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Conceptual model of the industry sector in an energy system model: A case study for Denmark

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ABSTRACT

The Paris Agreement highlighted that pathways towards a future with fossil fuel independent societies require the transformation of all sectors to reduce the levels of greenhouse gasses emissions. To this end the industry sector, characterised by a high share of emissions and an intense and diversified energy demand, holds a paramount role. In the framework of assessing the transformation of the industry sector towards more sustainable alternatives, due to interdependencies within an energy system, the adoption of measures to reduce fossil fuel use in industry (e.g. efficiency, fuel substitution, electrification and energy cascading) can influence the operation and transformation of the energy system. To this end, the study proposes a method to simulate and optimise operational aspects of the industry sector at high level of details. The conceptual model is then integrated in an established bottom-up energy system model, creating a benchmark for analyses that can focus simultaneously on the impact of changes in the industry and in the energy sector on a system wide scale. On the practical side, by mean of a Danish case study, the paper sheds light on particular characteristics of the industry sectors, focusing on the structure of industrial energy use in regards to end-use processes, aspects of energy consumption, and measures for fossil fuel reduction. Considerations sparking from the analysis show the potential applicability of energy cascading, electrification and fuel substitution for industrial processes, engaging elements and technologies interlinked within the energy system. Given the theoretical approach proposed, similar considerations can be investigated for other case studies, exploiting the simultaneous optimisation of power, district heat, industry dispatches and characteristics. In this framework, the transformation of the energy use in industry sector can be simulated according to more stringent policies capping CO_2 emission levels and specific support schemes, paving the way for carbon neutral societies and a more sustainable, yet resilient, future energy system.

1. Introduction

In light of the recent Paris Agreement, which highlighted the importance of decreasing the use of fossil fuels in energy intensive sectors for greenhouse gasses (GHG) emissions reduction purposes, the necessity to aim at carbon neutral societies and switch to 100% renewable energy systems is a clear goal. In Europe, similarly to other international contexts, two sectors stand out for substantial energy consumption and related GHG emissions: power and industry. In the last years the power sector has experienced a considerable transformation, with multiple interventions designed to shift primary sources of energy production towards more sustainable alternatives. Policies implemented and innovations have thus fostered renewable technologies, energy efficiency and sustainable fuels, reducing considerably the energy-production related GHG levels. Compared to the ongoing transformation in the power sector, measures for reducing GHG emissions in industry lags. With more than 125 TWh of electricity consumption, 851 TWh of fossil fuels used for energetic purposes and 671 TWh of fossil fuels feedstock, in 2010 the industry sector accounted for almost 25% of the total final energy consumption in the European Union (EU) (Eurostat, 2017a). The related GHGs corresponded to 9% of the total EU28 emissions stock, as both European statistic institution (Eurostat, 2017b) and researchers confirm (Lechtenbohmer et al., 2016). The need for action to reduce fossil fuels in industry is clear, but several barriers exist. One essential difficulty is the heterogeneity of the sector, given the diversity of processes involved and a worldwide variation in facilities. Furthermore trade exposure,

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cost sensitivity, and long lived facilities have contributed to a slow adoption rate of interventions to reduce industrial emissions (Bataille et al., 2018).

Three main established technology options to reduce industrial emissions are available: efficiency, fuel substitution and electrification. Energy cascading - that is, the use of high quality heat from a source to be reused for other processes or for general heating - can also be considered. These measures are also referred as “decarbonization lite” (Bataille et al., 2018), even though the true meaning of the word can be discussed, as some options (e.g. biomethane) actually include carbon. Applied examples of electrification (Lechtenbohmer et al., 2016), energy efficiency (Li and Tao, 2017) and fuel substitution (Rehfeldt et al., 2018) show successful application of these options to reduce industry related GHG emissions; furthermore, other studies focusing on future implementation of electrification (IRENA, 2014) and fuel substitution (International Energy Agency, 2012), forecast an intensive use of these measures for future scenarios.

Due to the interdependencies within an energy system, the adoption of measures to reduce fossil fuel use in industry influence the operation and transformation of the energy system. Intuitively, an increased electrification of industrial processes leads to an increase of the electricity demand that, consequently, implies changes in the operation of the energy system (e.g. transmission, power plant operation and investments). Similarly, energy efficiency might lower the need for fuels and electricity; energy cascading can result in similar impacts, potentially providing heat to other sectors in the form of district heat. Regarding fuel substitution, the need for gas and especially renewable gasses in industrial processes, correlates to the options to produce (biogas upgrading) and deliver (gas infrastructure) these gasses by the overall system. Hence, when considering interventions to reduce industrial emissions, it is paramount to study the impact, benefits or challenges on an energy system. Given the current state of industry modelling in existing bottom-up energy system models, this is not always possible.

