The role of industrial production levels in energy system optimization models

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Overview

The European industrial transformation will play a key role in the net-zero transition. Besides decarbonizing production processes themselves, industries are facing changes in the industrial production output as well. As pointed out by Mario Draghi in the 2024 report on European competitiveness [1], Europe is facing a competitivity crisis, warning about the region's lagging innovation, industrial strategy, and economic resilience compared to global competitors like the U.S. and China. As European production facilities are producing at an all-time low, increasing concerns surrounding the industrial competitivity in Europe have led to the 2024 Antwerp declaration, a call from industry to restore the business case in Europe [2]. Industries are facing the difficult challenge of balancing global competitivity with Europe’s climate ambitions, leading to increasing uncertainty on future European industrial production capacities.

Recent studies that investigate how to transition to net zero in Belgium [3], [4] often rely on the assumption that industrial production levels remain constant or increase slightly, with only a few exceptions. Other studies have explored the potential role of limiting energy demand through sufficiency measures, increased material efficiency or behavioral shifts [5], [6], [7]. These however fall short in understanding what drives the change of industrial production levels concerning the energy transition and broader macroeconomic trends. More recently, studies have emerged on the potential impact of so-called ‘green relocation’ of energy-intensive industries to areas with more favorable renewable generation conditions [8], [9]. Existing research identifies energy-intensive industries, such as steel [10], [11], as being at risk for green relocation, outlining the region-specific cost benefits of relocating parts of the future green value chain [8], [12]. However, they do not adequately address the effects of industrial relocation on (1) the energy system and (2) the feedback interactions with the economy [9].

In summary, a better understanding of the impact of a changing industrial demand on the energy transition is needed. To assess this interaction, a detailed energy-economy model can be deployed to endogenize the industrial demand within the framework. Ideally, a highly detailed energy-economy framework is developed by fully integrating a macroeconomic model with a long-term capacity expansion model. In practice, the uncertainty regarding consistency between the two models does not always outweigh the cost of building and running these types of models. Instead, this paper proposes an exploration of different more basic approaches to incorporate macroeconomic interactions in an energy system model. Moreover, we introduce a novel approach to endogenize the industrial demand by linking material demand to the deployment of renewable technologies.

Methods

We explore different approximative methods to incorporate macroeconomic characteristics in energy system models to account for a dynamic industrial production, avoiding the need to build expensive integrated assessment models that link a full energy system model with a full macroeconomic model. For the purpose of comparability, the same model is used in all methods which will be the Belgian TIMES model. The same scenario is executed for each approach, resulting in five different pathways (including the reference scenario) that all represent the same outlook. This paper aims to identify the strengths and weaknesses of the different approaches and compare their overall performance in national long-term capacity expansion models. The different approaches are described as follows:

0. **Exogenous assumption for a static industrial landscape**
   The stand-alone energy system model that assumes a constant industrial production output throughout the whole modelling horizon, serves as a reference case.

1. **Exogenous assumptions on the future industrial production trajectories**
   A first and simple approach is to implement an exogenously defined industrial production trajectory by replacing the basic (nearly) constant demand curves with the new pathways. These new pathways are based on findings in literature or recent reports of industries that indicate possible changes in future industrial activity for Belgium. They aim to illustrate the possible impacts on the energy transition in case of certain changes in the industrial landscape.

2. **Endogenous representation through price elasticities**
   A second strategy to endogenize industrial production in energy system models is the use of price elasticities that allow for a changing domestic industrial output depending on the production cost. Own price elasticities are not often used on long-term capacity expansion models, as they aim to determine the cost-optimal pathway to reach a certain demand, instead of determining the demand itself. Certain energy system models do include price elasticities to include demand response, which refers to a variable production output that can match a price signal to a certain extent [13]. This implementation of price elasticities does not aim to alter the total yearly production output but rather aims to analyse the possibility of power system balancing. In this paper, we aim to include price elasticities on the intermediate level of domestic industrial production, reflecting the possibility of domestic industries closing down as a result of increasing energy prices. This does imply a change in yearly production output, but it does not necessarily imply a reduction of final end-consumption of the product, as domestic production could be replaced by increased imports.

3. **Endogenous representation using macroeconomic modules**
   In this approach, we explore existing integrated energy-economy linkages. These modules typically include a macroeconomic model that can either exchange information with the energy system model or can be fully integrated into a single mathematical problem. Most often, one of the two models is reduced or aggregated to be compatible with the other model's architecture. This setup is what Helgesen and Tomasgard refer to as 'hard-linked' models [14].

