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Industrial energy use and carbon emissions reduction in the chemicals sector: A UK perspective

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HIGHLIGHTS

- Future decarbonisation of the UK *Chemicals* sector has been evaluated.
- The improvement potential of different technological interventions was assessed.
- 2050 ‘technology roadmaps’ were also developed for various alternative scenarios.
- *Best practice technologies* will prompt short-term energy and CO_2 emissions savings.
- The prospects for longer-term, ‘disruptive technologies’ are far more speculative.

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ABSTRACT

The opportunities and challenges to reducing industrial energy demand and carbon dioxide (CO_2) emissions in the *Chemicals* sector are evaluated with a focus on the situation in the United Kingdom (UK), although the lessons learned are applicable across much of the industrialised world. This sector can be characterised as being heterogeneous; embracing a diverse range of products (including advanced materials, cleaning fluids, composites, dyes, paints, pharmaceuticals, plastics, and surfactants). It sits on the boundary between energy-intensive (EI) and non-energy-intensive (NEI) industrial sectors. The improvement potential of various technological interventions has been identified in terms of their energy use and *greenhouse gas* (GHG) emissions. Currently-available *best practice technologies* (BPTs) will lead to further, short-term energy and CO_2 emissions savings in chemicals processing, but the prospects for the commercial exploitation of innovative technologies by mid-21st century are far more speculative. A set of industrial decarbonisation ‘technology roadmaps’ out to the mid-21st Century are also reported, based on various alternative scenarios. These yield low-carbon transition pathways that represent future projections which match short-term and long-term (2050) targets with specific technological solutions to help meet the key energy saving and decarbonisation goals. The roadmaps’ contents were built up on the basis of the improvement potentials associated with various processes employed in the chemicals industry. They help identify the steps needed to be undertaken by developers, policy makers and other stakeholders in order to ensure the decarbonisation of the UK chemicals industry. The attainment of significant falls in carbon emissions over this period will depends critically on the adoption of a small number of key technologies [e.g., *carbon capture and storage* (CCS), energy efficiency techniques, and bioenergy], alongside a decarbonisation of the electricity supply.

1. Introduction

1.1. Background

The chemical and petrochemical industry represents the largest contributor to industrial energy demand worldwide. It accounts for about 10% of global total final energy consumption and 7% of ‘greenhouse gas’ (GHG) emissions associated with industry [1]. Chemistry provides the fundamental basis for the synthesis of core intermediate and end products in order to satisfy human needs. It supplies inputs to matter transformation chains in other industrial sectors, e.g., plastics, composite materials, industrial gases, fertilizers, and so on [2]. These products are key to the modern global economy stretching from agriculture to medicine, through fuels, plastics and synthetic textiles.

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But the world landscape of the chemical industry has dramatically altered in recent years. Asian chemical companies displayed a major growth trend from 1980 onwards, driven by their domestic markets, and presently accounts for half of the global market [2]. A surge of new investment in chemical processing plant then took place in the Middle East after the turn of the Millennium, based on the natural (oil and natural gas) resources in that area [2]. However, large-scale shale gas exploration and development in the United States of America (USA), after 2006 in particular, has given their chemical sector a strong economic advantage when compared with competitors elsewhere [2–4]. The price of gas halved with an impact on competitiveness of a large part of the global chemical industry (both in terms of natural gas feedstock and fuel). Companies from across the world are locating themselves in the US to take advantage of this 'revolution' [3]: leading to a potential 'Golden Age of Gas', according to the *International Energy Agency* (IEA) [4]. The IEA sees shale gas as contributing about 14% to global gas production by 2035 [3,4].

The IEA [1] partnered with the *International Council of Chemical Associations* (ICCA) and *DECHEMA* (Germany's Society for Chemical Engineering and Biotechnology) in order to produce a technology roadmap for energy and GHG reductions in the world chemicals sector out to 2050. This roadmap was developed in the context of the IEA *2 °C Degree Scenario* (2DS) for global warming. It focused on the particular role of catalytic processes that account for roughly 90% of chemical processing [1]. The roadmap built on earlier studies of *Best Practice Technologies* (BPT) for improving energy efficiency in the sector [5] and of carbon abatement innovations. The former used mainly a top-down approach to examine some 57 processes and indicated energy saving potentials of 5–15% [5]. BPT are the most advanced, economically viable technologies on an industrial scale. ICCA commissioned the German *Öko-Institut*, with the support of *McKinsey & Company*, to critically review *Carbon Life Cycle Assessment* (cLCA) studies related to the chemicals industry [6]. This indicated the potential for GHG emissions {*carbon dioxide equivalent* (CO_{2e})} abatement 'from cradle to grave', i.e., over a value chain incorporating the extraction of feedstock material and fuels through to production, transport and distribution, product usage, and the 'end of life' (disposal or recycling) phases. More than one hundred cLCA studies were submitted by ICCA member companies from around the world to *McKinsey* for evaluation, and then the results or data were reviewed by the *Öko Institut*. They concluded [6] that the best option for reducing global GHG emissions could be achieved by ensuring that each life-cycle stage of the value chain yielded its optimum contribution. Otherwise, a given stage might prevent larger CO_{2e} reductions elsewhere along the chain, and consequently not elicit net global reductions overall.

