will be ambient heat harnessed through heat pump systems. Similarly, the future production of hot water is planned to come mostly from solar power and ambient heat pumps. Generally for both heating systems, a significant reduction of fuel oil is desired.

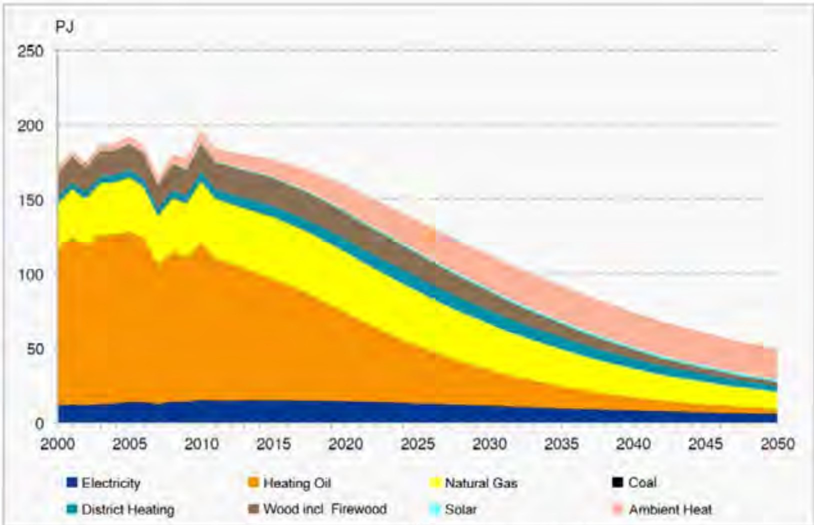


Figure 2.16: Scenario "new energy policy", private households: Final energy consumption for space heating 2000-2050 by energy sources, in PJ. Translated pictures from [4].

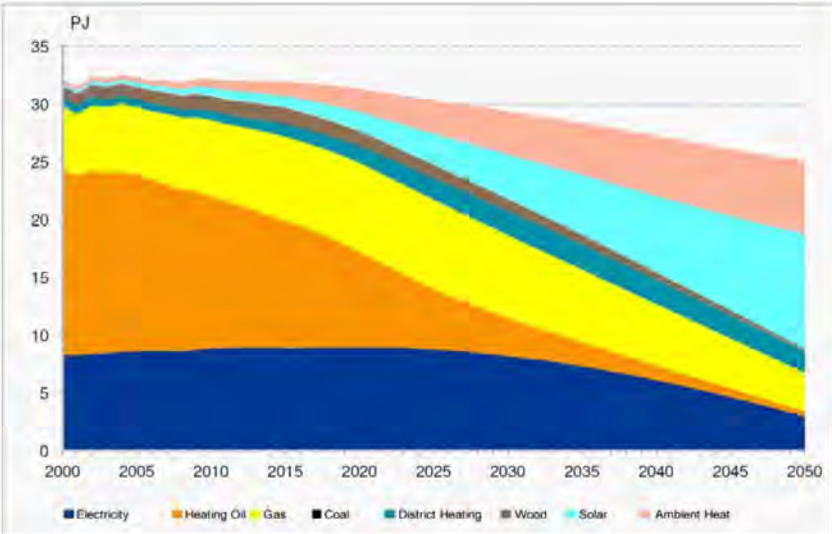


Figure 2.17: Scenario "new energy policy", private households: Final energy consumption for producing hot water 2000-2050 by energy sources, in PJ. Translated pictures from [4].

2.4. Customer preferences

The control of the heating system depends on which kind of heating system is installed. A heat pump system enables the consumer to control the power or temperature level in the home. The heat generation of a wood-fired heating system cannot be controlled, and therefore thermal storage must be added, to store part of the energy and release it over a longer time.

The flow temperature and the return temperature of the heating system adapts to the outside temperature and regulates the output in response. With radiator-based central heating systems, thermostats on the radiators in all rooms mean the temperature can be fixed at an appropriate level. Most radiator thermostats simply regulate the flow of heated water through them, depending on the temperature in the room. There are also smart radiator thermostats which can be controlled from an external central system. In most buildings the room temperature can be reduced during the night to save energy.

3. Analysis of the Swiss domestic heat pump market

3.1. Installed heat pump capacity

Technology: a/w, w/w, b/w, dx/w, a/a, GAHP:

Heat pumps are used in Switzerland in tens of thousands of applications. There is a high percentage and also a strong growth of using heat pumps to heat buildings (especially in smaller residential buildings). Currently there are more than 200,000 systems operating in Switzerland. A strong additional increase of an average of 20,000 units per year has taken place in the last 5 years. Basically, heat pumps in Switzerland are of high quality and efficiency. With approximately 62.1 % usage, air / water heat pumps are the most used ones, followed by brine / water heat pumps with about 35.5 %. The remaining 2.4 % are water / water (2 %) and air / air (0.4 %) heat pumps [7].

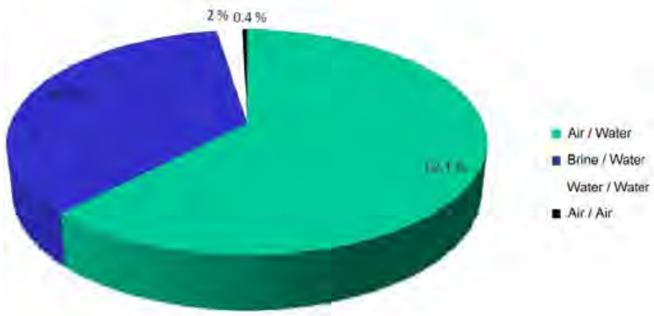


Figure 3.1: Percentage proportions of the type of installed heat pumps in Switzerland [7].

Heating capacity segmentation:

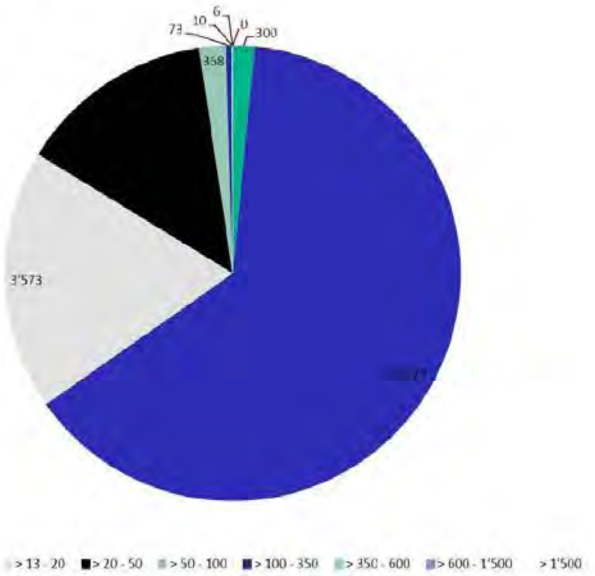


Figure 3.2: Number of installed heat pumps by power (kW) in 2013 [7].

3.2. Trends in the heat pump market

Figure 3.3: Number of installed heat pumps (1980 – 2013) [7].

The trends in the use of heat pumps are affected by: the price of energy (electricity, oil and gas); ecological sensibilities; and also political influences such as legislation. Since 2008 the sales of heat pumps have remained stable at 20 thousand units per year. This stagnation of sales can be traced back to achieving market saturation in new buildings being constructed. On the other hand there is no indication of saturation approaching in the renovation of old buildings.

So there are three possibilities for development in the heat pump market: renovation, installation of a heat pump system, or installation of a water-water system without renovation. In the case of the construction of systems, the trend is moving towards split-systems. The split-system is more favourable and space-saving, and further, these systems often integrate the heating system for the house and the domestic water heating system [15].

- **Displaced heating system type**:

  The figure shows the heating systems sold in Switzerland. As the figures indicate, oil boilers still have a relevant share of the heating system market, while the number of gas boilers sold is similar to the number of heat pumps.

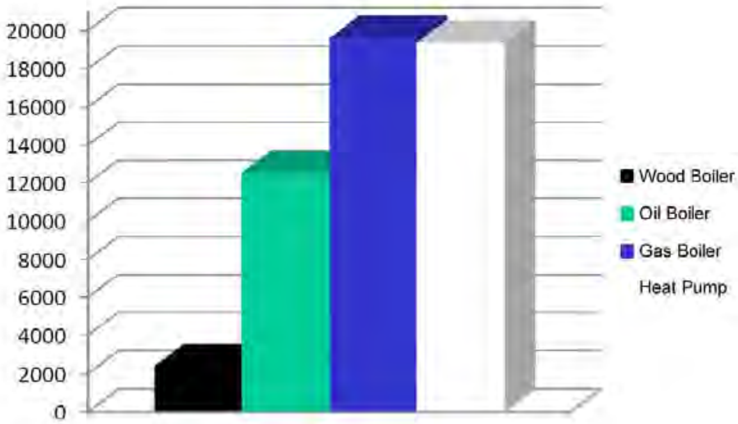


Figure 3.4: Heating systems sold in 2013 [7].

3.3. Market drivers

Ecological awareness and also government regulations have had, and will continue to have, a positive influence on the heat pump market. A decisive regulation in this field is the Ordinance on Air Pollution Control (OAPC, LRV Luftreinhalte-Verordnung) from 1985. This Ordinance is intended to protect human beings, animals and plants, their biological communities and habitats, and the soil against harmful effects or nuisances caused by air pollution.

Another program, the "Climate Cent (Klimarappe)" from the year 2005, includes but is not limited to, promoting energy-conserving renovation of cladding on building envelopes, adding a surcharge on fossil fuels and encouraging the reduction of CO_2 output.

As a result of the "Energiewende" the Energy Strategy 2050 was developed and decided. This strategy aims to:

- increase the renovation rate for old buildings,
- create incentives to replace fossil- and electric-fueled heaters,
- increase aid for conversion to renewable energy in the redevelopment area.

On the other hand, energy research is an important pillar. So far, the federal government has set aside 200 million francs a year for research. In the context of the Energy Strategy 2050 additional funds for energy research (CHF 202 million for the period 2013 -2016) and for pilot, demonstration and flagship projects of the BFE (an increase from the previous 5 to 35 million Swiss francs per year until 2015) are available.

The development of technology also has a positive aspect of heat pump sales until now and also in future. Thereby the COP (Coefficient of performance) and the SPF (Seasonal Performance Factor) play a decisive role. There is a demand in summer to cool houses, which further supports the sale of heat pumps and there are products on the market to fit the function of cooling in summer and heating in winter [15].

3.4 Market barriers

In the case of house renovation there isn't only the financial investment in a heat pump, there are additional costs for the planning and the disposal of the old heating system. Just as important as the installation of heat pumps is the renovation of the house's insulation, which needs to be completed first. These additional costs on top of the expected investment in a renovation are a financial block to the homeowner in deciding whether or not to install a heat pump.

Another barrier is created by the planning companies. Because of the complicated planning process of renovation and the installation of a new heating system, they advise their customers against choosing heat pumps. Indeed, some companies don't even mention the possibility of basing a system on a heat pump.

Bad experiences with appliances and systems have also had a negative impact on the heat pump market. One problem is the lack of skilled manpower. Therefore a lot of work, like installation or repair of system, has to be done by non-specialist workers from other branches of the construction industry, which can reduce the quality of the installation. [15].

4. List of smart heat pump projects in Switzerland

D-A-CH Smart Grid

To complement the existing international activities of Switzerland in the field of "Smart Grids", the "Memorandum of Understanding" (MoU) was signed on November 27, 2009, which should enforce cooperation between Germany, Austria and Switzerland in the field of research and development of ICT-based (ICT: Information and Communication Technology) energy systems.

Through the MoU, the three member countries should work together closely in the prospective promotion of ICT research and development. Thereby ICT products, procedures and development services for a sustainable and long-term stable electricity supply should be ensured.

The scope of cooperation includes the exchange of information and knowledge sharing and coordination of the funding policy measures. The D-A-CH cooperation provides the opportunity to initiate, fund and carry out concrete joint projects. A similar research project between Austria and Switzerland has already been started. In the context of the European Industrial Initiatives of the SET-plan, specifically in the area of "Networks" and "Smart Cities", the D-A-CH cooperation is becoming increasingly important.

Efficient air/water heat pumps with continuous capacity control

During preceding Swiss Federal Office of Energy research projects "optimisation of fin tube evaporators by reduction of ice and frost formation" and "exergy analysis for increasing the efficiency of air/water heat pumps" valuable findings concerning the increase in efficiency of air/water heat pumps were gained. These findings are now to be implemented in a practical and realistic manner. The aim is to develop universally valid design and planning criteria ("guidance") for the realisation of efficient, reliable and economic air/water heat pumps with continuous capacity control. The main measure to improve the efficiency of air/water heat pumps is to continuously adapt the generated heating capacity to the heat demand of the building. This study will give an incentive for further development in that area as well as the increase of efficiency of air/water heat pumps, both by heat pump and component manufacturers and also by designers of building services engineering.

An optimised process control strategy depending on the applied control principle of the heat pump has been developed, using simulations as well as experiments. To verify the theoretical findings as well as to investigate different control strategies, three different heat pump prototypes with capacity control and a test facility for air/water heat pumps have been realised. The investigations show that the optimal control strategy and the efficiency of the capacity controlled heat pump strongly depend upon the partial load efficiencies of the compressor and the fan. The experimental investigations have proved the great potential of the capacity control. By using the capacity control the seasonal performance can be increased by approximately 20–50% compared to air/water heat pumps with on/off control. This means the seasonal performance factors can be just as high as the values of brine/water heat pumps with on/off control [16].

- **Development of an optimum unit of heat pump and thermal energy storage**

The integration of a large amount of new renewable energy sources in the course of the "Energiewende" is an ambitious target. To operate an energy-generation system with a lot of wind- and solar energy requires additional flexibility, as the time discrepancy between production and consumption makes it necessary to upgrade the grids and storage solutions.

An interesting option is the connection of thermal storages. These are already available in great numbers such as hot water heaters and the house's mass being used as a thermal store. The production of heat (room- and process heat as well as hot water) accounts for more than 50 % of the national energy consumption. Local charge management enables the optimal use of the capacity from thermal storage, and in addition to the compensation of fluctuation from new renewable energy sources it makes possible cost reductions for the upgrading of the grid.

Already today's situation allows for offering the flexibility of thermal storage in the sector. The provision of operating reserve is a possible option. A way to define the value of the flexibility is the revenue opportunities of the sector. Besides determining the revenue opportunities, there are also the costs for the infrastructure (communication, monitoring and control) as well as the operating expense to define.

The WARMup project evaluates the economic efficiency of real scenarios. The focus is on large consumers. In the centre is a high level smart system as a connection between the sector and the flexible charge.

In the first period within the scope of this project a simulator is to be created to show the optimal management of thermal storages. The simulator decides the participation of each sector for every point in time and each different offer. This brings different thermal charges and sectors to model it close to the reality and the corresponding mathematic optimizations formulated [17].

5. Analysis of smart-ready products

5.1. The criteria for 'Smart-Ready': analysis of full range of "Smart" capabilities

We assess all the ways in which a heat pump can be "smart", through analysis of several layers of functionality that could be defined as 'smart-ready'. We will give an indication, for each criterion; of its importance for peak shifting (this importance to peak shifting could be seen as a measure of "smartness").

Criteria		Importance for peak shifting	Maturity	Future evolution
Heat pump functionality	Inverter-driven compressor which can ramp down rather than switch off	High[1]	Growth stage[2]	Hopefully to become mainstream technology
	On/off	High	Mature	Mainstream
Control strategies: building thermal mass & storage	Pre-heat algorithms	Low	Low	Some potential[4]
	'Learning' building thermal response	Medium/High depending on building[5]	Growth stage[6]	Promising[5]
	Optimising integration with storage	High	Medium[3]	Promising
Control strategies: outside environment	Weather compensation & variable capacity	Low	Mature[7]	Mainstream
	Responding to weather forecast data	Medium/High[8]	Growth stage	Niche
Control strategies: energy price	Responding to dynamic price signals	High	Low[9]	Depending on the electricity market
	Responding to pre-set price (& CO_2 signals?)	Medium	Low[11]	Depending on the electricity market
Communication capability	2-way communication	High[10]	Mature	Mature
	1-way communication	High	Mature	Mature

HOCHSCHULE LUZERN

Speed of response to communication signal	Dynamic response (minutes)	High	Low	2-way communication required
	Needs advanced notice (hours/days)	Medium[13]	Mature[14]	Mature
Communication protocol				
Thermal storage	Sensible heat storage (water tanks)	High[12]	Growth stage	Mainstream
	Advanced heat storage technologies e.g. phase-change materials	High[12]	Growth stage	Promising
Integration with 2nd energy source	bivalent system with set-point control to switch from HP to other source	Medium/High	Medium[12]	Some potential[16]
	hybrid which switch between heat sources according to price, CO_2	Medium/High	Low	Some potential[16]
	Sophisticated control hybrid which can switch between sources in response to dynamic tariffs	Medium/High	Low	Some potential[16]

(1) When properly regulated, inverter driven HPs are considerably more valuable in Smart Grids than HPs with On/Off regulation because of their increased controllability.
(2) The first high-efficiency appliances are available in the market.
(3) Latent heat storage units still require significant development work.
(4) Typical buildings in Switzerland exhibit a relatively high thermal inertia (floor heating, concrete constructions) which decreases the potential of a quick response system based on room occupation.
(5) Buildings with high thermal inertia exhibit a high potential- For example, if a period of cold weather is expected the thermal mass can be “loaded” in advance. The potential is limited in cases of buildings with low thermal inertia.
(6) Projects are currently running in Switzerland.
(7) Control based on heating curves.

(8) Big thermal storage units present a high potential. Buildings with “low thermal mass” a lower potential.
(9) There is no dynamic electricity pricing in Switzerland.
(10) Necessary especially for HPs with power control.
(11) (If High & Low Tariffs are also taken into consideration then the system is mature)
(12) Subject of current investigations.
(13) Depending on the system and the building a “Registration” in advance can make sense.
(14) Analogous to utility locks.
(15) Typical systems are HPs in combination with solar collectors.
(16) Bivalent systems are difficult to realise from an economic perspective.
(17) If the thermal inertia of the building allows it.

5.2. Defining the Minimum Capabilities for Smart-Ready Heat Pump Systems

The minimum capabilities for smart-ready heat pump systems can be summarized as follows:

- HPs with inverter driven compressors.
- Optimised systems with integrated storages (sensible & PCM).
- Optimised usage of the thermal inertia of the buildings[17].
- Respond to dynamic price signals.
- Communication capability for 2-way communication.
- Communication signal with dynamic response.

6. Acknowledgements

The authors would like to thank the Swiss Federal Office of Energy SFOE for funding the work within this IEA task and for funding the project 'Development of an optimum combination of heat pump and thermal energy storage'. Additionally, for funding the work of the Compentence Center Thermal Energy- and Process Engineering (TEVT) at Hochschule Luzern on heat pumps for many years and within various projects.

In particular, the authors thank Stefan Renz and Martin Pulfer for their support.

The authors would like to thank Hochschule Luzern for additional funding and support within these projects.

The authors thank the Commission for Technology and Innovation CTI of Switzerland for its support within the Swiss Competence Center for Energy Research (SCCER) Storage of Electricity and Heat for funding and supporting the Thermal Energy Storage Research Group at Hochschule Luzern.

The authors acknowledge the work of Business Development Holland b.v. for organizing this IEA ANNEX 42 'HEAT PUMPS IN SMART GRIDS', in particular the authors thank Peter Wagener for his engagement.

Finally, the authors thank Lindsay Sudgen from Delta-ee to compile the results of the participating countries.

7. References

[1] Bundesamt für Energie: Schweizerische Gesamtenergiestatistik 2013

http://www.bfe.admin.ch/themen/00526/00541/00542/00631/index.html?lang=de&dossier_id=00763

[2] Bundesamt für Energie: Energiesicherheit, 23.September 2011.

http://www.bfe.admin.ch/php/modules/publikationen/stream.php?extlang=de&name=de_767339349.pdf

[3] Bundesamt für Energie: Schweizerische Elektrizitätsstatistik 2013, 2014.

http://www.bfe.admin.ch/themen/00526/00541/00542/00630/index.html?dossier_id=00765

[4] Bundesamt für Energie: Schweizerische Statistik der erneuerbaren Energien 2013, Juni 2014

http://www.bfe.admin.ch/php/modules/publikationen/stream.php?extlang=de&name=de_899838018.pdf

[5] Bundesamt für Energie: Die Energieperspektiven für die Schweiz 2000-2050, Basel 2012.
http://www.bfe.admin.ch/php/modules/publikationen/stream.php?extlang=de&name=de_564869151.pdf&endung=Die%20Energieperspektiven%20f%FCr%20die%20Schweiz%20bis%202050

[6] Bundesamt für Energie: Strompreisentwicklung in der Schweiz, Juni 2011

http://www.bfe.admin.ch/php/modules/publikationen/stream.php?extlang=de&name=de_125044338.pdf

[7] Fachvereinigung Wärmepumpen Schweiz FWS / GebäudeKlima Schweiz

http://www.fws.ch/tl_files/download_d/Statistiken/2013/Statistiken_2013.pdf

[8] www.erdgas.ch

[9] M.Erb, P.Hubacher, M.Ehrbar: Feldanalyse von Wärmepumpenanlagen FAWA 1996-2003, Bundesamt für Energie, 2004. Retrieved from

http://www.bfe.admin.ch/php/modules/enet/streamfile.php?file=000000008070.pdf&name=240016.pdf

[10] Bundesamt für Energie: Bau- und Wohnungswesen 2012, Neuchâtel 2014. Retrieved from
http://www.bfs.admin.ch/bfs/portal/de/index/news/publikationen.Document.176116.pdf

[11] Bundesamt für Energie: Gebäudeparkmodell SIA Effizienzpfad Energie Dienstleistungs- und Wohngebäude; Vorstudie zum Gebäudeparkmodell Schweiz, Bern 2009.
http://www.bfe.admin.ch/php/modules/enet/streamfile.php?file=000000010241.pdf&name=000000290079

[12] Bundesamt für Energie: Analyse des schweizerischen Energieverbrauchs 2000-2012 nach Verwendungszwecken, Bern 2013. Retrieved from

http://www.bfe.admin.ch/php/modules/publikationen/stream.php?extlang=de&name=de_6635532.pdf&endung=Analyse%20des%20schweizerischen%20Energieverbrauchs%202000%20-%202012%20nach%20Verwendungszwecken

[13] Bundesamt für Statistik: Wohnverhältnisse. Retrieved from http://www.bfs.admin.ch/bfs/portal/de/index/themen/09/03/blank/key/bewohnertypen/entwicklung.html

[14] Bundesamt für Statistik: STAT-TAB – Die interaktive Statistikdatenbank. Retrieved from http://www.pxweb.bfs.admin.ch/Dialog/statfile.asp?lang=1&prod=09

[15] Wärmepumpen Schweiz: Markt-Einsatz-Verständnis, Agnieszka Banach & Andreas Fahrni, GKS Verlag

[16] Bundesamt für Energie: Effiziente Luft/Wasser-Wärmepumpe durch kontinuierliche Leistungsregelung, Jahresbericht 2010, 01. Dezember 2010

http://www.bfe.admin.ch/php/modules/enet/streamfile.php?file=000000010555.pdf&name=000000290340

[17] Bundesamt für Energie: WARMup: Optimale Verwertung der Flexibilität von thermischen Speichern, Jahresbericht 15, November 2012

http://www.bfe.admin.ch/php/modules/enet/streamfile.php?file=000000010957.pdf&name=000000290723.

[18] Bundesamt für Energie: Untersuchung von WP-Wassererwärmern in Einfamilienhäusern, Schlussbericht 2014, 09. Mai 2014

http://www.bfe.admin.ch/php/modules/publikationen/stream.php?extlang=de&name=de_288137773.pdf&endung=Untersuchung%20von%20WP-Wassererw%E4rmern%20in%20Einfamilienh%E4usern.

A2 Task Report 2: System Aspects and Opportunities

IEA HPP Annex 42: Heat Pumps in Smart Grids

Task 2: System Aspects and Opportunities -
Residential heat pump systems and applications

Switzerland

Draft 21st January 2015

Report compiled by:

Lucerne University of Applied Sciences and Arts

Lucerne University of Applied Sciences and Arts
HOCHSCHULE LUZERN

Contents

1. Overview of Residential Heat Pump Systems used in Switzerland

Installed heat pump capacity

- **Technology: a/w, w/w, b/w, dx/w, a/a, GAHP:**

  Heat pumps are used in Switzerland in tens of thousands of applications. There is a high percentage and also a strong growth of using heat pumps to heat buildings (especially in smaller residential buildings). Currently there are more than 200,000 systems operating in Switzerland. A strong additional increase of an average of 20,000 units per year has taken place in the last 5 years. In most cases, heat pumps in Switzerland are of high quality and efficiency. With approximately 62.1 % usage, air / water heat pumps are the most used ones, followed by brine / water heat pumps with about 35.5 %. The remaining 2.4 % are water / water (2 %) and air / air (0.4 %) heat pumps. More detailed descriptions of residential heat pump systems used in Switzerland are presented in the Country Report Switzerland (Task 1).

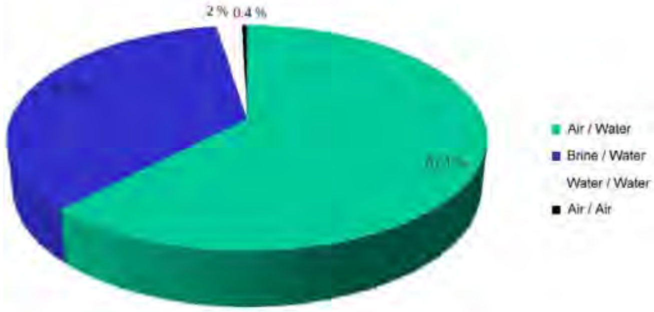


Figure: Percentage proportions of the type of installed heat pumps in Switzerland.

2. Motivation and Objectives for Smart Grid Interaction

With the Swiss Energy Strategy 2050 and the gradual phasing out of nuclear energy, gas will play an even more important role in Switzerland to ensure the energy supply.

Since hardly any mineable domestic deposits are present, the demand of about 30 TWh per year is 100 % covered by imports.

In order to estimate the future development of the energy situation in Switzerland, three electricity supply scenarios for the Federal Council were created. In the "New Energy Policy" scenario it is important to recognize that the annual consumption of electricity decreases from the year 2020. There is an increase of consumption until 2020, due to the expansion of pumped storage plants. The nuclear power plants all together should be turned off by the year 2035. The resulting gap in available energy or electricity is initially closed primarily through the development of renewable energy systems and combined cycle power plants. From the year 2035, renewable energy systems will be continuously expanded and therefore replace the combined cycle power plants.

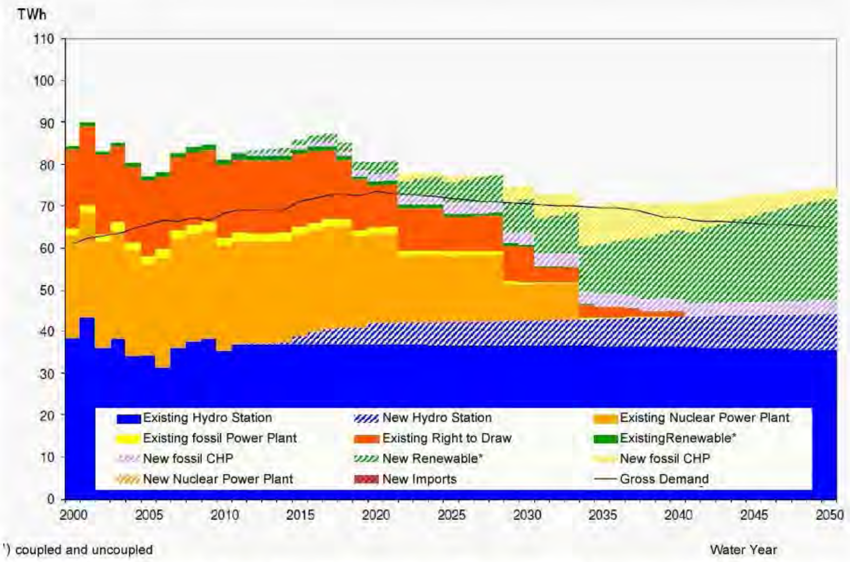


Figure: Development of the electricity supply by power plants up to 2050 in the "New energy policy" scenario.

A detailed overview of storage necessities based on this scenario shows high decentralized storage demands from 2035 on [2]. Therefore, objectives of the integration of heat pumps into smart grids are mainly given by:

- Peak load levelling (e.g. coldest week in winter) and
- Day/night shifting (due to photovoltaic mid-day peak)
- Week range shifting (due to changing weather conditions)

Comment: For the time being we are lacking sound predictions of energy production and demand e.g. for 2035. Therefore, we are using at the moment today's price effects of integrating new renewable energies as a measure for the necessities of the grid. We are assuming that the time characteristics of these effects will remain similar and that the effects will increase in the future.

3. Define Typical (or Prototypical) HP Case Scenarios for use in Task 3 Analyses

3.1. Explanation for Choosing which Scenarios

The dominant residential building in Switzerland is the family house. Single-family homes account for more than half (57 %) of all residential buildings. Slightly less than half (44 %) of all homes in Switzerland were built before 1961 and thus they are relatively old. The proportion of over 50 year-old single-family homes is 36 %.

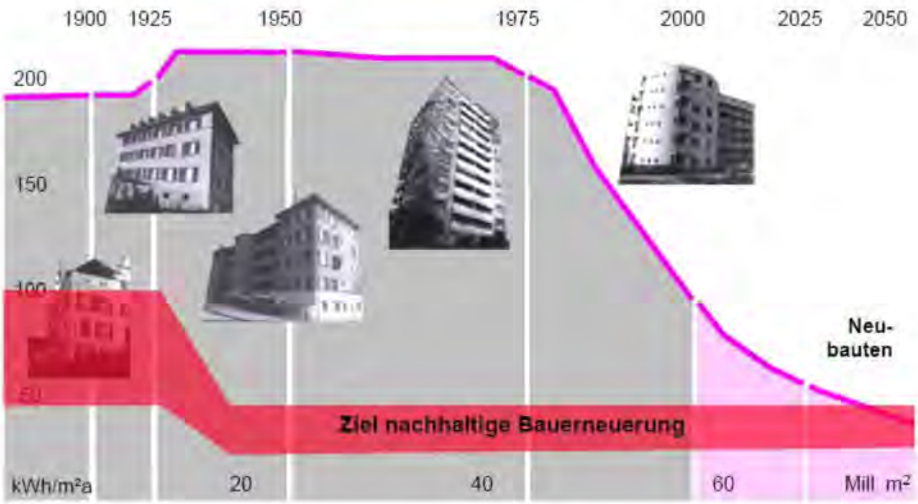


Figure: Heat demand for Swiss buildings by age of building stock

Existing buildings that are or will be renovated have the highest potential for decreasing the energy demand and for contributing significantly to gain flexibility in smart grids. Therefore, two of the four case scenarios (Case1 and 2) refer to existing renovated single family houses (reference building SFH100 with 100kWh/m^2/a). The other two cases refer to newer buildings. SFH45 (45kWh/m^2/a) (Case 3) represents a renovated building reaching good insulation quality of the building envelope and SFH15 (15kWh/m^2/a) (Case 4) represents a current building envelope with low energy demand. It fits the Swiss Minergie-P (Minergie 2010). These three reference buildings have been defined within IEA SHC Task 44 / HPP Annex 38 [1]. Two different control options are considered for heat pumps, i.e. On/Off-control and capacity control. On/Off-control (Case 2, 3 and 4) is the commonly used way in Switzerland to run the heat pump. Capacity control (Case 1) of an air/water heat pump includes a huge potential in smart grids. It guarantees more flexibility by means of a higher heat-range decoupled from the ambient-temperature and higher efficiencies for the heat pump itself. Additionally, thermal storages for hot water generation, for the heating system and the thermal mass of the building itself are considered in the defined cases. In all cases, the use of the building mass within the storage control concept is considered. The common Swiss heating systems types, i.e. radiator or floor heating, are chosen within the discussed cases.

3.2. Case Scenarios

The differences in the case scenarios are with bold print.

