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Forecasting global developments in the basic chemical industry for environmental policy analysis

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HIGHLIGHTS

- We develop a global cost-driven forecasting model for the basic chemical sector.
- We study regional production, energy-efficient technology, emissions and policies.
- Between 2010 and 2030, 60% of new chemicals capacity is built in non-OECD regions.
- Global CO_2 emissions rise by 50%, but climate policies may limit this to 30–40%.
- Measures beyond energy efficiency are needed to prevent increasing CO_2 emissions.

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ABSTRACT

The chemical sector is the largest industrial energy user, but detailed analysis of its energy use developments lags behind other energy-intensive sectors. A cost-driven forecasting model for basic chemicals production is developed, accounting for regional production costs, demand growth and stock turnover. The model determines the global production capacity placement, implementation of energy-efficient Best Practice Technology (BPT) and global carbon dioxide (CO_2) emissions for the period 2010–2030. Subsequently, the effects of energy and climate policies on these parameters are quantified. About 60% of new basic chemical production capacity is projected to be placed in non-OECD regions by 2030 due to low energy prices. While global production increases by 80% between 2010 and 2030, the OECD's production capacity share decreases from 40% to 20% and global emissions increase by 50%. Energy pricing and climate policies are found to reduce 2030 CO_2 emissions by 5–15% relative to the baseline developments by increasing BPT implementation. Maximum BPT implementation results in a 25% reduction. Further emission reductions require measures beyond energy-efficient technologies. The model is useful to estimate general trends related to basic chemicals production, but improved data from the chemical sector is required to expand the analysis to additional technologies and chemicals.

1. Introduction

The global chemical industry has become increasingly important for both industrialized and developing countries[1]. Through the increased use of its most important products, ranging from basic fertilizers for agriculture and polymers used in plastic products to more specialized chemical substances, the sector has become an essential part of the global economy. The global annual production volume of polymers (about 280 megatonnes (Mt) in 2011) has exceeded steel since 1989 and is used in packaging, construction work, automobiles and other industrial sectors (PlasticsEurope, 2011, 2012).

The chemical sector (defined here as Divisions 20 and 21 in International Standard Industrial Classification (ISIC) rev. 4; UNSD, 2008) is the largest industrial energy user (36 exajoules (EJ) in 2010), accounting for about 10% of the global final energy use (IEA, 2012a). About 60% of these energy carriers were used as raw material in the production of basic chemicals (*feedstock energy*) (IEA, 2012a). The remainder (43%) is consumed as heat and electricity in the production processes of chemicals (*process energy*). The sector's activities led to about 1.7 gigatonnes (Gt) direct CO_2 emissions worldwide in 2010 (IEA, 2012b), making it

Abbreviations: BPT, best practice technology; C&I, China and India; CO_2, carbon dioxide; EIT, economies in transition; EJ, exajoule (10^{18} J); EUR, Europe; GJ, gigajoule (10^9 J); Gt, gigatonne (10^9 t); HVCs, high value chemicals; MEA, Middle East and Africa; Mt, megatonne (10^6 t); NA, North America; ODA, other developing Asia; OECD, organisation for economic co-operation and development; PAC, Asia pacific; SA, South America; SEC, specific energy consumption; USD, United States dollar; yr, year

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[1] In this study, developed countries are represented by member countries of the Organisation for Economic Co-operation and Development (OECD). Developing countries are represented by non-OECD countries.

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the third largest industrial source of emissions after the iron and steel and cement sectors (IEA, 2012b).

Historically, the production of chemicals was mostly based in Organisation for Economic Co-operation and Development (OECD) countries, but in the last decade non-OECD countries (e.g. in the Middle East, Asia) have rapidly expanded their chemicals production as well (e.g. OGJ, 2010). This shift is partly caused by increasing demand for chemicals in these regions, but also due to their lower energy costs, which on average account for 50–85% of the production costs of bulk chemicals (Ren et al., 2006; UNIDO, 2011). This production relocation trend may increase the global energy use and greenhouse gas emissions of the chemical sector if production is moved to regions with lower *energy efficiency* (meaning production plants require more energy to produce the same amount of chemicals). The current level of energy efficiency of new plants installed in non-OECD countries is typically lower than those in OECD countries because of less stringent regulation, lack of capital and other economic factors, such as cheap feedstocks (e.g. in the Middle East) (Saygin et al., 2011a; UNIDO, 2011). The large potential for energy efficiency improvements and need for governmental support are frequently emphasized, for example for the Arabian Gulf (FNI, 2012) but also worldwide (IEA, 2012c). New capacity additions offer the possibility of implementing new and energy-efficient production technologies. While such technologies could potentially save up to 15% of the chemical sector's energy use (including feedstocks; Saygin et al., 2011a), they will typically come at higher costs due to more expensive equipment.

