Combined Heat and Power (CHP) plants fuelled by natural gas as a power generation solution for the energy transition - impact on the hourly carbon footprint of the electricity consumed in Switzerland

[Emilie Simon, University of Lausanne – HES-SO Valais-Wallis, ++41 27 606 90 94, emilie.simon@hevs.ch]
[Francesco Maria Cimmino, HES-SO Valais-Wallis, +41 27 606 90 94, francesco.cimmino@hevs.ch]
[Stéphane Genoud, HES-SO Valais-Wallis, +41 27 606 90 94, stephane.genoud@hevs.ch]

Overview

Switzerland has committed to a transition to a low-carbon energy system through the Energy Strategy 2050. One of the pillars of the strategy is phasing-out of nuclear power (OFEN, 2013). It means that the country will have to face the challenge of replacing nearly 30% of its domestic power generation (31.7% in 2017) (OFEN, 2018). In the long run, it should be compensated by the development of renewable energies and reduction in consumption, the two other pillars of the strategy. Currently, imports from the European Union are used when indigenous production is unable to meet demand. Indeed, for the last years, the use of electricity inflows from neighbouring countries has been growing, particularly in winter. The Federal Electricity Commission (ElCom) has warned about this winter dependency, among other things, about the fact that the majority of imports during this period are of fossil fuel origin (ElCom, 2018). These imports probably have an important impact on the carbon footprint of the electricity consumed in Switzerland as around 20% of the European Union's electricity production came from coal (21.5% in 2017) (IEA, 2019). Having the lowest combustion carbon intensity of the three major fossil fuels (IPCC, 2006), natural gas is sometimes presented as the fossil fuel of the transition, notably as a power generation solution (IEA, 2011). Combined Heat and Power (CHP), an internal combustion engine coupled to an electric generator, is a highly efficient energy conversion process. It produces both electricity and heat and can be fuelled by natural gas. From a thermodynamic point of view, this approach allows a more efficient use of natural gas compared to its direct combustion for heating purposes. Furthermore, this decentralized approach is also more efficient than other conventional gas-fire power plant where the heat generated cannot be recovered. As a result, this project intends to evaluate the environmental impact of a short-medium run solution allowing to produce electricity on the Swiss territory during winter : the development of decentralized power generation through natural gas-fired combined heat and power plants. More precisely, this study aims to answer the two following research questions :

1) What is the impact of the electricity inflows from neighbouring countries on the hourly carbon footprint of the electricity consumed in Switzerland ?
2) How the replacement of a part of the inflows from neighbouring by Combined Heat and Power (CHP) fuelled by natural gas impacts the hourly carbon footprint of the electricity consumed in Switzerland ?

Methods

For this study, the hourly granularity has been chosen in order to be closer to the real constraints of the electricity market. To answer the two research questions, four different parts were necessary (see figure 1).

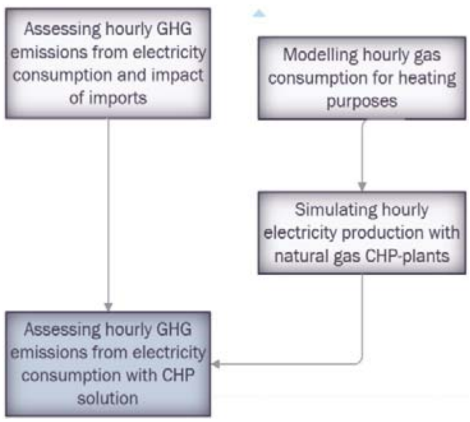

Figure 1 : The four parts of the research process

Assessing hourly GHG emission from electricity consumption and the impact of imports

This part has been realized by a combination of data from the ecoinvent database on Life Cycle Inventory technology and electricity related data from the ENTSO-E transparency platform (Frischknecht & Rebitzer, 2005; Hirth et al., 2018). The hourly carbon footprint of the electricity consumed in Switzerland has been assessed in accordance with the consumption principle (Vuarnoz & Jusselme, 2018; Bai et al., 2014; West et al., 2016). It means that the country's own electricity generation mix has been taken into account as well as the country's electricity cross-border physical flows (imports and exports). In this study, the GHG content of the electricity imports has been considered as being the same as the generation mix of the country of origin of the imports.

Modelling hourly gas consumption for heating purposes

Natural gas consumption for heating purposes has been modelled by means of the heating degree-hours method (Guttman & Lehman, 1992; Durmayaz et al., 2000). Hourly natural gas delivery data and outside temperature data have been made available thanks to the collaboration with the company which supplies and transport high-pressure natural gas to Western Switzerland.

