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# Sector coupling of power and gas with combined heat and power plants: an investment to foster the Swiss energy system decarbonization?

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## Abstract

Switzerland is currently phasing out from nuclear energy. This represents a real challenge for the country as it represents nearly 35% of its domestic power generation. This phasing-out might further increase the Swiss power import dependency, especially in winter. This winter dependency might become a threat to the security of supply, magnified with the electrification of the Swiss energy system with heat pumps and battery electric vehicles. In this paper, we explore how Combined Heat and Power (CHP) plants fuelled with natural gas or biogas might represent a short-term solution to produce power in winter on the Swiss territory. We analysed the effect of the deployment of this solution on the hourly carbon footprint of the electricity consumed in Switzerland. We used a four-step methodology developed in our previous work but extended the geographical scope of the analysis to Switzerland with its direct neighbours (France, Italy, etc.) and their neighbours (Spain, Danemark, etc.). We run the analysis from the years 2016 to 2020 which allows us to analyse the effect of the decommissioning of the Mühleberg nuclear in December 2019. The results show that the deployment of this solution could lower the GHG footprint of the electricity consumed in Switzerland up to 7.51%. However this effect is fading through time and even increase the electricity footprint for the year 2020. This is mainly due to the fact that the power generation mix of Germany is constantly getting cleaner. We also examined the barriers to the deployment of small CHP units for domestic usage in Switzerland. The results show that the technology is facing many obstacles. As long as there is no clear definition of a strategy regarding CHP technology at federal and cantonal level, a real market penetration seems compromised.

Key words: combined heat and power, sector coupling, hourly GHG emission factor, natural gas, regulatory and policy barriers

## 1. Introduction

The Fukushima nuclear disaster in 2011 combined with the release of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2013 (IPCC, 2013) highlighted the need to build a secure energy system capable of meeting energy demand while taking into account the absolute necessity of preserving the environment in order to mitigate global warming and natural resource depletion. A growing number of countries have therefore committed to a transition to a low-carbon energy system. This is the case of Switzerland, which has developed the Energy Strategy 2050. This strategy is based on three pillars: reducing energy consumption and increasing energy efficiency, promoting renewable energies and phasing-out of nuclear power. The latter represents a real challenge for the country as it represents nearly 35% of its domestic power generation capacity (OFEN, 2020). In addition, it means removing a low-carbon source of power in the medium-long run. Therefore, phasing-out of nuclear power represents an additional challenge to meet the country's policy objectives on climate change mitigation.

In the long term, the missing nuclear capacity should be fully compensated by the development of renewable energies and decrease in consumption. In the short-medium term, it might increase the already growing power import dependency, especially in winter. This winter dependency might become a threat to the security of supply, as pointed out by the Federal Electricity Commission (ElCom, 2020). This is why, the commission asked for the development of production capacities during the winter semester on the Swiss territory. The electrification of the Swiss energy system with heat pumps and battery electric vehicle might further increase those winter imports and increase the threat to the security of supply (Rüdisüli et al., 2019).

In this paper, we demonstrate how sector coupling of natural gas infrastructure and power infrastructure might play a welcome role in addressing this challenge. The main idea is to use small distributed combined heat and power (CHP) units fuelled with natural gas or biogas to produce power in winter on the Swiss territory. This simple, short-term solution might represent an investment opportunity for both sectors but also a reduction in GHGs, an improvement in the energy balance and a greater resilience of the electricity network.

Combined Heat and Power system (CHP) is a technology which produces electricity and captures the waste heat for different processes such as space and water heating. It is a highly efficient system which can lead to primary energy saving (Bianchi et al., 2013) and GHG emission reduction (IEA, 2008). Indeed, this combined system is more efficient than separate conventional technologies such as centralized power plant where the heat is not recovered and an on-site boiler. Another advantage is that by producing electricity locally, it reduces reliance on the electricity grid. Finally, it produces power in winter, and can, as a result offset the low power capacity of solar and hydropower during this season. This symbiotic relationship contribute to the stability of the electricity grid (Mostofi et al., 2011; Nosrat et al., 2014; Pearce, 2009)

Our study aims at exploring the impact of the deployment of such solution in terms of decarbonization. More precisely, it aims at answering the following research questions:

- What effect the deployment of small CHP units fuelled with natural gas would have on the hourly carbon footprint of the electricity consumed in Switzerland ?
- How this result would potentially change after the decommissioning of the Mühleberg nuclear power plant?
- What are the economic, regulatory and policy barriers hindering penetration of CHP in Switzerland?

