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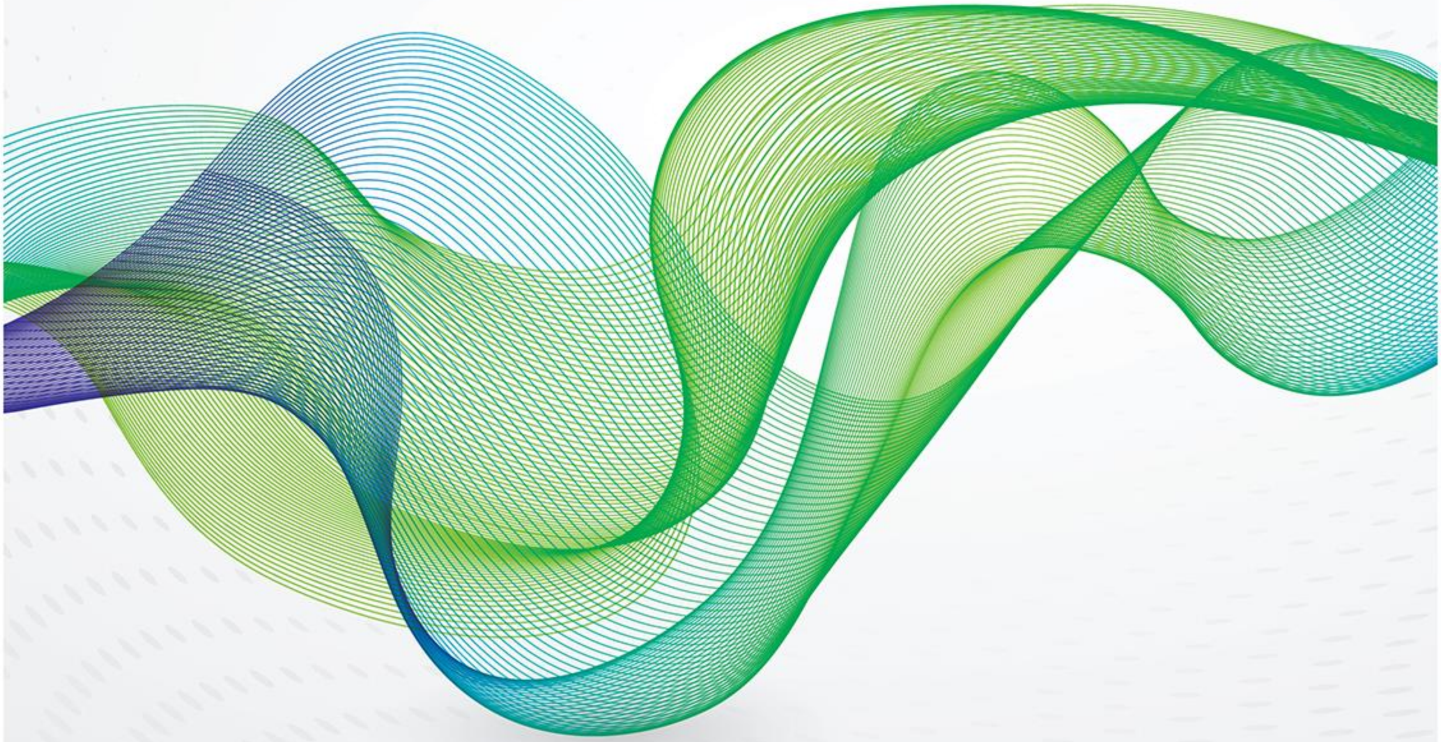
Decarbonization and industrial demand for gas in Europe



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All the opinions expressed and any remaining errors are my sole responsibility.

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Preface

The decarbonization of the European energy system has become a top priority for governments and policy makers, and a series of OIES papers has highlighted the key issues for the gas sector. Jonathan Stern has laid out the challenges which the gas industry must address if it is to avoid decline in Europe post-2030, while Anouk Honoré, the author of this paper, has written about the specific sectoral impacts. Her 2018 paper on the decarbonization of the Heat Sector provided important insights into an area that will require radical action if Europe is to meet its long-term climate targets, and this current paper provides a complimentary analysis of gas demand in the industrial sector, where heat is a key component.

It is perhaps not surprising that much of the focus of the decarbonization effort has been in the electricity sector, where the replacement of hydrocarbon inputs with renewable sources such as solar and wind provides an obvious and increasingly low-cost solution. However, the industrial sector must make an equally significant contribution to decarbonization if environmental goals are to be achieved, and as this paper reveals it is a much more complex and diverse question. The multitude of industrial processes and the wide range of options for reducing carbon output across a variety of economies means that there will not be a simple answer, and as such assessing the impact on the gas sector is difficult. However, with her usual methodical and rigorous analysis Honoré first breaks down the question into its constituent parts, provides a broad analysis of the potential options and then draws a range of conclusions for the gas sector. As she herself acknowledges, the pathways to a decarbonized future in the sector are many and varied, and as such arriving at a definitive answer at this stage is almost impossible. Nevertheless, we believe that this paper provides an important foundation for further analysis and offers some unique insights into the future for gas in the industrial sector in Europe.

