Electrification of the hard-to-abate chemical sector: implication for Net-Zero power systems in Europe

Working paper

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Overview

The net-zero emission target by 2050 for the European Union has been enforced to limit global warming. It requires large greenhouse has emissions reductions in all sectors and notably in the hard-to-abate sectors, that rely mostly on hydrocarbons in the current energy systems. Those referred to heavy industry (cement, steel, chemicals, and aluminium) and heavy-duty transport (shipping, trucking, and aviation). Yet, the pathways to reduce emissions and reach the net-zero emissions target for those sectors is still unclear. Most scenarios consider electrification, CCS[1], use of low-carbon hydrogen, and use of sustainable biomass as the key enablers to reach climate neutrality. Each of those alternatives would however require significant investment on the upstream to meet the growing demand, potentially years before the delivery as construction lead time could take several years. Typically, the more electrification would be required, the harder it gets for the power system to perform both its decarbonisation while meeting the increasing demand.

In this article, we will consider the chemical sector in detail to understand the interlinks between the power sector, considered as our upstream, and hard-to-abate sectors, considered as our downstream. The chemical sector is indeed one of the identified hard-to-abate sectors as it is based on many organic feedstocks and as most processes require constant heat furniture. Presently, both sustainable feedstock and future high temperatures provision would depend upon significant technological breakthroughs, as the low-carbon alternatives are not yet demonstrated at scale nor cost-efficient. The detailed transition to low-carbon emission is an important challenge for the petrochemical sector, that is underlooked in most top-down transition models. Indeed, in 2018, the chemical sector direct emissions amounted to 128 Mt CO_2e for the European chemical industry, which corresponds to 16% of EU industrial emissions. Worldwide, the chemical sector emits 6.3% of global GHG[2] emissions, making it one of the most important sub-sector emitters (Ge et al., 2020). The European chemical industry direct GHG have emissions have decreased substantially since the 1990s, with a reduction of more than half of the GHG emissions between 1990 and 2019, while the production increased by more than 47% (Cefic, 2022). This was achieved through improvements in processes and energy efficiency, the adoption of catalysts that prevent the emission of nitrous oxide and stricter regulation concerning the HFC (Montreal Protocol). Despite those reductions, CO_2 emissions have been mostly stable over the past decades, and further reductions should be achieved in a shorter period to meet the 2050 ambition. There is however no consensus on how the reduction could be achieved and to what extent electrification will be required for the chemical sector, and under which conditions. In other words, GHG reduction in the chemical sector as a whole through electrification is not well understood, and the necessary conditions for it to materialize are still unclear.

We address this research gap by examining the long-term industrial transformation required to accomplish the Net-Zero ambitions of the European chemical industry, by including the challenges and complementarities induced in the power sector. Our article notably expands the literature by providing a quantification of a low-emission pathway for both sectors. Specifically, we determine least-cost options for the hard-to-abate chemical sector while taking into account the required upstream investment for the power system. We developed a novel formulation of capacity expansion for the chemical values chains, jointly optimised with a long-term capacity expansion of the power sector (Palmintier and Webster, 2011; Sahinidis et al., 1989; You et al., 2011).

[1] CCS stands for Carbon Capture & Storage.
[2] GHG stands for Greenhouse Gases, encompassing notably carbon dioxide, methane and nitrous oxide.

Methodology and Scope

Our analysis focuses on the Central-West Europe (CWE) region, currently producing near 60% of the European Union chemical production. We use a brown-field approach, meaning that pathways start with the existing production capacities as of 2019. We consider a 5-year timestep, running to 2050, while both the power sector and the chemical sector face a common carbon price trajectory. We adopt a social planner perspective, for which the capacity and the dispatch are endogenously optimized both for the power and the chemical sector. Our analysis focuses on the extent of electrification of the chemical sector and the resulting investment realized in the power sector.

We developed a novel formulation of a capacity expansion problem for the chemical production chains based on Sahinidis et al. (1989) and You et al. (2011) combined with a long-term capacity expansion model of the power sector based on Palmintier and Webster (2011).

Demand has been kept constant for the chemical product, as of 2019, while the power demand is growing both exogenously by 25% to 2050, and endogoneously depending on the chemical sector power demand. We based the research on seven different carbon price trajectoriesAdditional sensitivities are performed, notably on the availability of CCS technologies for the chemical sector.

Results

The methodology allows to identify the low-carbon options for the chemical and power sectors and provide a first detailed quantification of the range of electrification needed in the chemical sector to reach net-zero. Our results indicate that the electrification level of the chemical sector when using fixed, exogenous assumption on the evolution of the power sector is overestimated by 50% to 81% depending on the year and the scenario. Regarding low emitting pathways of the chemical sector resulting from our model, the results indicate that a high level of electrification is however cost-effective for reaching deep decarbonisation of the chemical sector. The impact in terms of investment and carbon intensity of the electricity production in the power sector is as well assess, with all scenarios reaching low-emission thanks to the deployment of renewables and CCS. Comparing the resulting overall net present cost with the cumulated non-biogenic emissions over the entire period resulting from each scenario in Fig. 5., our results indicate that the average abatement price of carbon emissions is in the range of 400-500 EUR/t$CO_{2(e)}$, depending on the availability of carbon capture technology.

More generally, our study also highlights the need for rapid technology switches to meet the Net-Zero targets. This accelerated transition occurs both in the power sector, where renewables should expand significantly and in the chemical sector, where incumbent processes will need to phase out progressively.

Conclusion

In this paper, we applied a novel co-optimization of the power and the chemical sector from 2018 to 2050. We demonstrate that a tripling of the electricity demand is likely for the chemical sector to reach low emissions levels. We highlight the need to account for the feedback loops with the upstream power sector to assess the required pace of the energy transition and the associated level of carbon pricing.

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