The residential heat pumps' impact on national CO_2 emission

Elżbieta Niemierka[1,*]

[1]Wroclaw University of Science and Technology, Faculty of Environmental Engineering, Plac Grunwaldzki 13, 50-377 Wrocław, Poland

Abstract. The decarbonisation potential of residential heat pump technology strongly depends on the public electricity and heat production system. The study presents the national scenarios of replacing the individual heat sources with electrically driven heat pumps in residential space heating. The heat pumps impact on residential CO_2 emission and energy balance in public electricity and heat production system were assessed at national level. Application of particular scenario give an incommensurable effect. The space heating sector based on heat pumps may decrease the CO_2 emission up to 42.2% or not change the results despite the technology development.

1 Introduction

Nowadays the European residential sector consumes 293 Mtoe yearly while emitting 377 Mt CO_2 [1]. The growing environmental awareness of residents, deteriorating air quality and political decisions have been contributing to the implementation of the climate actions. Its foundations concerned the reduction of greenhouse gases emission, increased share of renewable energy and raise energy efficiency [2]. Applying the heat pump (HP) technology in residential heating sector could appear as the effective way to achieve all of these three credits [3−5]. Currently the mechanical HP units, driven by electricity are the leading renewables' technology in residential space heating. Their environmental impact is strongly indicated by emission resulting from the electricity production. The HP implementation in residential heating helps to eliminate the low efficient fuel combustion heat sources and local emission. At national level the electrically driven HP units increase the power demand and merely remove the local emission to the large scale energy sources in public energy system. It will result in unbalance of energy production in combined heat and power plants (CHP) and unfavourable changes of national emission. Therefore, the aim of the national HP based actions should be maintain of energy balance between HP, CHP and district heating, to achieve the lowest national CO_2 emission.

---

[*] Corresponding author: elzbieta.niemierka@pwr.edu.pl

2 Characteristics of national residential space heating sectors

Space heating is a necessity in cold climates. In overall European energy consumption for space heating plays an important role in energy sector and share nearly 65% [6]. The structure of national energy production and consumption in residential sector varies in European countries (figure 1). Due to differentiation in energy consumption structure, fuels or energy carriers mix and energy and power sector generation technologies, the HP based strategy will individually affect on the national residential CO_2 emission. To assess the HP impact on national level the specific residential heating sectors in four European countries was analysed and compared. In Bulgaria (BGR), Spain (ESP), Poland (POL) and Sweden (SWE) the space heating significant participate in overall consumption achieved values between 44.2% and 64.7% (figure 1). The highest share of heating became a premise to assess potential of applied environmentally friendly technologies, including electrically driven HP.
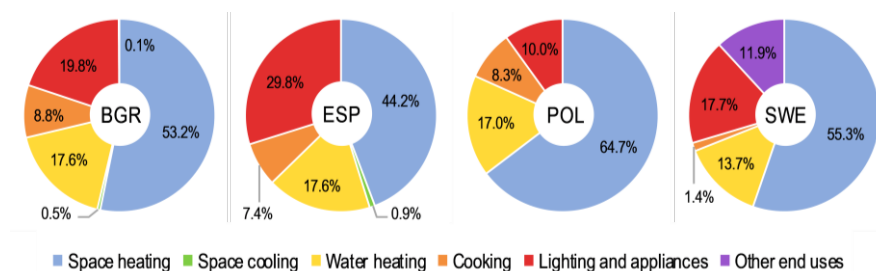