Given that industry accounts for one-third of global energy use, much analysis has been devoted to the analysis of its energy-intensive subsectors. Most work focused on the iron and steel, pulp and paper, and aluminium sectors, due to high data availability and their comparatively simple production processes. For these sectors, in particular (i) the effectiveness of policies (Oikonomou et al., 2008; Rehan and Nehdi, 2005), and (ii) the cost-effectiveness and future implementation of energy-efficient technologies have been studied (e.g. Pardo and Moya, 2013; Oda et al., 2009; Hasanbeigi et al., 2013; Möllersten et al., 2003). The chemical sector appears to lack such comprehensive analyses: CE Delft (2012) identified the techno-economic performance of novel emission abatement technologies for specific products, but does not draw sector- and region-wide conclusions; CEFIC Ecofys (2013) forecast various developments up to 2050 but only consider Europe; and Saygin et al. (2011a) estimate the global maximum energy efficiency potential without considering costs nor the stock turnover. The present work attempts to close the gap between the chemical and other industrial sectors by developing a global forecasting model for basic chemicals, accounting for regional production costs, demand and stock turnover. In our analysis, we focus on the location of new production capacity, the implementation of energy-efficient technology and global CO_2 emissions up to 2030. We subsequently apply this model to study the effects of different energy and climate policies on the same parameters.

In the following sections, Section 2 provides background information for the basic chemicals analysed in this study. In Section 3, we provide methodological details of the forecasting model. We show the results of our analysis in Section 4 and critically discuss the validity of our results in view of the uncertainties and methodological limitations in Section 5. Section 6 ends the paper with conclusions for policy-makers and chemical industry associations.

2. Background

The chemical sector produces thousands of different products, making it a challenging task to analyse its energy and mass flows. We therefore focus on four key types of chemicals for further analysis: high value chemicals (HVCs), ammonia, methanol and chlorine. We choose these products because of relatively high data availability and because they represent at least half of the chemical sector's energy use, both including and excluding feedstock use (IEA, 2012a). We refer to them as *basic chemicals* throughout this paper. In this section we review the current production capacities and energy efficiency levels per world region for each basic chemical, and consider historic developments and the influence of energy prices.

2.1. High value chemicals (HVCs)

HVCs include the production of ethylene, propylene, butadiene and aromatics (benzene, toluene, xylene) by the transformation of hydrocarbons (e.g. naphtha, ethane) via the steam cracking process[2]. HVCs production is the sector's most energy-consuming activity (3 EJ/yr), accounting for 8% of its global energy use (excluding feedstocks; Ren et al., 2006; Saygin et al., 2011a). Ethylene is the main output of the process, with a global production volume of 120 Mt/yr (OGJ, 2006). The total production of other HVCs is equivalent to 60 Mt/yr (Neelis et al., 2005; OGJ, 2006). While light feedstocks (e.g. ethane) offer higher ethylene yields in the HVC mix (~85%), heavier feedstocks (naphtha, gas oil) yield a higher share of other HVCs (~50%) (Neelis et al., 2005).

As of 2006, 70% of HVC steam cracking capacity is located in the OECD regions, namely North America, Europe and Asia Pacific (see Fig. 1a). However, the strongest capacity growth is found in non-OECD regions, which grew around 7%/yr between 2000 and 2010, compared to 1%/yr in OECD regions (OGJ, 2000, 2010). In particular, due to the availability of inexpensive ethane feedstocks in the Middle East and Africa (Ren et al., 2006), HVC capacity in the region tripled to 26 Mt/yr between 2000 and 2010 (OGJ, 2000, 2010), making it a competitive supplier of ethylene derivatives (see also below, Fig. 2). Furthermore, HVC capacity in China and India expanded to about 30 Mt/yr (OGJ, 2011), in part because China has become the world's largest polymers producer (PlasticsEurope, 2012), which requires substantial olefin production in addition to growing imports (see Section 2.5). Regarding energy efficiency, the specific energy consumption (SEC) values (Fig. 1a, left *y*-axis) show that HVC production is most efficient in the OECD regions Asia Pacific and Europe (excluding feedstock). In comparison, the least energy-efficient steam crackers are found in Transition Economies. We find that regions with high energy prices, such as Asia Pacific, are typically more energy-efficient (Fig. 1a, right *y*-axis).

2.2. Ammonia

Ammonia is a precursor to various nitrogen-based fertilizers (consuming about 80% of production) such as urea, and is also used for plastics and fiber production (Ullmann's, 2007). It is produced from natural gas, fuel oil or coal via the Haber-Bosch process (EFMA, 2000). According to Fig. 1b, global production of ammonia in 2006 was about 140 Mt/yr (IFDC, 2008). Together, China and India have the largest production capacity (47 Mt/yr). The remaining global capacity (~90 Mt/yr) is evenly distributed across regions, with OECD regions accounting for 25% of the total capacity. Between 2005 and 2011, production capacity grew by 4%/yr in non-OECD regions and about 1%/yr in OECD regions (IFDC, 2008). Europe and Asia Pacific are the most energy-efficient producers (including feedstock), and also have the highest natural gas prices. Less efficient regions such as Middle East and Africa, Transition Economies and China and India have lower energy prices. In China and India, about 60% of ammonia capacity is

[2] In this paper we use the definition of HVCs from Solomon Associates (see Saygin et al., 2011a) which includes ethylene, propylene from pyrolysis gas of steam crackers, contained amounts of benzene and butadiene in the HVC mix of steam crackers, acetylene and hydrogen sold as fuel.