4. **Endogenous representation of material demand emerging from the uptake of energy system technologies**
   Lastly, industrial production levels can be linked to the investment volumes of a decarbonization technology to reflect increased material needs as a result of the new capacities required for the energy transition. For instance, demand for steel should increase because of the increased deployment of wind turbines. This is a novel approach that, to our knowledge, has not been reported in literature before. We assess the magnitude of the impact of such a material link and explore its application possibilities.

Results and Conclusions

All four approaches are able to integrate a dynamic industrial demand in the long-term energy system outlooks. All pathways indicate that a reduced industrial production results in a more feasible energy transition, mainly referring to a reduction of investment needs in new capacities both for the industry sector and the power sector as the industrial energy demand decreases. However, only the third method, is able to capture the impact of the changing industrial activity on the economy to a limited extent. None of the approaches are able to capture the implications of carbon leakage into the outlooks, as a reduction in domestic production does not necessarily imply a reduction of final consumption within that country. On the contrary, it implies an increase in imports of energy-intensive products. A more detailed national energy-economy framework is needed to assess the feedback interactions between the energy system and the economic indicators. Such a framework could provide a more nuanced pathway that balances industrial activity and GDP growth with climate ambitions.

References

[1] "EU competitiveness: Looking ahead - European Commission." Accessed: Dec. 16, 2024. [Online]. Available: https://commission.europa.eu/topics/strengthening-european-competitiveness/eu-competitiveness-looking-ahead_en
[2] "The Antwerp Declaration for a European Industrial Deal." Accessed: Dec. 19, 2024. [Online]. Available: https://antwerp-declaration.eu/
[3] "PATHS2050 | Energy outlook." Accessed: Dec. 12, 2023. [Online]. Available: https://perspective2050.energyville.be/node/9
[4] Elia, "POWERING INDUSTRY TOWARDS NET ZERO," Elia group, 2022. [Online]. Available: https://www.eliagroup.eu/en/publications
[5] S. Bourgeois *et al.*, "Climate neutrality, Energy security and Sustainability: A pathway to bridge the gap through Sufficiency, Efficiency," 2023.

[6] J. Barrett *et al.*, “Energy demand reduction options for meeting national zero-emission targets in the United Kingdom,” *Nat Energy*, vol. 7, no. 8, Art. no. 8, Aug. 2022, doi: 10.1038/s41560-022-01057-y.
[7] Climact and BBL, “Een groene industriële revolutie: Hoe creëren we een klimaatneutrale Vlaamse industrie?,” 2021. [Online]. Available: https://www.bondbeterleefmilieu.be/artikel/bbl-berekent-zo-wordt-vlaamse-industrie-sneller-klimaatneutraal
[8] P. C. Verpoort, L. Gast, A. Hofmann, and F. Ueckerdt, “Impact of global heterogeneity of renewable energy supply on heavy industrial production and green value chains,” *Nat Energy*, vol. 9, no. 4, pp. 491–503, Apr. 2024, doi: 10.1038/s41560-024-01492-z.
[9] S. Samadi, A. Fischer, and S. Lechtenböhmer, “The renewables pull effect: How regional differences in renewable energy costs could influence where industrial production is located in the future,” *Energy Research & Social Science*, vol. 104, p. 103257, Sep. 2023, doi: 10.1016/j.erss.2023.103257.
[10] A. Devlin and A. Yang, “Regional supply chains for decarbonising steel: Energy efficiency and green premium mitigation,” *Energy Conversion and Management*, vol. 254, p. 115268, Feb. 2022, doi: 10.1016/j.enconman.2022.115268.
[11] A. Devlin, J. Kossen, H. Goldie-Jones, and A. Yang, “Global green hydrogen-based steel opportunities surrounding high quality renewable energy and iron ore deposits,” *Nat Commun*, vol. 14, no. 1, p. 2578, May 2023, doi: 10.1038/s41467-023-38123-2.
[12] J. Egerer, N. Farhang-Damghani, V. Grimm, and P. Runge, “The industry transformation from fossil fuels to hydrogen will reorganize value chains: Big picture and case studies for Germany,” *Applied Energy*, vol. 358, p. 122485, Mar. 2024, doi: 10.1016/j.apenergy.2023.122485.
[13] G. Kansal and R. Tiwari, “Elasticity modelling of price-based demand response programs considering customer’s different behavioural patterns,” *Sustainable Energy, Grids and Networks*, vol. 36, p. 101244, Dec. 2023, doi: 10.1016/j.segan.2023.101244.
[14] P. I. Helgesen and A. Tomasgard, “From linking to integration of energy system models and computational general equilibrium models – Effects on equilibria and convergence,” *Energy*, vol. 159, pp. 1218–1233, Sep. 2018, doi: 10.1016/j.energy.2018.06.146.