Fig. 1. The energy consumption in residential sector by major end uses (2015) in four analysed countries.
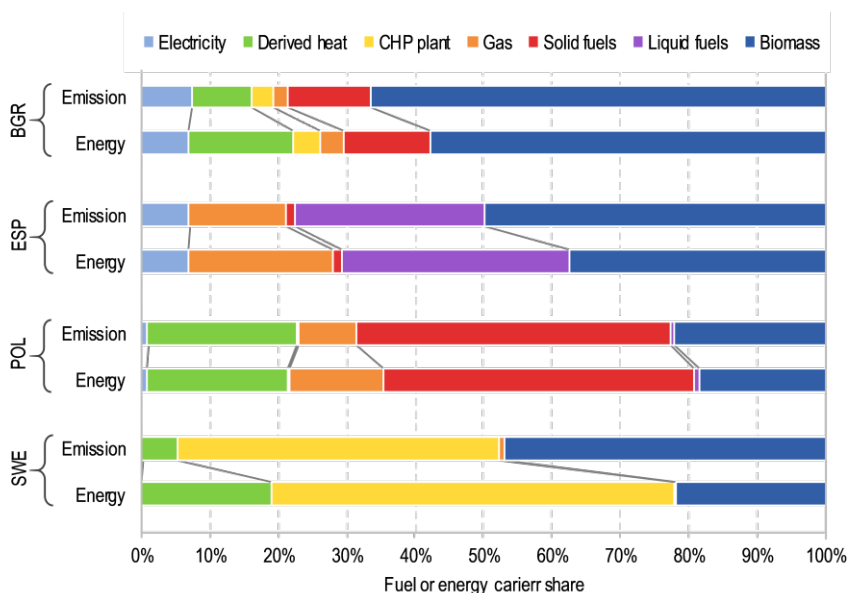

Fig. 2. The national fuel and energy carrier share in CO_2 emission and energy consumption in four analysed countries.

The national CO_2 emission depend on the energy consumption, the fuel structure and the combustion technology. Figure 2 compares the CO_2 emission, fuels and energy carriers structure, and energy consumption at national level in four analysed countries [7]. The correlation between energy demand and CO_2 emission describes the efficiency and environmental impact of fuel combustion technology. The high emission and low energy consumption point to inefficient fuel combustion technologies, while the low emission and high energy consumption - high efficient heat sources.

The fuels and energy carrier mix in each country are unique but the dominant energy sources are noticeable. In ESP the high contribution of liquid fuels and CHP absence is visible. The main fuel in POL is coal with the highest share around 40%. Sweden is characterised by high contribution of CHP and nearly zero fuels combustion sources. The space heating sector in BGR is the most diversify with the similar share of used fuels and energy carriers. The significance of biomass is similarly in all countries due to them high share.

3 The HP technology impact on the national energy systems

The electrically driven HP need auxiliary driving energy to accomplish transferring energy from renewable source to the heat sink. Wide scale of HP technology implementation affects on the power, heat and emission market at national level [8]. Compare to conventional fuel combustion heat sources the HP technology offers higher efficiency (Seasonal Performance Factor - SPF $\geq$ 3.5) and changes the type of energy consumed in heating systems, which affects on CO_2 emission in a certain way. The HP technology reduces the local CO_2 emission to zero by transferring it to the central energy sources in the public energy system. The additional emission dependents both on energy consumption and HP driving energy generation technology in public electricity and heat production sector, and defines its emission intensity (EI). In Europe the public energy sector consist of three groups of large scale energy sources: combined heat and power (CHP) plants, power plants and heat only boilers [9].

CHP plants offer higher efficiency in simultaneously power and heat generation and affected a lower CO_2 emission, which will be proportionally allocated into electricity and heat. Widespread using of CHP electricity as driving energy for large number of HP units has certain consequences in balancing of public electricity and heat production sector. The excess CHP heat, associated with increase of CHP electricity demand, need to be consumed or rejected to environment. The emission related to rejected heat will be assigned to the electricity production and causes growing of EI, according to the structure of national energy sector and used technologies. Using power plants' electricity as HP driving energy rise power demand, which increase the CO_2 emission without changing EI (at current generation technology).

The scenarios assume replacing all individual combustion heat sources with electrically driven HP units. The aim of the investigation is to assess the numerous HP units impact on the national CO_2 emission and on the energy balancing in public electricity and heat production sector. The best results in terms of environmental protection will be achieved by fitting the share of HP in order to fully use of CHP production. It needs to simultaneous increase number of HP units driven by CHP electricity and in number of CHP district heating consumers.

The HP implementation impact on national CO_2 emission will be defined for four analysed countries, taking into account their fuel, heat and energy market. In countries with CHP plants the maximum recommended share of HP units powered by CHP will be appointed.

4 The HP emission reduction potential

Based on the national inventories reports [10] the current CO_2 emission has been determined in BGR, ESP, POL and SWE. In 2015 the energy mix consist of solid, liquid and gaseous fuels, biomass and energy carriers, in different proportion in each country. The heat demand, CO_2 emission, structure of national energy mix and efficiencies of all heat sources were taken into account. The investigation includes three scenarios of replacing fuel combustion heat sources with HP units (with average HP technology with SPR=3.5) in residential heating sector in four European countries.