Section 2 presents the literature review, the methodology and the results of the effect of the deployment of small CHP units on the Swiss hourly carbon footprint. Section 3 presents the literature review and the results of the identified barriers to CHP development in Switzerland. Finally, the paper concludes with section 4 with conclusions and potential policy implications.

## 2. Effect of the deployment of small CHP units on the Swiss hourly carbon footprint of the electricity consumed

### *2.1 Literature review*

A great number of studies have explored the potential role CHP can play in reducing GHG emission and help cities or countries meet their objectives on climate change mitigation.

Most of the authors adopted a bottom-up approach and carried out analyses at the building level and then extrapolated it to the country or city level. This is the case for Howard et al. (2014) for New York City, H. Liu et al. (2017) for China and Kelly et al. (2014) for the UK. Another less common approach is the top-down approach, where global country/city heating demand is used to derive potential CHP power and heating generation by applying average power to heat ratio corresponding to the current technology (IEA, 2008). This is the method adopted in this study.

In the studies cited above, CHP systems are compared with a reference system for heat and electricity generation such as traditional boiler and electricity from the grid (Dorer & Weber, 2009; Howard et al., 2014; Howard & Modi, 2017; Hueffed & Mago, 2010, 2010; Mago et al., 2011; Mago & Smith, 2012; Rosato et al., 2013).

The GHG content of the electricity from the grid is often pointed out as a critical element when evaluating the benefit of CHP solution compared to another (Howard & Modi, 2017; H. Liu et al., 2017; Mago et al., 2011). In all those studies, the GHG content of the electricity from the grid has been considered as constant over time and only the domestic power generation mix has been considered. However, the latter changes continuously depending on the ever-changing demand and the energy resource availability. Moreover, electricity exchanges between countries may also affect the GHG content of the electricity consumed.

We addressed this gap in the literature in our previous work where we used an hourly approach and took into account Swiss power physical exchanges (imports and exports) with its neighbours (Simon et al., 2021). In the present paper, we took the analysis further by extending the geographical scope of the analysis to direct neighbours (France, Italy, etc.) and their neighbours (Spain, Denmark, Poland, etc.).

## *2.2 Methodology*

To answer the first research question, we used the four-step methodology developed in our previous work (Simon et al., 2021) (see figure 1) .

Firstly, we assessed, for the years 2016 to 2019, the GHG content of the electricity consumed in Switzerland applying the attributional Life Cycle Analysis (LCA) approach. We adopted a fine granularity (hourly) and took into account physical exchanges (imports and exports) with other countries. We extend the geographical scope of this analysis to Switzerland with its direct neighbours (France, Italy, etc.) and their neighbours (Spain, Danemark, etc.). It has been realized by a combination of data from the Ecoinvent database version 3.7.1 (Wernet et al., 2016) and data from the ENTSO-E transparency platform (Hirth et al., 2018).

Secondly, based on natural gas delivery data, we modelled hourly gas consumption for heating purposes. We adopted a top-down econometric approach using heating degree hours according to the Swiss SIA standard 381/3 (SIA, 1982). Data have been made available by the company which supplies and transport high-pressure natural gas to Western Switzerland.

Thirdly, based on the previous part, we simulated hourly electricity production with natural gas CHP plants. The hourly heating demand identified earlier had to be covered by the thermal output of the CHP plants. We considered the CHP plants as a linear model, or in other words, an energy converter with fixed electrical and thermal efficiencies.

Finally, we assessed the hourly GHG emission of the electricity consumed in Switzerland with the CHP solution. We used a conditional attribution of the electricity produced with the simulated CHP solution.

To answer the second question, we used the same methodology than previously explained but on the year 2020. Indeed, since 20 December 2019, Mühleberg nuclear power plant has been permanently shut down. This allowed us to see the impact in terms of GHG emissions.

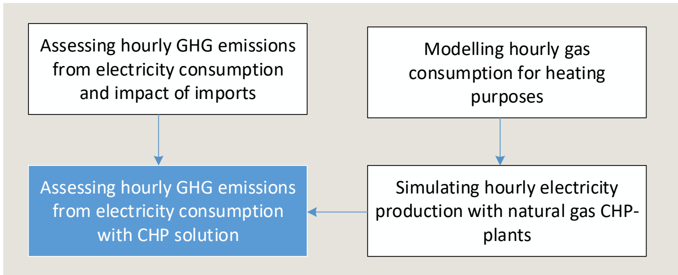


**Figure 1 : The four parts of the research process (Simon et al., 2021)**

## *2.3 Results*

The results show that the deployment of CHP plants fuelled with natural gas can lower the GHG footprint of the electricity consumed in Switzerland up to 7.51% (see table 1). Indeed, for the year 2016 the emission factor is 7.51% lower after the CHP simulation going from 149.30 g CO2eq/kWh to 138.09g CO2eq/kWh. However, the benefit of the simulation is fading through time and become even a disadvantage in 2020. Indeed, in 2020 the emissions factor increases by 8.67% after the simulation going from 80.58 g CO2eq/kWh to 87.56 g CO2eq/kWh.

