**The role of electrification in the decarbonization of Central-Western Europe**

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## Overview

The Europen Union has recently committed to reach climate-neutrality by 2050 and become the first continent fully decarbonizing its economy. As reviewed by the latest IPPC report [1], such mitigations pathway can only be achieved thanks to “energy demand reductions, decarbonization of electricity and other fuels, electrification of energy end-use, deep reduction in agricultural emissions and some form of carbon dioxide removal”. Yet, the importance of each of these elements in the decarbonization strategy is uncertain and will depend on regional conditions, socio-economic factors, and technological progress experienced in the key carbon-free technologies.

Among those five mitigation options, we focus on the role of electrification of energy end-uses for achieving the European ambition. Our paper starts with the recognition that there now exist several global studies of decarbonization (e.g. [2,3,4]) that each lead to different penetration of electricity in the final demand. We take these scenarios as coherent views of electrification that we want to study with respect to a different set of assumptions in order to assess the resilience of this mitigation option. On its advantages, electricity is the energy carrier that is most probably the less costly to decarbonize and where potentials are the highest (notably thanks to wind and solar technologies). This suggests to promote its direct use as it leads to fewer transformation losses or even produces gains for some sectors where electric technologies are more performant (e.g. motors, heat pumps,...). On its disadvantages, the direct switch to electricity can lead to a significant cost increase in infrastructure and technologies. To be more specific, electrification increases the supply cost as it might require more firm capacity to maintain the electric system resilient. Indeed, in a renewable-based system, the peak moment occurs during long-duration events with low renewables output and this peak can be aggravated if the consumption profile of the new electricity end-uses coincides with such events [5]. On infrastructure, electrification also leads to higher reinforcement needs on both transmission and distribution grid, to transport a very large volume of renewables across Europe to the load centers and to integrate new loads on the distribution grid. Finally, switching end-uses to electricity requires investment in technologies that are usually more capital intensive.

Our contribution is to quantify the economic benefits and limits of different degrees of electrification in the full decarbonization of Central-Western Europe. To do so, we design different scenarios regarding this electrification and quantify their economic performances thanks to an energy system model. Given the uncertainty on future technological cost (of electric renewables, whole value chains of synthetic fuels,...), we combine those scenarios with sensitivity analysis on those technological costs. Our results demonstrate that electrification is indeed an important element in the decarbonization strategy but should not impede the use of other carbon-free energy carriers, as they remain important in a cost efficient-transition.

## Methods

Our economic assessment is based on a detailed energy system model for central-Western Europe[[1]](#footnote-1). The model co-optimizes the supply of all the energy forms for all demands (power, methane, hydrogen, liquids, and solids), choosing for each technology the optimal investment and dispatch to meet those demands at an hourly granularity, along the decarbonization trajectory from 2020 to 2050 (with a five years timestep). On the supply side, the model includes generation capacities, storage assets and transformation processes (electrolyzer, steam methane reforming, methanation, Fischer-Tropch,...). Wind, solar and biomass energy are constrained by their energy potentials [**7**]. On the demand side, the demands are based on a bottom-up model (including capital stock evolution) focusing on the end-uses of the different sectors, i.e. transport (with seven different modes), residential and tertiary (space/water heating, lighting, and appliances) and industry (specific consumption of eight different branches). Each of those demands comes with a dedicated hourly consumption profile calibrated on calendar and weather variables. For space heating, we further detail the modeling by considering heat pumps of different types (air/air, air/water, hybrid) to appropriately account for their impact on the load profile [8]. Finally, all demands come with flexibility potential (e.g. electro-mobility and vehicle to grid application where most of the potential can be found).

## Results

We quantify three different electricity-driven decarbonization scenarios to highlight the benefits and limits of electrification. Those are constructed to span the level of electrification while sharing the same assumptions on the other mitigation options (i.e. energy demand reductions, decarbonization trajectory, biomass resources and potential of carbon dioxide removal). Given the limited potential of biomass and CCS in Europe, the difference in electrification is primarily complemented by synthetic fuels (i.e. fuels produced from decarbonized electricity). Those can alleviate the disadvantages of electrification cited above but one should remember that their production and value chain involve additional costs for the processes, infrastructure and the source of captured CO2.

Our quantification shows that electrification is indeed a crucial element of the mitigation strategy but should not impede the optimal use of all carbon free-energy carriers. Indeed the scenario with a massive electrification rate has the highest decarbonization cost, and this finding remains valid across our range of technological costs. This increase comes primarily from higher electricity expenditures as electrification of end-uses increases the need in firm capacity that is generating only a limited amount of hours each year. Our assessment concludes that the scenario with a balanced view on electrification is the most resilient one, as its decarbonization cost is either the lowest one, either very similar to the lowest one in our sensitivity analysis on future technological cost.

## Conclusions

Our paper highlights that sustained electrification is an essential lever for European decarbonization strategy but that this choice needs to be adapted to the end-uses by considering its impact on energy expenditures, electricity peak, and infrastructure cost. It also shows that synthetic fuels (with their biomass analogous) allow for a more efficient sector coupling: they provide flexibility in the power sector both as in production (via thermal assets) and dispatchable demand. Their use in hybrid and co-generation technologies, notably for heating applications, allows capturing the main benefits of electrification in terms of efficiency while maintaining the peak reasonable. Finally, those energy carriers are necessary as final energy for the application where switching towards electricity involves high switching cost (high-temperature industrial process, heavy trucks, ...)

## References

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1. Geographical scope: Austria, Belgium, France, Germany, Italy, Netherlands, United-Kingdom, Spain and Switzerland, [↑](#footnote-ref-1)