James Henderson
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Oxford, May 2019

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Introduction

The decarbonization of energy systems has become a key driver in Europe, as both the European Union (EU) and its member states attempt to achieve goals set out at the COP21 meeting in Paris to limit global climate change. The EU is committed to reducing its greenhouse gas (GHG) emissions to 80–95 per cent below 1990 levels. Such a transformation of the energy system will be a challenge, requiring new technological breakthroughs and renewable energy investments. A decarbonized European energy system will probably entail dramatically lower gas consumption by 2050, and indeed projections of EU gas demand under COP21 carbon reduction constraints show a decline in methane demand starting in the late 2020s and accelerating over subsequent decades.[1]

So far, the electricity sector has been the main focus of EU low-carbon policies. The increase of renewables in the mix has already had an impact on fossil fuel generation, especially on natural gas.[2] This trend is expected to continue in the future,[3] but if Europe is to meet its objectives, decarbonization efforts will need to expand to other sectors to achieve climate neutrality.[4] Heat and transport are the next two sectors to be targeted in public discussion about climate change. In this context, the 'heating sector' usually designates the energy used for space heating (and cooling) in buildings, especially residential ones.[5] Emissions from the energy used to produce process heat, or used as feedstock in the industrial sector, rarely feature on the agenda, although this energy emits about 15 per cent of total European GHG emissions.[6]

About a quarter (23 per cent) of all energy consumed in Europe is used by its industrial sector. Approximately 65 per cent of this energy is derived directly from fossil fuels, including natural gas (27 per cent).[7] Transitioning to a low-carbon industrial sector will change this mix and likely lower fossil fuel demand, but a previous paper[8] by this author on the decarbonization of heat in Europe showed that the consequences on natural gas demand (about a quarter of which comes from the industrial sector[9]) would probably not take place as quickly as in the other sectors (power and buildings), even assuming that policy makers follow through on their commitments to fight climate change and increase their efforts to shift toward a low-carbon society. The objective of this paper is to shed some light on the main reasons behind this assumption: how future developments in industrial energy due to decarbonization policies will impact future gas demand, where and by when?

One of the main features is that the industrial sector is not homogenous. It is composed of very different sub-sectors which include energy-intensive industries (such as iron and steel and the chemical sector) and light industries (such as food and manufacturing). In addition, in this paper, the energy used as feedstock for industrial production is also counted as part of industrial energy demand.[10] As a result of this diversity, the decarbonization of the industrial sector is particularly complex. There will necessarily be differences between low-carbon options from one sector to another and even within sectors; such options will thus need to be adapted for each combination of industrial activities and this will be a major challenge. For instance, in the UK alone, 350 combinations of sectors, devices, and technologies have been identified in the national industrial sector. Another example is given by the 2017 expert consultation for the Innovation Fund which identified the fact that in the EU28 over 80 low-carbon technology options could be envisaged, with multiple options per energy-intensive industry.[11] It is important to mention that this research was not aimed at getting into the nitty gritty technological details of industrial processes in the 28 EU markets, and it by no means

[1] Stern (2019).
[2] For more information, see Honoré (2018a), Honoré (2014).
[3] For more information, see Honoré & Sen (forthcoming 2019).
[4] For more information, see European Commission '2050 low-carbon economy' and Honoré (2018b).
[5] For additional information on the European heating sector and its use of natural gas, see Honoré (2018b).
[6] GHG emissions from combustion. Source: Eurostat data for 2016.
[7] Eurostat data for 2016.
[8] Honoré (2018b).
[9] 26%. Source: Eurostat data for 2016.
[10] See definition of the industrial sector at the beginning of section 1.
[11] Climate Strategy & Partners (2017).

claims to cover all the possible, or potential, pathways that could be taken in each of the industrial sub-sectors. A 40-page paper necessarily has to take a step back and look at the big picture, despite the magnitude and the complexity of the topic.

Following this introduction, the paper starts (Section I) by providing an overview of the industrial energy mix in Europe and underlines the necessity of focusing more attention on the decarbonization of the sector. The second section identifies some scenarios for decarbonizing industry in Europe and illustrates the impact on gas demand which is expected to decline dramatically over the coming decades. Unfortunately, the scenarios do not provide much detail either by sector or country. This lack of detail is problematic when trying to understand the consequences of decarbonization on industrial gas demand more specifically. As a result, the subsequent sections first take a closer look at the main options for the transition to a low-carbon industrial sector in Europe and the abatement of GHG emissions (Section III), before moving on to the main challenges in section IV. This highlights the fact that replacing fossil fuels, including natural gas, is not going to be a straightforward process. There will be no single silver bullet and the sector is going to face many critical energy challenges with few simple answers. The fifth section proposes a simplified framework which can be used to observe impacts on natural gas demand and to understand expectations (both per sector and country) of likely progress over the next three decades. The final section draws together some conclusions.

I. The European industrial sector: diverse but still heavily reliant on fossil fuels

This first section provides a brief overview of the industrial sector, its energy use and emissions. It highlights the still predominant role of fossil fuels, including natural gas, despite the recent changes observed over the past decade such as improved efficiency and a growing share of low-carbon sources in the mix, especially biomass. This background information also gives some indication on the sources of GHG emissions and, therefore, the main sectors to be prioritized by decarbonization policies.

1.1. Two-thirds of EU's industrial energy still comes from fossil fuels

Definition

In this paper, the definition of industry follows, broadly, the Eurostat definition and examines final energy consumed across all industrial sectors – but excludes the refinery sector and energy consumed for onsite electricity/heat generation. In other words, this paper only focuses on final energy demand and not on the energy used in the transformation sector. In 'final energy demand' we include both the energy consumed for final energy use and the energy consumed for non-energy use (as raw materials input that companies process into industrial products – for instance feedstock to the petrochemical industry).