Models of this type often represent and simulate industry in an aggregate way, neglecting the complexity of the different industry branches or the structure of the processes with regard to input fuels and potentials to abate emissions. Other relevant details, such as temperature heat levels, fuel use characteristics and temporal profiles of energy consumption, are also mostly disregarded. Consequently, analyses based on these models can sometimes fail to report correctly the impacts of changes in the industry sector and can lead to misleading results, both in terms of policy design and energy system operation and planning.

Our study is thus motivated by the following research questions. Which aspects characterise the unique structure of the industry sector, in terms of fuel use, processes and characteristics about temporal energy consumption? How can we adequately model such a heterogeneous sector and integrate it in established bottom-up energy system models? How can this conceptual model be used to perform reliable and thorough analyses on GHG emission mitigation measures in the industrial sector?

To address these research questions, we select the energy system model Balmorel (Ravn, 2017) and, within this framework, we propose a conceptual model to represent the industrial sector. To apply the method we focus on Denmark, a European country that is striving to find solutions to reduce GHG emissions, aiming at a fossil independent future in 2050, focusing intensively on the industry sector (Danish Energy Agency, 2017). Applied cases on a local scale show the convenience of reducing fossil fuels use through energy cascade (Bühler et al., 2017), electrification (Danish Energy Agency, 2014a), energy efficiency interventions (Buhler et al., 2016) and fuel substitution (Jensen et al., 2017). Although the studies indicate promising possibilities, none of the investigations considered a system wide context of changes in the industry sector. To this end, we consider Denmark as a case study.

This paper contributes to the field by developing novel methods, useful to draw practical findings for researchers, industrial institutions and policy makers. On the methodological side, the contribution of the paper consists of (i) proposing a detailed conceptual model of the industry sector and (ii) integrate such model in an established energy system model, creating a benchmark for analyses that can focus simultaneously on the impact of changes in the industry (e.g. energy efficiency, electrification, fuel substitution) and in the energy sector (e.g. renewables, energy efficiency) on a system wide scale. On the practical side, by mean of the case study, the paper sheds light on particular characteristics of the industry.

By providing a detailed conceptual model of the industry sector considering structure of the processes with regard to input fuels, temporal profiles of energy consumption and options to reduce fossil fuels use, the paper narrows the knowledge gap on modelling and representation of the industrial sector in bottom-up energy system models.

The remainder of the paper is structured as follows. In Section 2, we present the current status of industry modelling in bottom-up energy system models. In Section 3, we present the methods developed. In Section 4, we introduce the case study and in Section 5 we discuss implications from the study. We conclude in Section 6, highlighting the relevant findings and suggesting future research.

2. Literature review

When investigating the impact of energy-related interventions in diverse sectors of the energy system (e.g. household, industry, services, etc.), it is fundamental to use tools that consider details such as the fluctuating component of energy production and consumption, given the evermore increasing share of renewable energy sources in the recent energy systems. To this end bottom-up energy system models, including technological explicitness and detailed temporal variation, are the most suitable tools for the task (Herbst et al., 2012).

The literature proposes a variety of bottom-up models suitable for different analyses, with characteristics varying according to the focus (Connolly et al., 2010) or the geographical target (Hall and Buckley, 2016). Among the existing models, only a few consider the industry sector. Moreover, the level of details considered varies, in regard to disaggregated energy consumption, fuel types, temporal profiles of demand and interaction within the energy system. Some models, among others EnergyPLAN (Aalborg University, 2018) and E4cast (Syed and Penney, 2011), consider the industry as an aggregated sector, with demand data defined on an annual level (TWh per year) with no hourly distribution. Also, the energy model MiniCAM operates on a very aggregated level, without representing specific technologies, but rather considering broad classes of technologies aggregated by sector (transportation, buildings, industry) and secondary fuel-type (liquids, gas, coal, biomass, electricity, hydrogen) (Brenkert et al., 2003). Oppositely, models like ESME (ETI), consider more details about the industry, including use of energy in industry segmented into various sectors (Iron, Steel and non-ferrous metals; chemicals; metal products, machinery and equipment; food, drinks and tobacco; paper printing and publishing; cements, ceramics, glass and lime; refineries; agriculture and other industry) and generic categories of production processes (High and low temperature process, drying and separation, motors, space heating and other) (Heaton, 2014).

Although different models feature different characteristics with more or less depth, to our knowledge, none of the existing bottom-