Scenario 1: Existing Building (renovated) with air source heat pump (cap. control)

Building	Type	Single family house
	Heated area	140 m²
	Annual heating demand	around **100 kWh/m²** (according average Swiss weather conditions)
Heat pump	Heat source	Outside air
	Operation modes	Space heating and DHW
	Conventional Control	• **Capacity control** • heating temperature (max. about **55 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C) • DHW set-temperature around **50 °C** considering typical hysteresis
	Smart Control	
	El. Back up heater	no
Heating system	Medium	Water
	Heat transfer	**Radiators**
	Storage	**Yes (range of 2000l)**
Domestic hot water	Annual energy demand	
	Load	Tapping behavior (energy and temperature) for average family according DHW-calc (IEA-SHC Task 26)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	Yes (building mass incooperated in overall model)
Optimization/Problem	Goal	Increasing load shifting potential (flexibility of running heat pump) with highest possible efficiency of heat pump. This is quantified by: Objective function consisting of two parts: - Maximizing COP of heat pump - Maximizing flexibility for smart grid (quantified in first approach by minimizing costs according to EpexSpot prices) Weighing between these two objective functions to be defined.
	Realization	Optimization of the combination of heat pump (Capacity control) and innovative thermal energy storage for typical renovated buildings (heating and domestic water heating).
	Communication with heat pump	**Input of heating power as a function of time, supply temperature**
	Expected results	**In particular for this case sensitivity analysis of using capacity control for heat pumps on objective function.**
	Observation periods	Coldest average week, Typical Week in Spring, Whole year

IEA HPC Annex 42: Task 2 Scenario Descriptions Switzerland Page 7

Scenario 2: Existing Building (renovated) with air source heat pump (On/Off-control)

Building	Type	Single family house
	Heated area	140 m²
	Annual heating demand	around **100 kWh/m²** (according average Swiss weather conditions)
Heat pump	Heat source	Outside air
	Operation modes	Space heating and DHW
	Conventional Control	• **On/Off-control** • heating temperature (max. about **55 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C) • DHW set-temperature around **50 °C** considering typical hysteresis
	Smart Control	
	El. Back up heater	no
Heating system	Medium	Water
	Heat transfer	**Radiators**
	Storage	**Yes (range of 2000l)**
Domestic hot water	Annual energy demand	
	Load	Tapping behavior (energy and temperature) for average family according DHW-calc (IEA-SHC Task 26)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	Yes (building mass incooperated in overall model)
Optimization/Problem	Goal	Increasing load shifting potential (flexibility of running heat pump) with highest possible efficiency of heat pump. This is quantified by: Objective function consisting of two parts: - Maximizing COP of heat pump - Maximizing flexibility for smart grid (quantified in first approach by minimizing costs according to EpexSpot prices) Weighing between these two objective functions to be defined.
	Realization	Optimization of the combination of heat pump (Capacity control) and innovative thermal energy storage for typical renovated buildings (heating and domestic water heating).
	Communication with heat pump	**Input of on/off signal for heat pump, supply temperature**
	Expected results	**In particular effect of thermal storages and thermal mass of building on objectives.**
	Observation periods	Coldest average week, Typical Week in Spring, Whole year

Scenario 3: New standard building with air source heat pump (On/Off-control)

Building	Type	Single family house
	Heated area	140 m²
	Annual heating demand	around **45 kWh/m²** (according average Swiss weather conditions)
Heat pump	Heat source	Outside air
	Operation modes	Space heating and DHW
	Conventional Control	• **On/Off-control** • heating temperature (max. about **45 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C) • DHW set-temperature around **50 °C** considering typical hysteresis
	Smart Control	
	El. Back up heater	no
Heating system	Medium	Water
	Heat transfer	**Floor heating**
	Storage	**Yes (1000l)**
Domestic hot water	Annual energy demand	
	Load	Tapping behavior (energy and temperature) for average family according DHW-calc (IEA-SHC Task 26)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	Yes (building mass incooperated in overall model)
Optimization/Problem	Goal	Increasing load shifting potential (flexibility of running heat pump) with highest possible efficiency of heat pump. This is quantified by: Objective function consisting of two parts: - Maximizing COP of heat pump - Maximizing flexibility for smart grid (quantified in first approach by minimizing costs according to EpexSpot prices) Weighing between these two objective functions to be defined.
	Realization	Optimization of the combination of heat pump (Capacity control) and innovative thermal energy storage for typical renovated buildings (heating and domestic water heating).
	Communication with heat pump	**Input of on/off signal for heat pump, supply temperature**
	Expected results	**In particular effect of thermal storages and thermal mass of building on defined goals.**
	Observation periods	Coldest average week, Typical Week in Spring, Whole year

Scenario 4: Passive house with air source heat pump (On/Off-control)

Building	Type	Single family house
	Heated area	140 m²
	Annual heating demand	around **15 kWh/m²** (according average Swiss weather conditions)
Heat pump	Heat source	Outside air
	Operation modes	Space heating and DHW
	Conventional Control	• **On/Off-control** • heating temperature (max. about **35 °C**) according outside air temperature (heating curve) considering typical hysteresis (Room temperature aimed to be constant on 20 °C) • DHW set-temperature around **50 °C** considering typical hysteresis
	Smart Control	
	El. Back up heater	no
Heating system	Medium	Water
	Heat transfer	**Floor heating**
	Storage	**Yes (1000l)**
Domestic hot water	Annual energy demand	
	Load	Tapping behavior (energy and temperature) for average family according DHW-calc (IEA-SHC Task 26)
	Storage	Typical size (around 300 l)
Additional technologies or storages	PV	no
	Battery	no
	Gas/oil boiler	no
	active use of building mass	Yes (building mass incooperated in overall model)
Optimization/Problem	Goal	Increasing load shifting potential (flexibility of running heat pump) with highest possible efficiency of heat pump. This is quantified by: Objective function consisting of two parts - Maximizing COP of heat pump - Maximizing flexibility for smart grid (quantified in first approach by minimizing costs according to EpexSpot prices) Weighing between these two objective functions to be defined.
	Realization	Optimization of the combination of heat pump (Capacity control) and innovative thermal energy storage for typical renovated buildings (heating and domestic water heating).
	Communication with heat pump	**Input of on/off signal for heat pump, supply temperature**
	Expected results	**In particular effect of thermal storages and thermal mass of building on objectives.**
	Observation periods	Coldest average week, Typical Week in Spring, Whole year

References

[1] *R.Dott, M.Haller, J.Ruschenburg, F.Ochs, J.Bony: The Reference Framework for System Simulations of the IEA SHC Task 44 /HPP Annex 38. 2013*

[2] *C. Hewicker et al.: Energiespeicher in der Schweiz: Bedarf, Wirtschaftlichkeit und Rahmenbedingungen im Kontext der Energiestrategie 2050, BfE report, 2013*

A3 Task Report 3: Submitted abstract to the IEA Heat Pump conference 2017

12th IEA Heat Pump Conference 2017

Thermal storage improves flexibility of residential heating systems for smart grids

Philipp Schuetz[a,*], Damian Gwerder[a], Lukas Gasser[b], Ludger Fischer[a], Beat Wellig[a], Jörg Worlitschek[a]

[a] Lucerne University of Applied Sciences and Arts, Technikumsstrasse 21, 6048 Horw, Switzerland
[b] Alera energies Ltd, Hohenrainstrasse 36, 6280 Hochdorf, Switzerland

Abstract

Renewables energies such as photovoltaics are often available when there is little energy demand for space heating. One major strategy to enable this flexibility in heat pump operation is the short-term storage of thermal energy.

In our contribution, we explore the boundaries of flexibility achievable by the combination of heat pumps and thermal storage systems in residential heating. Flexibility is quantified based on the average fraction of hours per day with blocked heat pump and the costs for the consumed electricity on the German EPEX-Spot day-ahead market. The impact of different system designs (heating capacity of the heat pump and storage capacity), and control algorithms is examined with an experimentally verified model for the complete residential heating system. As an example for a typical old building in Switzerland, a single family house (SFH) with 100 kWh/m² annual heating energy consumption adopted from the IEA Annex task 44 is considered.

The integration of a thermal storage system together with scaling the heat pump power increases the flexibility (fraction of the day with blocked heat pump) by up to 43 %. Furthermore, the number of blocking periods longer than 12 hours increases by a factor up to 16. With the EPEX-Spot prices, the annual energy costs can be reduced by up to 28 %. In selected periods of the year, cost reductions of up to 30 % can be achieved with only 6 % reduction of efficiency. Future incentives for flexibility will help to increase the financial benefits, compensate for the costs of the required additional installations and thereby improve the integration of heat pumps into smart grids.

© 2017 Stichting HPC 2017.
Selection and/or peer-review under responsibility of the organizers of the 12th IEA Heat Pump Conference 2017.

Keywords: Heat pump integration; smart grid; flexibility; thermal storage.

1. Introduction

An extended integration of variable renewable energies such as wind power or solar energy intensifies the imbalance between electricity production and consumption if the current operation schemes are not adjusted. Due to the high energy demand for space heating (50 % in the European Union), the increasing distribution of heat pumps in Europe and the high efficiency of the latter, the heat pump technology is an optimal candidate for improving the balance between energy consumption and production. However, to decouple the provision of heat (consumption of electricity) from the heat demand of the building, heat has to be stored intermittently [1,2]. The storage capacity can be provided both by the building mass and the heating system as well as an additional thermal storage system.

An experimental verification of various configurations of buildings with different storage systems/sizes is prohibited by high costs and the high time demand for installation, monitoring and running the experiment. Therefore, computer simulations of parts or the whole heating system and its control are a viable alternative. In many cases, the simulations enable predictions in faster than real time [3–5] (simulations for a full year with a one-minute resolution can be performed in less than a few hours). The simulation approaches can be split into two different categories: In a top-down approach, existing monitoring data of different configurations are analysed to predict the energy demand over multiple years [6,7]. In a bottom-up approach, simplified models for the individual components are connected to describe parts or the whole heating system [3,7,8]. Both public buildings [3] as well as multiple houses [9] are in the focus of modelling studies. Also for the control algorithm, both simple three point control algorithms as well as complex model predictive control algorithms [10] are investigated.

In this contribution, we explore the potential to improve the flexibility of a heat pump in a residential heating system by the integration of additional thermal storage system. The investigation is centred around a single family house (SFH100) with an annual heating energy demand of 100 kWh/m^2/a [11], which is a typical example of a renovated old building in Switzerland. In section 2, the definition of flexibility is reviewed altogether with the key features and investigation scope of the Matlab/Simulink model [12] for the residential heating system. In section 3, the results of the simulation study are presented, and a conclusion is drawn in section 4.

2. Quantification of Flexibility and Modeling Methodology

2.1. Measures for flexibility

According to Eurelectric (Association of electricity industry in Europe), flexibility is the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal and activation) [13]. In their list of quantifiers for flexibility, Eurelectric includes the price for the primary energy, the duration of the modification and the amount of the power modulation.

For a residential heating system, these three quantities have to be reinterpreted: As price signal, the price of the electricity at the German EPEX-Spot Day ahead market is considered. In contrast to the available pricing schemes for end users, this price model does not consider only a few discrete price levels, but offers traded prices with a binding to electricity demand and supply. As a second quantity, the share of the day during which the heat pump operation is certainly stopped (averaged over the heating period) is considered. This fraction quantifies which share of the day the heat pump can be employed for ancillary service provision, i.e. the contribution to the power modulation. As a third quantifier, the fraction of blocks with certainly stopped heat pump longer than 12 hours is calculated. This quantifier measures the potential of modifying the consumption pattern over a period of 12 hours, which exceeds the currently common horizon of 2 – 4 hours.

2.2. Modelling of components and system and parameter range under investigation

The impact of the different configurations is studied with a Matlab/Simulink model [12,14,15] extending the Carnot toolbox [16]. To simulate the dynamics of the building a three-parameter model is implemented [12] based on an energy balance [17]:

$$C\frac{d\,\vartheta}{d\,t} = g\; I(t) + \; \dot{Q}_{int} + \dot{Q}_H - H\left(\vartheta(t) - \; \vartheta_A(t)\right) \qquad (1)$$

with the lumped heat capacity C, the conversion factor g for the solar intensity $I(t)$, $\vartheta(t), \vartheta_A(t)$ the room and ambient temperature, $\dot{Q}_H, \dot{Q}_{int}$ the heat flux due to the heating systems and internal appliances, respectively, and the heat transfer coefficient H through the envelope. In this contribution the parameters C, g, H are calculated for the reference single family house (SFH100) with an annual energy consumption of 100 kWh/m^2/a as defined in the IEA Annex Task 44 [11,18]. The heating medium transfers heat to the room via radiators, which are modelled by an elementary heat transfer model.

The operation of the heat pump is modelled via performance curves (heat capacity generated and coefficient of performance for different ambient temperatures). These performance curves (displayed in Fig. 1) are derived from detailed models of the heat pump including optimum defrosting procedures [19,20]. Considered in this paper is a heat pump ZHI-14 from Emerson Climate Technologies, St. Louis, MO. The capacity generated by the heat pump is chosen conventionally: the thermal design power of 8091 W fulfils the heat demand (7337 W) of the building at the design temperature – 10 °C plus the demand for domestic hot water. To facilitate an operation of the heat pump concentrated on few short time intervals, besides the conventionally selected heat pump also two models with 1.5 times and twice the power of the standard heat pump are considered.

As storage systems, water tanks of 1, 2, 4 and 8 m^3 volume are considered. The volume is chosen similar to the size of a conventional oil storage tank such that the study also considers the cases where conventional oil burner-based system are replaced with a modern heat pump based heating solutions. In the presented model, the water tank is modelled with the corresponding model from the CARNOT toolbox using a node model for the storage [12].

The system configuration is implemented according to STASCH6 [21] employing the piping models as implemented in the CARNOT toolbox.

To control the heat pump, two different algorithms have been implemented. First, a conventional two-point controller where the heat pump is switched on or off whenever the inlet-temperature to the heat pump leaves a 5 K wide corridor around the set temperature. The set temperature of the heat pump-control is set according to the heating curve of the building minus the six-fold difference (i.e. the gain is 6) between actual room temperature and target room temperature (20 °C) (i.e. the set temperature is increased by 6 K in case the room temperature is 1 K below the target temperature). To exploit the benefits of an additional thermal storage system, a predictive control algorithm with a target on low energy costs is implemented. As mentioned in Section 2.1, the German EPEX-Spot day ahead market prices are considered here, which are at 23.00 on the evening prior the day of action. The availability of certain price information the day before yields a natural planning horizon of 24 hours. For this planning horizon, the operation times of the heat pump are selected such that the heat pump provides the required heat during the hours with the cheapest electricity. All simulations are performed for Zurich as the location in the year 2013. The climatic data are extracted from IDA-Web from MeteoSuisse, Zurich, Switzerland [22].

2.3. Verification of the model

Simulations are performed here to evade cost-intensive real-world experiments. Therefore, a direct verification of the whole system simulation is not possible due to the absence of reference data. To ascertain a high prediction quality of the model, each component model has been verified individually.
The building dynamics is compared to detailed simulations performed with the reference software IDA Indoor Climate and Energy framework (EQUA Simulation AB, Solna, Sweden). For both models (three parameters and IDA-ICE), eight physical parameters (heat load, solar gains, transmission and air flow losses, ground heat exchange, room, flow and return temperatures) are compared for simulations of Strasbourg for the norm year and for Zurich in the year 2013 are compared. The agreement between the simulations was very good [12], however, the three parameter models overestimated the heat consumption of the building slightly. The deviation can most likely be attributed to missing control of the radiator system.
The storage model is verified based on measurements of a 100 m³ storage tanks in a district heating system in collaboration with Regiowerke Solothurn, Switzerland. If the simulations are corrected for an underestimated mass flow through the tank (the mass flow is overestimated as only measurements upstream a splitter serving three parallel tanks are available), the agreement on nine different levels within the storage tank is excellent [12].
The heat pump performance curves are derived from a detailed simulation software developed in-house [19]. As these models have been encompassingly verified experimentally, the performance curves represent the system behaviour reliably.

2.4. Optimisation in selected periods of the year

To push the limits of flexibility even further, a short period (21.3.2013 – 4.4.2013) has been investigated in more detail. The residential heating system is configured according to STASCH6, where the heat storage system is connected in parallel to the heat pump to enable an operation of the heating system where all heat is extracted from the heat storage system. The heat pump is selected conventionally, and a water tank with a volume of 2 m³ is included as thermal storage. The control algorithm has been manually fine-tuned for both high flexibility and efficiency.

3. Results of Simulation Study

3.1. Limits of flexibility (defined as fraction of the day with guaranteed non-operation of the heat pump)

In Fig. 1, the influence of different heat pump capacities as well as storage sizes on the flexibility (defined as the fraction of the day the heat pump is certainly not operational) is displayed. With the examined configurations, the flexibility can be improved by up to 43 %. Furthermore, the results in Fig. 1 indicate that the capacity of the heat pump has a stronger impact on the flexibility as the size of the water tank. An increase of the heat pump capacity by 50 % and 100 % increases flexibility on average about by 10 % and 15 %, respectively. In contrast, the extension of the water tank from 1 m³ to 2, 4 and 8 m³ improves flexibility by around 3.8 %, 6.5 % and 7.5 % (the last value is calculated only for the cases with 1.5 times and twice the generated capacity of the heat pump).

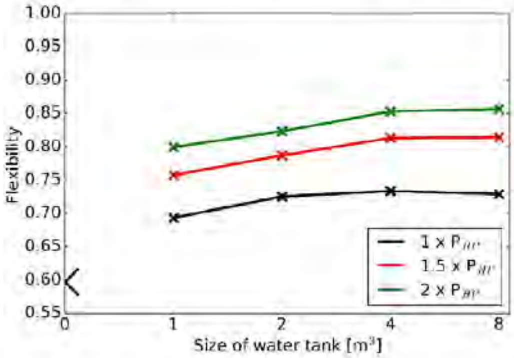


Fig. 1. Dependence of flexibility (fraction of the day with certainly blocked heat pump operation) on heat pump power (P_{HP}) and capacity of the storage system (size of the water tank). For all simulations, a prediction horizon of 24 hours in the predictive control algorithm has been employed.

The stronger contribution of the heat pump scaling to the flexibility as defined here was expectable since high flexibility implies short operation times. As the same required energy has to be provided in shorter time, the appliance has a higher power. In consequence, high flexibility also implies higher peak power.

3.2. Focussing the operation times to facilitate grid management

Besides peak power, long period, where the heat pump is certainly switched, are indicative of periods during which the power of the device can be called to balance production and consumption in the grid. In Fig. 2, the average duration of a period with certainly switched off heat pump is shown. In contrast to flexibility studied above, the average duration displays only a weak dependence on the power of the heat pump, whereas the influence of the size of the water tank is dominant. By the integration of the storage system, the average duration of the blocked heat pump periods can be increased by a factor of 11. Even the smallest storage causes an extension of the average duration by a factor of 7.2.
The contribution of the heat pump is predominately preventing a levelling of the influence of the storage size. With a conventionally selected heat pump the influence of the storage is already marginalised at a water tank size of 2 m³, whereas with double heat pump capacity even with 8 m³ water tank the average block size can be increased.

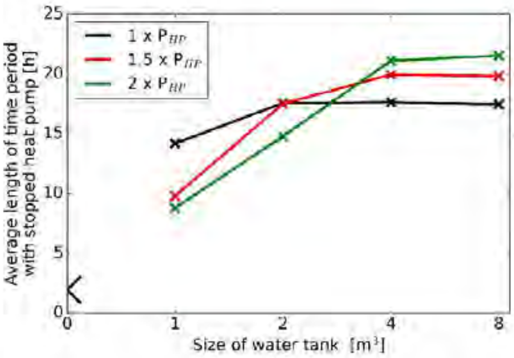


Fig. 2. Average length of the periods with stopped heat pump calculated for a residential heating system with the building type SFH100. Tested are three different heat pumps with scaled power (P_{HP}) and capacities of the thermal storage system. All simulations with storage system are performed with a predictive control algorithm with a horizon of 24 hours.

If the grid operator is interested in shifting the load from day to night or vice versa, the number of blocks longer than 12 hours is essential. In Fig. 3, the fraction of blocks with certainly stopped heat pump longer than 12 hours is displayed. The integration of a stronger heat pump and storage systems may increase the fraction of long blocks by a factor of up to 45. Even the integration of a small storage system with 1 m³ volume with conventionally selected heat pump, causes an increase by a factor of 19. The impact of heat pump capacity and storage size are similar to their effect on the average duration above: the size of the storage system has a stronger impact than the heat pump power. The latter predominately prevent an annihilation of the effect of the storage size.

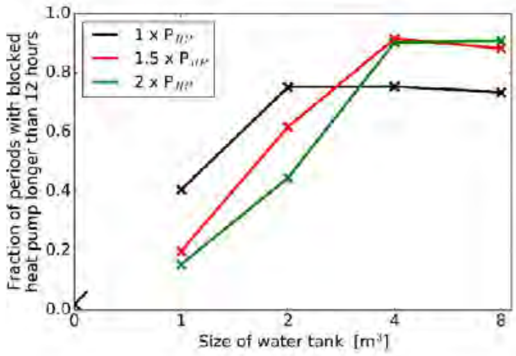


Fig. 3. Fraction of periods with stopped heat pump longer than 12 hours. The simulations are performed with the same parameters as Fig.1 and Fig. 2.

3.3. Cost reduction by storage integration

In Fig. 4, the influence of the different configurations and the action of the control algorithm on the primary energy costs is displayed. With large storage systems, a cost reduction of up to 20 % can be achieved. However, for small storage capacities, the electricity costs for a full year operation exceed even the costs of a conventionally (operated) system. More powerful heat pumps suffer from higher electricity costs due to shorter operation times, higher storage medium temperature and, therefore, reduced efficiency of the heat pump. In larger storage systems, similar quantities of heat are stored with lower medium temperatures. Therefore, the heat pump can be operated with higher efficiency.

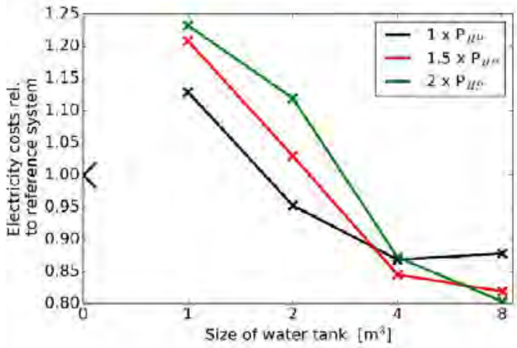


Fig. 4. Primary energy costs for full year heating operation relative to the respective value of the simulation with conventionally selected heat pump and two-point control algorithm. The simulations are performed with the same parameters as the previous Figures.

3.4. Drawbacks of flexibility providing operation mode

The elevated storage medium temperatures and the thermal losses of the storage system cause a reduction of the seasonal performance factor (SPF) as shown in Fig. 5. In particular, if a fixed prediction horizon of 24 hours is chosen, the reduction of the SPF (cf. Fig. 5.a) may be up to 28 %. However, if the prediction horizon is varied, the SPF is partially recovered and drops only by 12 % of the original value.
The general trend of the SPF on the variation of storage size and heat pump power is as expected: Large storage sizes enable lower storage medium temperatures, therefore, higher efficiency and, in consequence, higher SPF. For heat pumps with high capacity, the control algorithm compresses the running times of the heat pump and, thereby, causes higher storage medium temperatures yielding lower SPF.

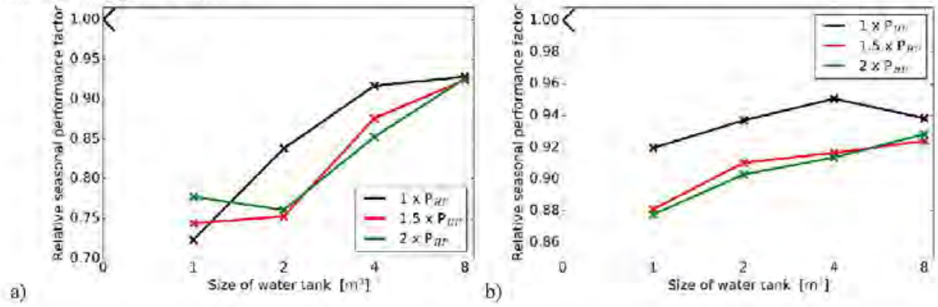


Fig. 5. Seasonal performance factor for different configurations of residential heating systems for the building SFH100. In the plot left (a), a fixed prediction horizon of the predictive control algorithm of 24 hours has been employed, whereas in the plot b) the optimum seasonal performance factor is determined among the solutions with prediction horizon 6, 12, 24 or 48 hours.

3.5. High flexibility with high efficiency (for a selected time periods)

In the previous sections, we focused on full year simulations and observed that increased flexibility and longer periods of blocked heat pump cause efficiency reductions. In this section, we concentrate on a fortnight in the second halve of March 2013. The obtained results are summarised in Table 1. With the fine-tuned control algorithm, the number of hours per day with blocked heat pump can be increased by a factor of 2 – 3, the electricity costs be reduced by 36 % and the number of switching events of the heat pump reducing the life expectancy of the device by 80 %. These benefits can be achieved with a reduction of the efficiency by only 7.1 %. Remarkably, these results have been achieved with a conventionally selected heat pump and a storage system with mediocre storage capacity.

Table 1. Results of optimisation study for the inter season period of 21.3.2013 - 4.4.2013.

System / Operation mode	Hours blocked [h/d]	COP [%]	Relative Electricity costs [%]	Relative Switching cycles [%]
No additional storage / 0 h blocked	0	100	97.3	100
No additional storage / 2 x 3 h blocked	2 x 3	97.9	100	78.7
Additional storage, predictive control	14 – 16	93.9	64.4	19.8

4. Conclusion

In this contribution, we investigated the potential of exploiting thermal storages for the provision of flexibility with heat pumps for the smart grid. Based on a simulation model of the whole residential heating system with experimentally verified components, the influence of additional thermal storages on the modulation strength of the heat pump, the duration of the modulation and the electricity costs is studied. As a typical example of the (Swiss) building park, a single family house with an annual energy consumption of 100 kWh/m²/a is considered.
The simulations indicate that the integration of an additional thermal storage may increase the flexibility (guaranteed off-time of the heat pump) by almost 50 %. With the same configuration, the average duration of these off-blocks can be increased by

a factor of up to 45 and the costs can be reduced by up to 28 %. Although these large improvements require a unconventionally high powered heat pump and a large storage tank, even with a small tank of only 1000 litres and a predictive control algorithm, the flexibility can be substantially improved. For instance, the average off-time can be increased by a factor of almost 20. The combined action of control algorithm, strong heat pump and large storage tank enable to save primary energy costs (assuming a demand-driven price structure). However, the potential of refinancing the additional investment for the house owner is very small if no further incentives are created by grid operators and electricity providers to foster flexibility provision with residential heat pumps.

Acknowledgements

The authors would like to thank the Swiss Federal Office of Energy for financial support under the project SI/500978 as well as the members of the IEA annex task 42 for useful discussions. Felix Eckl and Simon Maranda are acknowledged for their support in the experimental verification of the models presented here as well as Heinrich Manz and Christoph Stettler for useful discussions and benchmark data in the design of the dynamic building model.

References

[1] D. Six, J. Desmedt, J.V.A.N. Bael, D. Vanhoudt, Exploring the Flexibility Potential of Residential Heat Pumps, in: 21st International Conference on Electricity Distribution, CIRED, Frankfurt, 2011: pp. 6–9.
[2] R. De Coninck, L. Helsen, Bottom-up quantification of the flexibility potential of building, in: Conference: Building Simulation, 13th International Conference of the International Building Performance Simulation Association, 2013.
[3] J. Široký, F. Oldewurtel, J. Cigler, S. Prívara, Experimental analysis of model predictive control for an energy efficient building heating system, Applied Energy. 88 (2011) 3079–3087.
[4] P. Byrne, J. Miriel, Y. Lénat, Modelling and simulation of a heat pump for simultaneous heating and cooling, Building Simulation. 5 (2012) 219–232.
[5] E. Georges, G. Masy, C. Verhelst, V. Lemort, P. André, Smart Grid Energy Flexible Buildings Through The Use Of Heat Pumps In The Belgian Context, Science and Technology for the Built Environment. 21 (2015) 800–811.
[6] W. Chung, Review of building energy-use performance benchmarking methodologies, Applied Energy. 88 (2010) 1470–1479.
[7] M. Muratori, M.C. Roberts, R. Sioshansi, V. Marano, G. Rizzoni, A highly resolved modeling technique to simulate residential power demand, Applied Energy. 107 (2013) 465–473.
[8] J. Mazo, M. Delgado, J.M. Marin, B. Zalba, Modeling a radiant floor system with Phase Change Material (PCM) integrated into a building simulation tool: Analysis of a case study of a floor heating system coupled to a heat pump, Energy and Buildings. 47 (2012) 458–466.
[9] M. Elci, S. Narmsara, F. Kagerer, S. Herkel, Simulation of Energy Conservation Measures and Its Implications on a Combined Heat and Power District Heating System : a Case Study, in: 13th Conference of Building Performance Simulation Association, Chambéry, 2013: pp. 104–111.
[10] F. Oldewurtel, A. Parisio, C.N. Jones, D. Gyalistras, M. Gwerder, V. Stauch, B. Lehmann, M. Morari, Use of model predictive control and weather forecasts for energy efficient building climate control, Energy and Buildings. 45 (2012) 15–27.
[11] R. Dott, J. Ruschenburg, F. Ochs, J. Bony, M. Haller, The Reference Framework for System Simulation of the IEA SHC Task 44 / HPP Annex 38 - Part B: Buildings and Space Heat Load, Technical Report of Subtask C of the IEA SHC Task 44. (2013).
[12] D. Gwerder, P. Schuetz, J. Worlitschek, Experimentally verified model for the combination of heat pump and thermal heat storage systems for space heating, submitted, 2016.
[13] Eurelectric, Flexibility and aggregation - requirements for their interaction in the market, Brüssel, 2014.
[14] D. Gwerder, P. Schuetz, L. Gasser, B. Wellig, J. Worlitschek, Entwicklung einer optimalen Einheit aus Wärmepumpe und thermischen Energiespeicher, in: 21. Wärmepumpentagung, 2015: pp. 115–129.
[15] P. Schuetz, D. Gwerder, L. Gasser, L. Fischer, B. Wellig, J. Worlitschek, Improved flexibility for heat pumps by the integration of a thermal storage system, in: 10th International Conference of Renewable Energy Storage, Düsseldorf., 2016.
[16] C. Wemhöner, B. Hafner, K. Schwarzer, Simulation of Solar Thermal Systems With Carnot Blockset, in: Proceedings Eurosun 2000 Conference, ISES, Copenhagen, Denmark, 2000: pp. 1–6.
[17] H. Burmeister, B. Keller, Climate surfaces: a quantitative building-specific representation of climates, Energy and

Buildings. 28 (1998) 167–177.

[18] M. Haller, J. Ruschenburg, F. Ochs, J. Bony, R. Dott, The Reference Framework of System Simulations of the IEA SHC Task 44/HPP Annex 38 - Part A: General Simulation Boundary Conditions, Technical Report of Subtask C of the IEA SHC Task 44. (2013).

[19] K. Hilfiker, L. Gasser, B. Wellig, WEXA: Exergie-Analyse zur Effizienzsteigerung von Luft/Wasser-Wärmepumpen, Bundesamt Für Energie. (2008).

[20] L. Gasser, I. Wyssen, M. Albert, M. Häusermann, M. Kleingries, B. Wellig, Effiziente Luft / Wasser-Wärmepumpen durch kontinuierliche Leistungsregelung, Bundesamt Für Energie. (2011).

[21] H. Gabathuler, H. Mayer, T. Afjei, Standardschaltungen für Kleinwärmepumpenanlagen, Bundesamt Für Energie. (2002).

[22] IDAweb, Federal Office of Meteorology and Climatology MeteoSwiss. (n.d.). http://www.meteoswiss.admin.ch/home/services-and-publications/beratung-und-service/data-portal-for-teaching-and-research.html (accessed October 11, 2016).

A4 Task Report 3: Article in Heat Pump Technologies Magazine

Thermal Storages Improve Heat pump Flexibility for Smart Grids in Residential Heating

Philipp Schütz, Damian Gwerder, Lukas Gasser, Beat Wellig, Jörg Worlitschek - Switzerland

A heat pump is flexible for a smart grid when it can be switched on or off according to the load of the electric network. To fulfil the heat demand asynchronously from the building, the heat produced by the heat pump has to be stored intermittently. Here, we explore the limits of flexibility for a residential heating system with varying heat pump capacity when thermal storage systems (additional systems or building) are integrated. In our simulation study, the flexibility can be increased by up to 50 % at 10 to 20 % loss in seasonal performance factor.

Introduction

To maintain the voltage and frequency in an electrical network, supply and consumption of electric energy have to be mutually balanced. As space heating is one of the major consumers of primary energy, heat pumps could become a major actor for the energy balance. The successful integration of heat pumps into smart grids requires that heat pumps can be operated according to the grid's requirements and not according to the heating schedule of the building. To prevent discomfort for the inhabitants, the produced heat has to be stored either in the building, in the heating system or in an additional thermal storage element. See figure 1.

In this article, we explore how much flexibility is gained if thermal storage capacity is exploited. In a first section, three measures for flexibility are introduced. Subsequently, a computer model and heat pump control for an in-silico study is described. In the results sections, we describe which limits of flexibility have been identified and how adverse effects of increased flexibility control (such as reductions in efficiency) could be amended in the future.

Which flexibility and why to care?

So far, no commonly accepted definition of flexibility exists. Here, we focus on three different aspects.

The first aspect is the fraction of the day the heat pump is switched off during the heating period (defined by the days with average temperature below 15 °C). To penalise operation outside the allowed time windows, these windows are counted as running time. This quantity measures how well the heat pump operation times can be compacted into larger blocks. These large blocks can then be called according to the grid's needs. Further, it penalises running times during unscheduled periods, which cause an unexpected load increase in the network.

The second aspect is the number of time blocks longer than twelve hours that the heat pump is switched off, compared to the total number of blocks with stopped heat pump.

To quantify the capability of following a demand curve, the costs of the electricity at the German EPEX SPOT Day Ahead market is considered as a third key figure. This electricity market is supply and demand driven and fixes the energy prices at 23:00 on the evening of the day before, which yields a natural 24-hour planning horizon.

Computer model for residential heating

The flexibility is assessed with a computer model implemented in Matlab/Simulink [1]: A residential heating system is modelled based on models of the individu-

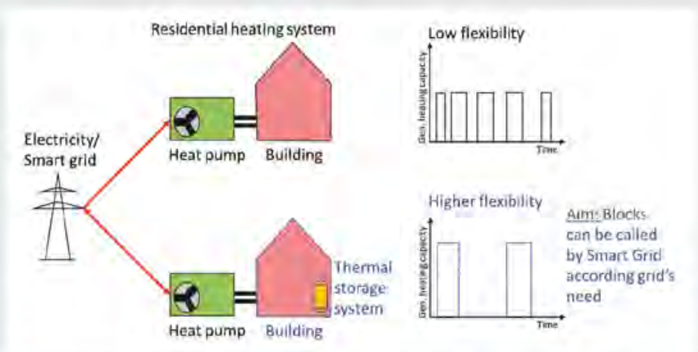


Figure 1. Concept overview for flexibilisation of heat pump operation by integration of thermal storage (additional systems, building or heating system). Suitable control of the heat pump exploiting the intermittent storage of heat enables a heat pump operation following the needs of the electricity/smart grid

al components. As one example of the building stock in Switzerland, a single family house with an annual heating energy demand of 100 kWh/a/m² is considered [2], [3]. The complex building dynamics are simplified with an established three-parameter model [4]. This model formulates an energy balance between the summative losses, solar irradiation, room temperature changes, and summative heat contributions from appliances and persons living in the building. The heating system is radiator based and modelled by a heat transfer model. The heat pump dynamics are modelled by extracting profiles for the heat generation capacity at different inlet and ambient temperatures from a detailed component model [5]. To provide additional heat pump capacity besides a conventionally designed heat pump (8 kW at the design temperature of −10 °C), also 25 %, 50 % and 75 % more powerful systems are considered. The models for piping and additional thermal sensible storages are extracted from the Carnot toolbox [6]. As additional storage elements, we consider sensible water storages with a capacity of 1, 2, 4 and 8 m³ of water, respectively.

The configuration of the residential heating system is selected according to the Swiss standard configuration (STASCH 6 [7]). The climatic information (ambient temperatures and solar irradiation) are taken from Meteosuisse for Zurich in the year 2013. As an example for a demand/supply curve, the prices on the German EPEX SPOT Day Ahead market for the year 2013 were considered.

Each component has been verified by comparison with experimental data.

Heat pump control for high flexibility

To explore the limits of flexibility, different control algorithms are required depending on the target function [8]. In this article, we focus on three different algorithms: For the target "optimum reproduction of supply/demand curve" (expressed here by the electricity costs), the operating hours for the heat pump are selected according to lowest price for each day. More precisely, the heating demand of one day is determined based on the ambient temperature data and the operation hours are selected starting from the hour with the cheapest electricity until the total energy is collected.