Sub-sectors

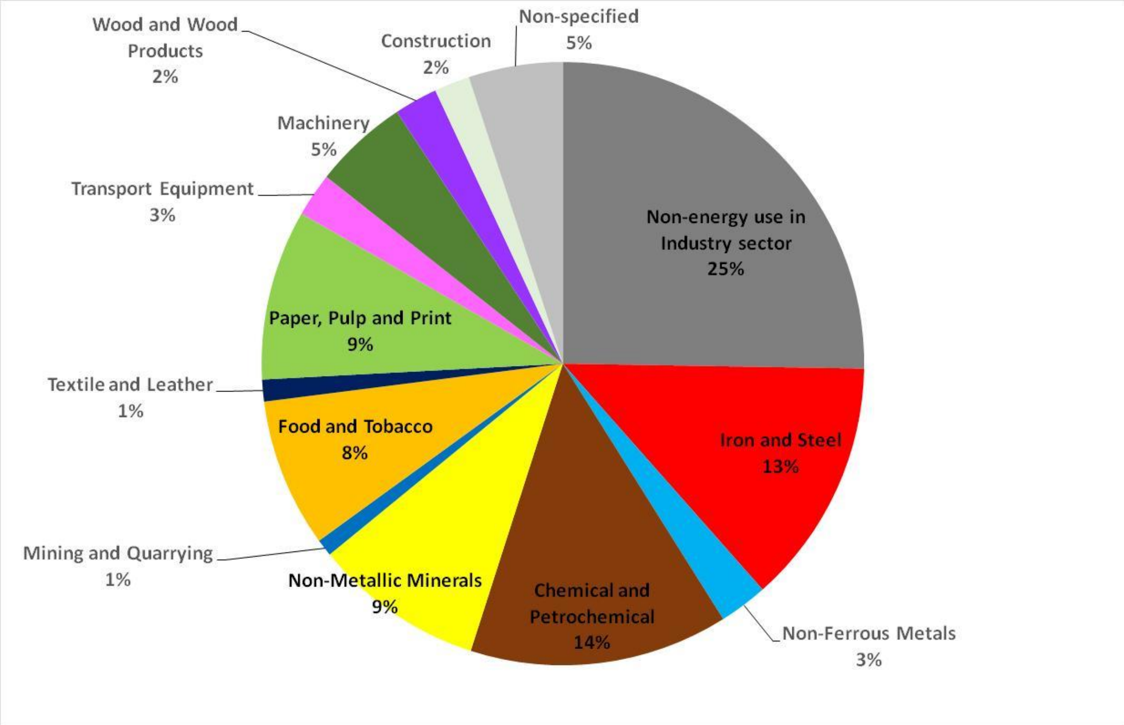
The Eurostat energy statistics classify the industry sector into a set of 13 branches; these include light industries with high value added and relatively low(er) emissions (for instance pharmaceuticals and electronics) and also the energy-intensive industries with high(er) energy and carbon emissions intensity (for instance steel and cement). As already mentioned, the energy used for non-energy purposes in industrial production is also counted as part of industrial energy demand which gives a total of 14 sub-sectors. This is an important characteristic of this sector because options, opportunities, and challenges in a low-carbon transition differ substantially between sub-sectors (and even within sub-sectors), as seen later in this paper.

As shown in **Figure 1**, the largest consumer of energy is the sector that covers non-energy uses which represents about a quarter of industrial final energy demand.[12] Energy used in combustion for heat production covers the rest (about 75 per cent of demand). Five sub-sectors account for more than half of this, with the largest shares being the energy-intensive sectors: 'chemical and

[12] Calculated from Eurostat, data for 2016.

petrochemical' (14 per cent) and 'iron and steel' (13 per cent). The other major consumers are the 'non-metallic minerals' sector and the 'paper, pulp and print' sector (9 per cent each), and the 'food and tobacco' sector (8 per cent).

Figure 1: EU28 industrial final energy demand by sub-sectors, 2016 (%)



Source: calculated from Eurostat.

Energy mix

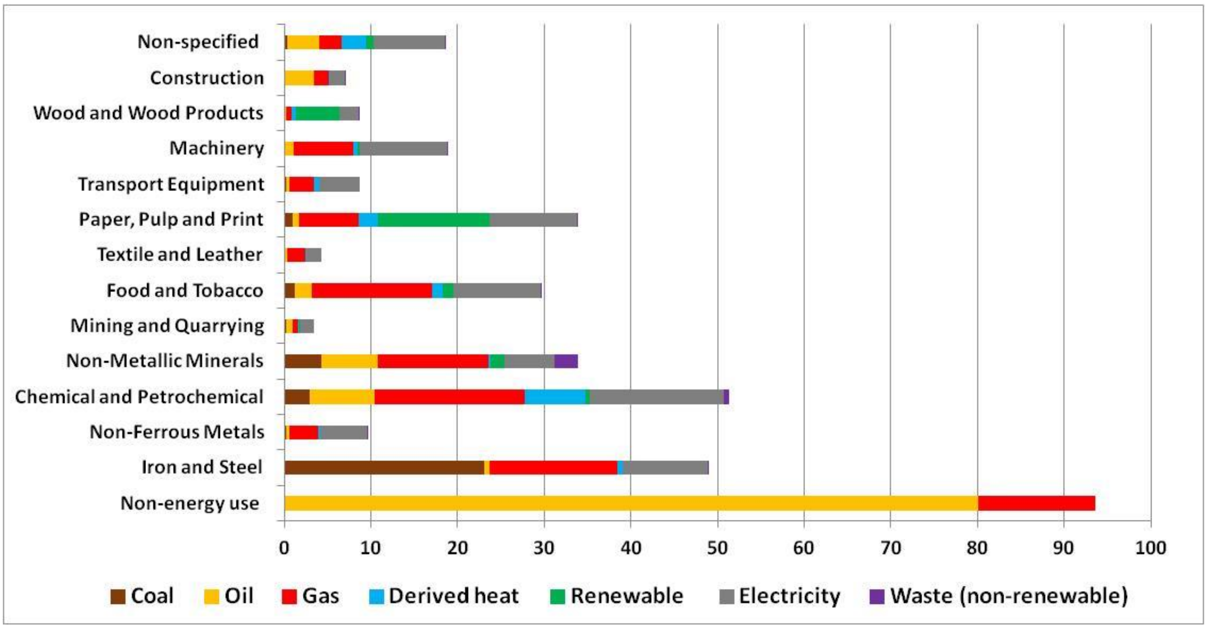
Approximately 65 per cent of the energy used in industry is derived directly from using fossil fuels. The energy used as feedstock comes entirely from oil products and natural gas, as seen in **Figure 2**.[13] As for the energy used in combustion, the share of fossil fuels is much less, at about 53 per cent, with almost a third (31 per cent) of this being natural gas. The other major source of energy is electricity (also 31 per cent). Coal and oil represent about 22 per cent, renewables just about 8 per cent of the mix, while derived heat[14] accounts for 6 per cent, and waste about 2 per cent.