In **scenario 1** all implemented HP units will be powered by power plants, significantly rising the electricity production to cover the increased demand. The electrically driven HP units transfer the emission to the central energy sources. Using current power generation technologies, the higher electricity consumption grows the national emission but not influence on EI in analysed country.

In **scenario 2** the increased power demand will be covered by growth the CHP electricity production. Due to combined CHP technology, it results in rise of CHP heat generation. The excess heat need to be rejected to environment as a waste energy. The CO_2 emission associated with rejected CHP heat is enclosed into electricity emission. It increases EI more than twice. The analysis in this scenario does not include the countries without CHP.

In **scenario 3** the balance of CHP electricity and heat production will be defined in each country, to achieve the lowest EI. The CHP electricity will supply increasing number of HP units, and excess CHP heat will be used to supply the rising number of district heating consumers. The recommended share of HP units powered by CHP will be appointed. The analysis does not include the countries without CHP or district heating technologies.

In analysed scenarios the HP units implementation will be realised in two different ways: (A) all fuels will be replaced in the same proportions and (B) the largest EI fuels will be replaced first (biomass, coal, liquid and gaseous fuels respectively).

5 Results

Figure 3 shows the emission changes at different HP share in all scenarios referred to the current national levels (2015 emission as 100% base). In the most of analysed cases application of the large number of electrically driven HP in residential heating reduces the CO_2 emission. In all scenarios the starting and ending points are the same for both variants A and B.

However, the paths depend on the EI value, efficiencies and energy generation technologies [9], and the change between replaced heat sources with different characteristics causes breakpoints in B variant. The greater difference in slope, the more diverse subsequent heat sources. The fuels replace sequence shapes the slope of CO_2 emission and always remain the tendency below the A variant.

The particular scenarios give different results in individual countries due to the divergences of the national energy sectors structure, the fuel and energy carrier mix and the combustion technologies. The achievable targets with the complete replacement fuel combustion individual heat sources with HP units are compared and shown in Figure 4.

