CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 3

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Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 3*. Department of Civil Engineering, Aalborg University.

Technology Assessment in a Future Cross Sectoral Heat and Power Market

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Abstract

To achieve the emission targets set by the German government for 2050, wind and PV are the main pillars of the energy system. These power production technologies are cost efficient with a high development potential and therefore can provide power not only for the conventional power sector, but also for the heat as well as the mobility sector.

The presented project focusses on the requirements and challenges that need to be dealt with to efficiently couple both of these sectors. Therefore a simulation platform has been established to find cost-optimal technology solutions, for both energy production (wind and PV) as well as energy end use (e.g. for heating buildings), based on the differencing political targets and boundary conditions. A wide range of different technology is integrated via key performance indicators into this platform. In turn, this platform offers the possibility of assessing existing and also possible future technology based on the ability of offering a cost efficient solution in a particular future market situation. Only such cost efficient solutions will be capable of surviving in a market in the long run.

This paper presents the outcome of the German nationally funded project "Interaction of renewable power, heat and mobility - Analysis of the interaction between the power, heat/cold and mobility markets in Germany regarding increasing shares of fluctuating renewable energies and in consideration of European market development".

Keywords – interaction; heat market; sector coupling; roadmap; heat pumps; power to heat

1. Introduction

The general frame for the presented project results are the precondition that the climate and emissions reductions goal set by the European politics of -80% reductions in Green-House-Gas (GHG) emission are to be reached in the entire European Union [1]. All energy related sectors are going to contribute evenly to reach the set goals. In this study it has been investigated how a cost optimal solution for all sectors, the electricity, heating and mobility sector, and the contribution of the sectors could be reached. The option to import biogenic or synthetic fuels from other parts of the world has not been considered.

2. Methodology

First, a cost-optimal energy supply system has to be determined under the precondition that the above mentioned climate goals will be met. In order to do this, the model of a cross-sectoral power plant use and development optimization system from Fraunhofer IWES has been used [3].

The calculation distinguishes between the target scenario for the year 2050 and the supporting years 2025 and 2035. For the year 2050, an optimal mobility and biomass scenario is estimated by use of the cross-sectoral power plant development optimization and its related sensitivity analyses. Based on the optimized biomass and mobility scenarios, an optimized electricity and heat scenario is estimated for Europe.

The optimization is based on an hourly power plant use plan in which the construction of new plants and implementation of new technology are considered. The technological and economic model is descripted as a linear mathematical model. This model takes the predefined technological boundary conditions for an optimal use and development of electricity producing and using units based on full cost estimation into account.

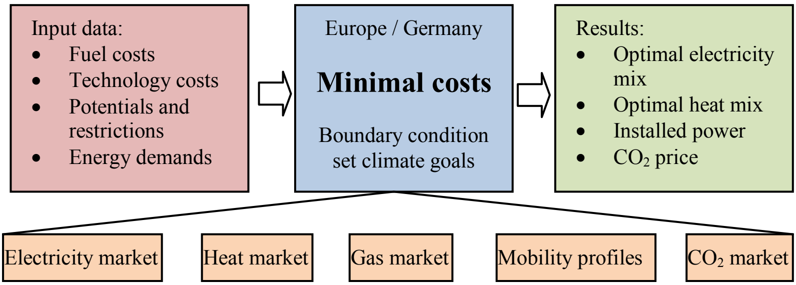

Fig. 1 Scheme of the cross-sectoral model

Based on the related fuel costs and the costs for the technology, a cost-optimal mixture of generation units for the entire system is estimated, where the electrical loads are met in all time steps. This procedure is done for all the different countries in Europe separately and the countries are coupled via exchange nodes. An additional barrier is the compliance with the set CO_2 goals during the year and the technical limits or potentials. For the heating sector, heat load profiles and energy quantities are defined for various temperature levels and use cases. These profiles have to be followed by either heating technologies or heat-electricity co-products. The technology combination (e.g Combined Heat and Power (CHP) with District Heating (DH) and gas boilers) must satisfy the entire heat load profile. The market penetrations for the different technologies are simultaneously optimized based on the total cost estimations both for the heat and electricity markets.

3. Building simulation and the development of the heating sector

In order to assess the future development of the heating sector and its interaction with the electricity sector, several aspects are regarded. The analysis can be subdivided into:

- Efficiency of heat pumps in existing buildings
- Flexibility potentials in the heating sector
- Restrictions and assessment of heat pump potentials
- Development of heat scenarios

To assess the efficiency (the seasonal energy efficiency ratio SEER) of the heat pumps, six residential building models and a heat pump model according to the TABULA study have been set up [2]. The coefficient of performance (COP) and the SEER are used to evaluate the performance of the entire heating system.

Both air source heat pumps (ASHP) and ground source heat pumps (GSHP) are regarded together with three different emission systems, these being floor heating (FH: supply 33-35°C), low temperature radiators (LTR: supply 45°C) and common radiator (RAD: supply 60°C) systems. Table 1 shows the studied simulation variants for the three single family houses (SFH) and three multifamily houses (MFH):

Table 1. Regarded simulation variants for residential buildings

		Heating curve regulated w/wo buffer storage w/wo load management					
		Air Source HP			Ground Source HP		
	Contr.	FH	LTR	RAD	FH	LTR	RAD
SFH1	Until 1978		X	X		X	X
SFH2	1979-94		X	X		X	X
SFH3	1995-2009	X			X		
MFH1	Until 1978		X	X		X	X
MFH2	1979-94		X	X		X	X
MFH3	1995-2009	X			X		

SFH: Single family house FH: Floor heating (supply 33-35°C)
MFH: Multifamily house LTR: Low temperature radiator (supply 45°C)
RAD: Radiator supply 60°C

The thermal mass or rather the thermal storage capacity of the regarded building stock has been investigated. Since thermal comfort should be provided throughout, the maximum temperature fluctuation of the thermal mass was set to +/- 1K compared to the air temperature set point. The heating curve is increased by 1K by the load management in low tariff times to store more heat in the building mass. In high tariff times, the heating curve is reduced by 1K to reduce the electricity use of the heat pumps.