Fossil fuels are used in most sectors but their use is concentrated in energy-intensive industries such as 'iron and steel', 'chemical and petrochemical', and 'non-metallic minerals'. Electrification is also spread across most sectors, especially in the 'chemical and petrochemical', 'food and tobacco', 'paper, pulp and print', and 'machinery' sectors. Renewables, on the other hand, are not so well disseminated across sectors. Almost all renewable energy use in the industrial sector is biomass and waste and is mostly found in 'paper, pulp and print' and in 'wood and wood products' where residues can be available for free.

[13] Some of these non-energy uses include natural gas in ammonia production, coal used as feedstock (and simultaneously as fuel) in iron and steel production, and crude oil used to make polymers for plastics and rubber production.

[14] 'Derived heat' is the share of heat produced in CHPs and heat plants that is sold to third parties. See Honoré (2018b) for more information.

Figure 2: EU28 industrial final energy demand by sub-sectors and by fuels, 2016 (Mtoe)



Source: calculated from Eurostat.

The role of natural gas

As for natural gas, it is used in all the industrial sub-sectors and covers almost half of the energy needs in 'textile and leather' (48 per cent) and 'food and tobacco' (47 per cent), and more than a third in the 'non-metallic minerals' (38 per cent), 'machinery' (36 per cent), 'non-ferrous metals' (35 per cent), and 'chemical and petrochemical' (34 per cent) sectors. The widespread use of natural gas in these industries can be explained by various factors:

- As seen in the 'chemical and petrochemical' sector for instance, gas can be used both as feedstock (it is the base ingredient for plastics, fertilizer, anti-freeze, and fabrics) and also for heat production, including high-heat temperature processes. It is one of the best energy sources for industries that use furnaces but also boilers in their production processes (such as glass, ceramics, textiles, food, cement, and metal casting).
- A wide range of – including very high – temperatures can be achieved using gas. It can be regulated to keep a constant temperature throughout the production process and also allows for optimal heat transmission.
- Continuous supply of gas also means there is no need for storage on site and it is easily switched on and off, so it can adapt to the variations of industrial processes.
- Finally, gas burns more cleanly than other fossil fuels, so GHG emissions are lower but also the equipment and burners used are easier to clean (meaning reduced maintenance and increased working lives).[15]

1.2. Slow evolution toward low-carbon sources

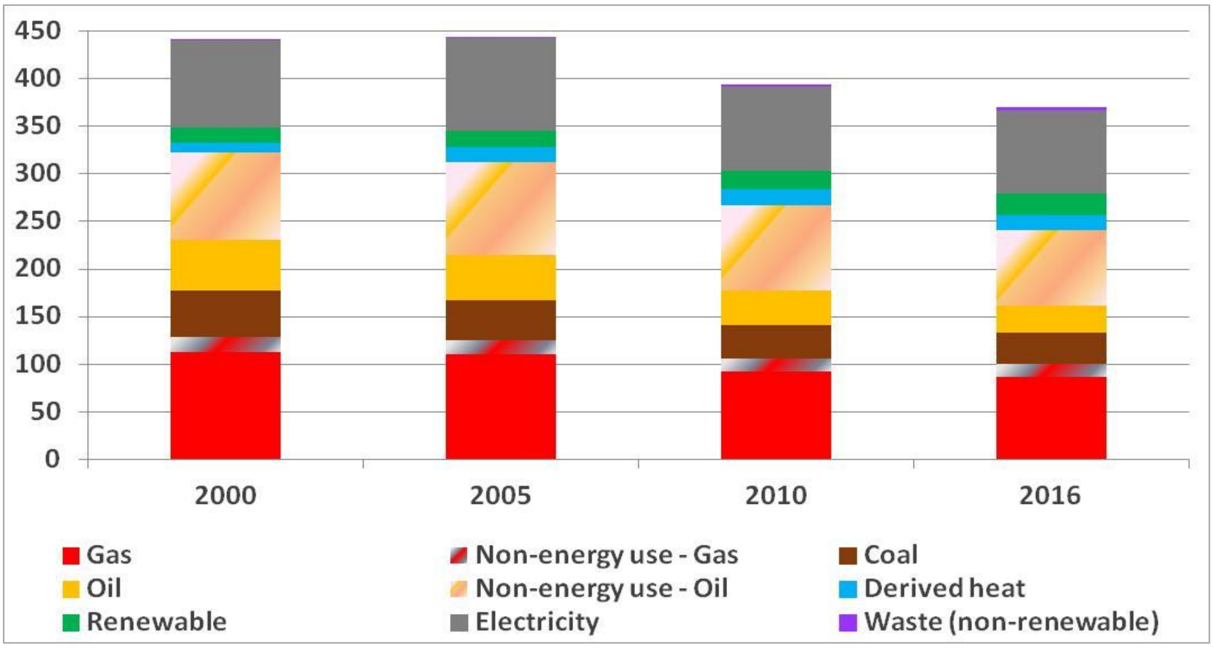
With two-thirds of its supply coming from fossil fuels, the energy mix of the industrial sector will need to evolve in the future in order to meet GHG emission reduction targets. Arguably, this transformation has already started, but the pace has been fairly slow.