In **scenario 1** the CO_2 emission falls in all analysed countries. The most favourable results occur in ESP and allow to reduce CO_2 emission by more than half (to 42.2%). The average CO_2 mitigation is achieved both in BGR (to 51.8%) and POL (to 54.9%) with the similar tendency in 1A scenario. Replacement of all fuel combustion individual heat sources in
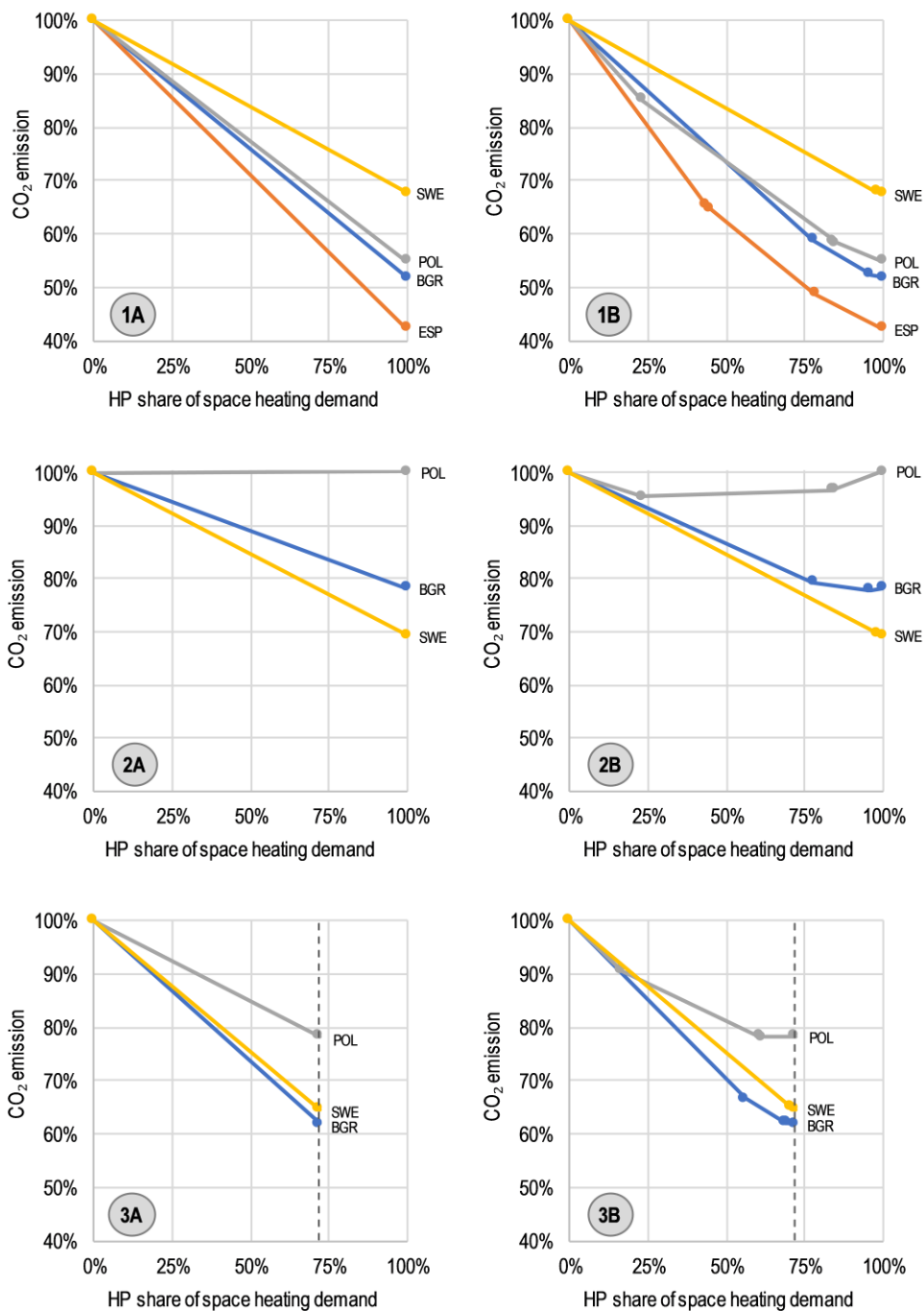
Fig. 3. The CO_2 emission trends in all analysed countries and scenarios for increasing share of heat pump in residential heat supply.

SWE gives moderate change with around 30% (to 67.6%). Variant A is characterised by line tendency while in variant B can be seen the slope variety. The breakpoints are caused by change between EI and combustion technologies of replaced heat sources. The linear 1B characteristic in SWE is caused by mono-fuel sources based on biomass combustion. The higher diversity in BGR and ESP cause the nonlinear tendency.

In **scenario 2** all new HP units are driven by CHP electricity with simultaneous heat rejection, cause unbalanced CHP production. The similar tendencies of POL, BGR and SWE cease below 23% share of HP. The further raise of HP share consequence to the sustained dynamic decline in SWE (to 64.9%), the decrease in BGR (78.3%) and the increase in POL (to 100.3%). The waste heat results in Poland an unfavourable CO_2 emission change. Unbalanced CHP damages the emission reduction development. The highest EI of replaced fuels and lower EI of CHP electricity generation, the greater decarbonisation. The CO_2 emission fluctuations are caused by of the same technical reasons as in 1B scenario.