**Table 1** - Actual emission factor of the electricity consumed and results of the CHP simulation (first and second ring countries)

| Year | **Emission Factor** Actual (gCO2eq/kWh) | **Emission Factor** After CHP simulation (gCO2eq/kWh) | **Variation** (%) |
|---|---|---|---|
| 2016 | 149.30 | 138.09 | -7.51 % |
| 2017 | 155.46 | 144.49 | -7.06% |
| 2018 | 121.24 | 116.63 | -3.81% |
| 2019 | 96.85 | 97.12 | 0.28% |
| 2020 | 80.58 | 87.56 | 8.67% |

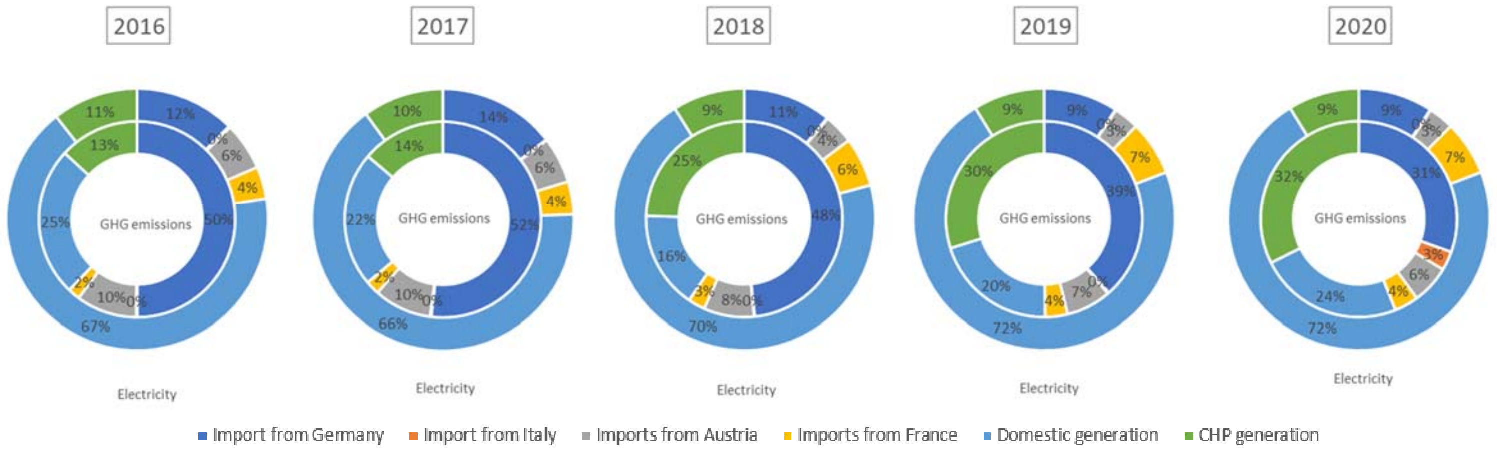


**Figure 2 : Source of the electricity consumed in Switzerland and its related GHG content after the CHP simulation**

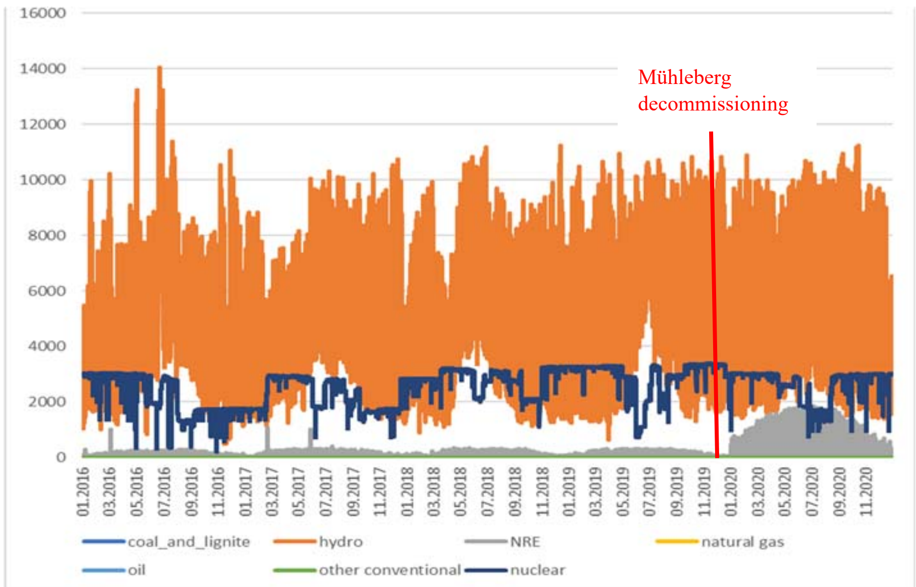


**Figure 3 : Hourly domestic generation mix of Switzerland**

This tendency is because of the growing part of new renewable electricity generation in Germany. Indeed, the impact of the imports from Germany on the carbon footprint of the electricity consumed in Switzerland, as shows in figure 2, went from 50% in 2016 to 31% in 2020. The proportion of the imports from Germany of the electricity consumed in Switzerland went from 12% in 2016 to 9% in 2020.

This tendency is also because of a growing part of new renewable electricity generation in Switzerland. This can be observed in grey in figure 3 which shows the hourly domestic generation mix of Switzerland from the years 2016 to 2020. In this figure, we can also observe the decrease in the nuclear generation due to the decommissioning of the Mühleberg power plant in December 2019. It produced 13.4 % of Switzerland 's nuclear electricity from 2016 to 2019 (OFEN, 2020).

This decrease in 2020 can be observed in dark blue in figure 3. It is hard to clearly identify the effect of the Mühleberg decommissioning because it has been accompanied by a large increase in new renewable energy generation. We cannot know if this increase is related or independent from the decommissioning. Further studies should be carried out in order to analyse this phenomenon.