Both the level and the share of all fossil fuels in industrial final energy demand have declined over the period 2000–2016 (see **Figure 3**), from a total of 73 per cent (29 per cent for natural gas) to 65 per

[15] Its special characteristics are important: for example in the glass sector, the glass comes out clean from the production process, while in the ceramics industry the use of natural gas decreases the formation of stains and discolouration on items during firing and drying.

cent (27 per cent). They were replaced by cleaner fuels such as electricity (whose share rose from 21 per cent to 24 per cent), renewables (4 per cent to 6 per cent), and derived heat (3 per cent to 4 per cent).

Figure 3: EU28 industrial final energy demand by energy mix, 2000–2016 (Mtoe)



Source: calculated from Eurostat.

Most importantly, the level of energy demand has declined by 16 per cent. The main factors involved in this trend were:

- Achievements in energy savings and the implementation of improved efficiency measures in energy-intensive industries,[16] together with increased use of recycled and re-used materials which require significantly less energy (and produce fewer emissions).
- A general shift in the EU economy (together with structural changes in the industrial sectors) towards less energy-intensive industries and services took place during this period.
- Finally, and maybe most importantly, the consequences of the recession and the economic situation post-2009 should not be underestimated, as industrial energy demand recorded a major drop in 2009 and has not rebounded to its pre-crisis level.

Lower energy demand and, to some extent, a higher penetration of renewables, are having an impact on energy demand for fossil fuels (including natural gas demand) in industry which declined by 22 per cent between 2000 and 2016. This happened in almost all sectors[17] but the sharpest declines occurred in the ‘chemical and petrochemical’ and the ‘iron and steel’ sectors.

1.3. The industrial sector represents 15 per cent of the EU’s GHG emissions

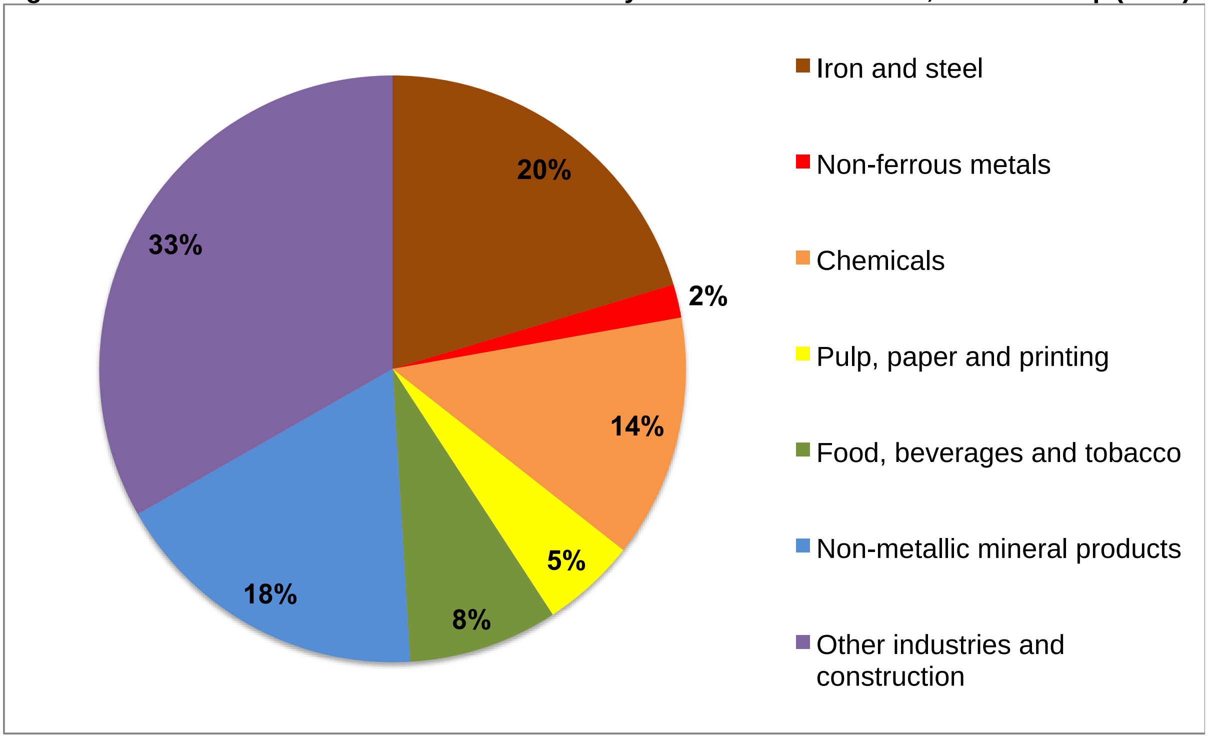
Industrial activity represents about 16 per cent of the EU28’s GDP and the emissions associated with fuel combustion used in industrial production processes account for about 15 per cent of total GHG emissions.[18]

[16] Supported by a series of EU regulations that set minimum energy performance requirements for energy-related products. See Honoré (2018b).
[17] With the exception of construction, wood and wood products, non-ferrous metals, and food and tobacco.
[18] GHG emissions from fuel combustion in manufacturing industries and construction represent 14.6% of total GHG from fuel combustion, and about 11% of total emissions including aviation. Source: Eurostat data for 2016.