The energy balancing of CHP in **scenario 3** requires consumption of all cogenerated CHP electricity and heat. Replacement individual combustion heat sources only with electrically driven HP does not allow to balance the CHP in national energy sector. Each increase of CHP electricity demand caused by new HP units, needs to be balanced by raise of CHP heat demand, for e.g. through new district heating users. Due to EI and efficiencies of CHP, HP and individual combustion heat sources, the required proportion of heat supply equal 72% of HP and 28% of district heating. In SWE and BGR the 3A and 3B trends of CO_2 emission are similar to scenario 2, but the development are higher (respectively 64.7% and 61.8%). In 3B the increasing the participation of HP above 61% in POL do not change the CO_2 emission at national level, but eliminates the low-stack emission by transferring it to the central energy plants.
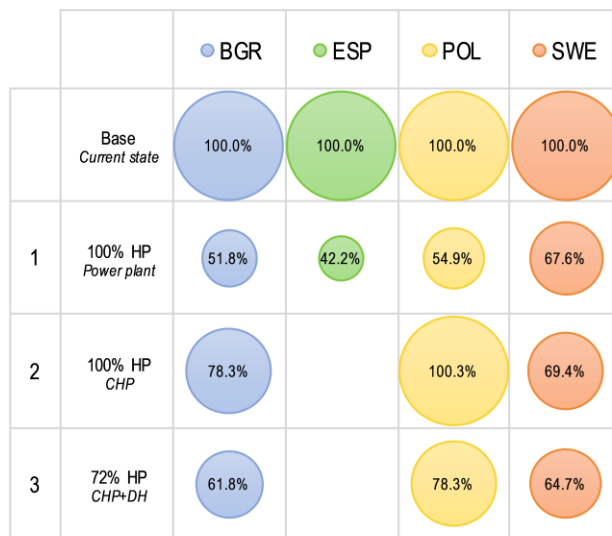
		● BGR	● ESP	● POL	● SWE
	Base *Current state*	100.0%	100.0%	100.0%	100.0%
1	100% HP *Power plant*	51.8%	42.2%	54.9%	67.6%
2	100% HP *CHP*	78.3%		100.3%	69.4%
3	72% HP *CHP+DH*	61.8%		78.3%	64.7%

Fig. 4. The final CO_2 emission in all analysed countries and scenarios.

The Figure 4 compares final CO_2 emission achieved in all analysed countries and scenarios. ESP due to the lack of CHP plants should trend to increase the efficiency of existing power plants or the renewables share. In POL can be seen the highest difference between particular scenarios (up to 45.4%). The inadequate decarbonisation scenario can increase the national emission. The medium values in each scenarios characterise BGR.

Driving HP unit with energy from power plant could be the beneficial path, except SWE. In SWE the best development arises through application HP driving with energy from balanced CHP. However, the discrepancy between scenarios in SWE are small (up to 4.7%) and choosing any path will be almost equally beneficial. Generally, the smallest CO_2 reduction or even them enlargement are caused by the HP based on the unbalanced CHP, while the balanced CHP and power only plant gives the highest CO_2 emission reduction. Replacement individual heat sources with HP are common way to reduce CO_2 emission.

6 Conclusions

The assessment of the heat pumps' emission reduction potential proves the scenario significance on the final results in national emission, with a double difference between the best and worst results of the scenarios. Solutions favourable in one country are less effective in the another. The benefits of balanced CHP electricity and heat was noted, while the barriers of unbalanced CHP are underlined. Apply HP can have various effects due to the different characteristics of the current national public electricity and heat production sectors. The analysis confirmed the relation between residential HP implementation and public electricity and heat production sector. The development strategies in national energy sector should include the energy sector balance with increasing participation of HP. The purpose of this paper is bi-directional. On the one hand, the application and development of relevant parts of the energy sector will contribute to HP's profitability and should be based on well-designed systemic and cross-sectoral strategy. On the other hand, the national residential space heating sectors concern the target of HP share and the path to achieve the goals of mitigation strategy. The sequence of replaced combustion based individual heat sources influence on the slopes of CO_2 emission trends and shapes the halfway results.

References

1. ODYSSEE and MURE Databases, http://www.odyssee-mure.eu
2. United Nations, *Kyoto Protocol to the United Frameworks Convention on Climate Change* (1998)
3. M. A. Sayegh, J. Danielewicz, T. Nannou, M. Miniewicz, P. Jadwiszczak, K. Piekarska, H. Jouhara, RENEW SUST ENERG REV, **68**, Part 2 (2017)
4. J. A. Kelly, M. Fu, J. P. Clinch, ENERG POLICY, **98** (2016)
5. E. Niemierka, P. Jadwiszczak, E3S Web Con, **17**, 00067 (2017)
6. Eurostat Database, *Energy consumption in households*, March 2017
7. United Nations Climate Change, *National Inventory Submissions* (2017)
8. M.A. Sayegh, P. Jadwiszczak, B.P. Axcell, E. Niemierka, K. Bryś, H. Jouhara, ENERG BUILDINGS, **166** (2018)
9. IPCC, *Guidelines for National Greenhouse gas inventories* (2006)
10. European Environment Agency, *EMEP/EEA air pollutant emission inventory guidebook 2016* (2017)