Table 2 shows the results of the simulation when only Switzerland’s direct neighbours (France, Italy, Germany and Austria) are taken into account. It is interesting to note that the actual emission factors (before CHP simulation) are lower when we take into account only direct neighbours than when we integrate second ring countries (Spain, Denmark, Poland, etc.) in the analysis. This is mainly due to Germany’s imports from Poland which are heavily carbonized.

**Table 2**
Actual emission factor of the electricity consumed and results of the CHP simulation (direct neighbour countries only)

| Year | Emission Factor Actual (CO2eq/kWh) | Emission Factor After CHP simulation (CO2eq/kWh) | Variation (%) |
|---|---|---|---|
| 2016 | 143.58 | 133.76 | -6.83 % |
| 2017 | 150.83 | 140.84 | -6.62% |
| 2018 | 118.18 | 114.36 | -3.23% |
| 2019 | 94.36 | 95.37 | 1.07% |
| 2020 | 79.15 | 86.49 | 9.27% |

Table 3 displays the results of the simulation when we consider that the CHP are fuelled both with natural gas and biogas. When CHP are fuelled with a proportion of 30% of biogas and 70% of natural gas, the benefit of the deployment of CHP goes up to 12.69% in 2016. The proportion of 30% corresponds to a commitment made by the Swiss gas association to reach 30% of renewable gas in the gas segment of the heating market by 2030 (ASIG, 2018).

**Table 3**
Emission Factor after simulation with different proportions of biogas

| Year | EF After sim. 10% biogas (CO2eq/kWh) | Var. (%) | EF After sim. 30% biogas (CO2eq/kWh) | Var. (%) |
|---|---|---|---|---|
| 2016 | 135.51 | -9.42% | 130.35 | -12.69% |
| 2017 | 142.04 | -8.63% | 137.14 | -11.78% |
| 2018 | 114.50 | -5.56% | 110.26 | -9.06 % |
| 2019 | 94.98 | -1.94% | 90.69 | -6.37 % |
| 2020 | 85.45 | 6.06% | 81.25 | 0.83 % |

In conclusion, the deployment of this solution could lower the GHG footprint of the electricity consumed in Switzerland. However, this observation does not hold with an increase in new renewable generation in Switzerland and Germany. It is important to consider not only the electricity exchange with direct neighbour countries (France, Italy, Germany and Austria) but also with second ring countries (Spain, Denmark, Poland, etc.). The effect of the decommissioning of the Mühleberg nuclear power plant on the GHG footprint of the electricity consumed in Switzerland is hard to isolate. Further studies should be carried out in this direction.