To prevent a too severe reduction of the efficiency, a similar control with a target on "high ambient temperatures" is formulated. For this algorithm, the operating hours are selected according to high ambient temperatures (when the heat pump efficiency is higher compared to colder periods).

As a reference, a conventional two-point control is implemented: The heat pump is switched on or off whenever the inlet-temperature leaves a 5 K wide corridor around the target temperature defined by the heating curve. In case the room temperature drops below 19.5 °C (i.e. more than 0.5 °C below the target temperature of 20 °C), the optimum inlet temperature is temporarily raised by the six-fold difference between target and actual room temperature. An excess of the room temperature above 20.5 °C is treated analogously.

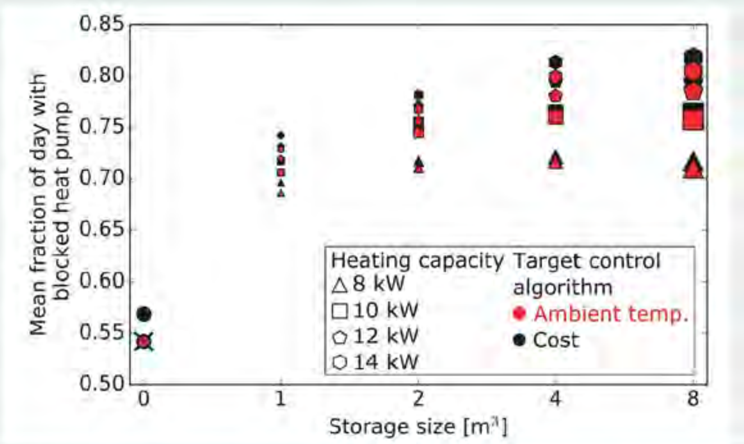


Figure 2. Flexibility dependence on the size of the thermal storage. The flexibility is quantified in the mean fraction of a day with blocked heat pump. The black and red symbols indicate a controller with cost and ambient temperature target, respectively (similar in Figs. 3-6). The cross indicates the results for a conventional two-point control employed here as a reference. The simulations are performed for a model of a single family house with an annual heat energy demand of 100 kWh/a/m². To improve the potential of flexibility besides the conventionally designed 8 kW heat pump also models with scaled power are considered.

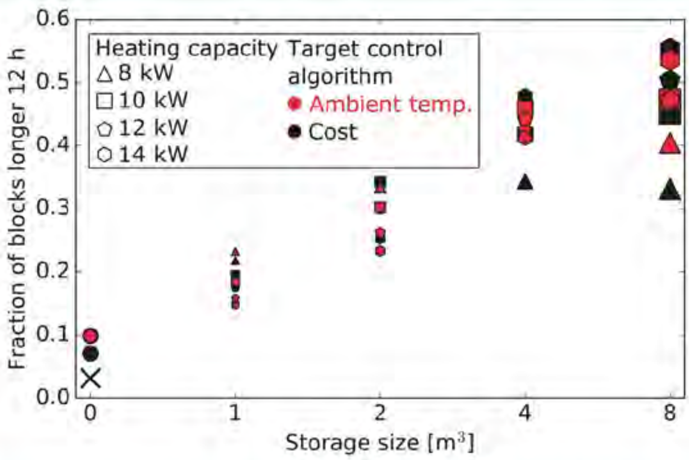


Figure 3. Dependence of the fraction of blocks with heat pump switched off on the size of the thermal storage (expressed in size of a sensible water storage). The cross indicates the results with the reference control (two-point). A heat pump capacity of 8 kW corresponds to the heating demand of the model building (single family house with an annual heating energy demand of 100 kWh/a/m²) at the design temperature of -10 °C.

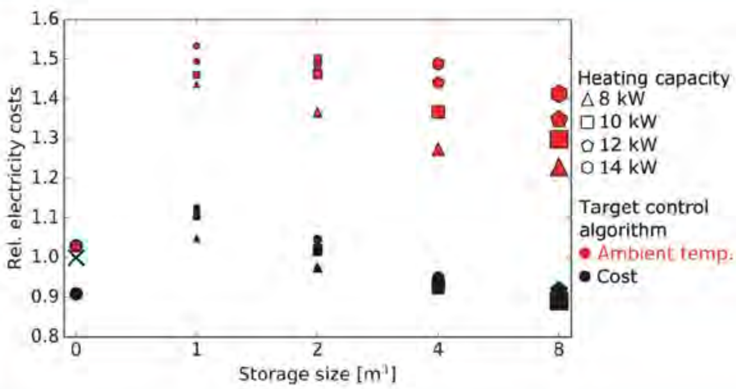


Figure 4. Dependence of electricity costs for the different sizes of the thermal storage. The electricity prices are adopted from the German EPEX SPOT Day ahead market in the year 2013. The high values for the small storage systems can be explained with the substantially higher storage temperatures in some cases.

Limits on flexibility

In Figures 2 – 4, the flexibility of the simulations in the different configurations is displayed. It is important to note here that the simulations are performed with an additional thermal storage system (water tank). However, given suitable capabilities of the building and the heating system, also the thermal inertia of the building can be exploited. The integration of a small storage system already increases the flexibility, measured as a mean fraction of the day the heat pump is blocked, by 25 – 40 %. If a large storage system is installed and the capacity of the heat pump is scaled, the flexibility can be boosted by up to 50 %. The control algorithm only has a minor impact on this result as can be seen from the results without storage system. The number of blocks longer than 12 hours (cf. Figure 3) can even be increased by a factor up to 16. For this indicator, the control algorithm bears a larger share and gives rise by a factor of 3 to 4 in the number of 12 hour-blocks (cf. results with 0 m³ water storage). As a third quantifier for flexibility, the electricity costs are considered (cf. Figure 4). Here, a cost reduction of up to 11 % can be achieved considering the prices

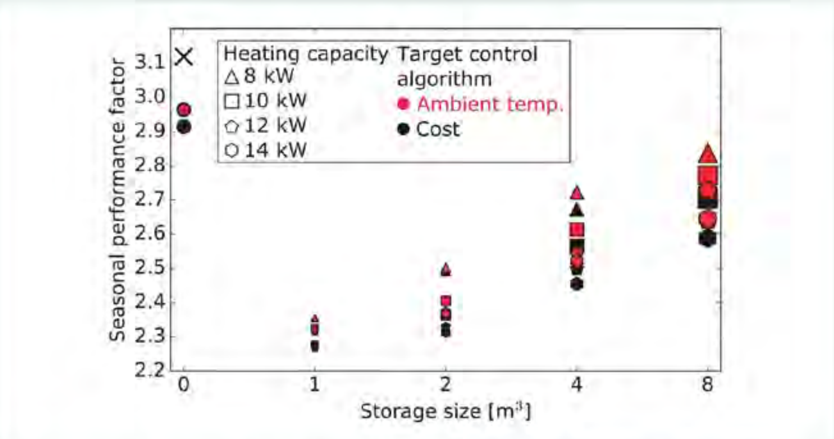


Figure 5. Dependence of seasonal performance factor on the size of the thermal storage. In the simulations, a model for a single family house with an annual heating energy demand of 100 kWh/a/m2 is considered. A heat pump capacity of 8 kW corresponds to a conventional design based on the heat demand of the building at design temperature (-10 °C). The cross indicates the results of the simulation with two-point control.

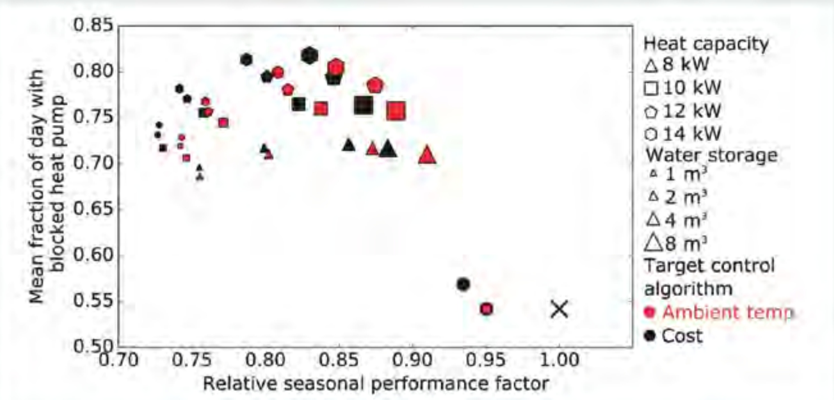


Figure 6. Dependence of seasonal performance factor on average fraction of the day with blocked heat pump for a single family house with 100 kWh/m² annual energy consumption. The reference two-point control solution (x) is compared with the results of predictive control algorithms with different target functions. For comparison, the solutions without additional thermal storage (o) are shown.

at the EPEX SPOT market. However, even without additional storage systems, a cost reduction of 9 % can be achieved given a suitable control algorithm. Therefore, if high flexibility is desired from the smart grid, additional incentives are required to motivate heat pump owners to invest in additional storage systems for flexibility.

Which factors drive flexibility?

Depending on the desired aspect of flexibility, a scaling of the heat pump capacity and the size of the storage system have different impacts. In case focusing the operation times to a narrow time corridor is key, the mean fraction of hours with blocked heat pump is essential (cf. Figure 2). This indicator can be more pronouncedly increased by a scaling of the heat pump power. Only for already scaled heat pump capacities, a scaling of the storage capacity by a factor of 8 has a comparable impact as increasing the heat pump power by 50 %, see Figure 5.

If a significant share of the load shall be transferred to the other half of the day, the number of blocks with stopped heat pump longer than 12 hours is key. For this indicator, the effect of the size of the storage system displays a logarithmic behaviour. The influence of the heat pump scaling is dominated by the size of the storage system for this quantifier.

As an additional storage and heat pump capacity requires further investments, the electricity costs are also vital (cf. Figure 4). In contrast to the previous two indicators, the target for the control algorithm plays a crucial role here. A target on high ambient temperatures (to achieve higher seasonal performance factors) causes additional costs of the order of 40 %. For small storage systems, even the algorithm with cost target does not find a solution with reduced electricity costs. For larger storage systems, solutions with cost reductions exist. However, the size of the storage system apparently has a higher impact on the cost saving potential than the scaling of the heat pump. If the target is purely economic, a change of the control algorithm helps to lower electricity costs by 9 % (given the max. 11 % reduction for the scaled heat pump with additional storage system).

Disadvantages of high flexibility

In Figure 6, the seasonal performance factors for the various configurations are shown.

In particular, small additional storage systems give rise to substantial reductions of the seasonal performance factor. To store a sufficient amount of heat, the temperature of the storage medium has to be lifted substantially above the medium temperatures required by the heating system. This overheating causes a substantial reduction of the efficiency. Combined with the losses of the storage system, this gives rise to a substantial reduction of the seasonal performance factors. Larger storage system can partially compensate these drawbacks.

Which thermal storage?

As pointed out earlier, the storage system does not always have to be an additional storage vessel with water. Alternatives can also be exploiting the thermal inertia of the building or the heating system (e.g. floor-based heating systems) or latent heat storage systems. However, radiator-based systems may be insufficient to activate the building mass.

An advantage of latent heat storage systems is that a significant amount of heat can be stored at a fixed temperature. In consequence, the heating medium has to be overheated less to improve the seasonal performance factor. However, the heating medium temperatures of the building have to be in a narrow range. The building considered in this study does not fulfil these conditions. Other buildings such as modern houses (SFH45) [2], [3] or Minergie P buildings (SFH15) would offer a much wider potential, which is explored elsewhere [1], [9].

Conclusions

Thermal storages (additional systems or the building/heating system inertia) offer a substantial improvement potential of flexibility. 50 % more off-time for heat pumps, 16 times more long blocks, and 11 % less electricity costs are the key findings. However, depending on the flexibility target, different configurations are optimal. Simulations help, in a cost-effective manner, to elucidate the different options and quantify the impact of the individual measures. In particular, with the current electricity markets and pricing schemes, the economic potential of flexibility revenues is small. To foster flexibility, future additional incentives are required.

Dr PHILIPP SCHÜTZ
Lucerne University of Applied Sciences and Arts – School for Engineering and Architecture
Switzerland
philipp.schuetz@hslu.ch

BSc DAMIAN GWERDER
Lucerne University of Applied Sciences and Arts – School for Engineering and Architecture
Switzerland
damian.gwerder.01@hslu.ch

BSc LUKAS GASSER
Alera Energy Ltd
Switzerland
l.gasser@alera-energies.ch

Dr BEAT WELLIG
Lucerne University of Applied Sciences and Arts – School for Engineering and Architecture
Switzerland
beat.wellig@hslu.ch

Prof Dr JÖRG WORLITSCHEK
Lucerne University of Applied Sciences and Arts – School for Engineering and Architecture
Switzerland
joerg.worlitschek@hslu.ch

References

[1] D. Gwerder, P. Schuetz, and J. Worlitschek, "Experimentally verified model for the combination of heat pump and thermal heat storage systems for space heating," Manuscript in preparation
[2] M. Haller, J. Ruschenburg, F. Ochs, J. Bony, and R. Dott, "The Reference Framework of System Simulations of the IEA SHC Task 44/HPP Annex 38 - Part A: General Simulation Boundary Conditions," Tech. Rep. subtask C IEA SHC Task 44, 2013.
[3] R. Dott, J. Ruschenburg, F. Ochs, J. Bony, and M. Haller, "The Reference Framework for System Simulation of the IEA SHC Task 44 / HPP Annex 38 - Part B: Buildings and Space Heat Load," Tech. Rep. subtask C IEA SHC Task 44, 2013.

TOPICAL ARTICLE

[4] H. Burmeister and B. Keller, "Climate surfaces: a quantitative building-specific representation of climates," Energy Build., vol. 28, no. 2, pp. 167–177, 1998.
[5] K. Hilfiker, L. Gasser, and B. Wellig, "WEXA: Exergie-Analyse zur Effizienzsteigerung von Luft/Wasser-Wärmepumpen," Rep. to Swiss Fed. Off. Energy, 2008.
[6] C. Wemhöner, B. Hafner, and K. Schwarzer, "Simulation of Solar Thermal Systems With Carnot Blockset," in Proceedings Eurosun 2000 Conference, ISES, Copenhagen, Denmark, 2000, pp. 1–6.
[7] H. Gabathuler, H. Mayer, and T. Afjei, "Standardschaltungen für Kleinwärmepumpenanlagen," Rep. to Swiss Fed. Off. Energy, 2002.
[8] F. Oldewurtel, A. Parisio, C. N. Jones, D. Gyalistras, M. Gwerder, V. Stauch, B. Lehmann, and M. Morari, "Use of model predictive control and weather forecasts for energy efficient building climate control," Energy Build., vol. 45, pp. 15–27, 2012.
[9] P. Schuetz, D. Gwerder, L. Gasser, L. Fischer, B. Wellig, and J. Worlitschek, "Improved flexibility for heat pumps by the integration of a thermal storage system," in 10th International conference of renewable energy storage, Düsseldorf., 2016.

A5 Task Report 3: Conference Paper for the BFE-Conference “Wärmepumpentagung”

1 *News aus der Wärmepumpenforschung*
21. Wärmepumpentagung vom 17. Juni 2015
BFE-Forschungsprogramm «Wärmepumpen und Kälte»

Damian Gwerder, BSc, Philipp Schuetz, Dr. sc. nat., Lukas Gasser, dipl. Ing. FH, Beat Wellig, Prof. Dr. sc. techn., Jörg Worlitschek, Prof. Dr. sc. techn.
Hochschule Luzern – Technik & Architektur
Technikumstrasse 21
CH-6048 Horw
joerg.worlitschek@hslu.ch
www.hslu.ch/tes

Entwicklung einer optimalen Einheit aus Wärmepumpe und thermischem Energiespeicher

Zusammenfassung

Durch Kombination einer Wärmepumpe mit einem thermischen Speicher lässt sich die Erzeugung der Wärme vom Verbrauch zeitlich entkoppeln. Bei optimaler Dimensionierung von Wärmepumpe und Speicher kann die Wärmeerzeugung flexibel und in Sequenzen erfolgen, die sich optimal an die Erfordernisse zukünftiger Smart Grids anpassen lassen. Entscheidend dabei ist, dass die Effizienz der Wärmepumpe möglichst hoch bleibt. Um den Flexibilitätsgewinn zu untersuchen, präsentieren wir in dieser Arbeit ein neues Modell, welches das Verhalten des gesamten Systems durch die Kombination von experimentell validierten Modellen der Wärmepumpe, Speicher und Haus über lange Zeit simulieren kann. Um den Flexibilitätsgewinn des Systems für den Einsatz im Zusammenspiel mit regenerativen Energiequellen zu quantifizieren, wurden die Preise an den Elektrizitätsbörsen Epexspot herangezogen. In grossen Parameterstudien (über 800 Simulationen) zeigte sich, dass eine Optimierung von Regelung und Speicher beträchtliche Einsparungen an Kosten bei minimalen Effizienzeinbussen ermöglicht. Ein Beispiel zeigt exemplarisch eine Kostenreduktion von 36 % bei einer Effizienzeinbusse von nur 4 % Prozent.

Abstract

Integrating a thermal storage into a heat pump driven heating system decouples the operating hours of the heat pump from the momentary heat demand. For future Smart Grids, it is desirable that the heat pump may only be operated during short sequences during the day also to facilitate an efficient use of energy from regenerative sources. Major goal of this project is to achieve a maximum flexibility gain at highest possible efficiency of the heat pump. To quantify the boost in flexibility, we developed a novel model for the complete heating system including validated models for heat pump, thermal energy storage, and, in particular, the complete building. To cope with climatic influences and the impact of energy from regenerative sources, the prices at the European Electrical Energy stock exchanges (Epexspot SE) have been integrated into the model. In a large scale parameter study (over 800 simulations), we observed a substantial cost reduction at comparable efficiency (COP). In one example, a cost reduction of 36 % was achieved at 96 % of the system's efficiency using a thermal storage combined with Model Predictive Control.

Ausgangslage

Mit zunehmender dezentraler Erzeugung von elektrischer Energie aus neuen regenerativen Energiequellen gewinnt die Koordination von Erzeugung und Verbrauch von Elektrizität stetig an Bedeutung. Insbesondere die Nutzung von Photovoltaik kann kurzzeitig zu hohen, lokalen Energieüberschüssen führen. Zahlreiche Studien zeigen, dass im Rahmen der Energiewende Konzepte, welche flexibel Energieangebote und -nachfrage erfüllen können, eine zentrale Rolle spielen [1,2]. Der Nutzung der thermischen Speichermöglichkeit im Gebäudepark kommt dabei innerhalb der Massnahmen zur Stabilisierung des elektrischen Netzes und der intelligenten Verbrauchssteuerung im Smart Grid grosse Bedeutung zu. Dies vor allem, da die Speicherung thermischer Energie gegenüber der elektrischen Speicherung die ökonomisch günstigere Variante darstellt [3]. Die Kombination aus Wärmepumpe (WP) und thermischem Energiespeicher ist eine der zentralen Speicheralternativen, um einerseits die Effizienz der Wärmeproduktion gegenüber herkömmlichen Heizsystemen (z.B. Gasbrenner) zu erhöhen und andererseits die erforderliche Entkopplung/Flexibilität zwischen Wärmeproduktion und Elektrizitätsverbrauch zu erreichen. Bereits heute sind vereinfachte Modelle mit dieser Zielsetzung im Einsatz.

Zielsetzung

In diesem BFE-Projekt sollen die Vorzüge der Kombinationen aus einer Wärmepumpe und thermischer Energiespeicher für Gebäude (für Heiz- und Brauchwassererwärmung) untersucht werden. Die Systeme werden so konzeptioniert, dass ein Maximum an Flexibilitätsgewinn mit einem Minimum an Effizienzeinbusse erreicht wird.

Das Projekt baut auf der langjährigen Forschungstätigkeit zur Effizienzsteigerung von Wärmepumpen an der Hochschule Luzern auf [4, 5, 6]. Beispielsweise hat das BFE-Forschungsprojekt „Effiziente Luft/Wasser-Wärmepumpen durch kontinuierliche Leistungsregelung“ bestätigt, dass die kontinuierliche Leistungsregelung bei Verwendung geeigneter Komponenten und Anwendung der bestmöglichen Regelstrategie markante Effizienzsteigerungen von Luft/Wasser-Wärmepumpen (L/W-WP) ermöglicht [5]. Ebenfalls sind die Arbeiten der Firma Misurio AG innerhalb des vom BFE geförderten Projekts WarmUp [7] zu erwähnen. Die Studien zeigen, dass bereits heute unter Einsatz von prädiktiver Regelung lukrative Möglichkeiten bestehen, die thermische Speicherfähigkeit des Gebäudeparks zu nutzen.

International gliedern sich diese Aktivitäten in den IEA Annex Task 42 – ‚Heat Pumps in Smart Grids‘ der Internationalen Energieagentur ein [8]. Die hier präsentierten Ergebnisse sind u.a. koordiniert mit dem Fraunhofer ISE in Freiburg, sowie der EDF (Electricité de France), die ähnliche Zielsetzungen verfolgen. Zusätzlich wurde von den Autoren innerhalb der IEA Kooperation der Bericht „IEA Annex 42 Country Report Switzerland“ erstellt, der die aktuelle Lage der Schweiz im Bereich Elektrizitätsmarkt, Gebäude und Wärmepumpe zusammenfasst [9].

In dieser Arbeit werden erste Resultate für die Auslegung der Kombination Wärmepumpe – thermischer Speicher präsentiert. Um das Potenzial dieser Kombination möglichst akkurat beurteilen zu können wird validiertes Modell erstellt und angewendet, welches alle relevanten Aspekte (Gebäude, Wärmepumpe, technische Speicher für Brauchwarmwasser und Heizung, sowie auch Randbedingungen wie Aussentemperatur und Elektrizitätspreise) umfasst (vgl. Bild 1).

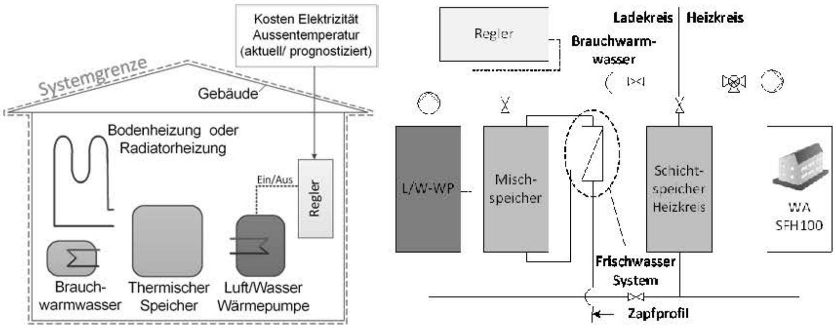


__Bild 1:__ (links) Übersicht über die betrachteten Komponenten im Gesamtmodell. Dieses Modell zeichnet sich durch drei Eigenschaften aus: Der Einfluss des Gebäudes (WA: Wärmeabgabesystem) wird explizit mitmodelliert, das Modell betrachtet dynamische Elektrizitätsmarktpreise und ermöglicht damit eine vorausschauende Regelung (u.a. Model Predictive Control). (rechts) STASCH [14] Darstellung des modellierten Systems zur Veranschaulichung der analysierbaren Systemvarianten.

Ausgangspunkt der Modellbildung sind validierte Modelle der einzelnen Komponenten, die so angepasst werden, dass das Gesamtsystem über lange Zeiträume untersucht werden kann. Als Wärmeerzeuger werden L/W-WP betrachtet, da diese ca. 60% der heute eingesetzten Wärmepumpen in der Schweiz repräsentieren. Für den technischen Speicher werden sensible Wasserspeicher betrachtet mit einer Entladedauer von 12-48 Stunden. Die Kapazität wird so gewählt, dass ein möglichst hoher Flexibilitätsgewinn der WP bei möglichst kleinem Investitionsaufwand und Effizienzverlust des Gesamtsystems erreicht wird. Um realistische Simulationen zu erhalten, fliessen Wetterdaten (Aussentemperatur und Sonneneinstrahlung) für das Jahr 2013 und die Stadt Zürich, sowie reale Elektrizitätspreise ins Modell ein.

Zentral für diese Arbeit ist, wie Flexibilitätsgewinn und Effizienzverlust quantifiziert werden. Die Effizienz wird gemessen über die Arbeitszahl (AZ) im betrachteten Zeitraum. Der Flexibilitätsgewinn wird durch zwei Kennzahlen quantifiziert: Die Länge der möglichen Abschaltperioden pro Tag und die Energiekosteneinsparungen unter Verwendung der Preise des Epexspot Elektrizitätsbörse.

Methodik und Modellierung

Ein Simulationsmodell des gesamten Systems (siehe Bild 1, rechts) wird aufgebaut, um die Effizienz und Flexibilität des Verbunds Wärmepumpe-technischer Speicher zu untersuchen. Ziel des Modells ist die Simulation eines zwei Speicher-Heizsystems in einem Einfamilienhaus, welches monovalent mit einer L/W-Wärmepumpe beheizt wird. Im folgenden Abschnitt wird die Modellierung der einzelnen wichtigen Komponenten und der Randbedingungen beschrieben.

Randbedingungen Meteorologie Daten, Elektrizitätsmarkt, Zapfprofil

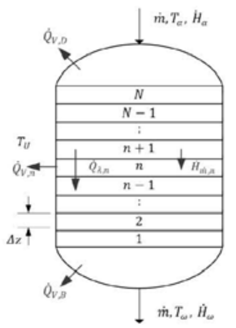
Es werden die meteorologischen Daten des Standorts Zürich verwendet, welche über Meteonorm und über das IDAWEB (Forschungsdienstleistung des Bundesamtes für Meteorologie und Klimatologie MeteoSchweiz) zur Verfügung stehen.

Es wird bewusst ein stark zeitabhängiges Tarifmodel für Elektrizitätspreise gesucht, da in der Studie mögliche Zukunftsszenarien betrachtet werden sollen. Dieser wird in dem Day-Ahead Markt der Elektrizitätsmarktbörse Epexsport abgebildet.

Das Trinkwasser-Zapfprofil wurde mit dem Programm ‚DHWcalc‘ generiert [10]. Das Programm erlaubt eine Diskretisierung des Brauchwarmwasserverbrauches in 6 minütigen Zeitschritten und wurde mittels umfassender experimenteller Daten validiert.

Thermisch technischer Energiespeicher

Um die technischen Energiespeicher in das Gesamtmodel zu implementieren, werden Temperaturdurchmischung und Verluste durch die Speicheroberfläche berücksichtigt. Verluste durch Verwirbelungen des Fluids oder Konvektionsströmungen werden vernachlässigt. Das Modell teilt den Speicher in N Schichten mit gleichem Volumen und jeweils konstanter Temperatur T(n) ein (vgl. Bild 2)



Totaler Wärmestrom:

$$\dot{Q}_{\lambda,n} = \dot{Q}_{\lambda,n,\alpha} - \dot{Q}_{\lambda,n,\omega} = \frac{d^2 \cdot \pi}{4 \cdot \Delta z} \cdot \lambda_F \cdot (T(n-1) + T(n+1) - 2 \cdot T(n))$$

Enthalpieströme durch interne, sowie ein- und austretende Massenströme:

$$\dot{H}_{\dot{m},\alpha} = c_p(n) \cdot \dot{m} \cdot (T_\alpha - T(n))$$

$$\dot{H}_{\dot{m},n} = c_p(n) \cdot \dot{m} \cdot (T(n+1) - T(n))$$

Gesamtwärmeverluststrom durch Speicherwand, Deckel und Boden:

$$\dot{Q}_{V,GES} = \sum_{n=1}^{N} \dot{Q}_{V,n} + \dot{Q}_{V,B} + \dot{Q}_{V,D}$$

***Bild 2**: Modelldarstellung des Speichers mit N Schichten und den bestimmenden Gleichungen. Das Modell berücksichtigt den Wärmeaustausch zwischen den Schichten und mit der Aussenwelt, sowie die Wärmeverluste an der Speicherausgrenze.*

Beim thermischen Energiespeicher für das Heizsystem werden der Energiebedarf und die Temperaturen am Speicheraustritt als Gesamtsystemparameter betrachtet und sind vom Regelalgorithmus abhängig. Für die Integration in das Gesamtsystems wird dabei ein geschichteter Speicher gewählt.

Der thermische Speicher für das Frischwassersystem besitzt für alle Betrachtungen ein Volumen von 900 l und wird als Mischspeicher ohne nennenswerte Schichtung betrieben. Für dessen Simulation wurde ein Speicher mit zwei Knoten nach dem oben angegebenen Modell angenommen.

Die Wärmepumpe (WP)

Die Modellierung der EIN/AUS-L/W-WP basiert auf einem detaillierten WP-Simulationsmodell, welches während den BFE geförderten-Studien „LOREF [6] und „Effiziente Luft/Wasser-Wärmepumpen durch kontinuierliche Leistungsregelung“[5] an der Hochschule Luzern entwickelt wurde. Dieses Modell beschreibt eine detailgetreue L/W-WP und berechnet die Arbeitszahl für einen Zyklus „Heizen +

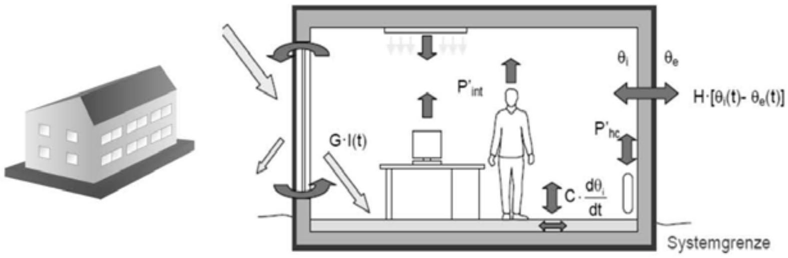
Abtauen" (AZ_{H+A}) mit optimaler Heiz- und Abtaudauer und maximaler Effizienz. Die WP-Modelle wurden im Verlauf der genannten Projekte umfassend experimentell validiert.

Das Gebäude als Speicher (WA)

Die Speicherkapazität und das dynamische Verhalten des Gebäudes fliessen vollständig in das Modell ein, um eine Analogie zum verwendeten technischen Speicher herzustellen. Es werden drei Gebäudetypen aus dem IEA SHC Task 44/HPP Annex 38 [12] betrachtet, um eine Verleichbarkeit mit anderen Studien zu gewährleisten:

- SFH100 (Single Family House, 100 kWh/m²/Jahr)
- SFH45 (Single Family House, 45 kWh/m²/Jahr)
- SFH15 (Single Family House, 15 kWh/m²/Jahr)

Das komplette Gebäude wird mit einem mittleren Gesamtenergiedurchlass G, einem mittlerer Verlustkoeffizient H und einer mittleren Wärmekapazität C modelliert. Aus dieser Vereinfachung ergibt sich folgendes Drei-Parametermodell (vgl. Bild 3).



$$G \cdot I(t) + P'_{\text{int}} + P'_{hc} - H[\Theta_i(t) - \Theta_e(t)] = C \cdot \frac{d\Theta_i}{dt}$$

***Bild 3**: (Links) Ansicht des modellierten Gebäude SFH10 [12]. (Rechts) Schematische Darstellung des vereinfachten Modelles nach [11]. In jedem Moment dient die Differenz der eingebrachten Energien (Sonnenstrahlung $G \cdot I(t)$, inneren Produzenten P'_{int} und Heiz- und Kühlanlagen P'_{hc}) und Wärmeverluste (Wärmeleitung $H[\Theta_i(t) - \Theta_e(t)]$) zur Änderung der Raumtemperatur $\Theta_i(t)$.*

Die Parameter (vgl. Bild 3) dieses schlanken dynamischen Gebäudemodells wurden bestimmt durch Vergleich mit Referenzsimulationen der Gebäudemodelle SFH100, SFH45 und SFH15 aus [12] implementiert in der Gebäudesimulation „Indoor Climate and Energy" (IDA ICE) (siehe Abschnitt Resultate Validierung Gebäudemodell für Details). Das Modell wurde in MATLAB&Simulink implementiert.

Referenzsystem Gesamtsystemmodellierung

Als Referenzsystem wurde die hydraulische Schaltung aus [14] inklusive der Regelung für Wärmepumpenanlage ohne Speicher mit Warmwassererwärmung (STASCH 2) gewählt. Die Wärmepumpe wird dabei über eine Zweipunktregelung der Rücklauftemperatur in Abhängigkeit zur Aussen- und Raumtemperatur geregelt.

Resultate

Flexibilitätsgewinn- und Kostenoptimierungs-Potenzial durch variable Elektrizitätspreise

Durch die Integration technischer Speicher und dank der thermischen Trägheit der Gebäude lässt sich der Betrieb von Wärmepumpen vom unmittelbaren Wärmebedarf des Hauses entkoppeln. Um das Potenzial dieser Strategie zu untersuchen, wurden historische Energiepreise der Elektrizitätsbörse Epexspot aus dem Jahr 2013 analysiert (vgl. Bild 4, links). Ein Vergleich der Preise in Deutschland und der Schweiz zeigt, dass die Preise in Deutschland während des Tages stärker fluktuieren und ausgedehnte Phasen mit tiefen Energiekosten zeigen. Eine Erklärung für diese Plateaus ist ein Energieüberangebot durch die Einspeisung von neuen regenerativen Energien, welche in Deutschland bereits ihre Wirkung zeigen. Vergleicht man für jede Stunde des Jahres die Kosten der Energie mit den Aussentemperaturen gemessen in Zürich (vgl. Bild 5, links), so erkennt man, dass in der Schweiz die Preise bei steigender Aussentemperatur sinken. Dies ist zu erklären durch den geringeren Energiebedarf zu diesen Zeiten und einem geringem Einfluss von neuen regnerativen Energien in der Schweiz. Hingegen in Deutschland sind die Preise fast entkoppelt von der Aussentemperatur (ein Vergleich mit den Temperaturwerten in Süddeutschland bestätigt diesen Trend). Daher werden im Folgenden die Preise für Deutschland betrachtet, um der erwarteten Deregulierung durch regenerative Energien in der Schweiz bereits heute Rechnung zu tragen.