Simulating hourly electricity production with natural gas CHP-plants
This part has been realized using the results of the previous part. The simulation has been conducting in order to maximize efficiency according to the second law of thermodynamics. Different scenarios have been made regarding CHP efficiency and the proportion of natural gas consumption convertible to the CHP technology.
Assessment of the hourly GHG emission from electricity consumption with the new solution
This part has been assessed based on the results of the previous parts. Various scenarios have been developed, such as concerning the proportion of biogas that can be found in the Swiss gas grid.

Results

The results show that, imports impact strongly and negatively the GHG footprint of the electricity consumed in Switzerland. More precisely, it is heavily impacted by imports from Germany and its coal-based power production. The results of the last part show that the development of decentralized power generation through natural gas-fired CHP plants can substantially lower the GHG footprint of the electricity consumed in Switzerland. Indeed, in all the scenarios, the natural-gas CHP solution is a less-GHG-emitting alternative to imports.

Conclusion

This study demonstrates that the Swiss growing dependency on electricity imports during winter has, indeed, a non-negligible impact on the environment. This tendency will probably continue as Germany intend to reach its total coal phase out only by 2038 (BMWi, 2019). The natural gas-fired CHP solution examined in this study represents a less-carbon intensive alternative. In addition, being based on existing technology and infrastructure (gas grid), this solution could be deployed in a very short span. This aspect is of particular importance because CO2 emissions shall start to diminish before 2030 if we want to limit global warming to 1.5C° (IPCC, 2018). The necessity to act before 2030 is an aspect that has been neglected in the Energy Strategy 2050 whose objectives are more farsighted. Policy makers should examine the fact that natural gas could play a temporary role in the energy transition. Further research in this area could be carried out in order to investigate the feasibility and the costs of deploying such a solution.

References

Bai, H., Zhang, Y., Wang, H., Huang, Y., & Xu, H. (2014). A Hybrid Method for Provincial Scale Energy-related Carbon Emission Allocation in China. *Environmental Science & Technology*, *48*(5), 2541–2550. https://doi.org/10.1021/es404562e

BMWi, B. für W. und. (2019). *Kommission „Wachstum, Strukturwandel und Beschäftigung" Abschlussbericht*. https://www.bmwi.de/Redaktion/DE/Artikel/Wirtschaft/kohleausstieg-und-strukturwandel.html

ElCom, C. fédérale de l'électricité. (2018). *Résumé Adequation du système électrique 2025 (System Adequacy 2025)—Etude sur la sécurité de l'approvisionnement en Suisse en 2025*. https://www.elcom.admin.ch/elcom/fr/home/documentation/medienmitteilungen.msg-id-70953.html

Frischknecht, R., & Rebitzer, G. (2005). The ecoinvent database system: A comprehensive web-based LCA database. *Journal of Cleaner Production*, *13*(13), 1337–1343. https://doi.org/10.1016/j.jclepro.2005.05.002

Hirth, L., Mühlenpfordt, J., & Bulkeley, M. (2018). The ENTSO-E Transparency Platform – A review of Europe's most ambitious electricity data platform. *Applied Energy*, *225*, 1054–1067. https://doi.org/10.1016/j.apenergy.2018.04.048

IEA, I. E. A. (Ed.). (2011). *World energy outlook 2011*. OECD.

IEA, I. E. A. (2019). *World Energy Balances 2019*. https://webstore.iea.org/world-energy-balances-2019

IPCC. (2018). *Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.*

IPCC, I. P. on C. C. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories—IPCC*. IGES. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf

OFEN, O. fédéral de l'énergie. (2013). *Le Conseil fédéral adopte le message sur la Stratégie énergétique 2050 [Online]*. https://www.admin.ch/gov/fr/accueil/documentation/communiques.msg-id-50123.html

OFEN, O. fédéral de l'énergie. (2018). *Statistique suisse de l'électricité 2017* (p. 2). https://www.bfe.admin.ch/bfe/fr/home/versorgung/statistik-und-geodaten/energiestatistiken/elektrizitaetsstatistik.html

Vuarnoz, D., & Jusselme, T. (2018). Temporal variations in the primary energy use and greenhouse gas emissions of electricity provided by the Swiss grid. *Energy*, *161*, 573–582. https://doi.org/10.1016/j.energy.2018.07.087

West, S. E., Owen, A., Axelsson, K., & West, C. D. (2016). Evaluating the Use of a Carbon Footprint Calculator: Communicating Impacts of Consumption at Household Level and Exploring Mitigation Options. *Journal of Industrial Ecology*, *20*(3), 396–409.