## 3. Identified barriers to CHP development in Switzerland

### *3.1 Literature review*

In the Netherlands, the UK, Germany, Japan and the USA, CHP systems are considered as part of the energy transition strategy (Brown et al., 2007; Kobayashi et al., 2005). These countries have put in place favourable conditions for the deployment of this technology. However, in those countries and elsewhere there are still barriers for an appropriate market penetration.

The financial barriers are one of the biggest obstacles. Indeed, the high capital investment is an important barrier both in the UK (Howard et al., 2014) and in the USA (M. Liu et al., 2014). Another critical financial aspect is the difference between the price of electricity and the price of gas. For instance, in the UK, the high volatility of those prices makes the return on investment uncertain. Those aspects, combined with an unstable carbon price are slowing down the pace of the CHP deployment in the UK (M. Liu et al., 2014).

The interconnection to the local utility is an important barrier to CHP market implementation in the USA (Howard et al., 2014; M. Liu et al., 2014). Indeed, the process to evaluate the impacts of a CHP on the existing grid is often long and complicated, adding extra cost to the project.

In their market studies, Kuhn et al. (2008) identified the fact that few systems were available as an explanation why there was so few progress in market penetration in the UK. They also pointed out that decision maker such as architects or civil engineering are not familiar with the system. Finally, the lack of installation and service network is also a barrier identified both in the UK and the Netherlands.

Small CHP units for domestic usage have a huge technical potential in Switzerland but are facing many obstacles such as technical problems in operation, high cost of installations and lack of operator skills. There, CHP systems are confronted to too many obstacles to penetrate the market by themselves in the coming year. On the other hands, CHP related to municipal waste incineration and water treatment are facing fewer barriers and as a result their potential is already almost fully exploited (Rieder et al., 2009).

### *3.2 Methodology*

Barriers for the deployment of CHP in Switzerland were identified by conducting documentary research enriched with exchanges with experts.

### *3.3 Results*

Legal barriers : improvement of the framework conditions but not enough

Generally speaking, the existence of strict and different legislations at national, cantonal and communal levels results in complex framework conditions in Switzerland.

However, at the federal level, we can notice an improvement of the conditions for CHP system plants with the new **Federal Energy Act** (2016). Those improvements are the following:

- network operators are obliged to accept and remunerate all the electricity fed-in from small CHP plants (≤3MWel or≤5000MWhel annually). The minimal remuneration is based on the current spot price on the electricity market (day ahead);
- CHP plants operators have the right to consume the electricity they produce on site (right to self-consumption). A grouping of several owners in order to maximize the self-consumption is also possible under certain conditions;
- the tax on CO2 levied on fossil fuels that are proven to be used to generate electricity (CHP) is refunded up to 60% upon request (only for plants which do not participate in emissions trading scheme and have a rated thermal input of between 0.5 and 20 MW).

The first and second points have improved the profitability of the installation. However, the measure concerning the tax on CO2 applies only for plants with a thermal output between 0.5 and 20 MW. Small plants (below 0.5 MW) are excluded while small CHP units for domestic usage have a huge technical potential. For installations that meet the size criteria, the CO2 tax is only partially refunded.

In Switzerland, it is the cantons that define the regulations that apply to buildings. In order to ensure a decent uniformization of the different cantonal legislation, they developed the Model Energy Regulations of the Cantons (MoPEC in French) to serve as a guide for the development of cantonal laws (2018).

The MoPEC provides eleven standard solutions for heating replacement. Owners can freely choose the solution that best suits their situation from those eleven standard solutions. CHP is one of these standard solutions as long as the installation achieves an electrical efficiency of at least 25% and covers at least 60% of the heat requirements for heating and hot water production. Being part of the eleven standard solutions, shows that the high efficiency of the CHP technology is recognized and tolerate. However, this measure is not subsidized when it is fuelled with fossil fuel and the usage of biogas certificates is not always recognized as a renewable energy.

In conclusion, improvements have been made but there are still obstacles for the implementation of CHP in Switzerland. The strategy regarding CHP technology at federal or cantonal level is not clearly defined. Indeed, the Commission on Environment, Land Use and Energy of the parliament have charged the Federal Council to develop a strategy for the regulation of CHP. The objective is to contribute to the security of winter electricity supply as long as they do not compete with renewable energy (Postulat 20.3000 - Stratégie d'avenir Pour Le Couplage Chaleur-Force, 2020).