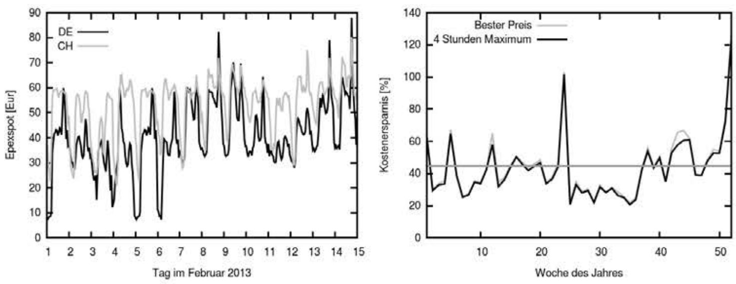


Bild 4: (Links) Day-Ahead Epexspot Preis-Verlauf für Februar 2013. Im Vergleich zum Schweizer Preisverlauf zeigt der deutsche Markt Tiefpreisphasen von mehreren Stunden. (Rechts) Vorhersage für Kosteneinsparung durch Laden eines Speichers zum günstigsten Preis an einem Tag (Bester Preis) und zum teuersten Preis während der 4 günstigsten Stunden. Die horizontale Linie zeigt die durchschnittliche Einsparung von 45 % über ein Jahr an.

Um das Potenzial der Kosteneinsparung (und der damit quantifizierten Flexibilitätssteigerung) grob abzuschätzen, wird zunächst ein sehr einfaches Modell erstellt (vgl. Bild 4, rechts). Der Energiebedarf des Systems wird als proportional zur Differenz von Aussentemperatur und Soll-Raumtemperatur (20 °C) angenommen (falls die Aussentemperatur über die Heizgrenze steigt, besteht kein Heizbedarf). Im Referenzmodell wird angenommen, dass die Wärmepumpe kontinuierlich arbeite. Optimale Strategien nutzen kurze Zeitfenster zum Laden. Im Modell „Bester Preis“ wird nur in der günstigsten Stunde, im Modell „4 Stunden Maximum“ in den günstigsten vier Stunden die Wärmepumpe laufen gelassen. Vernachlässigt man die Einflüsse der Arbeitszahl in dieser ersten vereinfachten Betrachtung, lassen sich die Kosten dieser Modelle durch das Produkt von günstigstem Energiepreis an einem

Tag oder dem 16%-Quantil (entspricht dem Maximum der vier günstigsten Stunden) und Energieverbrauch pro Tag berechnen. Die Resultate dieser Modellrechnung sind in Bild 4, rechts dargestellt. Es zeigt sich, dass durch die Konzentration der Speicherung auf wenige Stunden eine Energiekostenreduktion von maximal 45 % im Jahresmittel erwartet werden kann. Ferner zeigt sich, dass es genügt, die günstigsten 4 Stunden des Tages zu bestimmen ohne signifikante Einbussen an Kosteneinsparungen.

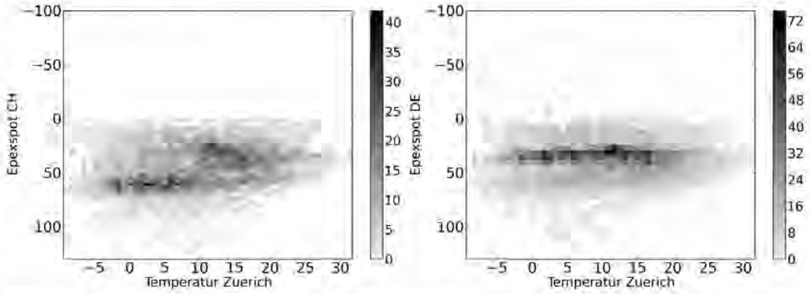


Bild 5: *Vergleich der Epexspot-Preise bei unterschiedlichen Aussentemperaturen in Zürich im Jahr 2013. Die Histogramme wurden getrennt für die Schweizer (links) und die Deutschen (rechts) Preise berechnet. Im Vergleich zu den Schweizer Preisen, zeigen die Preise in Deutschland eine sehr geringe Abhängigkeit von der Aussentemperatur und können negativ werden. Die Schweizer Epexspotpreise zeigen jedoch die zu erwartende Abnahme des Preises bei steigenden Aussentemperaturen.*

Validierung Modellkomponenten: Dynamisches Gebäudemodell

Für die Abbildung des Gebäudes im dynamischen Gesamtmodell (vgl. Bild 1) ist ein schlankes, auf Rechenzeit optimiertes Modell notwendig. Die Ergebnisse des vorgeschlagenen 3-Parametermodells (vgl. Bild 3) weichen im Jahresmittel um weniger als 10 % von den Referenzwerten einer umfassenden Gebäudesimulation mit IDA ICE ab (vgl. Bild 6). Somit eignet sich das vorgeschlagene 3-Parametermodell, um das Gebäudeverhalten im dynamischen Gesamtmodell realistisch abzubilden.

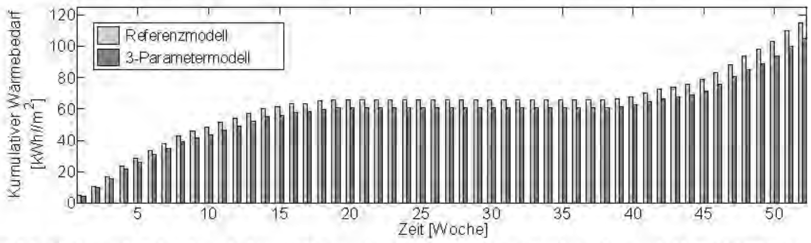


Bild 6: *Vergleich des Jahres-Wärmebedarfs für das Gebäudemodell SFH100 berechnet mit dem vorgeschlagenen 3-Parametermodell (implementiert in Matlab&Simulink) und dem umfassenden Referenzmodell berechnet mit IDA ICE. Dieser Vergleich zeigt, dass das präsentierte Modell den Wärmebedarf geringfügig, aber konsistent überschätzt. Diese Unterschiede sind für die Modellierung des Gesamtsystem auch deshalb unkritisch, weil es aufwändiger ist, einen höheren Wärmebedarf/Verlust zu erbringen/kompensieren.*

Validierung Modellkomponenten: Speichermodell

In Zusammenarbeit mit Regio Energie Solothurn konnte die Schichtungsqualität des Speichermodells (vgl. Bild 2) validiert werden. Untersuchungen für kleinere Speicher mit gutem Schichtungsverhalten bestätigen diese Resultate.

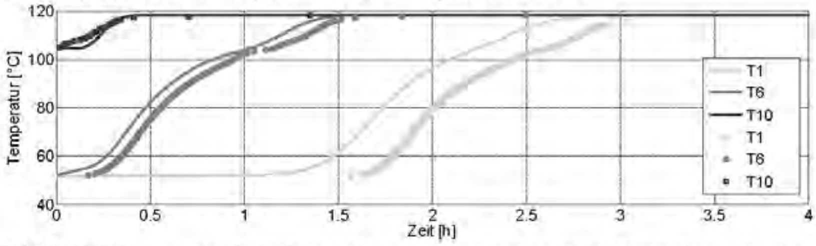


***Bild 7:** Validierung des Schichtspeichermodells mit einem Grossspeicher. An unterschiedlichen Positionen werden die gemessenen Temperaturen (Symbole) mit den numerischen Resultaten (Linien) verglichen. Das Verhalten des Speichers wird korrekt vorhergesagt, einzig wird die Verzögerung bis zum Einsetzen der Temperaturänderungen unterschätzt. Dies ist auf Abweichungen in der Massenstrommessung über mehrere Speicher zurückzuführen.*

Der Vergleich zeigt, dass das Modell sehr gut den realen Schichtspeicher widergibt. Die Messwerte verlaufen parallel zu den Vorhersagen, was bedeutet, dass sich die Schichten in dem Speicher analog des Modells entwickeln.

Validierung Modellkomponenten: Wärmepumpencharakteristik für dynamische Gesamtsimulation

Die L/W-WP wird innerhalb der dynamischen Gesamtsimulation über eine berechnete Antwortfunktion modelliert (vgl. Bild 8). Auf diese Weise gelingt die Einbindung einer detaillierten Wärmepumpenmodellierung bei hoher Performanz des dynamischen Gesamtmodells.

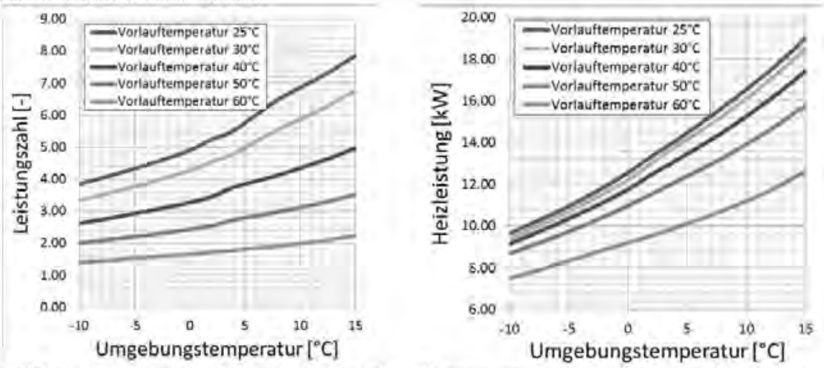


***Bild 8:** Kurvenscharfunktionen für die Wärmepumpenmodellierung. (Links) Aus dem komplexen Modell für die L/W-WP wird in Funktion der Umgebungstemperatur und Vorlauftemperatur die Heizleistung (links) und daraus die Leistungszahl (rechts) bestimmt. Die erforderliche Heizleistung für das Gebäude SFH100 von 7.4 kW im Auslegepunkt bei -10° C wird erreicht.*

Regelung des Gesamtsystems mittels Model Predictive Control

Das Gesamtmodell bietet vielfältigste Konfigurationen, um die Wärmepumpe und den technischen Speicher zu verbinden. Um das Ziel nach Maximierung der Flexibilität bei minimaler Effizienzeinbusse zu erreichen, wird ein Controller entwickelt, der auf der Basis von Model Predictive Control basiert. Dieser Algorithmus sucht mit einer vorgegebenen Zielfunktion in einem festgelegten Zeitfenster die gewünschten Einschalt-Zeitpunkte (in Stunden-Blöcken). Als Zielfunktion für die optimalen Blöcke können verschiedene Kriterien und Inputs betrachtet werden:

- Hohe Umgebungstemperatur beim Wärmepumpen-Betrieb zur Erreichung hoher Arbeitszahlen
- Niedrige Elektrizitätskosten (vgl. Bild 4 und 5) zur Quantifizierung der erreichbaren Flexibilitätssteigerung
- Minimierung der Einspeisung von Erträgen aus lokalen PV- Anlagen für lokales Supply Demand Management (Erhöhung Autarkiegrat)
- Sperrzeiten vorgegeben durch die Elektrizitätsanbieter

Dabei wird berücksichtigt, dass der technische Speicher, wenn möglich immer über eine Stufenladung (konstante Temperaturdifferenz zwischen Rück- und Vorlauftemperatur der Wärmepumpe) geladen wird, da eine Schichtladung (Vorlauftemperatur der WP ist die gewünschte Endtemperatur des Speichers) die AZ der Wärmepumpe signifikant verschlechtert.

Analyse Beispiel 1: Zusammenspiel Flexibilitätsgewinn und Effizienz

Bild 10 zeigt für die Schweizer Epexspotmarktpreise die Änderung der Arbeitszahl der Wärmepumpe (Effizienzänderung) bei den erreichten Elektrizitätskosten. Das Bild betrachtet einen typischen 2 Wochen Zeitraum in der Übergangszeit (mit starken Temperaturschwankungen) bei Einsatz eines 2000 l Wasserspeichers für Heizzwecke. Die Ergebnisse zeigen analog Bild 4 und 5, dass in der Schweiz eine direkte Kopplung der Epexspotpreise mit der Aussentemperatur vorliegt und somit die Einflüsse neuer regenerativer Energiequellen nicht abgedeckt werden können.

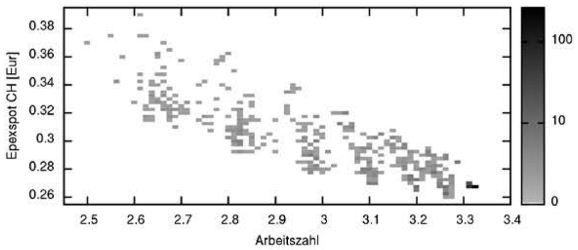


***Bild 10:** Einfluss von unterschiedlichen Ladestrategien auf die Arbeitszahlen und den erreichten Elektrizitätspreis (CH-Epexspot-Preis) berechnet für 2 Wochen. In 864 Stimulationen wurde der Einfluss von unterschiedlichen Schalttemperaturen untersucht. Dabei setzen sich diejenigen Ladestrategien durch, welche vor allem während den Warmphasen die WP betreiben. In diesen Zeiten sind die Aussentemperaturen und Arbeitszahlen hoch und damit der Energiebedarf niedrig. Da der Schweizer Energiemarkt nur geringe Tagesschwankungen zeigt, setzt sich somit die Strategie mit niedrigen Energiebedarf (und damit hoher Arbeitszahl und tiefen Kosten) durch.*

Analyse Beispiel 2: Konkrete Auslegung einer Wärmepumpen Speicher Kombination für ein Gebäude vom Typ SFH100

Im folgenden Beispiel wird eine optimierte Kombination für ein Gebäude des Typs SFH100 präsentiert. Diese Lösung besteht aus einem sensiblen Heizspeicher von 2000l für die Gebäudeheizung, sowie einem 900l Speicher für das Frischwassersystem. Die Model Predictive Control Regelung betrachtet ein realistisches Zeitfenster von 24 Stunden für den Regelungshorizont. Im Folgenden werden die Resultate für 2 Wochen vom 21.3.2013 bis 4.4.2013 repräsentativ diskutiert. Es ergeben sich 8 bis 10 pro Tag mögliche Einschalt-Stundenblöcke. Dies ermöglicht eine aktiv wählbare Sperrzeit für die Wärmepumpe von 14-16 Stunden.

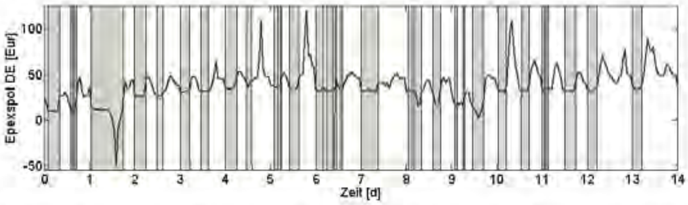


Bild 11: *Prädiktive Auswahl der optimalen Ladeblöcke auf Basis der Flexibilitätsoptimierung mittels Epexspotpreisen. Die Ladeblöcke werden auf Zeiten mit tiefen Epexspotpreisen gelegt, um den Wärmebedarf des Tages in diesen Fenstern decken zu können. Durch die Integration eines Wärmespeichers genügt die in dieser Zeit geförderte Wärme, um die Raumtemperatur im Haus konstant zu halten. Für Netzbetreiber und Endverbraucher bietet dies einen grossen Flexibilitätsgewinn, da die Zeiten mit tiefen Energiekosten genutzt werden können.*

Die hydraulische Grundschaltung basiert auf STASCH 6 (Auslegehilfe vom Bundesamt für Energie für Wärmepumpenanlage mit Parallelspeicher mit Wassererwärmung) [14]. Diese wurde mit Ventilen erweitert, welche ein aktives Ansteuern des Speichers ermöglicht. Anhand dieser Schaltung können folgende Zustände gefahren werden:

- Laden des Speichers mit gleichzeitiger Wärmeabgabe an den Heizkreis
- Laden des Speichers ohne Wärmeabgabe an den Heizkreis
- Entladen des Speichers über den Heizkreis (gleichzeitiger WP-betrieb zum Laden des Speichers für das Frischwassersystem möglich)
- Zweipunktebetrieb ohne Speicher. Vergleichbar mit STASCH 2 [14].

System / Modus	**Sperrzeit [h/d]**	**AZ [-]**	**Endpreis Epexspot [Eur]**	**Anzahl WP Taktungen [Taktungen/2 Wochen]**
Referenzsystem / A	0	3.3	24.50	268
Referenzsystem / B	2x3	3.23	25.16	211
System mit Speicher und MPC	14-16	3.10	16.20	53

Tabelle 1: *Direkter Vergleich der Leistungsparameter der Systeme mit und ohne thermischen Speicher für die Heizanwendung (Schichtspeicher Heizkreis). Es zeigt sich dass der Speicher im Zusammenspiel mit Model Predictive Control (MPC) eine Kostenreduktion von 36 % und eine Reduktion der Taktung um 75 % bei einer Effizienzeinbusse von nur 4 % ermöglicht. Die Sperrzeit im Referenzmodell B wurde so gewählt, dass die Gebäudeträgheit voll genutzt wird.*

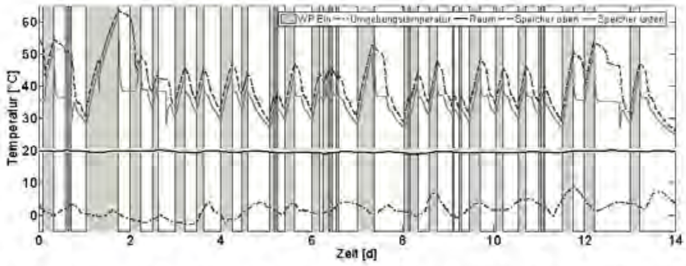


Bild 12: *Einfluss der Model Predictive Control Regelstrategie auf die Speichertemperaturen und im Raum. Zum Vergleich ist auch die Aussentemperatur dargestellt, die verwendet wird, um den Bedarf an gespeicherter Energie abzuschätzen.*

Um dem aktuellen Elektrizitätsmarkts Rechnung zu tragen, werden zwei unterschiedliche Modi für das Referenzmodell (vgl. Abschnitt „Referenzsystem Gesamtsystemmodellierung“) betrachtet: Modus A ohne Sperrzeiten und Modus B mit 2 x 3 Stunden Sperrzeit. Die Reduktion der AZ von Modus A zu B ergibt sich durch die höhere Vorlauftemperatur aufgrund der Raumeinflusssteuerung, welche die fehlende thermische Energie während der Sperrzeit kompensiert. Die Sperrzeit im Modus B wurde so gewählt, dass die Gebäudeträgheit voll ausgeschöpft wird respektive die Raumtemperaturen im Komfortband bleiben.

Ein Vergleich der Systeme in Tabelle 1 zeigt, dass das System mit integriertem Speicher eine Kostenreduktion von 36 % ermöglicht, wobei die Effizienz nur um 4 % reduziert wird. Die ideale Auswahl des Speichers im Zusammenspiel mit der Model Predictive Control führt darüber hinaus zu einer Reduktion von 75 % der Wärmepumpentaktung.

Schlussfolgerung

Die Integration eines technischen Speichers in ein Heizsystem ermöglicht die zeitliche Entkoppelung von Wärmegewinnung und -verbrauch. Durch die damit gewonnene Flexibilität können Fenster von tiefen Energiekosten (Überangebot durch die Einspeisung von erneuerbaren Energien) optimal zur Erfüllung des Energiebedarfs genutzt werden. Um das Potenzial für Energiekosteneinsparung nicht durch reduzierte Effizienz zu mindern, sind neue Algorithmen für die Wärmepumpensteuerung erforderlich und die Speichergrössen, sowie hydraulische Verschaltung müssen optimal angepasst werden. In dieser Arbeit wurden unterschiedliche Szenarien von Regelalgorithmen und Systemgrössen in umfangreichen Parameterstudien mit über 850 Simulationen auf die Effizienz der Wärmepumpe, sowie auf die Energiekosten untersucht. Durch den Einsatz eines Speichers konnte in einem Beispiel eine Kosteneinsparung (und damit dargestellter Flexibilitätsgewinn) von 36 % und eine Reduktion der Wärmepumpentaktungen auf einen Viertel bei geringer Effizienzeinbusse erzielt werden. Ferner stellt diese Studie ein theoretisches Kosteneinsparpotenzial von 45 % im Jahresmittel durch die Speicher-Integration in Aussicht. Zukünftige Untersuchungen innerhalb des Projekts zielen auf weitere Variationen der thermisch Speicher (inkl. Latentwärmespeicher) sowie auf die Untersuchung der aktiven Nutzung der Gebäudeträgheit und der Verwendung von leistungsgeregelten Wärmepumpen für einen Flexibilitätsgewinn ab.

Danksagung

Die Autoren danken dem Bundesamt für Energie (BFE) herzlich für die Unterstützung des Projekts, der Kommission für Technologie und Innovation (KTI) für die Unterstützung im Rahmen des SCCER Storage of Electricity and Heat und der Misurio AG und der KWT Kälte-Wärmetechnik AG für die wertvollen Diskussionen im Rahmen der Begleitgruppe. Die Autoren danken der Carnot-Usergroup [13[.

Quellen

[1] J. Nitsch, T. Pregger, et al., Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global; BMU - FKZ 03MAP146, 2011.

[2] Ch. Hewicker, J. Raadschelders, et al., Energiespeicher in der Schweiz - Bedarf, Wirtschaftlichkeit und Rahmenbedingungen im Kontext der Energiestrategie 2050, Bundesamt für Energie, 2013.

[3] I. Stadler, Storage solutions for smart cities: interlinking electricity, heat and gas infrastructure, IRES, 2015.

[4] L. Gasser, B. Wellig, K. Hilfiker: WEXA – Exergie-Analyse zur Effizienzsteigerung von Luft/Wasser-Wärmepumpen, Bundesamt für Energie, 2008.

[5] L. Gasser, I. Wyssen, et al.: Effiziente Luft/Wasser-Wärmepumpen durch kontinuierliche Leistungsregelung, Bundesamt für Energie, 2011.

[6] R. Sahinagic, L. Gasser, et al.: Optimierung des Lamellenluftkühlers/Verdampfers von Luft/Wasser-Wärmepumpen, Bundesamt für Energie, 2008.

[7] S. Pfaffen, K. Werlen, WARMup - Optimale Verwertung der Flexibilität von thermischen Speichern, Bundesamt für Energie, 2012.

[8] P. Wagner et al.: International Energy Agency Annex 42.

[9] F. Eckl, D. Gwerder, et al.: IEA HPP Annex 42: Heat Pumps in Smart Grids, Market Overview Switzerland, 2014

[10] U. Jordan, K. Vajen, Proc. ISES Solar Word Congress, Orlando, 2005.

[11] H. Manz: Bauphysik II – Aussenklima thermischer Komfort Wärme Luftaustausch Energie, 5. Auflage, Horw, 2014

[12] R. Dott, M. Haller, et al.: The Reference Framework for System Simulations of the IEA SHC TASK 44/ HPP Annex 38; Part B: Buildings and Space Heat Load, International Energy Agency, 2013.

[13] CARNOT Toolbox für Matlab/Simulink Ver 6.0, Februar 2015.

[14] H. R. Gabathuler, H. Mayer, et al.: Standardschaltungen für Kleinwärmepumpenanlagen, Teil 1: STASCH-Planungshilfen, Bundesamt für Energie, 2002.

A6 Task Report 4: Application and monitoring Switzerland

IEA HPP Annex 42: Heat Pumps in Smart Grids

Task 4: Application and monitoring

Switzerland

October 2016

Report compiled by:

Lucerne University of Applied Sciences and Arts

Lucerne University of Applied Sciences and Arts
HOCHSCHULE LUZERN

Table of contents

List of figures

List of tables

List of abbreviations and acronyms

TES	Thermal energy storage
BFE	Bundesamt für Energie
Lucerne UASA	Lucerne University of Applied Sciences and Arts
SFOE	Swiss Federal Office of Energy
IEA	International Energy Agency
HPC	Heat Pump Centre
ESTI	Federal Inspectorate for Heavy Current Installations
VSGS	Verein Smart Grid Schweiz
AS	Ancillary service (Systemdienstleistungen)
DSO	Distribution system operators
TSO	Transmission system operator
SES	Swisscom Energy Solutions
VSE	Verein Schweizerischer Elektrizitätsunternehmen
COP	Coefficient of Performance
PV	Photovoltaic
GDP	Gross domestic product
NPO	Non-Profit-Orgaization
DR	Demand Response
DSM	Demand Side Management
ElCom	Electricity Commission
EU	European Union
EPEX SPOT SE	European Power Exchange SE
FWS	Fachvereinigung Wärmepumpen Schweiz
EE-sector	Renewable energies sector
KEV	Feed-in remuneration at cost (Kostendeckende Einspeisevergütung)

1.1 Current projects

The aim of this chapter is to gain knowledge about current projects concerning heat pumps in smart grids in Switzerland.

The criteria for projects differ for different projects types.

Software These projects should include software that could help to integrate heat pumps in a virtual network or help to evaluate the optimal strategies to operate an electricity grid or a heat pump in combination with thermal storages.

Others Other projects should include ways to optimize the operation of heat pumps. This could be by integrating heat pumps in a large network, considering local grid conditions, combining heat pumps with other technologies, and other approaches.

1.1.1 Results

This chapter includes short descriptions of all identified projects in Switzerland. This is part of task 4 of the IEA Annex 42. All countries are supposed to fill in a standardised template concerning the projects. This template was used in this bachelor thesis as well. The template with short descriptions of all sections in the following tables can be found in the appendix (A3).

It may not be possible to fill in all sections for each and every project, since some projects do not contain a field test, where the technologies were tested. The unavailability of data might also be a reason for incomplete sections.

1.1.1.1 Project WARMup

Table 1. WARMup
Source: Information from (BFE (b), 2013).

Overall project info	
Wider context	Initiated by the SFOE, Switzerland
Participants – Identification & motivation	Executed by Misurio AG, Switzerland Partners: Elektrizitätswerk der Stadt Zürich ewz; EnAlpin; IBM; Elimes; Fachhochschule Westschweiz; ETH Zürich
Funding	Co-financed by: SFOE; Foundation "The Ark"
Timing	Phase 1: February 2012 – October 2013 Phase 2: Follow-up project WARMup[2]
Project overall driver	Basic research in the optimized utilization of flexibility in thermal storages
Project aim	Proof that the flexibility of thermal storages in buildings has a profitable value.
Scope	
Project scale	WARMup consists of a virtual network with the specific circumstances of Switzerland (e.g. temperatures, sunshine, electricity production). In the simulator, 5000 heat pumps (brine/water) in reference buildings are observed.
Geographical coverage	The simulation takes place in Visp, Switzerland.
Range of building types	A real multi-family house in Zurich builds the basis of the simulation. The building provides 22 accommodations and was built in 2008.
What technologies?	WARMup concentrates on the pooling of heat pumps with attached thermal storages. Examples for thermal storages are boilers or the building itself.

	The simulation software was developed by Misurio AG (SimEnergy).
End-user engagement	It was assumed that the end-user cannot intervene in the control of the heat pump.
What is it specifically testing in relation to heat pumps?	
Extent and method of control/influence of HP	-
Time resolution of control	-
HP requirements	Heat pumps need an interface for the receipt of control commands.
Storage	Thermal storages (boilers and the building itself) were used in the simulation.
Methods being used/tested	The usage of thermal storages in order to leverage flexibility was applied. Furthermore, the possibility to increase the temperature (higher than necessary) was also applied. In contrast to the common thinking, efficiency was not reduced but slightly improved due to the temperature increase (BFE (b), 2013, S.35).
Details of testing procedures	
Time resolution of monitoring	Quarter hourly
Monitoring equipment	-
Results	
Flexibility	Flexibility in thermal storages is tested.
Customer response	No statement possible.
Challenges	The market of the future needs dynamic tariffs. The current high/low-tariff is not adequate anymore. To be able to provide a dynamic tariff structure, it is necessary to measure electricity consumption quarter hourly. Therefore, smart meters are an important technology in the future.
Conclusions	Thermal storages provide an attractive potential in the load management. Flexibility has a profitable value. During the course of the simulation, costs could be reduced and revenues could be achieved due to the optimized operation of the heating systems. Nowadays, flexibility has a low value. The increasing amount of decentralized electricity production requires that this electricity should also be stored decentral instead of being transported far distances.
Next steps & gap analysis	
Next steps	WARMup^2 is a pilot project which includes the execution of WARMup in a real market. At the beginning, a scope of approximately 10 heat pumps is planned. The target of WARMup^2 is gaining experience in the connection of heat pumps and thermal storages. Furthermore, the value of flexibility in thermal storages needs to be evaluated.
Exploring scope for further work	WARMup^2 is an upcoming field test of WARMup.
Gaps	-

1.1.1.2 Project Tiko

Table 2. Tiko.
Source: Information from (Geidl, 2015) and (Vogel, 2015).

Overall project info	
Wider context	Tiko power is carried out by Swisscom Energy Solutions AG (SES).
Participants – Identification & motivation	SES is a joint venture of Swisscom and Repower AG. Swisscom is the biggest communication supplier in Switzerland and Repower is a large energy supplier.
Funding	SES
Timing	Formation: 2012 First supply of control energy: December 2014 – April 2015
Project overall driver	Provision of control energy to the Swiss control energy market and diversification of the existing business model.
Project aim	For customers: Costs and energy consumption are reduced. Monitoring of the current energy consumption via smart phone application. For distribution networks: Substitution/expansion of ripple control system, peak shaving, active network management. For SES: Provision of control energy generates value (Geidl, 2015).
Scope	
Project scale	Tiko connects approximately 5500 households in Switzerland in one of the biggest smart grids in Europe. Tiko connects heating systems (including heat pumps) and boilers of those households.
Geographical coverage	Nationwide in Switzerland.
Range of building types	All types of residential buildings. Several industries are also connected to the Tiko network (Geidl, 2015).
What technologies?	Tiko utilizes a particular communication network of Swisscom. Two different modules are installed at each household: One M-Box is installed to communicate with the SES network. Additionally, one K-Box is installed for each electric device (e.g. heat pump, boiler, electric heating system). If Swissgrid requires control energy, the SES headquarter sends a signal to the M-Boxes in the households. These M-Boxes are connected to the K-Boxes. Therefore, the electric devices can be remote controlled (Geidl, 2015).
End-user engagement	End-users receive a smart phone application that they can monitor their energy consumption with. Additionally, they can reduce the heating power if necessary (e.g. during holidays).
What is it specifically testing in relation to heat pumps?	
Extent and method of control/influence of HP	On/Off-control of heat pumps.
Time resolution of control	1 second (Geidl, 2015)
HP requirements	Heat pumps need an interface for the receipt of control commands. The algorithm of tiko analyses the following data prior to control a heat pump: local weather conditions, high or low tariffs, current conditions of the heat pump, required control energy by swissgrid, living comfort, and behaviour of participants (Geidl, 2015).
Storage	Thermal inertia of the building and water boilers.
Methods being used/tested	Tiko connects heating systems (including heat pumps) and boilers of

	those households. These systems are relatively flexible because the heating process can start within a time frame of a couple minutes without affecting living comfort. Therefore, loads can be shifted in order to reduce the loads on the grid during peaks (Vogel, 2015).
Details of testing procedures	
Time resolution of monitoring	-
Monitoring equipment	-
Results	
Flexibility	Tiko uses the flexibility of heating systems to reduce the loads in the grid.
Customer response	The feedback from customers is very positive. The operation of the mobile application is very simple and allows monitoring the energy consumption. During peak times, an inert heating system can easily be shut down without affecting living comfort.
Challenges	-
Conclusions	-
Next steps & gap analysis	
Next steps	Tiko is expanding the size of its network constantly and is expecting a final size of approximately 70'000 households that could supply 70MW of control power.
Exploring scope for further work	Further integration of other loads (e.g. batteries, electric cars) into the tiko network is currently in development. Due to these additional loads, the seasonality of the tiko network could be reduced.
Gaps	-

1.1.1.3 Project Gridbox

Table 3. Gridbox.
Source: Information from (Gridbox, online).

Overall project info	
Wider context	GridBox is a technology of the BKW Energie AG, one of the biggest utility companies in Switzerland.
Participants – Identification & motivation	BKW Energie AG Group Supercomputing Systems AG BACHER ENERGIE AG Ewz
Funding	Co-funded by SFOE
Timing	September 2013 - Project start July 2014 – Pre-rollout, proof-of-concept of platform March 2015 - Development finished, algorithms simulated, begin of full system operation March 2016 – Technology verification finished Pilot grids are operating until mid-2016.
Project overall driver	Providing transparency of what happens in low- and middle voltage levels.
Project aim	Development and testing of a smart management system for a future smart grid. Reduce necessary expansion of the grid. Reduce increases in voltage and optimize regional self-sufficiency.

Scope	
Project scale	Gridbox is currently being tested in two different pilot grids, the BKW pilot grid and the ewz pilot grid. The pilot grids consist of approximately 150 measurement devices (GridBoxes) to monitor the conditions in the grid.
Geographical coverage	The ewz pilot grid is located in Affoltern, Zurich. The BKW pilot grid is located in a rural area of the canton of Bern.
Range of building types	All types of buildings.
What technologies?	GridBox is a technology with a distributed network of real-time measurement devices synchronized by GPS. All these devices measure parameters such as voltage and current phasors with a high accuracy in real time and transmit the data to the GridBox master. The GridBox master collects and processes all measured data and is able to implement further smart applications.
End-user engagement	The end-user cannot intervene in the control of the heat pump.
What is it specifically testing in relation to heat pumps?	
Extent and method of control/influence of HP	On/Off control of heat pumps.
Time resolution of control	The system monitors the grid with control intervals of 1 second.
HP requirements	Heat pumps need an interface for the receipt of control commands.
Storage	GridBox controls storage systems and optimizes self-sufficiency.
Methods being used/tested	GridBox can control a lot of different devices. It can control production systems such as photovoltaic systems, controllable loads such as heat pumps, or storage devices such as batteries. The concept of GridBox enables an active network management by distribution system operators.
Details of testing procedures	
Time resolution of monitoring	The system monitors the grid with control intervals of 1 second.
Monitoring equipment	Measurement sensors are installed at nodes within the distribution grid to provide measurement data to the gridbox master.
Results	
Flexibility	GridBox enables the user (DSO) to find a balance between smart grid technologes and the conventional grid development measures (expansion of the grid) in the short-, middle- ,and long-term.
Customer response	-
Challenges	-
Conclusions	-
Next steps & gap analysis	
Next steps	-
Exploring scope for further work	-
Gaps	-

1.1.1.4 Project BKW Home Energy

Table 4. BKW Home Energy.
Source: Information from (BKW (d), online).