Direct GHG emissions from on-site fossil fuel combustion[19] are concentrated in the 'iron and steel' sector -this is explained by the use of coal and coke in blast furnaces during the production of pig iron or steel; these processes are energy intensive and necessitate high temperatures that can be easily reached with fossil fuels- and in the 'non-metallic mineral' sector (the production of cement clinker, but also lime, glass, bricks, and ceramics[20]) and to a lesser extent in the 'chemical industry' sector (the production of ammonia, ethylene, and methanol) as seen in **Figure 4**. A switch to less-polluting fuels would impact the level of direct emissions, but tackling these emissions will not be straightforward as not all energy sources are suitable for all temperatures or all processes (see Section IV for more information).

Indirect emissions from the consumption of electricity and heat are important in all sectors – especially the 'chemical industry' sector and the 'engineering and other metal' sector.[21] Emissions here, however, are dependent on the electricity and heat generation mix in the transformation sector and are not directly related to any industrial activity. They are therefore not looked at in this paper.

Figure 4: GHG emissions from fuel combustion by source sector in EU28, in Mt CO_2 eq. (2016)



Source: calculated from Eurostat.

Lower energy demand (minus 20 per cent between 1990 and 2016) and, to a lesser extent, a reduced share of fossil fuels in the mix, have already had some impact on the level of EU emissions which have declined by about 43 per cent between 1990 and 2016 (**Table 1**).[22] Some sectors, such as the paper industry ('pulp, paper and printing') (which already uses a high share of both electricity and renewables – mainly biomass), have fairly low levels of emissions and therefore seem to be the most advanced on the decarbonization path. Interestingly, some energy-intensive industries, such as those in the 'iron and steel' and the 'chemicals' sectors, have reduced their GHG emissions dramatically – by about 48 and 44 per cent respectively between 1990 and 2016 – while the 'non-metallic mineral products' sector reduced its emissions by about 37 per cent.

[19] Direct GHG emissions result from diverse processes, including the on-site combustion of fossil fuels (for heat and power) and chemical processes used for instance in iron, steel, and cement production.
[20] SET-NAV (2018-1).
[21] SET-NAV (2018-1), p.5 (Figure 2).
[22] Author's calculations from Eurostat data.

Table 1: GHG emissions from fuel combustion by source sector in EU28, in Mt CO_2 eq. (1990 vs 2016)

	1990	2016	Change (%)
TOTAL	841.06	474.35	-43.60
Iron and steel	184.01	96.56	-47.52
Non-ferrous metals	16.64	8.73	-47.51
Chemicals	112.63	63.53	-43.59
Pulp, paper and printing	34.63	24.75	-28.54
Food, beverages and tobacco	52.12	39.03	-25.11
Non-metallic mineral products	132.66	84.04	-36.65
Other industries and construction	308.38	157.70	-48.86

Source: calculated from Eurostat.

Despite these impressive declines, energy-intensive products/processes will need to reduce their emissions further in the next decades if Europe is to achieve its climate targets. The 2011 EU Roadmap for moving to a competitive low-carbon economy in 2050 set a target of 83–87 per cent for GHG emission reductions in industry by 2050 compared to 1990.[23] According to the Commission, emissions in the industrial sector:

> 'could be reduced thanks to the application of more advanced resource and energy efficient industrial processes and equipment, increased recycling, as well as abatement technologies for non-CO_2 emissions (e.g. nitrous oxide and methane). ... In addition, carbon capture and storage would also need to be deployed on a broad scale after 2035, notably to capture industrial process emissions (e.g. in the cement and steel sector)'.[24]

Additional measures and a continued shift toward low-carbon energy will be needed to meet these ambitious targets, which will inevitably mean some reduction of fossil fuel demand, including natural gas, but exactly how much, where, and by when is, as yet, uncertain.

II. Scenarios for a decarbonized industrial sector in Europe: identifying possible pathway(s) and impacts on natural gas demand

The literature relating to industrial decarbonization in Europe is not sparse and it is possible to find a large spectrum of scenarios of what *should* be done to reach the 2050 emissions targets, although evaluating potential pathways of what *could* be done is not as straightforward. Substantial attention has been paid to decarbonizing electricity generation, transport, and buildings, but knowledge and understanding on how to decarbonize the industrial sector (especially energy-intensive industry) lags these other sectors. Comparing various scenarios can be confusing as the assumptions and priorities differ from one scenario to another and the final messages are complex, diverse, and sometimes even contradictory. However, they still provide some information on what the options are (or could or should be), what timescale needs to be considered, and also give an order of magnitude for the changes to be expected in gas demand. The paragraphs below consider some of the scenarios available in the public domain. The choice was limited by the availability of details relating to these scenarios, which needed to have a picture for both the European region and for natural gas demand in the industrial sector. The scenarios considered below have been published by four entities: two companies (Shell and Equinor) and two international organizations (the IEA and the European Commission).[25]