Financial barriers : small CHP plant fuelled with natural gas are barely profitable

As seen in the literature review, financial barriers are one of the biggest obstacles also in Switzerland. The high capital investment combined with the CO2 tax makes small CHP pants fuelled with natural gas barely profitable. In addition, some type of installation such as engines have high maintenance costs. However, the possibility of self-consumption introduced with the new Federal Energy Act has improved the profitability of the installations.

For CHP fuelled with renewable energy such as biomass and waste, the profitability is better thanks to the subsidies.

Historical barriers: Swiss utilities never fully adopted this technology

Swiss utilities never have fully adopted this technology. It is mainly historical. Indeed, at the origin of the electrification of the country, there were the hydroelectric dams. After, the country has moved toward nuclear power generation and never toward thermal power generation. Utilities have never had to integrate this technology into their production portfolio. The first CHP were accompanied with strong resistance from electric utilities. Today this technology is fully accepted by the market players. However, it is not promoted either by utilities or by architects or civil engineer. It is a niche technology that is more complicated to set up, which gives them more work.

Technical barriers: wide range of type of installations and size makes harder to communicate and train operators

The range of type of CHP installations is extremely wide. This is due to the fact that different CHP systems (prime mover) exist such as turbines, engines and fuel cells. But also because they can work at different scales (from micro-scale to large-scale). In addition, different operation strategies can be adopted (electric or thermal demand management). Furthermore they can be deployed for different uses such as residential, industrial, commercial, for district heating or in combination with heat pumps. Finally, CHP can be fuelled with different energy carrier such as natural gas, biogas or hydrogen.

This wide variety makes it difficult to raise awareness of the technology and to define a clear strategy. Indeed, there is no consensus among experts as to the type of installations that are optimal to achieve the objectives of the 2050 energy strategy. This wide variety also makes hard to properly train technicians to ensure the maintenance and the repair of the devices.

Confronted with this great variety, there are very few devices available on the market

Conclusion

The barriers to CHP development in Switzerland have not changed much since the study from Rieder et al. in 2009. Improvement of the framework conditions have been made with the introduction of the new Federal Energy Act in 2016. However, those improvements do not seem to make much difference in the deployment of this technology.

As long as there is no clear definition of a strategy regarding CHP technology at federal and cantonal level, a real market penetration seems compromised. Indeed market players would necessitate clear measure such as a general exemption from the CO2 tax for all CHP or CO2 tax of the heavily carbonized electricity imports in order to enter the market.

## 4. Conclusions and Policy Implication

In this paper, we explored how Combined Heat and Power (CHP) plants fuelled with natural gas or biogas might represent a short-term solution to produce power in winter on the Swiss territory. More precisely, we analysed the effect of the deployment of this solution on the hourly carbon footprint of the electricity consumed in Switzerland. We used a four-step methodology developed in our previous work but extended the geographical scope of the analysis to Switzerland with its direct neighbours (France, Italy, etc.) and their neighbours (Spain, Danemark, etc.). We run the analysis from the years 2016 to 2020 which allows us to analyse the effect of the decommissioning of the Mühleberg nuclear in December 2019. The results show that the deployment of this solution could lower the GHG footprint of the electricity consumed in Switzerland up to 7.51%. However this effect is fading through time and even increase the electricity footprint for the year 2020 by 8.67%. This is mainly due to the fact that the power generation mix of Germany is constantly getting cleaner. The results improved significantly when the CHP are fuelled with a proportion of biogas going from an improvement of 12.69% in 2016 to a small increase of 0.83% in 2020.

The effect of the decommissioning of the Mühleberg nuclear power plant on the GHG footprint of the electricity consumed in Switzerland is hard to isolate because it has been accompanied by a large increase in new renewable energy generation.

We also examined the barriers to the deployment of small CHP units for domestic usage in Switzerland. The results show that the technology is facing many obstacles. As long as there is no clear definition of a strategy regarding CHP technology at federal and cantonal level, a real market penetration seems compromised.

However, Switzerland needs to find a solution to the power import dependency in winter which will be magnified with the electrification of the Swiss energy system with heat pumps and battery electric vehicles. Our paper showed that this simple, short-term solution might represent a solution.

Further research in this area could be carried out in order to investigate more deeply the effect of the phase-out of nuclear power in Switzerland. In addition, further investigations should be done in order to compare alternative solutions to produce power in winter.

### *4.1 5. Limitations and further research*

## 5. Acknowledgement

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