Overall project info	
Wider context	BKW Home Energy is a technology of the BKW Group, one of the biggest utility companies in Switzerland.
Participants – Identification & motivation	BKW Group
Funding	BKW Group
Timing	Currently available.
Project overall driver	BKW Home Energy is a system to optimize the energy utilization in a household. BKW Home Energy especially optimizes the utilization of decentralized produced electricity by a photovoltaic-system.
Project aim	Increase of self-sufficiency.
Scope	
Project scale	-
Geographical coverage	Within the distribution network of BKW.
Range of building types	All types of buildings can utilize BKW Home Energy.
What technologies?	The core of BKW Home Energy is an intelligent control system, which is based on the Solar-Log™-technology. This software visualizes and distributes the produced electricity (by photovoltaic), in order to maximize self-sufficiency. The Solar-Log™-technology was developed by "Solare Daten Systeme (SDS)", a subsidy from BKW.
End-user engagement	The end-user is able to monitor and control the flow of electricity via a computer or smartphone-application.
What is it specifically testing in relation to heat pumps?	
Extent and method of control/influence of HP	Systems are controlled according to the current circumstances. The system operates heating systems when electricity is available and stores the maximal amount of electricity (produced by photovoltaic systems) in storage batteries.
Time resolution of control	-
HP requirements	Heat pumps and other systems are controlled on site by the BKW Home Energy system. Therefore, heat pumps need an interface for the receipt of control commands.
Storage	The system uses batteries to store excess energy produced by photovoltaic systems. Additionally, heat pumps are operated during high decentral electricity production and the heat is stored in thermal storages.
Methods being used/tested	Heat pumps and storage batteries operate together in order to increase self-sufficiency. The control system can activate and deactivate respective systems according to the current conditions.
Details of testing procedures	
Time resolution of monitoring	-
Monitoring equipment	Measurement devices for produced electricity.
Results	
Flexibility	The BKW Home Energy system optimizes the energy flow in a household and utilizes most of decentral electricity production on

	site. Therefore, less electricity is fed in the grid and peak loads can be reduced.
Customer response	-
Challenges	-
Conclusions	-
Next steps & gap analysis	
Next steps	-
Exploring scope for further work	-
Gaps	-

1.1.1.5 Project GridSense

Table 5. GridSense.

Source: Information from (Gridsense (a), online) and (Gridsense (b), 2016).

Overall project info	
Wider context	GridSense is carried out by the Alpiq InTec AG, a subsidiary of Alpiq Holding AG.
Participants – Identification & motivation	Alpiq Holding AG Partners: Mennekes GmbH & Co; Fronius GmbH; Fenecon GmbH & Co; AEK Energie AG; EBM; Fachhochschule Südschweiz; Adaptricity GmbH; Helion Solar AG; Canton of Solothurn; SFOE; ZVEI; VDE
Funding	Alpiq Holding AG
Timing	Field test: 18 months, from May 2015 until November 2016
Project overall driver	Demonstration of the functionalities of GridSense.
Project aim	Connection of households into a smart grid with the aim of reducing costs and gaining experience with GridSense.
Scope	
Project scale	4 single-family houses, each with a heat pump, a photovoltaic system, and a boiler. All of these households are connected to the same transformer.
Geographical coverage	Biel-Benken, Switzerland
Range of building types	New single-family houses.
What technologies?	Heat pumps, boilers, and photovoltaic systems are tested and controlled. Additionally, two of the four households have a charging station for electric vehicles. Furthermore, all of the houses were supplied with a storage battery (GridSense (b), 2016).
End-user engagement	Customers can always control electric loads according to current needs.
What is it specifically testing in relation to heat pumps?	
Extent and method of control/influence of HP	The core of GridSense is a self-learning algorithm. This algorithm controls all devices with high energy consumption (e.g. heat pumps, boilers, batteries, charging stations for electric vehicles). It also controls decentralized electricity production systems such as photovoltaic systems. Devices connected to GridSense can take optimum action without external orders. The aim of GridSense is reducing electricity consumption and grid loads. By efficiently operating the grid, peak loads can be avoided and, therefore, a maximized amount of renewable energy can be fed into the grid

	and investments to expand the grid can be reduced. Additionally, weather forecast information and electricity tariff information can help to improve the operation of the energy systems. Due to artificial intelligence, the algorithm can learn how the user usually behaves. The algorithm improves itself continuously (GridSense (a), online).
Time resolution of control	5 minute update intervals of the algorithm output.
HP requirements	Heat pumps need an interface for the receipt of control commands. GridSense is a decentralized system which reduces peak loads directly in the building. The intelligence is within the GridSense technology. The algorithm continually measures parameters such as grid load, tariffs, power consumption, and power generation.
Storage	A storage battery and thermal buffer storages are used in the field test.
Methods being used/tested	Optimized control of the heat pump can lead to a higher flexibility in the energy system of a single building.
Details of testing procedures	
Time resolution of monitoring	The system monitors the grid in 1 second intervals.
Monitoring equipment	-
Results	
Flexibility	GridSense uses flexible systems such as heat pumps and boilers to reduce peak loads. Furthermore, GridSense increases self-sufficiency of households with photovoltaic systems.
Customer response	-
Challenges	-
Conclusions	After 8 months, on January 20th, the persons in charge assessed the technology and approved its profitability. An expensive expansion of the grid could be avoided owing to GridSense. The main characteristics which were assessed are the operation of onsite consumption and the ability to relieve the grid by reducing peak loads.
Next steps & gap analysis	
Next steps	SoloGrid uses GridSense in a larger scale to test different scenarios. (see chapter 1.1.1.6)
Exploring scope for further work	(see chapter 1.1.1.6)
Gaps	-

1.1.1.6 Project SoloGrid

SoloGrid is a follow-up project of GridSense in chapter 1.1.1.5. The start of the project was in January 2016, therefore, only few information can be published concerning the project.

Table 6. SoloGrid.
Source: Information from (SoloGrid, 2016).

Overall project info	
Wider context	Follow-up project of the initial field test of GridSense.
Participants – Identification & motivation	Alpiq InTec Partners: AEK Energie AG; Adaptricity GmbH; Landis+Gyr; Canton of Solothurn; SFOE
Funding	Alpiq Holding AG; SFOE; Canton of Solothurn
Timing	From January 2016 until June 2017
Project overall driver	Demonstration of the functionalities of GridSense in combination with other technologies.
Project aim	Connection of a neighborhood into a smart grid to analyze the usage of smart technologies in a distribution network. Another important target of the project is the comparison of GridSense and other market solutions (e.g. conventional network expansion, in-line voltage regulators, and distribution transformers with on-load tap changers, reactive power control and dynamic ripple control).
Scope	
Project scale	40 single-family houses with heat pumps.
Geographical coverage	Riedholz, Switzerland
Range of building types	Modern buildings
What technologies?	The first step of the project will be a simulation of the pilot network with the dynamic action of GridSense. The software to execute this type of simulation was developed by Adaptricity, a spin-off company of ETH. It is necessary to simulate different scenarios because it is barely possible to express all scenarios in reality. The actual measurements of the 40 households are added to the simulation to form a realistic conclusion. In order to incorporate measures from the households, a smart meter from Landis+Gyr will be integrated in the GridSense system through an IEC62056-21 interface.
End-user engagement	Customers can always control electric loads according to current needs.

1.1.1.7 Project Adaptricity

Adaptricity develops software for the simulation of grid scenarios without a specific focus on heat pumps. Therefore, the standardised template cannot be filled in entirely.

Table 7. Adaptricity.
Source: Information from (Adaptricity (a), 2015).

Overall project info	
Wider context	Adaptricity is a spin-off company of the ETH (Eidgenössische Technische Hochschule) in Zurich.
Participants – Identification & motivation	Adaptricity GmbH
Funding	ETH Zurich; Adaptricity GmbH
Timing	-
Project overall driver	Adaptricity develops and sells software for the simulation of distribution grids.
Project aim	Simulation of the impacts of smart grid technologies on distribution grids in comparison to the traditional grid expansion. Evaluation of appropriate grid strategies.
Scope	
Project scale	-
Geographical coverage	-
Range of building types	-
What technologies?	Adaptricity develops simulation software called DPG.sim, which enables users to simulate different scenarios in a specific grid. Scenarios usually include the main challenges such as a high decentralized electricity production (e.g. photovoltaic, wind energy) or electro mobility; and simulate those challenges connected with both decentralized storage systems and local grid transformers, or with the traditional expansion of the grid. DPG.sim is based on functional models of different producing systems (e.g. photovoltaic), loads (e.g. heat pump) and storage systems (e.g. batteries). The dynamic properties of those elements and their interaction with the grid during the consumption or the release of energy are represented by precise mathematical rules. In DPG.sim, since households can either consume energy or produce energy, all parties are called prosumer (producer and consumer). All prosumers are defined by sub-models such as static and dynamic models of production-, load-, and storage systems. Furthermore, smart meter models and individual electricity tariffs can be implemented in the prosumers data. Each prosumer has different variable intake/ discharge of real and reactive power, which are shown in a simulation of time series. A distinction between static and dynamic units is also possible. An example for a static unit is wind energy or a photovoltaic panel, without a variable inner condition. A dynamic unit is for example a thermal storage, which also has a time variable inner condition (temperature) (Adaptricity (a), 2015). DPG.sim enables the user to integrate existing data from geographical information systems and smart meter data from real

	grids in the simulation.
End-user engagement	-
What is it specifically testing in relation to heat pumps?	
Extent and method of control/influence of HP	-
Time resolution of control	-
HP requirements	-
Storage	-
Methods being used/tested	-
Details of testing procedures	
Time resolution of monitoring	Adaptricity is currently applied in different projects in Switzerland. They usually include the usage of smart meters with a measure interval of 15 minutes (Adaptricity (b), online)
Monitoring equipment	Smart meter systems.
Results	
Flexibility	The simulation allows the integration and evaluation of different smart grid technologies.
Customer response	-
Challenges	-
Conclusions	-
Next steps & gap analysis	
Next steps	-
Exploring scope for further work	-
Gaps	-

1.1.1.8 Project Lucerne UASA – Development of an optimum unit from a heat pump and a thermal energy storage

Table 8. Project HSLU.

Source: Information from (Worlitschek, personal interview, June 2).

Overall project info	
Wider context	The project is part of the Swiss National research network "Swiss Competence Center for Energy Research (SCCER) Storage of Electricity and Heat". Additionally, Lucerne University of Applied Sciences & Arts participates in the IEA Annex 42 with this project.
Participants – Identification & motivation	Lucerne University of Applied Sciences and Arts, CC Thermal Energy Systems & Process Engineering. Misurio AG, KWT Viessmann AG
Funding	SFOE Lucerne University of Applied Sciences and Arts
Timing	2014 – 2016
Project overall driver	Research
Project aim	The target of the project is to aim for the connection of heat pumps and thermal storages to the smart grid, so that the flexibility is maximised and efficiency losses are minimized.
Scope	
Project scale	The project is based on experimentally verified computational models for three types of single family house buildings, various heat pump types and all scales of thermal energy storages.
Geographical coverage	Switzerland

Range of building types	SFH 15 (new building with 15 kWh/m² per year heating demand), SFH 45 (new building with 45 kWh/m² per year heating demand), SFH 100 (new building with 100 kWh/m² per year heating demand)
What technologies?	Dynamic building, heat pump, thermal storage (sensible and latent), controller, heating system, domestic hot water generation.
End-user engagement	-
What is it specifically testing in relation to heat pumps?	
Extent and method of control/influence of HP	The simulation uses a predictive control to operate heat pumps. The heat pump is on/off or power controlled.
Time resolution of control	1 minute
HP requirements	The analysis is independent, if the control of the heat pump is done locally or based on a centralized system. The heat pump must allow the control system to switch on/off and, in the case of power regulated heat pumps, to set the desired power.
Storage	The project includes thermal storages (sensible and latent) for hot water and space heating, as well as the building as a thermal storage.
Methods being used/tested	The project aims for a parameter study to elaborate on the effects of varying control algorithms, types and sizes of storages, as well as types and power of heat pumps on flexibility and efficiency.
Details of testing procedures	
Time resolution of monitoring	All single components have been experimentally verified with short time resolution monitoring in the second range.
Monitoring equipment	-
Results	
Flexibility	Quantification of flexibility by periods that heat pumps can be switched off and by electricity costs reached with different EPEX Spot market prices.
Customer response	The model guaranties keeping the home temperature within defined ranges.
Challenges	Increasing the flexibility to switch heat pumps based on smart grid requirements leads to a decrease in efficiency. The main challenge tackled by this project is to keep efficiencies high when increasing the flexibility.
Conclusions	Flexibility can be significantly increased by smart predictive control algorithms using the thermal mass of the building as an active storage. The flexibility can be further increased by technical thermal storages. Controlling temperatures in the storages in a smart way can keep efficiency losses to a very low extent. E.g. an analysis of the project showed that slight efficiency losses of 4% appeared and cost reductions of 36% were achieved. Furthermore, a reduction of 74% of cycle numbers could be realised.
Next steps & gap analysis	
Next steps	Combination of the results with activities of companies that control heat pumps to provide control power to the grid (e.g. Swisscom Energy Solutions).
Exploring scope for further work	Multiple benefits should be analysed, e.g. the use of big data resulting from heating system control to improve operation and efficiency of the system.
Gaps	The project itself so far relied on experimentally verified simulation data without additional field tests.

1.1.2 Interim Conclusion 2

Heat pump manufacturers do not carry out any relevant projects by themselves. The operation of a smart grid and relevant technologies are very dependent on software and IT-specific know-how. Those areas are not considered to be in the core competencies of a heat pump manufacturer. The core competencies of heat pump manufacturers include the design, research and development, and of course the manufacturing of heat pumps.
Heat pump manufacturers usually do not install their heat pumps at the customer's residence by themselves. The heat pumps are sold to the respective installers and those are responsible for the installation.

The identified projects can be categorized by their control method. This categorization was chosen because this thesis is made for a research institute at the Lucerne UASA and the potential readers are most likely going to be involved in the heat pump or electricity industry.
The first category includes projects with a central control of heat pumps. An external company controls the operations of heat pumps. The customer's comfort still has a top priority and revenues for the customers are achieved. The target of these projects is the smart control of heat pumps to avoid peak loads in the grid. Moreover, the offer of control power to swissgrid is prioritized.
The second category includes projects that control heat pumps according to local grid conditions. The offer of control power to swissgrid usually does not have a priority in these projects.
An additional category is formed by projects that develop valuable software for the simulation of scenarios in electricity grids or for the optimized connection between heat pumps and thermal storages.
Figure 1 shows the three categories and their respective projects.

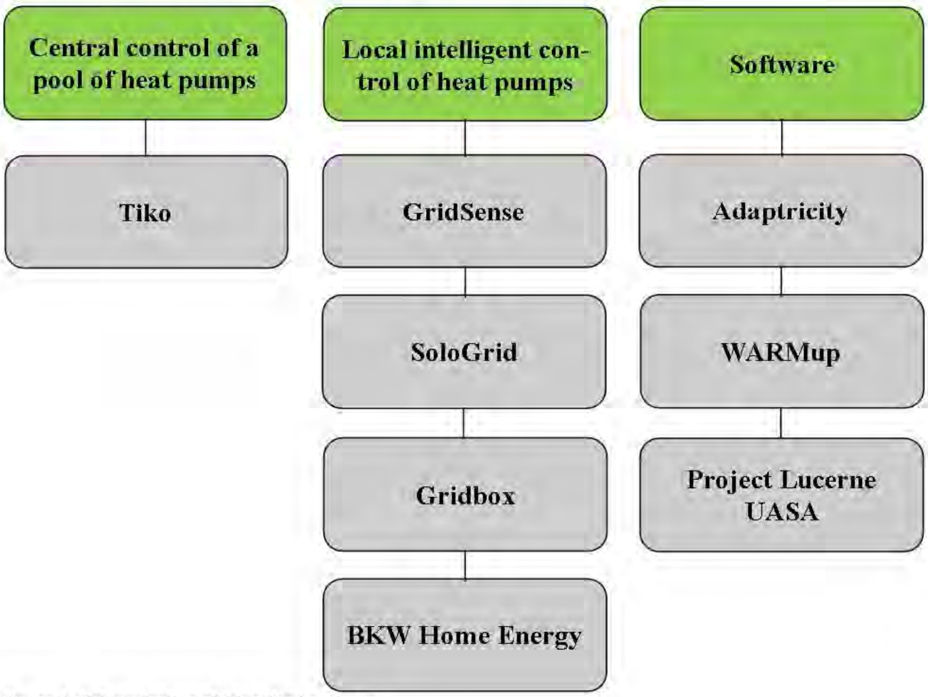


Figure 1. Categorization of identified projects.
Source: Own figure.

Figure 2 shows two different possibilities and their respective factors to integrate heat pumps in smart grids.
Central control of a pool of heat pumps: This method utilizes the possibility to pool electric loads to meet the requirements of swissgrid discussed in chapter 1.2.6.1. A big pool of heat pumps can supply swissgrid with control power to keep the grid in balance.
Local intelligent heat pumps: This method utilizes the measurement of grid conditions and controls heat pumps accordingly. Peak loads can be reduced and self-sufficiency can be increased by shifting loads such as heat pumps. Therefore, the voltage in the grid can be decreased and investments into the grid can be reduced.
The following environmental analysis refers to those types of heat pump integration if necessary.

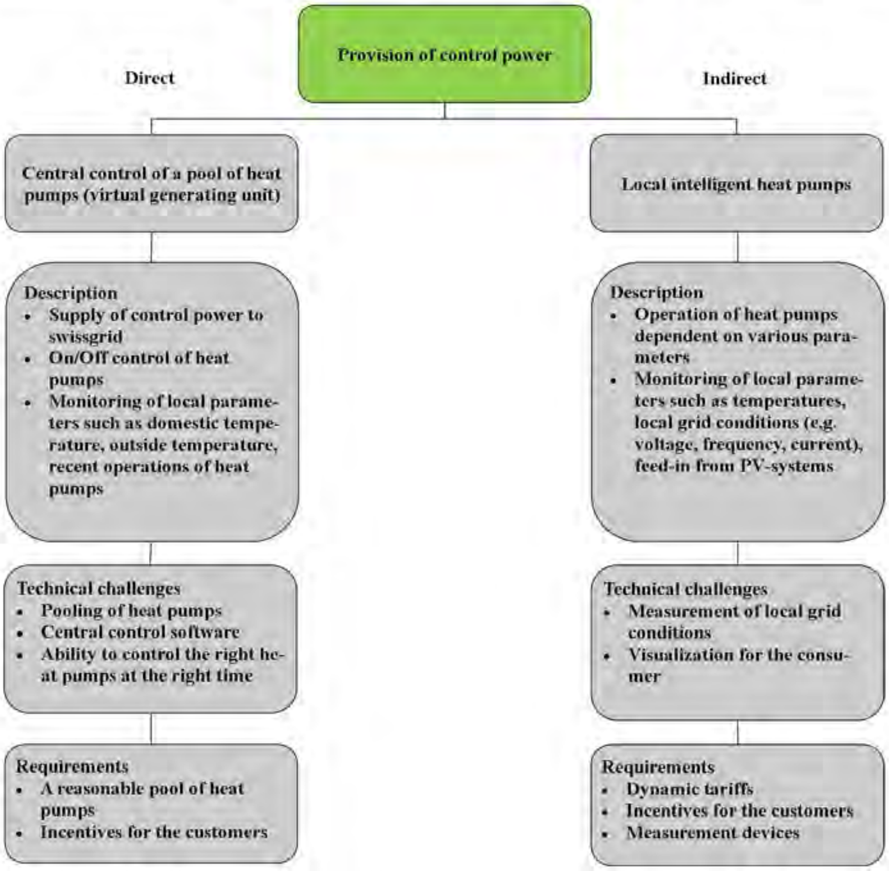


Figure 2. Integration of heat pumps in smart grids.
Source: Own figure.

1.2 Environmental analysis

In this chapter, the market of heat pumps and its surroundings are analysed. The focus is on the utilization of heat pumps in a smart grid. The advantages and disadvantages of heat pumps in a smart grid are discussed and the overall potential is evaluated.

1.2.1 Political factors

In this chapter, political factors of the PESTEL analysis are discussed.

1.2.1.1 Adjustments of MuKEn in favour of heat pumps

The "Mustervorschriften der Kantone im Energiebereich" (MuKEn) includes model rules in the building sector. The cantons in Switzerland introduce these rules in their respective cantonal energy legislation and make minor adjustments according to cantonal peculiarities if necessary.
Within the scope of tightening of the MuKEn, many changes concerning energy efficiency are planned for the future. The main areas of adjustment are the energy consumption in buildings and the utilization of new renewable energy systems. The latest MuKEn was adopted January 9, 2015.
Adjustments of the MuKEn are planned in all three scenarios of the government. There are several changes that have a significant impact on the future potential of heat pumps in Switzerland.
First of all, the CO_2-emissions are planned to be reduced in all three scenarios. Therefore, taxes for CO_2-emissions are going to be increased over the next years. This has a positive impact on the utilization of renewable energy systems for heating purposes. Heat pumps have significant lower CO_2-emissions compared to other heating systems. When operating a heat pump with green electricity, a heat pump releases approximately 14g of CO_2 per kWh into the environment. In comparison, an oil heating system releases approximately 290g of CO_2 per kWh (CO_2-Rechner, online). A side-effect of the higher CO_2 taxes is that the additional revenues are partly invested in funding programs. By investing in the building program, more elder buildings can be renovated and, therefore, made adequate for the utilization of a heat pump (BFE (c), 2015).
In new buildings, requirements for heat insulation are tightened and the specific heating power (W/m^2) in living-, administration-, and school-buildings is restricted. Therefore, more efficient heating solutions with heat pumps can be realized (BFE (c), 2015).
Furthermore, the MuKEn already prescribes that all electric heating systems and all electric boilers have to be replaced within 15 years after the enactment of the MuKEn 2014 (EnDK, 2014, Art. 1.35 & Art. 1.37). Only heating systems that additionally use other energy sources (e.g. sun energy, environmental energy) are allowed. The installation of electric heating systems or electric boilers in new buildings is not allowed anymore. Additionally, the replacement of an existing electric heating system by a new electric heating system is not allowed (EnDK, 2014, Art. 1.13).
It is planned that the cantonal energy legislations are adjusted with the latest MuKEn regulations by 2018. Furthermore, the new regulations of the MuKEn are supposed to come into force by 2020 (EnDK, 2014, p.11).

The key points in brief:

- Taxes for CO_2-emissions increase over the next years and, therefore, the operation of traditional heating systems (e.g. oil heating) will become more expensive.
- Requirements for building insulations are tightened and, therefore, heat pump systems can be more efficient.
- The installation of electric heating systems or electric boilers is not allowed anymore.
- Only heating systems with the additional use of renewable energy sources are allowed.
- Electric heating systems and electric boilers have to be replaced by heating systems that additionally use renewable energy sources.

1.2.1.2 Subsidies in Switzerland

There are different types of subsidies that affect heat pumps in Switzerland. The government encourages the utilization of heat pumps with contributions to the 26 cantons in Switzerland. Each canton has its own funding program and, therefore, a national statement cannot be made. After analysing the funding programs of each of the 26 cantons, it can be said that 20 out of the 26 cantons (BFE (d), 2016) make contributions to either the replacement of electric heating systems and/or the installation of a heat pump. It can be seen from the funding programs that mostly brine/water- or water/water-heat pumps are financially supported.

Additionally, the government introduced a national flagship project program. In this program, various projects are included that contribute an important share towards the targets of the Swiss energy strategy 2050. The goal of the Swiss flagship program is the publication and appreciation of these projects in Switzerland and beyond the country borders. Tiko and SoloGrid, which were mentioned earlier, are examples of Swiss flagship projects.

Furthermore, many electricity utility companies in Switzerland have their own funding program. Examples for this are the BKW AG in the canton of Berne and the cantonal electricity utility of Nidwalden.

1.2.2 Environmental factors

In this chapter, environmental factors of the PESTEL analysis are discussed.

1.2.2.1 Relieve of nature

Smart grid technologies can help to reduce CO_2-emissions by better integrating renewable energy systems. For example, if the stochastic electricity production of photovoltaic (PV) systems could be integrated in a smart grid, the operations of other non-renewable energy systems could be reduced.

By integrating heat pumps in a smart grid, the market becomes more independent of other non-renewable heating systems.

Furthermore, electricity losses due to transmission in the grid are inevitable. By the smart control of heat pumps, decentralized produced electricity can be used and stored decentral as well. Transmission losses can be reduced and the grid in Switzerland becomes more efficient overall (BFE (f), 2015, p.78).

Another benefit from integrating heat pumps in a smart grid is the reduced expansion of the distribution grid by consuming electricity where it is produced. The loads in the grid are reduced and expansions of the grid can be reduced or at least postponed. As a result, less additional landscape needs to be used for power lines or transformer stations (BFE (f), 2015, p.78).

The key points in brief:

- The utilization of heat pumps is encouraged in Switzerland
- The government and electricity utility companies financially encourage heat pumps.
- Nature can benefit from a better integration of heat pumps, other electric loads, and electricity production systems in a future smart grid.

1.2.3 Social factors

In this chapter, social factors of the PESTEL analysis are discussed.

1.2.3.1 Trend environmental protection

The awareness of the own responsibility for the protection of the environment is growing in Switzerland. According to a recent study, the number of people, who assume that their own behaviour is above average (in terms of protection of the environment), increased from 49% to 57% (Schaub, 2014, p.3). The belief that new technologies can solve the environmental problems grew by 2% (Schaub, 2014, p.3). Therefore, people in Switzerland are becoming less sceptical about new technologies such as heat pumps or smart grids. This can help these new technologies to become more established in the market.

1.2.3.2 Population growth

The past showed that there is a correlation between the electricity consumption and the growth of population and economy. The gross domestic product (GDP) is a good indicator for this issue. The growth of the GDP is indirectly correlated with increasing electricity consumption. On the one hand, a higher GDP is related to more jobs within Switzerland and on the other hand, a higher income leads to a larger living area and higher electricity consumption per person. Furthermore, the number of electric devices in a household is steadily increasing due to evolving customer needs. A correlation between population growth and economic growth intensifies this evolution. A good state of the economy leads to higher numbers of immigration (VSE (a), 2013, p.1-2). Population growth leads to an increasing heating demand. In connection with the increasing electrification of heat, a smart control of heat pumps is needed.

1.2.4 Technological factors

In this chapter, technological factors of the PESTEL analysis are discussed. This section of the PESTEL-analysis offers a wide range of technologies that could be part of a future smart grid in Switzerland.
Figure 3 shows an overview of these technologies. Different areas of solution were identified and various approaches or technologies were associated to each area. Not all areas are directly related to heat pumps in smart grids; nevertheless, all areas are important for a future smart grid. The focus in this thesis is on the green highlighted area in Figure 3. Few important technologies from other areas of solution are also described and a connection to heat pumps is established.

The key points in brief:

- The awareness of the own responsibility for the protection of the environment is growing.
- Population growth leads to an increased electricity consumption.

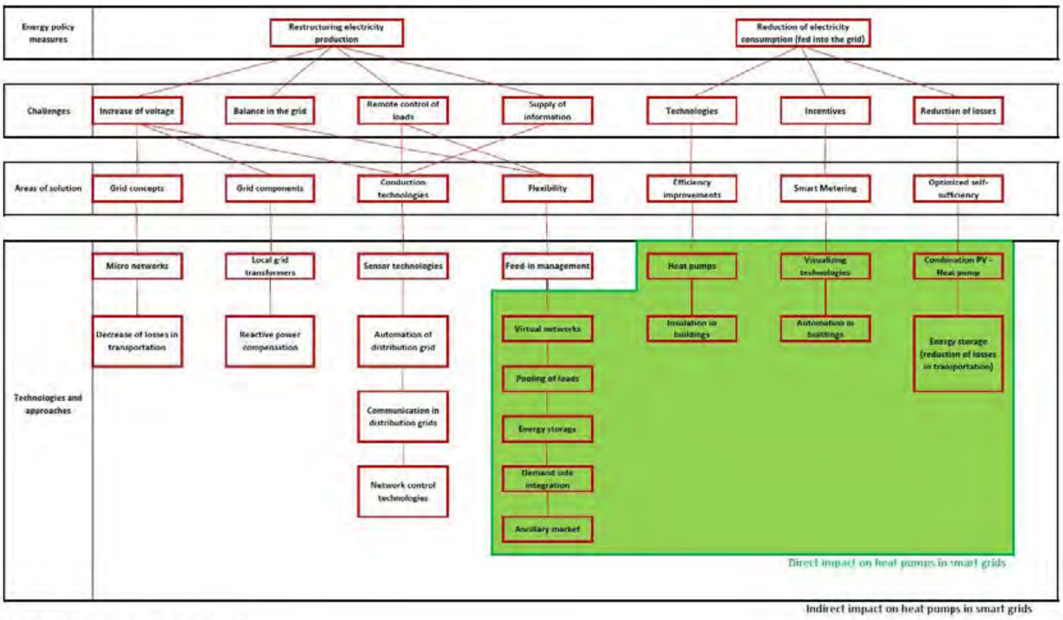


Figure 3. Technologies in the energy market.
Source: Own figure. Adapted from (BFE (f), 2015, p.43).

1.2.4.1 Grid concepts

One potentially advantageous grid concept is the micro network. A micro network is an integrated energy system with decentralized production systems, energy storage systems, and various electric loads (e.g. heat pumps). The micro network is operated parallel to the national grid (macro grid) as an autonomous network. The capability to reintegrate a micro network into the national grid is crucial for the value of these networks. By the operation of micro networks, the resilience of the macro grid is improved. Therefore, the national grid can operate autonomously and safely even if malfunctions in a micro network appear. The same applies for the reverse case – if a malfunction in the national grid appears, a micro network can operate autonomously for some time. Micro networks cooperate with the existing national grid, communicate with external information systems, and are able to feed in electricity into the national grid to support a safe energy supply (ABB, 2014).
Figure 4 shows the most used components of a micro network. Production technologies, storage technologies and various loads are integrated into the micro network and a connection to the macro grid is available.

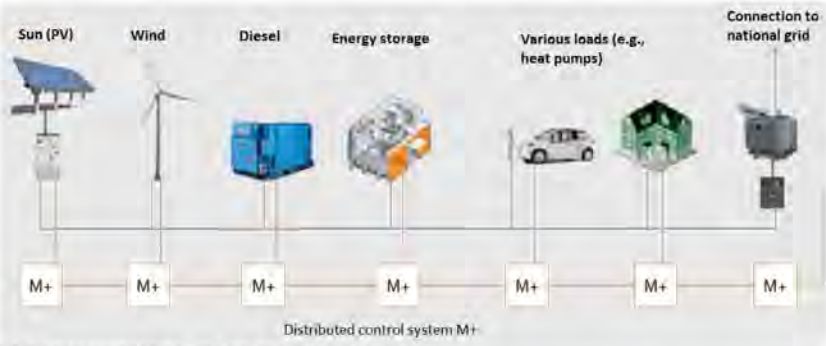


Figure 4. Components and structure of a micro network.
Source: Translated from (ABB, 2014).

The concept of micro networks could be used in a future thermal grid. It is being said that the storage of thermal energy is less difficult and expensive than the storage of electricity (ABB, 2014). Peter Wagener, chairman of the Dutch Heat Pump Association, states that a combination of thermal grids and electricity grids, with heat pumps as a linkage between those grids, can improve the energy situation (Wagener, 2014). The advantage of a thermal grid is that it is less complicated to store energy in this grid, since it is simpler in behaviour. Temperature, pressure, and flow are the main aspects in a thermal grid, whereas an electricity grid has more variables, which need to be controlled. Households within a defined area could be connected with a thermal distribution grid in order to store and share heat. The infrastructure of the existing local heat networks is a first step towards a thermal grid in Switzerland. A thermal grid offers new possibilities to store excess electricity as heat in the thermal grid.

The key points in brief:

- Micro networks allow operating autonomous grids parallel to the national grid.
- An exchange between the micro grid and the national (macro) grid is still possible.
- The concept of micro networks could be applied for a thermal grid.
- A thermal grid offers the ability to store electricity as heat and exchange it via thermal distribution grid.

1.2.4.2 Grid components

In this chapter, the controllable local grid transformer is analysed and its stage of development is reviewed.

The principle of a controllable local grid transformer is relatively simple. A local grid transformer is able to stabilise the voltage in distribution grids. This is achieved by compensating the lift in voltage, which is a result of the high decentralized electricity production. Furthermore, the decrease of voltage due to additional loads such as electric vehicles or heat pumps can be compensated as well.

A commonly used local grid transformer is unable to compensate changes in voltage caused by decentralized electricity production or loads. Since the voltage is already low in these levels, the additional electricity causes a significant voltage increase. Therefore, less additional electricity or loads are necessary to reach the upper or lower limit of the voltage range of +/- 10% of the nominal voltage.
Figure 5 shows that the tolerance for decreasing or increasing voltage is relatively low (5% in decrease and 3% in increase). As a result, only a small amount of decentralized produced electricity can be fed into the grid without reaching the limit in the voltage range. This leads the operators of distribution grids to an expensive expansion of the grid (SGB-SMIT Group, 2013).

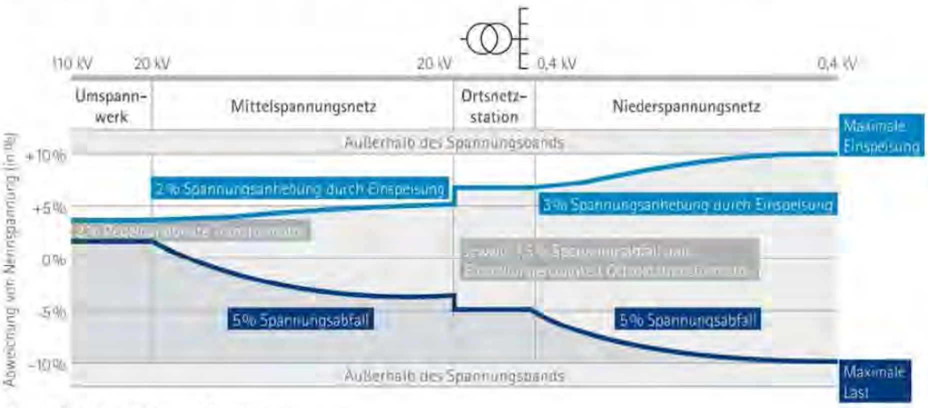


Figure 5. Local grid transformer.
Source: Retrieved from (SGB-SMIT Group, 2013).

It can be said that the compliance of the acceptable voltage deviation from the nominal value is key to the safety of the grid. The controllable local grid transformer decouples network levels 5 and 7 in order to be able to dynamically control the voltage. As a result, the maximum electricity, which can be fed in the grid decentral, increases. Therefore, changing loads such as heat pumps or electric vehicles can be supplied with electricity without causing the voltage to reach the lower limit of the voltage range.
Figure 6 shows that a lift in voltage of 11% is acceptable in a controllable local grid transformer and this can be used for feeding in decentral produced electricity from renewable energy systems. Therefore, the capacity of the existing grid increases and a bigger share of the necessary electricity can be produced from renewable energy sources (SGB-SMIT Group, 2013).
A side-effect of the utilization of a controllable local grid transformer is that the expansion of the grid can be omitted or at least postponed. Moreover, costs for the expansion of the grid can be reduced.