Worldwide assessments of the chemicals industry have been supplemented by regional ones. Europe, or the *European Union* (EU) countries, in particular has instigated a number of studies of an energy-efficient and low-carbon chemicals sector including, for example, those sponsored by the *European Commission* (EC), via their *Joint Research Centre* (JRC) [7], the *European Chemical Industry Council* (Cefic) [8], and the *European Climate Foundation* (ECF) [9]. The JRC report [7] used a bottom-up model to evaluate the European chemical and petrochemical sector. It assessed the current technological status of 26 basic chemical products (including fertilizers, organic and inorganic substances, polymers, etc.), as well as the associated sectoral energy use and GHG emissions out to 2050. Over this period, it was found that the EU chemicals industry would experience a 39% rise in energy consumption, but a 15% fall in GHG emissions compared with the early 2010s [7]. Around 50 *Best Available Technologies* (BAT), the most effective innovations presently known, were examined. The importance of replacing fossil fuel feedstocks by sustainable alternatives such as hydrogen (from electrolysis driven by renewables) and biomass was recognised. Two cross-cutting technologies [*combined heat and power* (CHP), already widely used in the chemicals sector, and *carbon capture and storage* (CCS)] were recommended as having a potentially significant role in energy and GHG emission reductions going forward [7]. Cefic [8] were aided by *Ecofys*, the energy and sustainability consultancy, in the development of their 2050 European chemicals roadmap to a competitive, low-carbon future. They emphasised the importance of making changes to the sectoral fuel mix, particularly for heat generation and Nitrous Oxide (N_2O) production. This would yield again about 15% reduction in GHG emissions by 2050, although they noted that deeper cuts could be achieved via the decarbonisation of the power system and the adoption of CCS facilities [8]. Both the latter options would be costly and necessitate technological breakthroughs. Indeed, a novel feature of the Cefic study [8] was the focus on the adverse impacts that energy and climate policy costs are likely to have on European competiveness vis-à-vis chemicals production in the USA and other regions. The ECF were likewise concerned about price competitiveness [9], albeit in the context of the so-called energy policy *trilemma*: competitiveness, sustainability and security of supply. They studied the transition dynamics in the chemicals industry drawing on the Cefic roadmap [8]. ECF argued [9] that substantial GHG emissions reduction could be achieved through process and energy efficiency improvements, alongside greater resource 'circularity' or value chain collaboration. Thus, they suggested that by seeking out "cross-process, cross-company, cross-sector, and cross country abatement opportunities" European price competiveness in the chemicals sector could be maintained.

Aggregate studies of the chemicals industry on a global or region scale have their limitations. Each country has, in reality, its own distinctive historical background, structural characteristics (including access to resources), and potential for energy savings and decarbonisation. Therefore the present work seeks to draw out lessons from the chemicals sector and its development in Britain. Industry as a whole in the United Kingdom (UK) accounts for some 21% of total delivered energy and 29% of carbon emissions. There are large differences between industrial sectors in the end-use applications of energy, especially in terms of products manufactured, processes undertaken and technologies employed (see Fig. 1 [10]; where the final demand for energy by broad UK industrial sectors is depicted against various energy use categories). It is clear that the chemicals sector as seen in Fig. 1 gives rise to the highest industrial energy consumption; mainly due to low temperature heat processes (30%), electrical motors (19%), drying/separation processes (16%), and high temperature heat processes (11%) [10]. UK industry overall has been found to consist of some 350 separate combinations of sub-sectors, devices and technologies [11,12]. Nevertheless, it is the only end-use energy demand sector in the UK that has experienced a significant fall of roughly 40% in final energy consumption since the first oil price shock of 1973/74 [11,12]. This was in spite of a rise of over 40% in industrial output in value added terms. However, the consequent aggregate reduction in energy intensity (MJ/£ of gross value added) masks several different underlying causes: *end-use efficiency* {accounting for around 80% of the fall in industrial energy intensity; largely induced by the price mechanism); *structural changes in industry* [a move away from *energy-intensive* (EI) industries towards *non-energy-intensive* (NEI) ones, including services [11,12]}; and *fuel switching* (from coal and oil to natural gas and electricity that are cleaner, more readily controllable, and arguably cheaper for the businesses concerned).

1.2. The issues considered

The present study builds on work by Dyer et al. [11] commissioned by the UK *Government Office of Science* (GOS) and on a recent 'Advanced Review' by Griffin et al. [13]. In each case, a variety of assessment techniques for determining potential energy use and GHG reductions were discussed. Griffin et al. [13] then evaluated the wider UK industrial landscape with the aid of decomposition analysis [14] in order to identify the factors that have led to energy and carbon savings over recent decades. They then assessed the improvement potential in two