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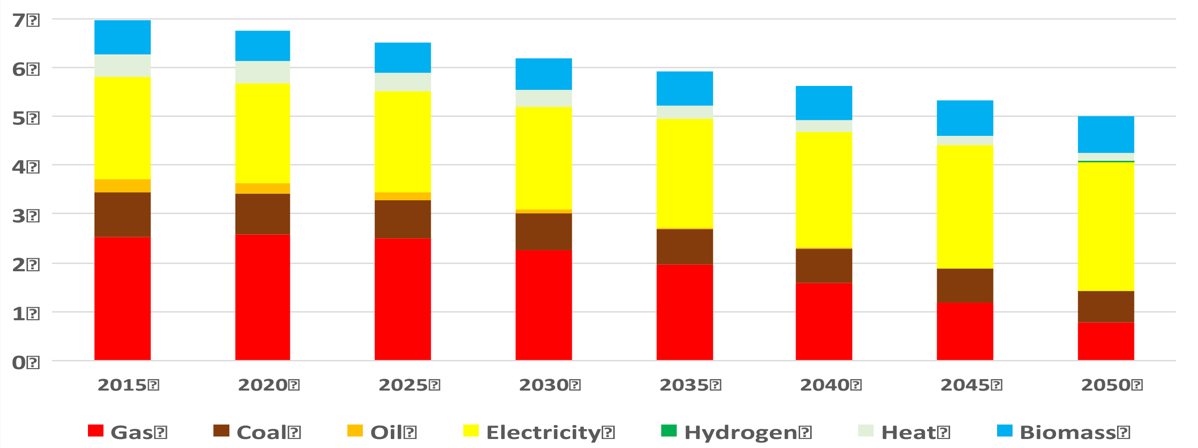
[23] The targets are: –20% by 2005, –34 to –40% by 2030, and –83 to –87% by 2050. Source: European Commission (2011).
[24] European Commission (2011).
[25] BP has five scenarios for global gas demand but only gives regional projections in two of them and none offers a split by sectors. Source: BP (Energy Outlook) website.

2.1. Shell: Sky scenario 2018

The Shell Sky scenario goes up to 2100 and is designed to achieve a 'less than two degrees' world, which is compatible with the Paris targets. The Sky scenario shows European gas demand stable up to 2030 with significant decline thereafter, although even in 2050 demand is only 33 per cent below 2015 levels (note that the 'European region' in the Sky scenario is actually wider than the EU28 region[26]).

As for industrial gas demand, Sky scenarios focus on heavy industries[27] and they show both a steady decline and a profound transformation of their energy mix up to 2050. Natural gas drops from about 36 per cent in 2015 and 2030 down to 15 per cent in 2050, being replaced essentially by electricity and some biomass (**Figure 5**). Hydrogen electrolysis systems only begin to emerge as a material energy carrier in 2050, but are expected to grow steadily in subsequent years.[28]

Figure 5: Shell Sky scenario 2018: energy demand for heavy industries in Europe, by fuel, 2015–2050 (EJ/year)



Source: Shell, Sky scenarios (2018 data).

In the Sky scenarios, the transformation of the industrial sector is important and the main assumptions (worldwide) are:

- Continuous improvement of efficiency, with most industrial processes approaching thermodynamic and mechanical efficiency limits by the 2050s. Industry also benefits from an increased focus on the circular economy,[29] which sees large-scale recycling expand throughout the century, to the extent that some resource extraction declines as a result.
- Some processes shift towards electricity, particularly those in light industry where electricity use doubles from 2020 to 2040. Hydrogen also emerges as an important fuel for light industry by 2050 as natural gas use declines. But a similar change for heavy industry doesn't emerge until after 2050, with hydrogen, biomass, and electricity substituting for natural gas and some coal use (not shown in Figure 5).
- Coal remains important in the metallurgical sector and for some other processes right through the century, but with government-implemented carbon prices rising, Carbon Capture and Storage (CCS) emerges as the solution.

[26] The European region in the Sky Scenario also includes countries such as Norway, Switzerland, Georgia, Azerbaijan, Moldavia, and Iceland. Source: Shell, Sky scenarios (2018).
[27] Heavy industries consist of the following sub-sectors: iron and steel, chemical and petrochemical, non-ferrous metals, non-metallic minerals, and paper, pulp and print. Source: Shell, Sky scenarios (2018).
[28] Shell, Sky scenarios (2018), p.31.
[29] See definition in section III footnote 46.

2.2. Equinor: Energy Perspectives 2018

Equinor has three scenarios for energy demand up to 2050, as seen in **Figure 6**.

- In the Reform scenario (Ref), energy markets build on recent and current trends within market and technology development (rather than relying on policy support) as the main drivers of change.
- Renewal (Ren) represents a future trajectory, supported by strong, coordinated policy intervention, that delivers energy-related emission reductions consistent with the 2 °C target on global warming. In this scenario, there is a transition towards lighter industry and a service-based economy that coincides with stricter energy efficiency and climate targets.
- Rivalry (Riv) describes a volatile world, where development and policy focus are determined mainly by geopolitics and by political priorities other than climate change.[30]

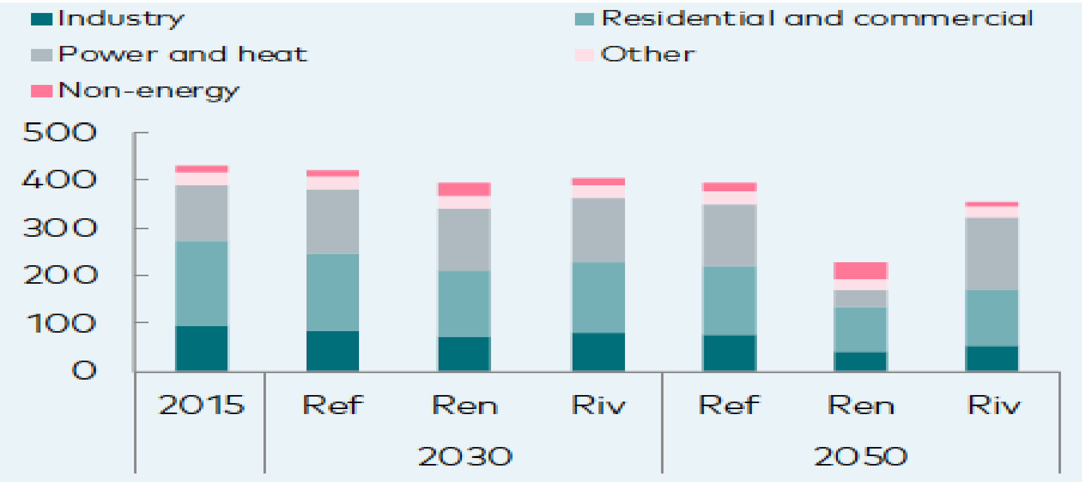
The three scenarios show European gas demand slowly declining up to 2030 (by –3 to –8 per cent compared to 2015). The major differences between the scenarios appear in the period 2030–2050. By 2050, demand has contracted slightly in the Reform scenario (–11 per cent compared to 2015). In the Rivalry scenario, demand drops by –19 per cent compared to 2015, but the sharpest decline is seen in 'Renewal' – which is a policy-driven scenario where COP21 targets are met – in which gas demand is almost cut in half compared to its 2015 level (–47 per cent).