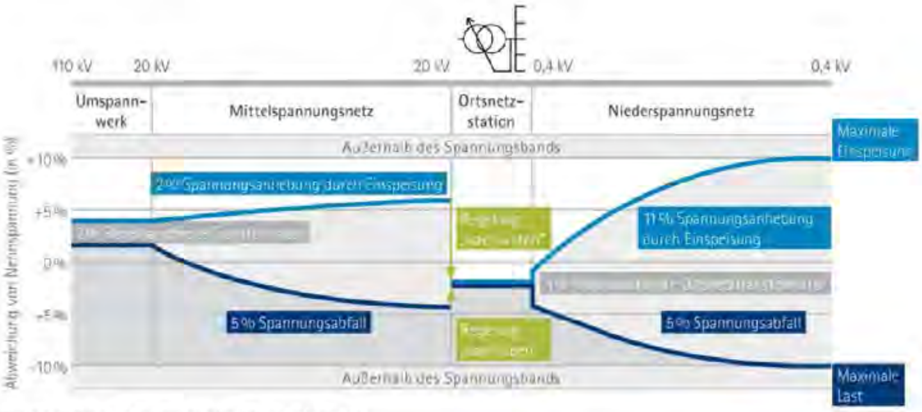


Figure 6. Controllable local grid transformer.
Source: Retrieved from (SGB-SMIT Group, 2013).

The utilization of controllable local grid transformers in Switzerland is relatively low today. These transformers are available in Switzerland, but long-term experience has not been established yet (VSGS, 2015, p.19).
Since existing local grid transformers (installed in network level 6) have similar dimensions as the controllable version, they can be easily replaced during a renovation of a transformer station. Nowadays, the costs of controllable transformers are approximately twice as high as costs of traditional transformers. With an increasing diffusion, costs could decrease in the near future (VSGS, 2015, p.30-36). The costs for a new controllable transformer account for approximately 50'000 CHF.

There are various companies that are executing pilot-projects with controllable local grid transformers.
One example is the Swiss Energypark in Villeret, powered by the BKW AG. BKW installed a controllable local grid transformer in July 2015 with the target to evaluate the performance in a real situation. Without the controllable local grid transformer, the grid in Villeret would have been too weak for the feed-in of the electricity production of the photovoltaic system. The grid would have only allowed 30% of the maximum electricity production, which would not be reasonable. The performance of the controllable local grid transformer allows operating the photovoltaic system at 100% (BKW (b), 2015).

The key points in brief:

- Controllable local grid transformers enable a higher decentralized electricity production in network level 7.
- The safety of the electricity distribution is increased.
- Higher shares of renewable energies (e.g. from PV) can be fed in the system and loads (e.g. heat pumps) can be supplied with electricity safer.
- Utilization today is relatively low but needed in a future Swiss smart grid.

1.2.4.3 Ripple control & smart meter

Today, most of the distribution system operators (DSO) use a ripple control system. A ripple control system is used to transmit control signals through the grid.
The utilization of a ripple control system allows the DSO to relieve the grid by disconnecting several different electric loads (e.g. heat pumps, washing machines, or boilers). The off-time is used differently by DSOs in Switzerland. Usually, the previously mentioned loads are disconnected during lunchtime, from 11AM until 1PM. Additional off-times are allowed and applied by few DSOs.
Off-times were introduced to reduce peak loads in the grid. The disconnection of heat pumps usually does not affect living comfort because of the thermal inertia of buildings. Furthermore, heat pumps are often operated shortly before off-times in order to bridge the gap.

Heat pumps need an interface for an external control by DSOs. Nowadays, most heat pumps have such an interface already available (Geidl, interview, May 10). All interviewed heat pump manufacturers confirmed Geidl's statement. For example, Buntschu (personal interview, April 15) states that heat pumps from Elcotherm AG already have a controller inside that enables the integration of smart grid functions. Smart grid functions include for example an external control of the heat pump or an increase of the target temperature (of hot water) in order to store electricity as thermal energy (Bundesverband Wärmepumpe, 2013).
It is being said that most, if not all, used heat pumps in Switzerland are able to receive external control signals. Since a potential smart grid needs to be able to remote control loads, this is already an initial step towards a smart grid in Switzerland.
In the future, smart meters could potentially substitute the current ripple control systems. It is being said that smart meters allow a communication between electric loads and electricity production systems. By the usage of smart meters, flexible loads and decentralized electricity production systems can be integrated in the grid intelligently (BFE (h), 2014, p.23).
Further details about the functions of a smart meter are discussed in chapter 1.2.4.4.

An external control of heat pumps is especially important when a pool of heat pumps is centrally controlled (see Figure 2). This means that an existing ripple control system could already be sufficient, since heat pumps are mostly on/off controlled when the grid requires control power.
The substitution of a ripple control system by a smart meter system could potentially be required when operating local intelligent heat pumps (see Figure 2). A smart meter system analyses the current tariffs, grid conditions and conditions in a building, and controls the heat pump accordingly.
The integration strategy of heat pumps in a smart grid (central control vs. local intelligent control) is crucial for the usage of smart meter systems (Artenoglu, Interview, April 8).

CKW, an electricity utility company in Central Switzerland, executed a pilot project, where 1'000 smart meters were installed in households. Additionally, dynamic electricity tariffs were partially implemented. Customers in the project were supposed to monitor the tariffs and act accordingly. The results showed that electricity consumption could be reduced by 3 – 5%. This does not provide a sufficient financial incentive for the customer to actively participate in the market in the long-term. According to Graf, a selective usage of smart meters still remains useful and needed in the future (Graf, 2013).

The key points in brief:

- Ripple control systems enable a DSO to disconnect electric loads from the grid.
- Ripple control systems transmit control signals through the grid to the respective electric loads.
- Most heat pumps in Switzerland can receive external control signals.
- The existing interface to receive control signals can be used in a future smart grid.
- Smart meters potentially replace a ripple control system.

1.2.4.4 Smart Metering

Nowadays, most households only have a simple electricity meter that is used to quantify the electricity consumption. The distribution system operator (DSO) analyses the data few times per year and charges the appropriate price in the next bill. Additional data such as customer behaviour or maximum voltage in the grid cannot be evaluated.

Smart meters are an essential part of a future Swiss smart grid. A smart meter allows monitoring the voltage time curve in high resolution. Furthermore, a smart meter transmits measured data to the control centre of the local DSO. Therefore, a quantification of the electricity consumption on site is no longer required and as a result, costs can be reduced.

The usage of smart meter systems improves the accuracy of forecast methods, since voltage and other grid parameters are monitored in real time. This leads to an optimized operation of heat pumps and renewable energy systems such as photovoltaic.

A smart meter acts as a bi-directional communication device. This allows the transmission of current information and electricity tariffs to the customer and helps to operate electric loads more intelligent (Consentec, 2013, p.93-94). Figure 7 shows the information flow in a smart meter system.

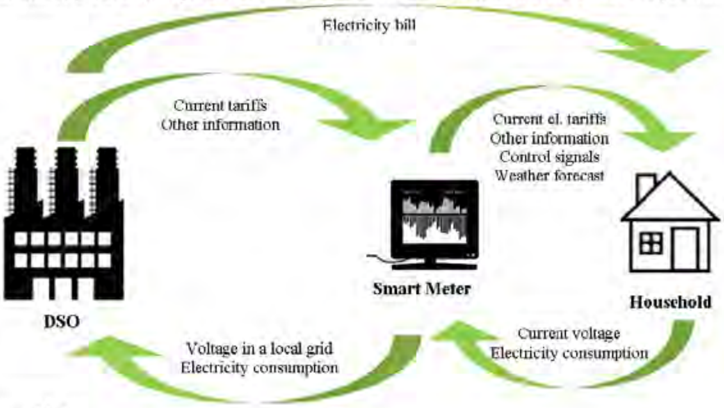


Figure 7. Smart Meter.
Source: Own figure.

The devices and communication technologies for an extensive usage of smart meters in Switzerland are available (Consentec, 2013, p.95). There are several projects in Switzerland that already use smart meters in their grid (e.g. GridSense, SoloGrid).

The main problem is the high costs that are associated with an extensive usage of smart meters. According to the current regulations in Switzerland (see also chapter 1.2.7.2), the DSOs have to bear almost the full costs of a smart meter rollout (Ecoplan, 2015, p.10). Since households benefit most from a smart meter rollout, DSOs do not have a sufficient advantage from the investments in the introduction of smart meters yet.

The key points in brief:

- Smart meters allow an optimized operation of electric loads (e.g. heat pumps) and decentralized energy producers (e.g. photovoltaic).
- Smart meters enable a DSO to remote quantify the electricity consumption of a household.
- Technologies are available.
- An extensive usage of smart meters is not profitable for a DSO due to the current regulations.

1.2.4.5 Optimized self-sufficiency

On the demand side, as already discussed in chapter 1.2.1.1, the electrification of heating in Switzerland is increasing. This leads to a larger amount of electricity being used for heating purposes. Therefore, heating contributes a large share to the increasing loads in the grid and to the upcoming challenges in the electricity sector. Nowadays, the utilization of heating oil and electric heating systems is decreasing, while the utilization of heat pumps is increasing. The existing electric heating systems will most likely be replaced by a heat pump system in the near future, which increases the amount of renewable heat produced.

Meanwhile, on the supply side, decentralized electricity production by photovoltaic (PV) systems is increasing. This leads to a high feed-in of power in low voltage network levels, which can lead to an inadmissible voltage increase in the grid (see also chapter 1.2.4.2).

A large amount of decentralized electricity production combined with an increasing electrification of heating leads to a possibility to relieve the grid. The decentralized produced electricity could be used on-site for heating purposes without being fed in the grid.

Figure 8 shows the daily consumption and production of a normal household in the left part of the figure. Nowadays, electricity production and consumption do not align with each other. Therefore, most of the electricity is fed in the grid and increases the voltage in the grid. The households only receive the energy price for the supplied electricity (e.g. 10Rp/kWh). In contrast to that, households have to pay the whole price (see also chapter 1.2.5.3) for the consumed electricity (e.g. 25 Rp/kWh). The prices vary by canton, time of the day, and other parameters.

With an optimized self-sufficiency, it is possible to use electricity when it is produced. A heat pump is often operated during high electricity production of the PV system and the heat is stored in the buffer storage or in the building itself (see also chapter 1.2.4.6). Approximately 10-15kWh can be stored in hot water storages and 6kWh can be stored in buffer storages per day (BFE (i), 2015, p.2). When using the locally produced electricity, only the energy price has to be paid since the electricity was not fed in the grid. In this example, 15Rp/kWh can be saved by aligning consumption and production (BFE (i), 2015, p.1-2).

A combination of PV systems and heat pumps can contribute to a lower decentralized feed-in of electricity in the grid and ultimately, it can help to reduce the necessary expansion of the grid.

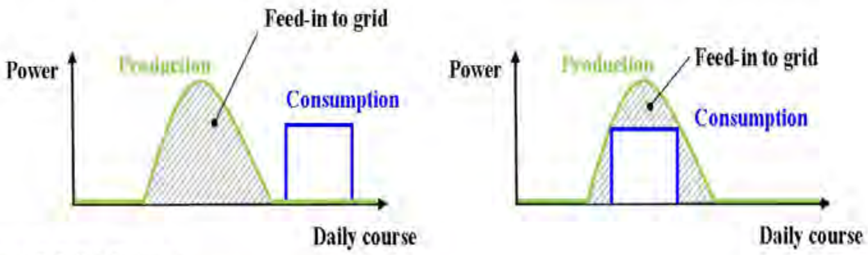


Figure 8. Self-sufficiency.
Source: Own figure. Adapted from (BFE (i), 2015, p.1)

The key points in brief:

- Alignment of consumption and production.
- A combination of a PV system and a heat pump can be beneficial for the household owner and for the grid operator.
- Feed-in of electricity in the grid can be reduced by consuming electricity when it is produced.
- Losses due to transmission in the grid can be reduced.

1.2.4.6 Flexibility

Increasing numbers of stochastic electricity producers make it more difficult to keep the grid in balance. In order to provide a safe electricity supply in the future, additional flexibility in the grid is required.
In this context, flexibility is the ability to influence the amount and the time curve of power consumption and supply.
Dynamic loads and especially the inertia of thermal loads can be used to increase flexibility. Heat pumps can provide flexibility because the heating process can usually be postponed within a particular timeframe without affecting living comfort. The grid can be relieved by postponing the operation of heat pumps during peak times. Furthermore, the quality of insulations in buildings in Switzerland is steadily improving. Therefore, it takes more time until the temperature inside reaches the lower tolerance level.

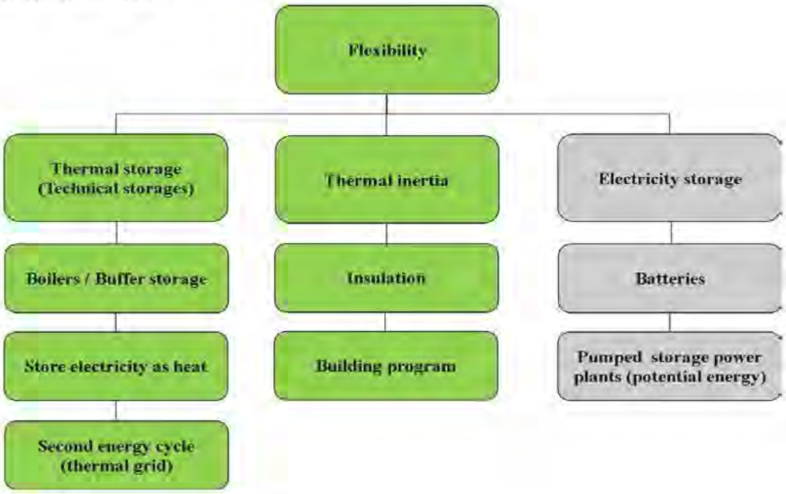


Figure 9. Flexibility.
Own figure.

The increasing electrification of heating in Switzerland leads to peak loads in the grid. Since heating with oil, wood, or gas is decreasing, a larger amount of electricity is converted to heat. This growing overlap also allows storing electricity as heat. Figure 9 shows an overview of different types of flexibility. In terms of heat pumps, thermal storages are more important than electricity storage. The relevant subjects are highlighted in green, while less important subjects are highlighted in grey.

Usually, the required supply temperature is determined after analysing the outdoor temperature. Electricity can be stored as heat. When the supply is high and the demand is low, it is possible for a heat pump to consume more electricity from the grid in order to increase the temperature in the buffer storage or in the hot water boiler. A higher temperature in the buffer storage or in the boiler leads to an extended acceptable downtime of heat pumps. Therefore, a heat pump in connection with a thermal storage can use electricity smart. In connection with a weather forecast system, it is possible to evaluate the optimal operation time of a heat pump. For example, if the weather forecast predicts that the next days will be relatively cold, the heat pump can increase the supply

temperature in order to improve the living comfort and decrease the heating power in the following days (BFE (b), 2013, p.8).
The opinions concerning targeted overheating of heat pumps vary widely.

Reto Studer, managing director of Striega-Therm Wärmepumpen, states (personal interview, April 6) that overheating of heat pumps is not profitable and should be avoided. With every additional degree Celsius of temperature, the COP (Coefficient of Performance) deteriorates. The COP describes the ratio of consumed electric power and produced thermal power. The higher the COP, the more efficient is the heat pump.
In contrast to that opinion, the results of WARMup (see also 1.1.1.1) have a different view. The flexibility of thermal storages can be utilized. Utilizing flexibility means postponing heating processes and overheating water if necessary, even though local efficiency losses (lower COP) could be a result. On the contrary, the simulation showed that due to the proactive operation of the heat pump, local efficiency losses could be compensated (BFE (b), 2013, p.37). The utilization of the flexibility of thermal storages can help to keep the grid in balance and improve the overall efficiency in the Swiss grid. In addition to that, heat pumps in the WARMup simulation were able to reduce peak loads in the grid and costs of customers.
It is being said that flexibility does have a value for the grid and local efficiency losses can be compensated by the smart control of heat pumps.
Thermal inertia describes the behaviour of buildings to exchange temperature with the environment. The thermal inertia of new buildings is very high, which means that heat is exchanged relatively slow with the environment. Therefore, once a building was heated, the heat pump can be turned off since the heat remains inside the building. The better the insulation, the longer the time between heating cycles. Due to renovation of elder buildings, the heating demand can be decreased by approximately 50% (Das Gebäudeprogramm, online). The Swiss building program financially supports renovations of elder buildings in order to reduce energy consumption. For profitably using a heat pump, a building requires a good insulation.

Electricity storage can provide additional flexibility by storing electricity when it is available and using it when the demand is high. This enables the indirect or direct provision of control energy, since more electricity is consumed during times with low demand and vice versa.
Electricity storage systems include chemical storage systems, short-term electricity storage (e.g. batteries) and long-term electricity storage (e.g. pumped storage power plants) (Energie-Cluster, online).

The key points in brief:

- Flexibility is required to handle the increasing amount of stochastic electricity suppliers.
- Flexibility includes for example shifting heating processes during peak loads in the grid and limiting electricity production during times of low demand.
- Flexibility can be provided by thermal storages, thermal inertia (which is also a thermal storage) and electricity storages.
- Overheating of heat pumps is a controversial issue across heat pump manufacturers and other involved parties.
- Flexibility has a value for the grid and, therefore, overheating can be useful in order to relieve the grid.
- Thermal inertia can help shifting heating processes during peak loads.

1.2.4.7 Utilization of flexibility

The flexibility of heat pumps can be used to align consumption and production of electricity. In chapter 1.2.4.6, different types of storages were discussed. This chapter focuses on how to use these storages. In general, there are two different ways to use flexibility.

The first way to use flexibility is called demand response (DR). In this case, dynamic electricity tariffs from the distribution system operators (DSO) are required. In this context, the term DSO refers to an integrated distribution system operator. This means that the DSO additionally produces electricity and sells it to the end-customers. Furthermore, the dynamic tariffs have to be communicated to the end-customers. To sum up, the DSO gives incentives to shift electric loads from times of high demand to times of low demand by offering appropriate electricity tariffs. The potential of DR to reduce peak loads is relatively low, since most of the expected shifts of electric loads are relatively short (VSE (b), 2013).

Another way to use flexibility is by externally controlling electric loads (e.g. heat pumps) to improve the balance in the grid. This is also called demand side management (DSM). DSM allows the operation of electric loads by a DSO or other parties. In comparison to DR, DSM has a higher potential to reduce peak loads in the grid (VSE (b), 2013).

Table 9 shows the percentage of the electricity demand that can be shifted on average. This percentage depends on how the flexibility is used (DR vs. DSM) and on what type of device is controlled. Mainly devices that are usually not directly controlled by the customers (e.g. heat pumps, boilers), can be used for DSM. Devices, which are usually directly controlled by the customers (e.g. dish washer, washing machine), can be used for DR (VSE (b), 2013).

Table 9. Potential of load shifting.
Source: Based on (VSE (b), 2013, p.2-3).

Duration of shift	<15min	<1h	<2h	<4h	>4h
DR	15%*	10%*	5%*	0%*	0%*
DSM - heat pumps (room heating)	100%*	100%*	100%*	50%*	5%*
DSM - Hot water storage	100%*	100%*	100%*	95%*	60%*

* of total electricity demand

Storages (as discussed in chapter 1.2.4.6) offer a possibility to increase the percentage of the electricity demand available for load shifting. A technical thermal storage can be overdesigned in order to increase the loads that can be shifted. Overdesigning storages usually only makes sense when the storage is also used for room heating purposes. Overdesigning storages only for the provision of flexibility to the grid is usually not reasonable. An overdesigned storage might not be reasonable from an energy-efficient perspective, but it can be beneficial for the overall grid efficiency (VSE (b), 2013).

The key points in brief:

- DR includes communicating current electricity tariffs to the customers and letting them decide, whether they want to operate an electric device or not.
- DSM includes controlling electric loads (e.g. heat pumps) by a central control system according to local grid conditions.
- Heating processes offer the highest potential in the utilization of flexibility.

1.2.4.8 Cooling with heat pumps

Heat pumps produce thermal energy in order to heat buildings. This being said, heat pumps are rarely used during summer, since there is less need to heat buildings. The diffusion of heat pumps for the purpose of hot water heating today is relatively low. Only 7% of single-family houses and 4% of multi-family houses use heat pumps for hot water heating (HPT (a), 2014).
As already discussed in the Swiss market overview, approximately 69.7% of energy is used for room heating and 13% is used for hot water heating (HPT (a), 2014). Therefore, the potential of heat pumps to provide control power during summer is significantly lower than in cooler months.
The effective potential of the provision of control power during summer is discussed in chapter 1.2.7.3.

Nowadays, it is possible to additionally cool buildings during hot summer days with heat pumps. Heat is transported from inside the building to the outside. This topic was discussed with Aldo Buntschu from Elcotherm AG. Buntschu (personal interview, April 15) states that there are two different ways to cool buildings:

Free cooling: The excess heat within the building can be absorbed by the underfloor- or wall heating and be transported to the heat source (e.g. earth, ground, or water) via a heat exchanger. In this type of cooling, the operation of the compressor is not required and, therefore, less electricity is needed. Only the operation of the circulator pump is necessary. Free cooling can decrease the temperature inside by 3 to 4 degrees Celsius with a minimal amount of electricity used. In modern buildings, free cooling usually is already sufficient.

Active cooling: In this case, a heat pump basically has the same function as a refrigerator. This allows a defined cooling power to decrease the temperature inside. In contrast to free cooling, the compressor is operated and, therefore, the electricity consumption is higher.

In Switzerland, the total electricity consumption by air conditioning units amounts to approximately 1200GWh per year (BFE (I), 2013). It is being said that most of this accumulates in the service industries (e.g. shopping centres, hospitals), since air conditioning in households is not very common in Switzerland.
On the one hand, widespread cooling with heat pumps in households during summer could theoretically increase the potential provision of control power. On the other hand, it is questionable whether an artificial increase of electricity consumption (with the purpose of providing control power to the grid) is appropriate. According to the targets of the Swiss energy strategy 2050, electricity consumption per head should be decreased, not increased.

The key points in brief:

- Potential of heat pumps to provide control power is relatively low during summer.
- Cooling with heat pumps could increase the electricity consumption. Therefore, the potential provision of control power increases since a larger amount of electricity is used by heat pumps.
- The artificial increase of electricity consumption does not match the targets of the Swiss energy strategy 2050

1.2.5 Economic factors

In this chapter, economic factors of the PESTEL analysis are discussed.

1.2.5.1 Reduction of investments for the expansion of the grid

The main part of today's transmission network is elder than 40 years. Originally, the grid was not designed to transport the amount of electricity, which is currently transported daily. Furthermore, the decentralized production of electricity is an additional challenge in the future. Electricity is fed into the grid in all network levels, which is something the grid was not designed for either.

The reinforcement and renewal of the existing grid is an important element in order to reach the targets of the Swiss energy strategy 2050.

According to Matthias Galus, project head of the Smart Grid Road Map Switzerland, the expected investments for expansion of the grid account for 13 Mia. CHF until 2050 (Galus, 2013). These investments can be reduced by introducing a smart control of the grid, since peak loads can be diminished and a larger amount of the grid can remain unmodified. Studies of the SFOE show that investments can be reduced to less than 5 Mia. CHF (Galus, 2013).

1.2.5.2 Economic relevance of renewable energies

The industry of renewable energies (EE-sector) is steadily growing in Switzerland. In 2010, 22'800 employees were counted in this industry and a gross value added of 4.8 Mia. CHF was achieved. Depending on the scenario, growth rates between +1.6% and +2.9% are expected (BFE (m), 2013, p.11-12). Compared to the expected growth rate of the gross domestic product (GDP) of +1.2% (BFE (k), 2013, p.4), the EE-sector has a higher growth rate. Therefore, the EE-sector makes an above-average contribution to the economic growth.

The planning, installation and manufacturing of heat pumps lead to economic activities. In the future, the further integration of heat pumps in a smart grid leads to increased economic activities in the software industry and in the operation of the grid. This creates additional jobs in electricity utility companies and in the EE-sector.

Investments in the installation of new renewable energy systems amounted to 2.1 Mia. CHF in 2010. The installation of new heat pumps accounted for 740 Mio. CHF, which is 35% of total investments for renewable energy systems (BFE (m), 2013, p.69). That being said, heat pumps became an essential part in the EE-sector over the last decade and are expected to become even more important in the course of the Swiss energy strategy 2050.

The key points in brief:

- The utilization of smart grid technologies can reduce the necessary expansion of the grid.
- Investments in the expansion of the grid can be reduced by more than 60%.
- The industry of renewable energies is growing above-average compared to the total economic growth.
- Heat pumps contribute a big share to the economic value of renewable energy systems.

1.2.5.3 Components of the electricity tariff

In Switzerland, the electricity tariff is dependent on four components.

In this chapter, the structure of the electricity tariff is analysed. The findings from this chapter are important for the regulations discussed in chapter 1.2.6.2.

System usage charge:

The costs for the utilization of the grid for the transmission of electricity to the consumers are part of this component. The revenues of this component are mainly used for the necessary maintenance and expansion of the grid (e.g. new transformers, powerlines, or power poles) (BFE (e), 2011, p.6). The system usage charge has to be paid to upstream network levels (e.g. the DSO in network level 7 has to pay costs for the system usage charge to the grid operator in network level 5, which supplied electricity to network level 7).

Energy:

The effective costs for the production of the electricity form this component of the electricity tariff. These can either be the production costs in the power plants of the electricity utility company or the costs for purchased electricity from other electricity producers (also in adjacent states) (BFE (e), 2011, p.6). Electricity is traded at the European Power Exchange SE (EPEX SPOT SE).

Levies to the municipal:

This component includes the levies that are given to the municipals, the cantons, or the government. Services in return for these costs are for example the streetlights in cities or municipals (BFE (e), 2011, p.6).

Levies for the funding of renewable energy systems:

The feed-in remuneration at cost (KEV) in Switzerland is a levy for the funding of renewable energy systems for the production of electricity. The KEV covers the difference between production cost and market price for suppliers of electricity from renewable sources (BFE (e), 2011, p.6). Therefore, electricity from renewable energy systems is supported by this levy. Supported systems are hydropower, photovoltaics, wind energy, geothermal energy, biomass and biological waste (BFE (o), online).

Figure 10. Components of the electricity tariff.
Source: Translated from (BFE (e), 2011, p.8).

In 2010, the system usage charge accounted for 47%, the energy price for 40%, levies for 11%, and the KEV for 2% of the tariff (BFE (e), 2011, p.8). Figure 10 shows the components of the electricity tariff. The figure is not true to scale for visualization purposes.

The Electricity Commission (ElCom) can review the system usage charge and the energy component of the tariff and adjust them if necessary.

1.2.6 Legal factors

In this chapter, legal factors of the PESTEL analysis are discussed.

1.2.6.1 Swiss ancillary service market

In Switzerland, there are different organizations with different responsibilities to secure a safe electricity supply. The main players are the following:

- **Swissgrid:** Swissgrid owns and operates the Swiss transmission grid that secures the transport of electricity to Swiss households. Swissgrid is also responsible for the maintenance and necessary expansion of the transmission grid (VSE (c), 2011, p.3). One of the main tasks of Swissgrid is the safe operation of the grid. This involves the constant observation of the frequency in the grid and other parameters. Swissgrid is responsible for the supply of distribution systems with electricity. Swissgrid coordinates the Swiss AS-market (Swissgrid (c), online).
- **Distribution system operators (DSO):** A DSO is responsible for the distribution of electricity in its area. In Switzerland, approximately 800 DSOs (swissgrid (f), online) are in charge of the distribution of electricity in their respective area. In addition to that, a DSO needs to provide measurement data to other players, which are active in the grid management (e.g. AS-market). Each DSO is responsible for the maintenance and expansion of its distribution grid (VSE (c), 2011, p.3).

Demand and supply always have to be equal in order to provide a safe electricity supply.
In order to achieve a balance in the grid, the Swiss ancillary service (AS) market has been introduced in 2009 (swissgrid (c), online). Therefore, swissgrid purchases the necessary control power from appropriate electricity producers. Control power can either be negative or positive, which leads to two different kinds of participants within the AS-market. In case of an excess supply or excess demand, swissgrid contacts the AS-provider, who then performs their pre-defined services (e.g. increasing or decreasing electricity production/demand).
Nowadays, the AS-market is dominated by hydropower. Since the electricity market is in a phase of restructuring, new renewable energy sources will become more important to provide positive and negative control energy in the future (Chacko, 2016).
A participant in the AS-market needs to meet various requirements. The most important requirements are shown in Table 10.

Table 10. Products in Ancillary service market.
Source: Based on (swissgrid (e), 2015).

Type control power	Primary	Secondary	Tertiary
Amount	± 74 MW	± 400MW	+ 450 MW - 300 MW
Range per offer	Min. ± 1MW Max. 25MW	Min. ± 5 MW Max. 50 MW	Min. + 5 MW or -5 MW Max. 100 MW
Tendering period	Weekly, Monday 00:00 – Sunday 24:00	Weekly, Monday 00:00 – Sunday 24:00	Daily in 4 hour periods or weekly

Since a single heat pump does not provide enough power to meet the requirements of Swissgrid, heat pumps can be pooled in a virtual generating unit and operate as one supplier of control power.
Heat pumps can either provide primary, secondary and tertiary control power. The provision of primary or secondary control power requires a model predictive control, which enables to anticipate if and when control power is needed.
When supplying swissgrid with secondary or tertiary control power, 5 MW is the minimal amount of power that can be offered.
According to Swisscom Energy Solutions (Vogel, 2015), every household, which is externally controlled in order to provide control power to Swissgrid, can supply 1kW of power. This value is assumed for the following calculation. This value of 1kW already assumes that not each and every household can supply Swissgrid with control power at the same time, since some of the heat pumps are always in operation or just recently stopped operating. Tiko aims for the supply of 5 MW of control power (Vogel, 2015).

Power per household = 1kW
Amount required = 5MW

Households required = $\frac{\text{Amount required}}{\text{Energy per household}} = \frac{5\ \text{MW} * 1000}{1\ \text{kW}}$ = <u>5000 Households</u>

According to the calculation above, at least 5000 households are required to be able to provide secondary or tertiary control power to Swissgrid. To provide a safe amount of control power, even more households are required.

The legal basis of pooling electric loads to fulfil the requirements of Swissgrid was established in 2013. Swissgrid, in cooperation with the association of Swiss electricity companies (VSE), published a document concerning the control energy pooling to enable ancillary services. Two main changes were applied:

- Technical systems in network levels 5 and 7 are allowed to bundle their energy systems into a virtual generating unit for supplying control energy. There are no limitations in terms of size and type of the virtual generating unit (swissgrid (d), online).
- Technical systems can be integrated into balance-group-neutral control energy portfolios across Switzerland regardless of their balance group affiliation (swissgrid (d), online).

These changes enable a broad range of potential control energy suppliers to contribute their energy to the grid. Due to these changes, the dependence on hydropower decreases. Consequence of which is a diversified control energy supply and, therefore, risks in the Swiss electricity supply are reduced.
This approach is currently discussed in other AS-markets in Europe. This approach is considered a consistent and innovative solution (swissgrid (d), online).

The key points in brief:

- Swissgrid purchases control energy from appropriate electricity producers in order to keep the grid in balance.
- Pooling of heat pumps is allowed in Switzerland.
- 5MW is the minimal amount that has to be provided by a pool of heat pumps.
- Approximately 5000 households (with heat pumps) are necessary to provide 5 MW of control power.

1.2.6.2 System usage charge in Switzerland

As previously discussed in chapter 1.2.5.3, the electricity tariff is divided into four components. Relevant for this chapter is the system usage charge of the tariff. Usually, revenues made from this component of the tariff are used for the maintenance and expansion of the grid. The Swiss Federal Electricity Commission (ElCom) can review this part of the tariff and decrease it if necessary (BFE (e), 2011). For distribution system operators (DSO), it is important to know which activities are chargeable to the system usage charge.

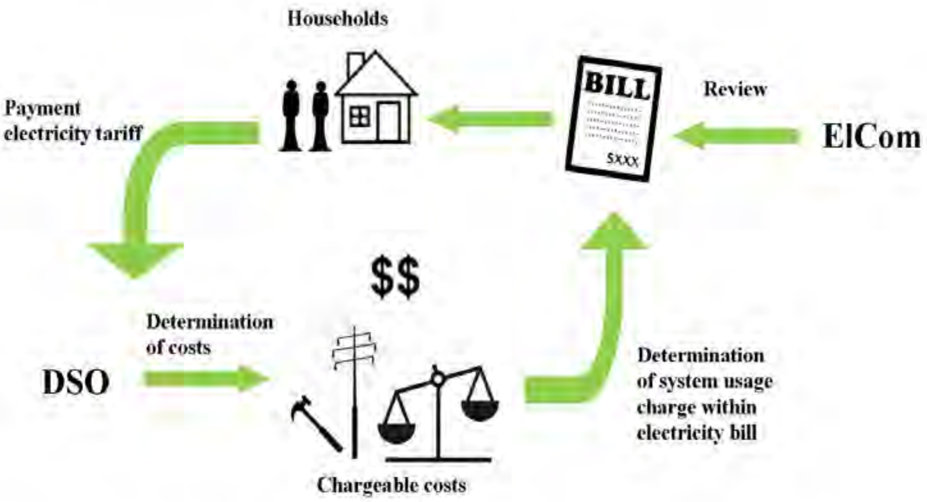


Figure 11. System usage charge.
Source: Own figure.

Figure 11 shows the process of how the system usage charge is determined. First of all, the DSO determines all relevant operational and capital costs. These costs include especially all costs for maintenance of the grid and all costs for required control power. The expected revenues of the system usage charge generally have to be equivalent to the imputed costs of the grid. Afterwards, the system usage charge is reviewed by ElCom and decreased if necessary. The system usage charge usually remains unaltered for one year at a time. Once the system usage charge has been approved by the ElCom, households receive their respective invoices and the DSO gets paid (Cuderman, (2014), p.19-23).

It is the responsibility of ElCom to secure that only the right costs (e.g. control power, maintenance of the grid) can be charged to the system usage charge (to the customer) in order to avoid an excessive tariff. In the past, ElCom often communicated that pilot projects, which involve the utilization of smart grid technologies, are chargeable under certain preconditions. A precondition for the chargeability is that the costs of these projects are necessary for an efficient, productive and safe electricity grid in the future (ElCom, 2015).