4. Results

As shown by the model calculations, the reduction goals in GHG emissions are only reached by large-scale electrification of the heating sector. First, efficient technologies such as heat pumps need to be used, instead of heating rods, to restrict the increasing electricity use. Thereby, the additional use of land areas for electricity production via PV and wind power could be limited as well. On the other hand, highly flexible bivalent systems are needed to integrate the fluctuatingly produced renewable electricity into the heating sector without necessitating large and expensive electricity storage.

The following diagram shows the optimized technology mix for one scenario. For single family homes, a high penetration rate of heat pumps is estimated. Because of technical limits and the space requirements of GSHP, ASHP will be integrated as well. For multifamily houses (depending on the year of construction) heat pumps or bivalent district heating technologies will be used, which are also coupled with large heat pump systems on a community level. For the trade and industry sector, heat pumps will be complimented with bivalent CHP systems (with heating rod). In the high temperature sector, highly efficient technology will be used. For hot water preparation up to 100°C, large heat pumps will be used. For steam production up to 500°C, CHP systems with electro boiler systems will be used and for steam above 500°C, biomass boilers and electricity will be used.

It has been shown that building renovation and energy efficiency measures in the building stock have a great impact on the optimal energy system. In Germany, the political goal is an increase of the building retrofit rate from 1 to 2% p.a. and a reduction of 20% of the heat use by 2020 as well as an 80% reduction in (fossil) primary energy use by 2050. In turn, the German building stock shall be quasi climate-neutral by 2050. In addition to the retrofit rate, the retrofit intensity has a big impact on the future energy use of German building stock. The impact on the results by the retrofit intensity has also been investigated within this project by the calculation of variants. Deep retrofit measures are reducing the energy demand of the residential and trade sectors. Furthermore, more highly efficient, low temperature heat emission systems could be integrated and heat pumps will operate more efficiently.

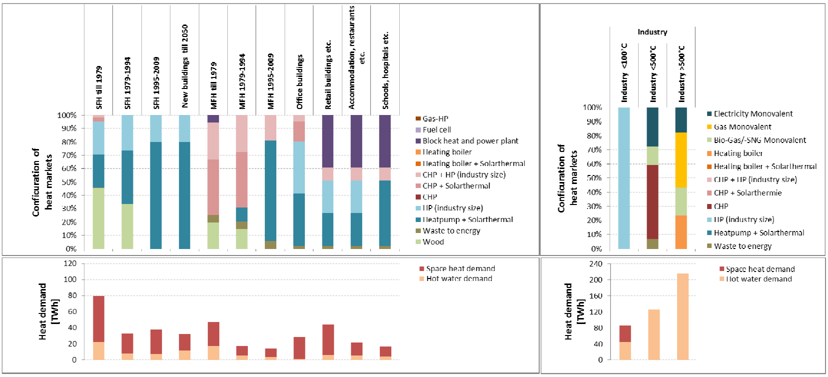

Fig. 2 Technologies in a future heat market: scenario high insulation standard

In the actual market situation, these electricity-based technologies are retarded when compared with common fossil-based technologies, because of the high costs linked with electricity used for heating in Germany (due to different taxes and charges etc.). These competition drawbacks cannot be evened out by the given incentives or privileges. For the direct use of electricity in power-to-heat systems or bivalent district heating schemes, financial support is only given in an indirect way through supporting heating grids or heat storage systems. Under such boundary conditions, it is not economically attractive to use excess renewable electricity for heating, instead the production is limited by regulating the plants.

5. Conclusions

To achieve a sustainable energy system, cross sectoral interaction of the heating and electricity sector is necessary. Electricity-based technologies combined with renewable-based electricity production are the most economically competitive and efficient methods of reducing CO_2 emission in the heating sector. With the increasing electricity demand and bearing in mind the related additional use of space for solar plants and wind power plants, efficiency in the heating sector as well as increased efforts in the retrofit of building stock are important to reach the CO_2 goals.

Decentral and central heat pumps are the key technology for increasing the share of renewable energy in the heating sector. The share of heat pumps needs to be increased continuously. The efficiency of the heat pump systems is dependent upon the quality of the building retrofit and the system temperatures. Furthermore, the flexibility of the heating sector is a key issue too. Thus, flexible and bivalent heating systems, such as CHP and power-to-heat systems, are promising technology approaches. The limited biomass resources should only be used where system temperature levels cannot be reduced, as is the case with the existing building stock e.g. in rural areas or for high temperature industrial uses. Finally district heating systems also need to be transformed.

Only much lower system temperatures will enable the efficient integration of heat from large heat pumps or solar sources. District heating is especially important in high density urban areas.

To foster this development of a higher integration of renewable electricity into the heating sector, it should be reconsidered how the different relevant technologies and approaches can be penalized by levying taxes or charges as well as how to economically support highly efficient heat transformation technologies and how to finally motivate and stimulate their implementation and use.

Acknowledgment

The project has been conducted as a joint effort form the ifeu Heidelberg, the Umweltenergierecht Foundation, Fraunhofer IBP and IWES [3]. The authors gratefully acknowledge the financial support given by the German Federal Ministry for Economic Affairs and Energy (BMWi).

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