In 2015, ElCom specified the chargeability of projects to the system usage charge. According to the newsletter 03/2015, ElCom announced that projects, whose value for the operation of the grid is not predictable, cannot be charged to the system usage charge. Moreover, only criteria of article 15 of the Federal Electricity Supply Act (StromVG) are decisive for the assessment of the chargeability of costs (ElCom, 2015).
It is being said that costs (of the electricity utility companies) for the expansion of the grid are definitely chargeable and, therefore, those investments can be shifted to the end-customers (BFE (f), 2015). Projects that include the expansion of the grid are cost intensive, but they directly contribute to a safe grid in the future. Therefore, the value for the grid is obvious.
In contrast to that, the value of projects that include new innovative measures to reduce peak loads in grids or other smart grid technologies, do not have an obvious value for the grid. It is difficult to estimate the future value for the safety of the grid (BFE (f), 2015, p.69-71). As a result, innovative measures cannot be shifted to the end-customers according to current regulations.

Art. 15 of the StromVG (2012) (in german):

> 1 Als anrechenbare Kosten gelten die Betriebs- und Kapitalkosten eines sicheren, leistungsfähigen und effizienten Netzes. Sie beinhalten einen angemessenen Betriebsgewinn.
> 2 Als Betriebskosten gelten die Kosten für die mit dem Betrieb der Netze direkt zusammenhängenden Leistungen. Dazu zählen insbesondere die Kosten für Systemdienstleistungen sowie für den Unterhalt der Netze. [...]

It is questionable whether this approach is sufficient or not. This system fails to provide incentives for investing in innovative measures and technologies. Investments in new technologies are always associated with financial risks. The conventional expansion of the grid is a safe investment compared to the engagement in new technologies and, therefore, many companies choose to pursue the safe option of expanding the grid.

Nowadays, heat pumps themselves could be relatively intelligent, since they can be remote controlled if necessary. Nevertheless, a heat pump itself cannot contribute control energy to a future Swiss smart grid. An intelligent infrastructure is required for the smart control of heat pumps.

The key points in brief:

- Article 15 of the StomVG is decisive for the assessment of chargeability.
- Conventional measures (e.g. expansion of the grid) are definitely chargeable, since they have a direct contribution to a safe and efficient grid
- New technologies (e.g. smart grid/ smart meter-technologies) are not chargeable, since they have an unpredictable impact on the grid.
- New technologies have a higher financial risk.
- A smart grid infrastructure is required in order to integrate heat pumps.

1.2.7 Potential of heat pumps in the ancillary service market

As previously discussed in chapter 1.2.6.1, heat pumps are able to contribute control power to Swissgrid in order to provide a safe energy supply in Switzerland. The share of heat pumps is very low today. In the last 4 years (2012 – 2015), the peak value of control power amounted to approximately 500MW (Swissgrid (b), 2015). Tiko's network of heat pumps and other heating devices can contribute 5MW to Swissgrid. This accounts for 1% of the required amount of control power during peak times. Since there are more heat pumps installed in Switzerland than those in the Tiko network, there is undoubtedly potential for heat pumps in smart grids.

Figure 12 shows a graph with operating numbers of heat pumps and their power consumption. The black line indicates the total number of installed heat pumps in Switzerland. The grey line indicates the annual number of heat pumps sold in the respective years. The dark green line indicates the total power consumption by those heat pumps and the purple line shows the maximum control power required by Swissgrid in the last 4 years. The bright green line indicates the thermal power produced by those heat pumps.
The values used in the diagram can be found in the appendix (A6).

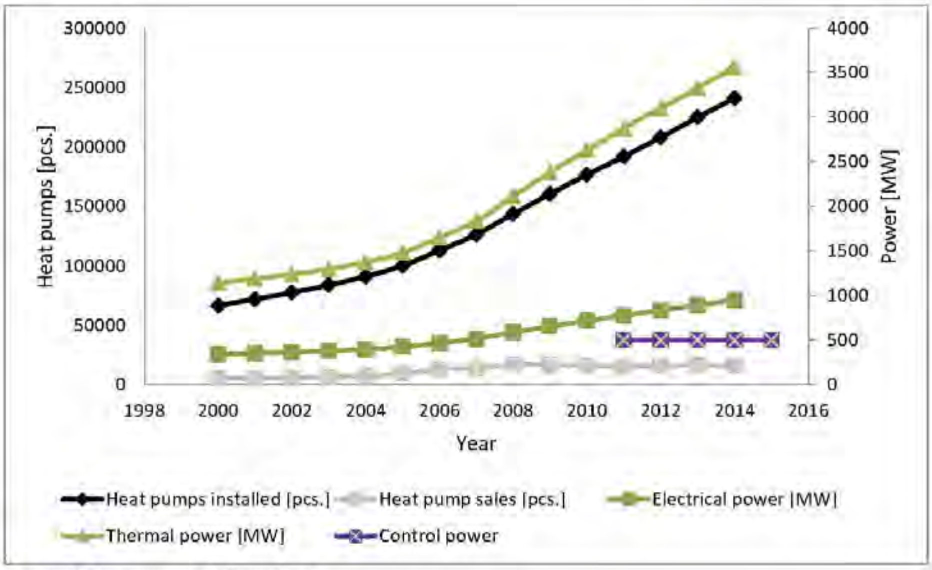


Figure 12. Heat pumps in Switzerland.
Source: Own figure. Based on (BFE (g), 2015) and (Swissgrid (b), 2015).

In the early 2000's, heat pump sales were steadily increasing until 2008. In 2008, heat pump sales were peaking and they remain relatively steady since then. Heat pump sales amount to approximately 16'200 units per year on average since 2008. In 2014, a total of 240'887 heat pumps were installed in Switzerland.

As the number of heat pumps is increasing, the amount of electric power used by heat pumps is increasing accordingly. The amount of electric power consumed by the installed base is steadily increasing and most recently amounted to 950 MW in 2014 (BFE (g), 2015, p.52). Compared to the average amount of control power needed by Swissgrid, this is almost twice as much.

From 2011 to 2015, the maximal required control power amounted to 400MW – 500MW. For the purpose of the following scenarios, a peak value of 500MW is assumed.

In comparison to the increasing electric power consumption, the output of thermal power shows a stronger increase. This is a good indicator for the efficiency improvements over the last decade.

1.2.7.1 Scenario "TIKO"

In the Tiko network, every household (indirectly every heat pump) is assumed to be able to provide 1 kW of control power. Today's heat pumps have power ranges from less than 20 kW to more than 100 kW. Therefore, a single household is most likely able to provide more than 1 kW, but since not all of the households are able to provide their power at the same time, a general value of 1 kW is assumed. This value is assumed for the following calculation.

Tiko was interviewed about their predictions for the future. They assume to reach a final size of 70'000 households in their network (Vogel, 2015). Geidl assumes that other loads (e.g. batteries, electric cars) could also be integrated in the Tiko network (Geidl, Interview, May 10). Therefore, this value could potentially further increase.

Power per heat pump	=	1 kW
Assumed final amount of heat pumps in the Tiko network	=	70'000
Total contribution of control power	=	1 kW * 70'000
"	=	<u>70 MW</u>
Required maximum amount of control power (2014)	=	<u>500 MW</u>
Share of heat pumps in providing control power	=	$\frac{70\ MW}{500\ MW}$
"	=	<u>14%</u>

The calculation above shows that almost one fifth of the required control power could potentially be provided by heat pumps in the Tiko network during wintertime.

Only small heat pumps are integrated in the Tiko network since mostly households form the network. If also larger heat pumps could be integrated, the share could be potentially higher. This is evaluated in an additional scenario in the following chapter.

The key points in brief:

- The amount of installed heat pumps is steadily growing.
- The peak value of control power amounted to 500 MW in recent years.
- Tiko currently connects approximately 5500 households to a smart grid and provides 5 MW of control power to Swissgrid during wintertime.

1.2.7.2 Scenario "overall"

This scenario assumes that all heat pumps in Switzerland could contribute their share to a national network similar to Tiko. For the purpose of this scenario, the Tiko scenario is viewed differently:

- The Tiko network mainly includes small heat pumps from the range <20kW. For the purpose of this scenario, it is assumed that all heat pumps in the Tiko network have a power of **10kW.**
- Since the Tiko network values all heat pumps as 1kW, it is assumed that all heat pumps can contribute **10%** ($\frac{1kW}{10kW}$) of their power as control power.

Figure 13 shows all installed heat pumps and their respective power.

As mentioned, for the purpose of this scenario, all heat pumps in the first category (P<20kW) are assumed to have a power of 10kW. This assumption continues through all power categories, as is shown in the appendix (A6).

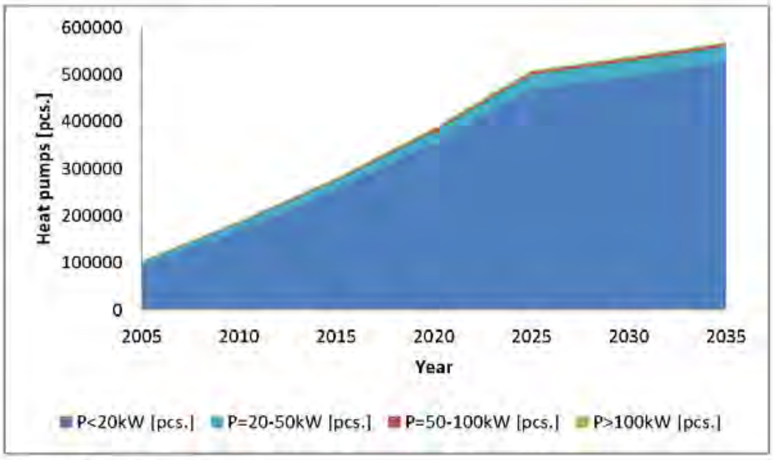


Figure 13. Power of installed heat pumps.
Source: Own figure. Based on (Leuzinger, 2015, p.58)

The assumed power in each category is multiplied with 10% and the number of heat pumps in the respective year and category. All values in one year can be summarized to a total amount of control power, which can be provided by the installed base of heat pumps. The calculated values for all periods can be found in the appendix (A6).

Control power (2020)	= 479'081kW	= 479,081MW	(95.8% of max. control power)
Control power (2035)	= 706'151kW	= 706,151MW	(141% of max. control power)

The calculation shows that the potential for control power supply is high. It is assumed that the demand of control power remains steady, even though the tendency currently shows that the necessary amount of control power is decreasing (swissgrid (b), 2015, p.17). The expansion of PV-systems could potentially lead to an increasing demand of control power in the future.

The key points in brief:

- There is a high potential for the supply of control power by heat pumps in Switzerland.
- Theoretically, the demand of control power could be covered by heat pumps during wintertime in 2035.

1.2.7.3 Scenario "overall summer"

In the scenario "overall", the heat pump was used for both room heating and hot water heating. In this scenario, it is assumed that there is no need for room heating during summer. Therefore, only the percentage of hot water heating is required.
Since the process of hot water heating is also a flexible process, which can be postponed for a certain amount of time, there is a potential to provide control power. By heating water when electricity demand is low and postponing water heating when demand is high, the grid can be relieved.
It is being said that this is a simplified scenario that should give a first impression of the provision of control power during summer. In reality, other parameters (e.g. variable COP for room heating and hot water heating purposes, efficiency deviations) would have to be considered.

First, the total electricity consumption was analysed. According to the SFOE, 12.3 PJ (3416,7 GWh) was used for room heating and 8.5 PJ (2361.1 GWh) was used for hot water heating (BFE (n), 2015, p.28). It is assumed that only electric heating systems and heat pumps use electricity for room and water heating purposes. Therefore, the share of heat pumps of the electricity consumption has to be calculated. The calculation can be found in the appendix (A7).
The results of the calculation show that in room heating and hot water heating, 53.2% and 13.3% respectively are used by heat pumps. This amounts to 1817.7 GWh (room heating) and 313.4 GWh (hot water heating) respectively. According to these values, a ratio of 1:5.8 is evaluated
This ratio is used to calculate the required power by hot heat pumps for water heating purposes. The installed electric power of heat pumps amounted to 950MW in 2014 (BFE (g), 2015). According to the previously calculated ratio, a power of 139.7MW is required by heat pumps for hot water heating purposes.
Since the flexibility of hot water storages is higher than the flexibility of room heating, it is assumed that a higher percentage of the required power can be provided as control power. In this scenario, it is assumed that 25% of the required power can be provided as control power. Therefore, control power provided by heat pumps during summer amounts to 34.9MW.

In summary, considering that all heat pumps in Switzerland combined are able to provide this amount of control power, the potential is relatively low. The pooling of loads during summer is not profitable for a smaller amount of heat pumps.
Nevertheless, there is a high potential of decentralized intelligence for heat pumps in summer. Since hot water can be stored in hot water storages throughout the day, it can definitely help to reduce peak loads by heating water when the demand is low. As previously discussed in chapter 1.2.4.7, hot water storages have a high flexibility. It takes several hours until the temperature in the water storage decreases past the lower tolerance limit. Therefore, the operations of heat pumps in summer can be shifted without affecting living comfort. In order to do so, it is necessary to act smart. Grid conditions have to be monitored, weather forecast could be analysed, and/or dynamic tariffs have to be provided by DSOs.

The key points in brief:

- During summer, the control power provided by heat pumps is relatively low concerning that all heat pumps in Switzerland are included in the calculation.
- There is still a high potential for the smart operation of heat pumps in order to reduce peak loads.

1.2.8 Evaluation of PESTEL analysis

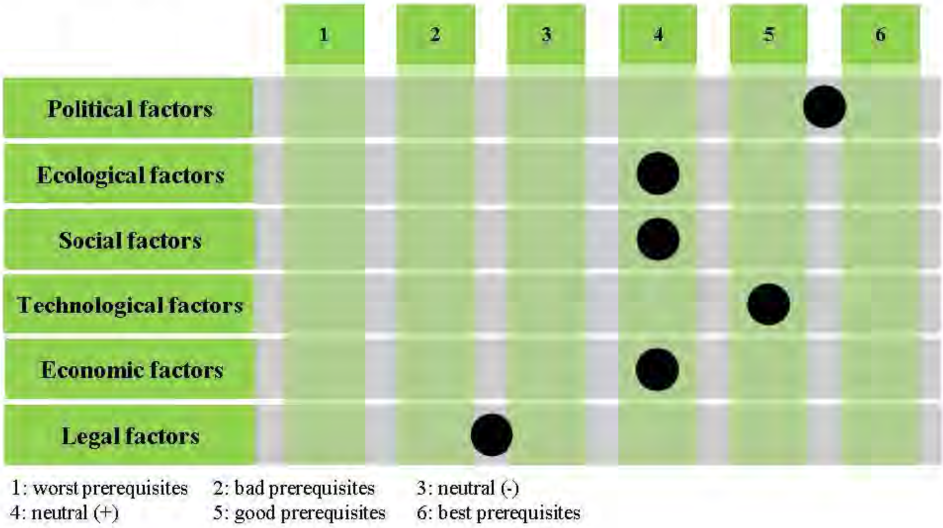


Figure 14. Evaluation of PESTEL analysis.
Source: Own figure.

Figure 14 shows an evaluation of every factor within the PESTEL analysis. Every factor is ranked from 1 (worst prerequisites) to 6 (best prerequisites). Rankings 3 and 4 are neutral with a tendency to either good or bad prerequisites.

Political factors:
The energy strategy builds a foundation for the integration of heat pumps in smart grids. The targets of the Swiss energy strategy 2050 help to accelerate the process. The prohibition of pure electric heating systems or electric boilers encourages the installation of heat pumps. Furthermore, the increasing CO_2-taxes make heat pumps the ideal alternative to traditional fuel based heating systems, since heat pumps have low CO_2-emissions.
Existing buildings can be renovated to make an efficient heat pump system achievable. The building programme in the three scenarios supports the renovations of buildings.
To sum up, the politics in Switzerland overall encourage the utilization of heat pumps and, therefore, with an increasing market share, the integration of heat pumps in a smart grid is further developing.

Ecological factors:
Ecological factors do not have a significant impact on the integration of heat pumps in a smart grid. It is being said that nature will benefit from a broader utilization of heat pumps because CO_2-emissions could be significantly decreased. A prerequisite for lower CO_2-emissions is that the production of electricity also uses renewable energy sources.
In summary, ecological factors are ranked as neutral with a tendency to good prerequisites because the environment can benefit from an integration of heat pumps.

Social factors:
The awareness for environmental issues has a positive effect on the utilization of heat pumps. People tend to be more interested in topics such as their own electricity consumption and where their electricity originally comes from.
The social factors do not have a direct impact on the integration of heat pumps. The increasing interest in energy related questions will have a positive effect in the long-term. To sum up, the social factors are ranked neural with a positive tendency.

Technological factors:
Nowadays, heat pumps are technologically ready for smart grid integration. Heat pumps can be controlled externally and are able to operate on different levels, depending on required power consumption. Heating processes offer a high flexibility to the grid, since a temporal deferral of electricity consumption is possible.
The necessary technologies for a smart infrastructure in Switzerland are available, but have not reached diffusion in the market yet. Distribution system operators (DSO) do not extensively use these technologies today.
Since the technologies are available, the technological factors are ranked positive as good prerequisites.

Economic factors:
The increasing decentralized electricity production leads to a necessary expansion of the grid. The utilization of smart grid technologies allows reducing this expansion. The integration of heat pumps in a smart grid is one possibility to significantly reduce the expenses for modifications of the grid.
Furthermore, an integration of heat pumps in a smart grid can create new jobs in the sectors of research & development, planning and installation of heat pumps, and maintenance of the grid.
To sum up, the economic factors are ranked neutral with a positive tendency.

Legal factors:
The possibility to shift costs to the end-customers is important for DSOs. Current regulations state that costs for the maintenance of the grid are chargeable to the system usage charge, which is paid by all end-customers as a part of the electricity tariff. Even more important is the fact that innovative measures such as the implementation of smart grid technologies or smart metering are not chargeable to the electricity tariff. This leads to hesitations of DSOs to invest in new technologies, since the financial risk is high.
In addition to that, the requirements of Swissgrid are relevant for heat pumps. A single heat pump does not have enough power to supply control power to Swissgrid. Pooling of heat pumps in a virtual generating unit is allowed and, therefore, participation in the ancillary service market is possible.
To summarize, the legal factors are ranked as slightly negative prerequisites because of the obstacles in investing in new smart technologies.

1.3 Stakeholder analysis

A stakeholder analysis is a tool to identify the key stakeholders for a project or any other activity. It is important to know who the stakeholders are, where they are located and what their interests are. The main target of such an analysis is to ensure that all stakeholders are observed and that their interests are satisfied. It is important to constantly review a stakeholder analysis in order to recognize new stakeholders, which could arise.

In this chapter, the most important stakeholders concerning the utilization of heat pumps in a smart grid in the future are analysed.

The stakeholder analysis in this thesis is based on the PESTEL-analysis in the previous chapters. All involved parties, which emerged in the process of the environmental analysis, are summarized in this analysis and other parties are added.

1.3.1 Methodology

The stakeholder analysis process includes several steps:

1. Identification of all Stakeholders
   - ➔ Brainstorming, mind mapping
2. Stakeholder analysis
   - ➔ Categorization of stakeholders according to interest and influence
3. Assessing of results

1.3.2 Results

The first step included a mind map to identify all important stakeholders. All involved parties from the PESTEL-analysis and beyond were visualized.

Afterwards, all stakeholders were categorized into a stakeholder matrix. Influence of a stakeholder was chosen as the Y-axis, since it is important to know, which parties have the biggest impact on the integration of heat pumps in a smart grid. The X-axis is described by the interest of a stakeholder.

Figure 15 shows the stakeholder matrix with all identified stakeholders.

IEA HPC Annex 42: Task 4 Application and monitoring

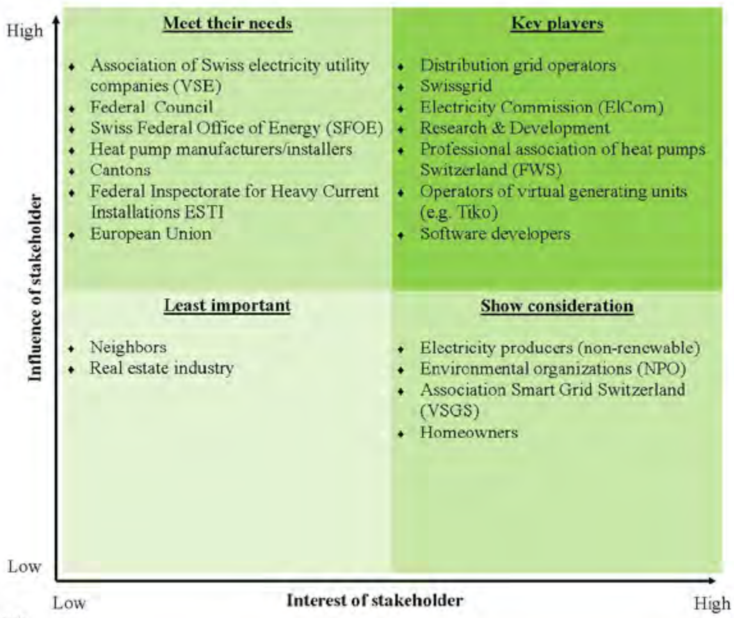


Figure 15. Stakeholder matrix.
Source: Own figure.

49

1.3.3 Evaluation of stakeholder analysis

<u>**Key players**</u>

Distribution grid operator	DSOs are responsible for the maintenance and operation of the distribution grid in Switzerland. The diffusion of smart technologies such as smart meters and others, which is important for making a smart operation of heat pumps possible, is crucial for the success of a future smart grid integration of heat pumps. DSOs are interested in making heat pumps smart since it can be beneficial for the balance in the grid.
Swissgrid	Swissgrid is interested in a better integration of loads (such as heat pumps) in the electricity grid to reduce the required control energy. Swissgrid is interested in a diversified Swiss ancillary service market. An AS-market, which is dominated by one or very few players, is vulnerable for artificially higher market prices for control power. Whereas an AS-market with many additional players (e.g. Tiko) tends to be more balanced (discussion, Swissgrid, May 31). It is being said that Swissgrid is especially interested in new players, which control a virtual generating unit of heat pumps in order to provide control power to Swissgrid. Swissgrid owns the transmission network, which delivers electricity to the distribution network. Therefore, Swissgrid has also a high influence.
ElCom	ElCom is responsible for the chargeability of costs of DSOs. They have a high influence since they can accept or decline charged costs of DSOs. This has a significant impact on investments, which are made by DSOs. Therefore, the diffusion of smart grid technologies is also dependent on regulations that are enforced by ElCom.
Federal council	Similar to ElCom, the federal council is indirectly responsible for the Federal Electricity Supply Act (StromVG). The StromVG is decisive for the chargeability of costs to the system usage charge. The federal council can apply changes in the StromVG that can have a significant impact on the behaviour of DSOs.
Research & Development	An efficient operation of heat pumps in a smart grid is highly dependent on software knowhow and appropriate control systems. R&D, for example in universities or companies in this sector, is unofficially responsible for the development of necessary technologies.
Operators of virtual generating units (e.g. Tiko)	Operators of virtual generating units can have a high impact on the AS-market, since the market structure alters when additional small suppliers of control power enter. The interest of these operators is high, since they are active in this sector.
Software developers	One key technology of the integration of heat pumps in a smart grid is appropriate software. The connections of loads as well as the communication between different parties in the distribution grid are crucial functions, which are required in a smart grid. Therefore, software developers are a key player in the industry.

A future Swiss smart grid requires a lot of work and manpower. Therefore, software developers are interested in an implementation of the Swiss smart grid vision.

Meet their needs

VSE The VSE is an organization that supports electricity utility companies in Switzerland. The VSE co-creates the political framework concerning the Swiss electricity sector. Therefore, they can have a high influence on the financing of smart technologies. Furthermore, VSE acts as a communication platform and informs the public about the electricity sector.

FWS The FWS bundles all organisations that are active in the Swiss heat pump sector. The target of the FWS is to exhaust the whole potential of heat pumps by coordinating activities and spreading information to all involved parties. Furthermore, the FWS introduced the "heat pump-system-module"-label, which is used to standardise the procedure of planning and installation of heat pumps. This label could potentially help to promote heat pumps as an attractive alternative to other heating systems.

SFOE The SFOE has a big impact on the development of new technologies, which are related to heat pumps. The SFOE co-finances and supports several projects of universities and other involved parties to accelerate the progress. Furthermore, the SFOE is involved in the elaboration of new regulations.

Heat pump manufacturers Heat pump manufacturers are responsible for further development of heat pumps. The efficiency (coefficient of performance) and the distribution in the market belong to their core competencies. They have a high impact on the diffusion in the market, since their products have to convince potential customers. The potential supply of control power depends on the diffusion of heat pumps in the market.

Cantons All cantons in Switzerland have their own cantonal energy legislation. The introduction of the MuKEn is important in order to accelerate the diffusion of heat pumps. Therefore, each and every canton has the responsibility to introduce a good legal basis for heat pumps. Cantons have a high influence on the diffusion of heat pumps and thus on the potential supply of control power.

ESTI ESTI is responsible for the compliance of safety regulations and strictly monitors those. Projects for the public and private power supply in Switzerland have to be verified and approved by ESTI. An early involvement of ESTI is advantageous and can help to reduce problems in the project.

European Union (EU) The European Union has a high influence on the Swiss electricity market. The pressure from the EU to fully liberalise the electricity market is high. A liberalised market would have a high influence on the diffusion of smart grid technologies and, therefore, on the integration of heat pumps in a smart grid.

Show consideration

Electricity producers	Electricity producers could be interested in a better integration of loads such as heat pumps since the grid becomes more efficient by doing so. Therefore, an efficient grid can distribute more electricity, which potentially increases the sales of energy.
Environmental organizations	Environmental organizations have an interest in a better integration of loads, since this leads to a potentially reduced expansion of the grid. The Swiss landscape can be protected and the material consumption for power lines is reduced. Environmental organizations are often involved in objections that were made concerning the expansion of the grid or other projects. An early involvement of these organizations is important in order not to have problems in later stages of a project.
VSGS	VSGS is a Swiss organization that bundles 12 electricity utility companies. The target of VSGS is to encourage all members to develop a Swiss smart grid solution. It allows a communication across all members and beyond. VSGS has an interest in the smart integration of loads, since this would be an essential part of a Swiss smart grid.
Homeowners	Homeowners have a high interest in terms of financial benefits. By operating their heat pump optimally, electricity costs can be reduced. A basic prerequisite for this purpose is the provision of dynamic electricity tariffs by DSOs.

Least important

Neighbours	Neighbours can have an influence when it comes to the installation of outdoor air/water heat pumps. These might have a relatively high noise level, which could disturb neighbours.
Real estate industry	The real estate industry can have an influence on the diffusion of heat pumps, which is important for the future potential. The interest or influence of the real estate industry is relatively low in terms of the integration of heat pumps in a future smart grid.

2 Roadmap

In this part of the thesis, we take a closer look on the integration of heat pumps in a smart grid. The reasons for this particular integration are identified and necessary actions are evaluated. Furthermore, challenges ahead are analysed and the heating sector of the future is assessed.

The following questions are answered in this chapter:

- Why do we need heat pumps in smart grids?
- What are the options of making heat pumps smart?
- What is the current state and what needs to be done next?
- What does the increasing electrification of heat mean for the electricity grid?

2.1 Methodology

The methodology used in this chapter is called backcasting. The fundamentals of this method were outlined by John B. Robinson. Backcasting is used to identify the necessary actions to achieve a certain goal.
The first step in this methodology is the definition of a desirable future (targeted state). The future is predicted by current trends and regulations. In this particular case, various factors for a future integration of heat pumps in a smart grid are identified.
The next step includes comparing the targeted state to the current state. As a result, it is possible to evaluate necessary actions and policies that are required to reach the targeted state.
This methodology was also used in the Smart Grid Roadmap Switzerland (BFE (f), 2015).

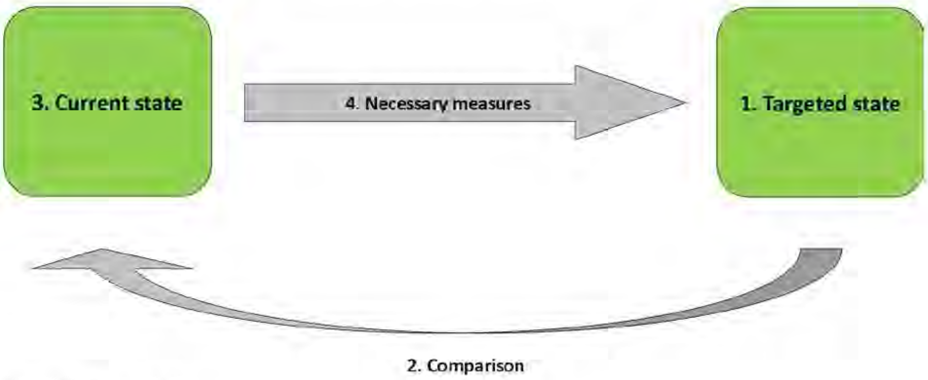


Figure 16. Backcasting.
Source: Own figure.

2.2 Results

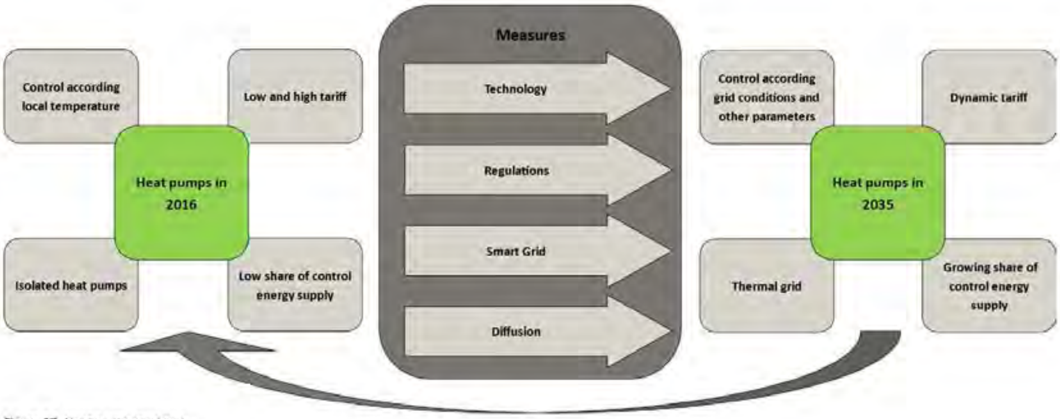


Figure 17. Heat pump roadmap.
Source: Own figure.

Figure 17 shows the heat pump roadmap. Both states include 4 parameters, including control of the heat pump, tariff structure, connection of heat pumps and the share of control power supply.

Control of the heat pump: In the future, a heat pump should be controlled according to local grid conditions and other parameters in order to relieve the grid. Nowadays, heat pumps are controlled according to local measured temperatures (inside & outside) by an ambient sensor. External control signals are only used during few times per day (ripple control system).
Tariff structure: In order to provide incentives for end-customers, it is necessary to have a dynamic tariff structure in the future. Nowadays, only a high tariff and a low tariff are available.
Connection of heat pumps: Today, heat pumps are isolated from other heat pumps. In the future, a thermal grid could provide a possibility to improve the flexibility in the electricity grid.
Share of control power: Nowadays, the share of control power provided by heat pumps is very low. In the future, as more electric heating systems are replaced by heat pumps, the share could potentially grow.
Achieving the mentioned targeted state requires several different measures.

2.2.1 Technology

New technologies

Nowadays, heat pumps are technically ready for the usage in a smart grid. Many Swiss heat pump manufacturers orient themselves to the "SG Ready"-label from Germany. Therefore, heat pumps can easily be remote controlled and the integration of other smart grid functions is possible.
The transmission grid (network level 1) is already actively smart controlled. Lower network levels are not controlled actively. This needs to change in the future in order to integrate heat pumps effectively. The monitoring of local grid conditions and the evaluation of these measured data are required in order to be able to provide control power with heat pumps. In order to do so, sensors in the grid are necessary. There are already projects (e.g. GridBox) that are working on this topic.
Furthermore, the measured grid conditions have to be evaluated and heat pumps or other devices have to act accordingly. One possibility to control heat pumps accordingly is via smart meters. It seems useful to make smart meters intelligent instead of heat pumps, since there are already thousands of heat pumps installed. Smart meters could operate heat pumps with the purpose of reducing peak loads and costs. Another possibility is to develop plug-on devices that allow a smart operation of heat pumps retrospectively. GridSense already produces plug-on solutions that can be integrated in heat pumps, boilers, or photovoltaic-systems (GridSense (a), online).
To sum up, a future smart grid requires an active monitoring of the conditions in a distribution grid and an accordingly intelligent control of heat pumps has to be realised.

2.2.2 Regulations

Chargeability of costs

Today's regulations hamper the development and utilization of smart grid technologies, which are required to extensively use heat pumps to provide control power. Current regulations define that only costs of the DSO, which are required for a safe and efficient grid, are chargeable to the system usage charge. Marianne Zünd, head of media & politics at SFOE, states that if it was defined, that an efficient grid is considered a smart grid, costs for innovative technologies could also be charged to the system usage charge. According to Zünd, this would be an incentive to invest in smart grid technologies. Zünd assumes that regulations will be adapted accordingly in the near future (BKW (c), 2015, 36:25).

Reduction of system usage charge

An additional regulation, which could help to encourage the utilization of heat pumps, is the reduction of the system usage charge for homeowners with heat pumps. Homeowners that use heat pumps to produce heat could benefit from a lower system usage charge. Germany is a role model in this context. Homeowners in Germany have the possibility to concede the control of their heat pump to a local DSO for network relief purposes (EnWG, online, § 14a) and in return, they receive a lower system usage charge. Only the control of interruptible devices (e.g. heat pumps, electric cars) can be conceded to DSOs in Germany.

Liberalisation of Swiss electricity market

Today, the Swiss electricity market is partly liberalised. This means that consumers, which have an electricity consumption higher than 100MWh per year, can freely choose their electricity supplier in a free market. Consumers with less than 100MWh electricity consumption per year are bound by their local electricity utility company and its respective offer.

The complete market liberalisation is requested by the European Union for a long time in the course of the bilateral electricity agreement. A complete liberalisation is planned to be in force by 2018 – depending on the agreement of the parliament and a possible referendum (BFE (f), 2015, p.70).

A liberalisation of the electricity market would also have an impact on the diffusion of innovative smart grid technologies. A liberalisation generally increases the competition in the electricity market and, therefore, provides an incentive to invest in innovative technologies in order to have a unique selling proposition compared to competitors.

Noah Heynen, managing director of Helion Solar, states that the non-liberalised electricity market is an obstacle for the diffusion of innovative technologies in the Swiss market (presentation, May 31, Powertage 2016).

To sum up, new regulations are important to encourage investments in new technologies rather than investing in a traditional expansion of the grid. The electricity market is likely to alter significantly after a possible complete market liberalisation.

2.2.3 Smart grid

Electrification of heat

Nowadays, room heating and hot water heating account for approximately 19.4% and 13.5% respectively of the total electricity consumption (BFE (n), 2015, p.29). With increasing numbers of heat pumps installed, this amount is going to significantly increase in the course of the Swiss energy strategy 2050. While the consumption of other energy sources (e.g. fuel, gas) is going to decrease, the electricity consumption for heating purposes is likely to increase (VSE (a), 2013, p.6).

A smart control of heat pumps can reduce the increase of electricity consumption. Furthermore, measures to improve energy efficiency can decrease the electricity consumption additionally.

A smart grid itself does not reduce the electricity consumption. Heat pumps still require electric energy. Optimized operations of heat pumps can decrease electricity consumption. Therefore, a smart grid is a tool to efficiently manage the existing capacity of the grid.

Smart meters

In a future smart grid, a dynamic tariff structure is required. This is important to enable customers to act according to the situation in the grid (DR). The dynamic tariff will be transmitted to a smart meter system, which is also necessary in the future.

According to conditions in the European single market, the diffusion of smart meters within EU countries has to be realised by 80% by 2020 (VSE (b), 2013, p.5). The standardisation and compatibility with smart meter regulations in Europe will have a high impact on the smart meter strategy in Switzerland. In Switzerland, the investments for approximately 4 Mio. smart meters are high and require several years. It has yet to be defined, who has to bear the costs for an extensive smart meter installation. Since the main benefit lies at the customer side, costs should at least be chargeable to the system usage charge for DSOs. The initial measure package of the Swiss energy strategy 2050 should include adapted regulations (Art. 15 of the StromVG, see also chapter 1.2.6.2) concerning the chargeability of costs for defined smart meter systems (VSE (b), 2013, p.8).

2.2.4 Diffusion

Adjustments of the MuKEn

In order to increase the share of control power provided by heat pumps, the absolute market size of heat pumps needs to grow. The MuKEn already prescribes that all electric heating systems need to be replaced within 15 years after the enactment of the legislation. Most of the electric heating systems will most likely be replaced by heat pumps (VSE (a), 2013, p.6). Additionally, the increasing taxes for CO_2-emissions also encourage the utilization of heat pumps.

Separate electricity tariff

Another approach, which could potentially improve the diffusion of heat pumps, is a current project of the BKW Energie AG. BKW is currently planning to introduce a separate electricity tariff for heat pumps. This would give customers in the BKW network an incentive to replace their existing heating system by a heat pump. On the one hand, this new tariff would be used to relieve the grid. On the other hand, this new tariff would be less expensive than the previous one, which would encourage using heat pumps (discussion, BKW, May 31).

Future business models

A future business model for DSOs is the so-called heat contracting with heat pumps. In this case, a DSO could cooperate with partners, for example with a heat pump manufacturer, to distribute entire heating solutions. The DSO could use its strong regional presence to leverage the new business model. In heat contracting, the DSO is responsible for the planning, installation and financing of the heating system. In return, the homeowners pay a monthly fixed price for the installation, maintenance and operation. Additionally, a variable energy price has to be paid. Heat contracting can help to accelerate the diffusion of heat pumps, since many homeowners have concerns to make the initial investment. Few DSOs in Switzerland already offer heat contracting, mainly with other heating systems. One example is the AEW Energie AG in Aarau, in the canton of Aargau.

It is being said that the diffusion of heat pumps in Switzerland is further growing with the existing policy framework.

3 Discussion

This chapter is used to critically reflect back on the applied methodologies and the key findings in this thesis.

3.1 Expansion of the grid

The main reason for the potentially necessary expansion of the grid is the decentralized electricity production. With the discussed measures in this thesis, the expansion can be reduced. In regards to heat pumps as a tool to reduce peak loads, the ratio between decentralized electricity production and the flexible power of heat pumps is relatively low. This means that the maximum power of decentralized electricity production is significantly higher than the installed flexible power of heat pumps (BFE (f), 2015, p.66).
That being said, the grid needs to be dimensioned in a way that the maximum decentralized electricity production can be fed in the grid at any time. The worst case would be a high decentralized electricity production coupled with very low consumption (as it can occur in summer). As a result, even if the loads in the grid can be operated smart, the grid still has to be dimensioned according to the maximum possible decentralized electricity feed-in.
This does not mean that load management is not reasonable. In most of the time, load management can contribute an important share to the safety of the grid. Whereas in bottleneck situations, load management is not sufficient and the decentralized feed-in has to be managed additionally.
A possible solution for this issue is feed-in management, which allows restricting the electricity production of decentralized systems such as photovoltaic or wind turbines.

3.2 Intelligence of heat pumps

It is a controversial issue, whether the necessary intelligence should be in the heat pump, in an internal (in the household) hub or in an external (e.g. at the DSO) hub.
Many Swiss heat pump manufacturers orient themselves to the German SG-ready label. This label defines 4 different operating conditions, which have to be possible to implement. It is questionable, whether these operating conditions are sufficient in a future smart grid. For an optimal operation of a heat pump, more parameters should go into consideration. Generally, the smarter a heat pump is, the bigger are the opportunities when it is integrated in a smart grid.
Capacity control of an air/water heat pump includes a big potential in smart grids. It guarantees more flexibility in terms of a higher heat-range decoupled from the ambient-temperature and higher efficiencies for the heat pump itself. To increase flexibility, it should be possible to control heat pumps according to their power input. The possibility to targeted overheat heat pumps could be beneficial for the grid. In order to implement such approaches, the internal control system of heat pumps has to be further developed.

3.3 Improving efficiency and reduction of electricity consumption

The potential provision of control power is dependent on the total consumption of electricity by heat pumps. Improvements in the efficiency of heat pumps lead to lower electricity consumption, which is generally desirable and valuable. Furthermore, the insulation of buildings becomes better in terms of thermal inertia. This means that heat is exchanged with the surroundings at a slower pace. Therefore, the electricity consumption for heating purposes can be reduced as well.
These improvements can potentially lead to a lower provision of control power to the grid.
On the contrary, increasing numbers of installed heat pumps have an opposite (positive) effect on the potential of heat pumps to provide control power.

4 Final considerations and outlook

This chapter summarizes all key findings from this thesis and identifies the need for research in the future.

4.1 Summary of the results

The trigger for the question, whether heat pumps should be integrated in a smart grid, is the abandonment of nuclear energy. In the future, renewable electricity production (e.g. photovoltaic, wind energy) is encouraged in the course of the Swiss energy strategy 2050. This leads to high decentralized electricity production and to a high feed-in in lower voltage levels. Lower voltage levels are not designed for the high feed-in in the future. Therefore, voltage problems are likely to occur.
A possibility to decrease voltage deviations from the nominal value is the utilization of controllable local grid transformers or reactive power consumption. Moreover, the decentralized feed-in can be reduced by optimizing self-sufficiency (e.g. with BKW Home Energy). Heat pumps can help to locally store electricity as thermal energy in a buffer storage (technical thermal storage) or in the building itself.
Furthermore, stochastic electricity suppliers complicate the balance between supply and demand, which is crucial for the safety of the electricity supply. Deviations in the frequency from the nominal value of 50Hz require control energy. There are different possibilities to produce control energy. Direct supply of control energy includes the centralized control of many heat pumps to increase or decrease (negative or positive control energy) the electricity consumption (e.g. Tiko).
Indirect supply of control energy includes the local smart control of heat pumps. The target is to reduce peak loads in the grid by operating heat pumps during times of low demand and postponing the operation during times of high demand. Heat pumps have a high flexibility to postpone heating processes, whereas other loads, such as illumination or entertainment electronics, are not flexible. Monitoring of grid conditions is crucial for the operation of local smart heat pumps (e.g. Gridbox, GridSense).
Software developers are an essential part of a future Swiss smart grid. It is important to find a balance between the utilization of smart grid technologies and the traditional expansion of the grid. Specific software tools can help to simulate different scenarios (e.g. Warmup, Adaptricity).
The overall potential of heat pumps to provide control energy is dependent on the total diffusion in the Swiss market. Current regulations encourage the utilization of heat pumps. The MuKEn prescribes that all electric heating systems have to be replaced within 15 years after the enactment of the legislation. Furthermore, taxes for CO_2-emissions are going to be increased in the near future. This favours heat pumps since CO_2-emissions are low.
While regulations concerning heat pumps in general are advantageous, the integration of heat pumps in smart grids faces challenges. The extensive utilization of smart grid technologies, which are important for a further integration of heat pumps, develops at a slow pace. The costs for smart grid technologies cannot be charged to be end-consumers by DSOs. As a result, investments in smart technologies are always associated with financial risks.
Calculations show that there is a high potential to provide control energy with heat pumps. The potential differs during the four seasons, since heating demand is low during summer. There is still a high potential to control hot water heating of heat pumps according to the local grid conditions in summer.

4.2 Recommendations for the company

This bachelor thesis includes task 4 of the IEA Annex 42. Nevertheless, the Swiss electricity market should be monitored in order to identify additional relevant projects, which either were not identified in the course of this thesis or might arise in the future.

Policies and regulations concerning the utilization of heat pumps are likely to alter in the next 5 to 10 years. A constant observation should take place to ensure that developments are heading towards the right direction.

4.3 Future need for research

4.3.1 Access to electric loads

Nowadays, there are two points of view when it comes to the control of electric loads such as heat pumps. The first point of view, which is dominant today, is the control according to the market. This means that it is minimised to operate heat pumps during times of high tariff in order to reduce costs for electricity. The second point of view, which is subordinate today, is the control according to the grid. The ripple control of electric loads is a common approach of DSOs to reduce peak loads during regular times of the day (e.g. during lunchtime).

Today, the market-oriented view and the grid-oriented view often align with each other, since the ripple control disconnects electric loads during lunchtime (when loads and prices are high).

In the future, with an increasing expansion of decentralized electricity production, prices for electricity are subject to high fluctuations due to fluctuations in the production of electricity. Imports of electricity from adjacent countries further intensify this effect. As a result, the dependency of the electricity price from the situation in the grid decreases (Ecofys, 2015, p. 55). Electricity is an economic resource that is traded at the European Power Exchange SE (EPEX SPOT SE). The changing energy mix has a high impact on prices for electricity.

The liberalisation of the Swiss electricity market will lead to an incentive for electricity suppliers, to offer dynamic electricity tariffs to their customers (to the market) (Ecofys, 2015, p. 54). If an electricity supplier can offer attractive electricity tariffs, the number of customers is likely to grow. This approach of using attractive electricity tariffs in order to gain customers is only possible in a fully liberalised electricity market. The market-oriented control of loads will be intensified in the course of the market liberalisation.

The control accesses of the electricity suppliers and DSOs do not necessarily coincide and, therefore, it is not clearly defined whose access is prioritized (Ecofys, 2015, p. 53-56). It is possible that different control signals from market- and grid-oriented parties arrive simultaneously. One of the signals must be prioritized.

In the future, it needs to be defined, whose access is prioritized in which situation. DSOs need to know, if the available flexibility (e.g. from heat pumps) in the grid can be controlled and utilized in order to improve the safety of the grid.

4.3.2 Flexibility index

As discussed in the environmental analysis, a heat pump offers flexibility to the grid since it can be postponed without negatively affecting living comfort. More flexibility in a grid leads to a higher amount of supply and demand, which does not need to be balanced (Wagener, 2014, p.77).
Unfortunately, a DSO does not know how much flexibility is available in its grid. In order to change that, a flexibility index could be implemented. Different systems could be rated with different indicators to give the DSO an idea, how much flexibility is available. Additionally, it would be important to know, how much capacity is available for how long, fluctuations in flexibility, and other factors (Wagener, 2014, p.77).
A flexibility index would give heat pumps an actual value for the grid and, therefore, a separation to other systems could be visualized.

4.3.3 Standardisation

Today, heat pump manufacturers use several different control systems for their products. Additionally, there is no national standard for the communication interface to the grid. This complicates the further connection of heat pumps with the distribution grid, especially in regards to local intelligent heat pumps.
It is the responsibility of all involved parties to find a common solution. In particular, organizations that bundle activities in this sector (e.g. SFOE, FWS) are in charge of a better communication across all parties.

4.4 Key message in brief

The integration of heat pumps in a smart grid is a complex project with many variables and involved parties. Switzerland pursues a policy that is open for innovations. The electricity market is in a phase of restructuring and many years are required to implement the necessary technologies and legislations. Overall, Switzerland provides an innovative environment with a lot of knowledge.
The question as to when heat pumps and other loads will be fully integrated in a Swiss smart grid cannot be answered today. The necessary integration of heat pumps in a smart grid depends on various external factors, such as the diffusion of photovoltaic-systems and storage batteries.
It can be said that heat pumps provide an opportunity to make the grid in Switzerland more efficient.

Bibliography

ABB. (2014). Mikronetze. Etablierung von Mikronetzen mithilfe von ABB-Technologien. Retrieved April 15, 2016, from https://library.e.abb.com/public/128de58b654138c883257dc500401fae/54-60%204m480_DE_72dpi.pdf

Adaptricity (a). (2015). Zeitreihenbasierte Netzsimulation und Bewertung von SmartGrid-Ausbauoptionen für Verteilnetze. Retrieved April 11, 2016, from https://www.adaptricity.com/files/publications/adaptricity_otti_2015.pdf

Adaptricity (b). Projekte. Retrieved April 20, 2016, from https://www.adaptricity.com/projects.html

Annex 42. (2014). Project Breakdown. Retrieved March 14, 2016, from http://www.annex42.nl/wp-content/uploads/2015/06/PM-Annex-42-project-breakdown-1.1.pdf

BKW (a). Privatkunden. Retrieved March 14, 2016, from http://www.bkw.ch/privatkunden/waerme/

BKW (b). (2015). Swiss Energypark. Retrieved April 26, 2016, from http://swiss-energypark.ch/info-ront/

BKW (c). (2015). Breakout Session mit Christophe Bossel [Video]. Bern. Retrieved May 21, 2016, from https://vimeo.com/141024954

BKW (d). Home Energy. Retrieved April 26, 2016, http://www.bkw.ch/privatkunden/home-energy/

Bundesamt für Energie (BFE) (a). Die Wärmepumpe: Unerschöpfliche Wohlfühlwärme aus Luft und Erde. Retrieved March 16, 2016, from http://www.bfe.admin.ch/dokumentation/publikationen/index.html?lang=de&marker_suche=1&ps_text=Geb%E4&start=150

Bundesamt für Energie (BFE) (b). (2013). WARMup; Optimale Verwertung der Flexibilität von thermischen Speichern – Schlussbericht. Retrieved April 5, 2016, from http://www.bfe.admin.ch/forschungnetze/01246/03570/index.html?lang=de&dossier_id=05724

Bundesamt für Energie (BFE) (c). (2015). News aus der Wärmepumpen-Forschung (p.18 – 28). Retrieved April 22, 2016, from http://www.fws.ch/tl_files/download_d/Downloads/Tagungsband%2021.%20Waermepumpen-Tagung.pdf

Bundesamt für Energie (BFE) (d). (2016). Finanzielle Förderung. Retrieved April 22, 2016, from http://www.energieschweiz.ch/wohnen/finanzielle-foerderung-subventionen/gebaeudeprogramm-und-kantonale-programme.aspx

Bundesamt für Energie (BFE) (e). (2011). Strompreisentwicklung. Retrieved April 22, 2016, from http://www.bfe.admin.ch/dokumentation/publikationen/index.html?start=0&lang=de&marker_suche=1&ps_text=strompreisentwicklung&ps_nr=&ps_date_day=Tag&ps_date_month=Monat&ps_date_year=Jahr&ps_autor=&ps_date2_day=Tag&ps_date2_month=Monat&ps_date2_year=Jahr&ps_show_typ=no&ps_show_kat=no

Bundesamt für Energie (BFE) (f). (2015). Smart Grid Roadmap Schweiz. Retrieved April 15, 2016, from http://www.bfe.admin.ch/smartgrids/index.html?lang=de&dossier_id=06308

Bundesamt für Energie (BFE) (g). (2015). Schweizerische Elektrizitätsstatistik 2014. Retrieved May 3, 2016, from http://www.bfe.admin.ch/themen/00526/00541/00542/00630/index.html?dossier_id=00765

Bundesamt für Energie (BFE) (h). (2014). Grundlagen der Ausgestaltung einer Einführung intelligenter Messsysteme beim Endverbraucher in der Schweiz. Retrieved May 6, 2016, from http://www.bfe.admin.ch/smartgrids/index.html?lang=de&dossier_id=06242

Bundesamt für Energie (BFE) (i). (2015). Regelstrategien für die Optimierung des Eigenverbrauchs von Gebäuden. Retrieved May 7, 2016, from http://www.velasolaris.com/files/20151211e_bfe_schlussbericht_eigenverbrauchsregelung.pdf

Bundesamt für Energie (BFE) (k). (2013). Energieperspektiven 2050. Zusammenfassung. Retrieved March 16, 2016, from http://www.bfe.admin.ch/themen/00526/00527/06431/index.html?lang=de&dossier_id=06420

Bundesamt für Energie (BFE) (l). (2013). Klimageräte im Sommer sparsam einsetzen. Retrieved May 11, 2016, from http://www.bfe.admin.ch/energie/00588/00589/00644/index.html?lang=de&msg-id=49667

Bundesamt für Energie (BFE) (m). (2013). Volkswirtschaftliche Bedeutung erneuerbarer Energien in der Schweiz. Retrieved May 21, 2016, from http://www.news.admin.ch/NSBSubscriber/message/attachments/29634.pdf

Bundesamt für Energie (BFE) (n). (2015). Analyse des schweizerischen Energieverbrauchs 2000-2014 nach Verwendungszwecken. Retrieved May 29, 2016, from http://www.bfe.admin.ch/themen/00526/00541/00542/02167/index.html?dossier_id=02169&lang=en

Bundesamt für Energie (BFE) (o). Kostendeckende Einspeisevergütung. Retrieved April 22, 2016, from http://www.bfe.admin.ch/themen/00612/02073/index.html?lang=de

Bundesverband Wärmepumpe. (2013). Regularium für das Label „SG Ready“ für elektrische Heizungs- und Warmwasserwärmepumpen. Retrieved May 2, 2016, from https://www.waermepumpe.de/fileadmin/user_upload/waermepumpe/02_Waermepumpe/Qualitaetssicherung/SG_Ready/2012-11-01_SG_Ready_Regularien_Version1.1.pdf

Chacko, A. (2016). Der Regelleistungsmarkt in der Schweiz: Status Quo und künftige Entwicklungen. Retrieved March 29, 2016, from http://www.control-reserves.ch/

CO_2-Rechner. Heizungsvergleich. Retrieved April 21, 2016, from http://www.co2-emissionen-vergleichen.de/Heizungsvergleich/CO2-Vergleich-Heizung.html

Consentec. (2013). Zustandsanalyse und Entwicklungsbedarf von Technologien für ein Schweizer Smart Grid. Retrieved May 3, 2016, from http://www.en.consentec.de/publications/studies

Cuderman, L. (2014). Netznutzung in der Schweiz und im Ausland. Retrieved April 28, 2016, from https://www.eeh.ee.ethz.ch/uploads/tx_ethpublications/Cuderman_SA_2014.pdf

Das Gebäudeprogramm. Ziele. Retrieved May 11, 2016, from http://www.dasgebaeudeprogramm.ch/index.php/de/das-gebaeudeprogramm/ziele

Ecofys. (2015). Zukünftige Energiemärkte und die Rolle der Netzbetreiber. Retrieved May 21, 2016, from http://www.bfe.admin.ch/smartgrids/index.html?lang=en&dossier_id=06311

Ecoplan. (2015). Smart Metering Roll Out – Kosten und Nutzen. Retrieved May 5, 2016, from http://www.bfe.admin.ch/smartgrids/index.html?lang=de&dossier_id=06577

ElCom. (2015). Newsletter 03/2015 der ElCom. Retrieved April 23, 2016, from https://www.elcom.admin.ch/elcom/de/home/dokumentation/newsletter.html

EnDK - Konferenz Kantonaler Energiedirektoren. (2014). Mustervorschriften der Kantone im Energiebereich (MuKEn). Retrieved April 22, 2016, from https://www.energie-zentralschweiz.ch/fileadmin/user_upload/Downloads/Fachinformationen/MuKEn/15_MuKEn2014_d20150109.pdf

Energie-Cluster. Stromspeicher. Retrieved May 5, 2016, from https://www.energie-cluster.ch/de/wissenstransfer/kompetenzen-technologiematrix/energie-speicherung/stromspeicher-2655.html

Energiewirtschaftsgesetz (EnWG). Gesetz über die Elektrizitäts- und Gasversorgung. Retrieved May 19, 2016, from https://www.gesetze-im-internet.de/enwg_2005/__14a.html

Fachvereinigung Wärmepumpen Schweiz (FWS) (a). Funktionsweise. Retrieved March 16, 2016, from http://www.fws.ch/funktionsweise.html

Fachvereinigung Wärmepumpen Schweiz (FWS) (b). Wärmequellen. Retrieved March 16, 2016, from http://www.fws.ch/waermequellen.html

Fachvereinigung Wärmepumpen Schweiz (FWS) (c). Wärmepumpenstatistik. Retrieved March 16, 2016, from http://www.fws.ch/tl_files/download_d/Statistiken/2013/Statistiken_2013.pdf

Galus, M. (2013). Interview mit Matthias Galus. Das System wird viel klüger werden müssen. Retrieved April 19, 2016, from http://www.bfe.admin.ch/smartgrids/index.html?lang=de

Geidl, M. (2015). tiko – das Energiespeichernetz. Von Swisscom Energy Solutions. Retrieved April 6, 2016, from https://www.energie-cluster.ch/admin/data/files/file/file/293/ig-sp_06-05_13-oktober-2015-tiko-swisscom-geidl-web.pdf?lm=1447080583

Geothermal Heat Pumps (GHP). Key components. Retrieved March 5, 2016, from http://www.nzgeothermal.org.nz/ghanz_heatpumps.html

Graf, F. (2013). Pilotprojekt "Smart Metering". Luzern: Centralschweizerische Kraftwerke.

Gridbox. A holistic smart grid approach. Retrieved April 22, 2016, from http://www.gridbox.ch/en-gb/page/GridBox/GridBox-Concept-30111

GridSense (a). Das Energie-Gesamtsystem GridSense. Retrieved April 6, 2016, from https://www.gridsense.ch/de-ch/gesamtsystem-gridsense.html

GridSense (b). (2016). Wirtschaftlichkeit von GridSense im Rahmen von EBM-Feldtest bewiesen. Retrieved April 6, 2016, from https://www.gridsense.ch/de-ch/news-events/alle-news/archiv-news-2016.html#wirtschaftlichkeit-von-gridsense-im-rahmen-von-ebm-feldtest-17

Heat Pump Centre (HPC) (a). About HPT. Retrieved March 14, 2016, from http://www.heatpumpcentre.org/EN/ABOUTHPT/Sidor/default.aspx

Heat Pump Centre (HPC) (b). Annex 42. Retrieved March 14, 2016, from http://www.heatpumpcentre.org/en/projects/ongoingprojects/annex42/Sidor/default.aspx

Heat Pump Technologies (HPT) (a). (2014). IEA HPP Annex 42: Heat Pumps in Smart Grids. Task 1: Market Overview Switzerland. Project Lucerne University of Applied Sciences and Arts.

Heat Pump Technologies (HPT) (b). (2015). IEA HPP Annex 42: Heat Pumps in Smart Grids. Task 2: System Aspects and Opportunities Switzerland. Project Lucerne University of Applied Sciences and Arts.

Johnson, G., (2015). When Radiation isn't the Real Risk. Retrieved March 13, 2016, from http://www.nytimes.com/2015/09/22/science/when-radiation-isnt-the-real-risk.html?_r=0

Leuzinger, A., (2014). Heat Pumps in Smart Grids. Project Lucerne University of Applied Sciences and Arts.

MindTools. Porter's Five Forces. Retrieved April 2, 2016, from https://www.mindtools.com/pages/article/newTMC_08.htm

Schaub, A., (2014). UNIVOX Umwelt 2014. Zürich: gfs-zürich, Markt- & Sozialforschung. Retrieved May 11, 2016, from https://assets.wwf.ch/downloads/gfszh_umwelt_2014_def.pdf

SGB-SMIT Group. (2013). RONT – Der regelbare Ortsnetztransformator. Retrieved April 27, 2016, from https://www.sgb-smit.com/fileadmin/user_upload/downlaods/Broschueren/OElverteiltransformatoren/2013-VT-RONT-deutsch.pdf

SoloGrid. (2016). Ein Leuchtturmprojekt für die Zukunft. Retrieved April 9, 2016, from http://www.sologrid.ch/das-projekt-sologrid/

Swissgrid (a). Netzebenen. Retrieved March 19, 2016, from https://www.swissgrid.ch/swissgrid/de/home/grid/transmission_system/grid_levels.html

Swissgrid (b). (2015). Netzdaten 2015. Retrieved March 19, 2016, from https://www.swissgrid.ch/dam/swissgrid/company/publications/de/netzdaten_2015_de.pdf

Swissgrid (c). Systemdienstleistungen. Retrieved March 29, 2016, from https://www.swissgrid.ch/dam/swissgrid/company/publications/de/systemdienstleistungen_de.pdf

Swissgrid (d). Regelpooling. Retrieved April 2, 2016, from https://www.swissgrid.ch/swissgrid/de/home/reliability/power_market/control_pooling.html

Swissgrid (e). (2015). Grundlagen Systemdienstleistungsprodukte. Retrieved April 9, 2016, from https://www.swissgrid.ch/dam/swissgrid/experts/ancillary_services/Dokumente/D160111_AS-Products_V9R1_de.pdf

Swissgrid (f). Verteilnetzbetreiber. Retrieved April 10, 2016, from https://www.swissgrid.ch/swissgrid/de/home/experts/dso.html

Verband Schweizerischer Elektrizitätsunternehmen (VSE) (a). (2013). Einflussfaktoren auf die Stromnachfrage. Retrieved May 13, 2016, from http://www.strom.ch/fileadmin/user_upload/Dokumente_Bilder_neu/010_Downloads/Basiswissen-Dokumente/01_Einflussfaktoren_Nachfrage.pdf

Verband Schweizerischer Elektrizitätsunternehmen (VSE) (b). (2013). Nachfrageflexibilisierung: Steuerung des Stromverbrauchs. Retrieved May 16, 2016, from http://www.strom.ch/fileadmin/user_upload/Dokumente_Bilder_neu/010_Downloads/Basiswissen-Dokumente/04_Nachfrageflexibilisierung.pdf

Verband Schweizerischer Elektrizitätsunternehmen (VSE) (c). (2011). Schweizer Stromnetz. Retrieved April 29, 2016, from http://www.ewn.ch/uploads/pdf/inhalt/VSE_Stromnetz-Fragen-Antworten_11-2011_01.pdf

Verein Smart Grid Schweiz (VSGS). (2015). Weissbuch Smart Grid Vol. 2. Retrieved March 22, 2016, from http://www.smartgrid-schweiz.ch/index.asp?Language=DE&page=smartgrid-schweiz-home

Vogel, B. (2015). Tiko belebt den Regelenergie-Markt. Bern: Bundesamt für Energie.

Wagener, P. (2014). Heat pumps in smart energy grids for sustainable cities. In News aus der Wärmepumpen-Forschung, Wärmepumpen sind (auch) smart. Retrieved April 28, 2016, from http://www.bfe.admin.ch/forschungwkk/index.html?lang=de&dossier_id=04851

Appendix

A1 - Template of the IEA Annex 42 Task 4

A2 - Table with the values to Figure 23 and Figure 24

A3 - Calculation "Scenario overall summer"

A1 - Template of the IEA Annex 42 Task 4

Overall project info	
Wider context	For example: Is this project a part of a wider group of projects or a singular activity? Is it industry or Government or research led?
Participants – identification & motivations	Who are the participants? What are their roles? What are their motives for participating?
Funding	Who is funding the project? To what extent?
Timing	Provide a rough overview of the project timeline so far and next steps. What will be done by when?
Project overall driver	What is the driver of the project? Commercial? Demonstration/Proof of concept? Basic research?
Project aim	What are the project´s aims? What are they trying to do and why? If there are several aims to one project please be specific.
Scope – indicates robustness of testing / how scalable the results are	
Project scale	What is the scale of the project? How many HPs / HP types or other technologies are going to be tested? How many participants (home/business owners)?
Geographical coverage	Where is the project being implemented? If relevant name any particular challenges which have led to choosing this area (e.g. current or future energy shortages in summer/winter or other)
Range of building types	What types of buildings are participating in the project? Residential or commercial? Existing stock or new build? Renovated or non-renovated?
What technologies?	Which technologies are being tested? This includes on-site technologies, like the HPs/boilers/controllers as well as off-site technologies, such as aggregation software, communication protocols, etc.
End-user engagement	How are end-users being engaged in the project? How is their participation being assured? What challenges have been met?
What is it specifically testing in relation to heat pumps	
Extent and method of control / influence of HP	How are the HPs / other technologies being controlled? This includes the method of control (protocols and hardware/interfaces) as well as the extent of the control (indirect/suggestive vs direct control, hard-switch off times vs flexible signal, prices vs on/off signals, etc. etc.)
Time resolution of control	What is the time interval of the control? If direct it could e.g. be minute intervals or if indirect via price it could e.g. be day-ahead hourly price signal.
HP requirements (how smart are they / should they be)	Is the decision to run / not to run taken on site or off-site? Based on which parameters? Is the intelligence in the HP, in an on-site hub or off-site? Can the HP controller override external decisions if given parameters (e.g. around comfort) are not met or there's a risk of them not being met?
Need storage?	Is there a need for storage in order to participate in the project? If so, which storage solutions are being implemented?
Methods being used/tested for getting flexibility – technology & system	What options for leveraging flexibility are being applied/tested? (E.g. modulation, concrete core heating/cooling, storage/buffer tank temperature increase, other?)
Details of testing procedures	
Time resolution of monitoring	Time resolution of the monitoring (minute by minute, quarter hourly, etc.)

Monitoring equipment	How are the systems being monitored? Which system boundaries are being used?
Results aimed for / available	
Flexibility	What types of flexibility is the project trying to test? (e.g. response to a flexible tariff, DR signals related to network stress, mirroring/participation in DR markets)
Customer response	How have customers reacted to the test? How have they reacted to their heating system being controlled (if applicable) or to the indirect/suggestive control/influence of their behaviour (if applicable)?
Challenges which have emerged	What customer/technology/design related issues has the project had?
How has the data been analysed	Which types of conclusions have been taken from the project? Are there additional ways to analyse the data which could answer more questions but which hasn't been pursued because they were outside the scope of the project or outside budgetary means?
Next Steps & Gap Analysis	
Planned Next steps for project	What are the next steps for the project (if any)? This includes steps going beyond the specific project, e.g. roll-out of smart metering solutions or a DR aggregation platform if demonstrator has proven successful.
Exploring scope for further work	How could the project be extended in order to answer additional questions currently not in its scope? How could future projects best build on the findings of the project?
Gaps & additional data which project partners would ideally like	With regards to the "ideal" demonstration project which gaps have been left open in the project? What other data/insight would project partners ideally like but maybe haven't been able to include into the scope e.g. due to budget restraints/timing/etc.?

A2 - Table with the values to Figure 12 and Figure 13

Figure 23

Year	Heat pumps installed	Heat pump sales	Electrical power [MW]	Thermal power [MW]	Max. control power [MW]
2000	66622	5129	343	1140	
2001	71936	5314	353	1188	
2002	77306	5370	363	1236	
2003	83662	6356	378	1297	
2004	90940	7278	396	1372	
2005	100003	9063	423	1478	
2006	112824	12821	466	1648	
2007	126263	13439	515	1836	
2008	143543	17280	586	2111	
2009	160350	16807	654	2378	
2010	176506	16156	717	2630	
2011	191818	15312	778	2874	500
2012	207975	16157	835	3100	500
2013	224657	16682	891	3325	500
2014	240887	16230	950	3565	500
2015					500
Source	(BFE (g), 2015)				(Swissgrid (b), 2015)

Figure 24

Year	P<20kW [pcs.]	P=20 - 50kW [pcs.]	P=50 - 100kW [pcs.]	P>100kW [pcs.]	Total control power = 10%*assumed power*number of heat pumps
2005	94964	6318	948	646	130647
2010	169742	15028	2007	658	243972.5
2015	258492	17320	2534	1187	349987
2020	357283	22423	3397	1784	479081
2025	469725	31420	4664	2322	637895
2030	496757	33060	4890	2306	672202
2035	527078	33643	5059	2338	706151
Source	(Leuzinger, 2014)				
P<20kW	Assumed power of 10kW per heat pump				
P=20-50kW	Assumed power of 35kW per heat pump				
P=50-100kW	Assumed power of 75kW per heat pump				
P>100kW	Assumed power of 100kW per heat pump				

A3 - Calculation “Scenario overall summer”

Sought: Potential control power supply by hot water heating in 2014.

$W_{RoomHeating}$	= 3416,7 GWh	(BFE (n), 2015, p.28)
$W_{HotWaterHeating}$	= 2361,1 GWh	(BFE (n), 2015, p.28)
$P_{HeatPumps2014}$	= 950 MW	(BFE (g), 2015, p.52)
Assumption control power	= 25%	

Usage of heat pumps in single-family houses (SFH) and multi-family houses (MFH) (HPT (a), 2014):

Purpose	Type	Electric heating system	Heat pump
Room heating	SFH 68.67%	12%	14%
	MFH 31.33%	7%	7%
Ratio room heating		((12%*69%) + (7%*31%)) = 0.104 (46.8%)	((14%*69%) + (7%*31%)) = 0.118 (53.2%)
Consumption of electricity		46.8% * $W_{RoomHeating}$ = 1599 GWh	53.2% * $W_{RoomHeating}$ = <u>1817.7 GWh</u>
Hot water heating	SFH 68.67%	44%	7%
	MFH 31.33%	30%	4%
Ratio hot water heating		((44%*69%) + (30%*31%)) = 0.396 (86.7%)	((7%*69%) + (4%*31%)) = 0061 (13.3%)
Consumption of electricity		46.8% * $W_{HotWaterHeating}$ = 2047.7 GWh	53.2% * $W_{HotWaterHeating}$ = <u>313.4 GWh</u>

Ratio room heating : hot water heating = 1817.7GWh / 313.4GWh
= <u>5.8 : 1</u>

Power consumption hot water heating = $P_{HeatPumps2014}$ / 6.8
= <u>139.7 MW</u>

Control power = 25% * 139.7 MW
= <u>34.9 MW</u>