As for industrial gas demand, the level drops by less than a quarter in the Reform scenario (built on recent and current trends in market and technology development) between 2015 and 2050, but it declines sharply in the two other scenarios:

- by about 50 per cent in the Rivalry scenario, with most of the decline happening in the period 2030–2050;
- by more than 50 per cent in the Renewal scenario, starting in the period up to 2030 thanks to efficiency gains driven by policy intervention.[31]

This highlights the need for changes as soon as the period up to 2030.

Figure 6: Equinor Energy Perspectives 2018: scenarios for natural gas demand by sector in the EU28, 2015–2030–2050 (bcm)



Source: Equinor, Energy perspective 2018, p.40.

[30] Equinor, Energy perspectives 2018.
[31] Author's estimates based on **Figure 6**

2.3. International Energy Agency: World Energy Outlook 2018

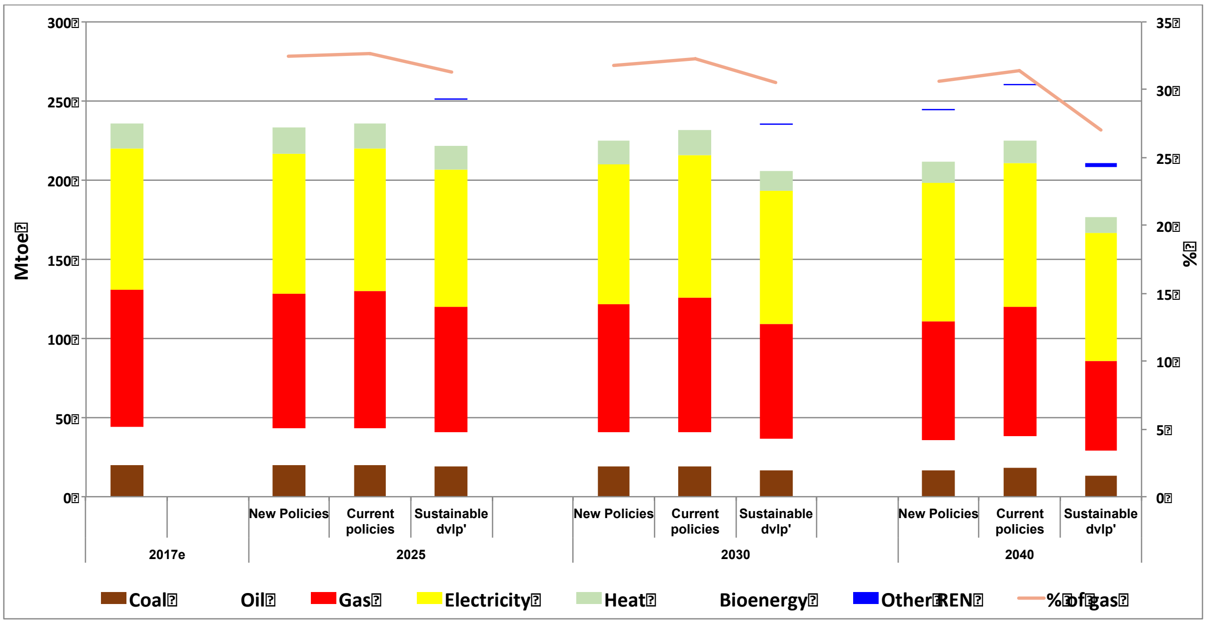
The IEA's 2018 World Energy Outlook shows three scenarios up to 2040:

- New Policies Scenario provides a measured assessment of where today's policy frameworks and ambitions, together with the continued evolution of known technologies, might take the energy sector in the coming decades.
- Current Policy is based solely on existing laws and regulations as of mid-2018, and therefore excludes the ambitions and targets that have been declared by governments around the world.
- Sustainable Development starts from selected key outcomes (such as delivering on the Paris Agreement) and then works back to the present to see how they might be achieved.

In their main scenario (the New Policies scenario) total gas demand in the EU28 declines by about 7 per cent to 2030 and 16 per cent to 2050 (compared to 2017). This decline is driven by lower total energy demand but also by higher levels of bioenergy and other renewables. The decline is even more significant in the Sustainable Development scenario (–15 per cent and –35 per cent respectively), while it increases in the Current Policy scenario.

As for industrial gas demand, the WEO shows limited impact up to 2030 and also, arguably, up to 2040 (both in volume and as a share of total energy use), except in its Sustainable Development (2 °C) scenario, which shows a much more dramatic decline (**Figure 7**). However, even in this scenario, natural gas still represents about 27 per cent of the mix by 2040 (33 per cent in 2017). Maybe the reason for this rather pessimistic evolution toward a low-carbon industrial sector in Europe is because 2040 is too short a timeline to notice major impacts of decarbonization targets on industrial gas demand, and extending the timeline could show different results.

Figure 7: IEA World Energy Outlook, scenarios for energy demand in EU28 industrial sector by fuel, 2017–2040 (Mtoe and %)

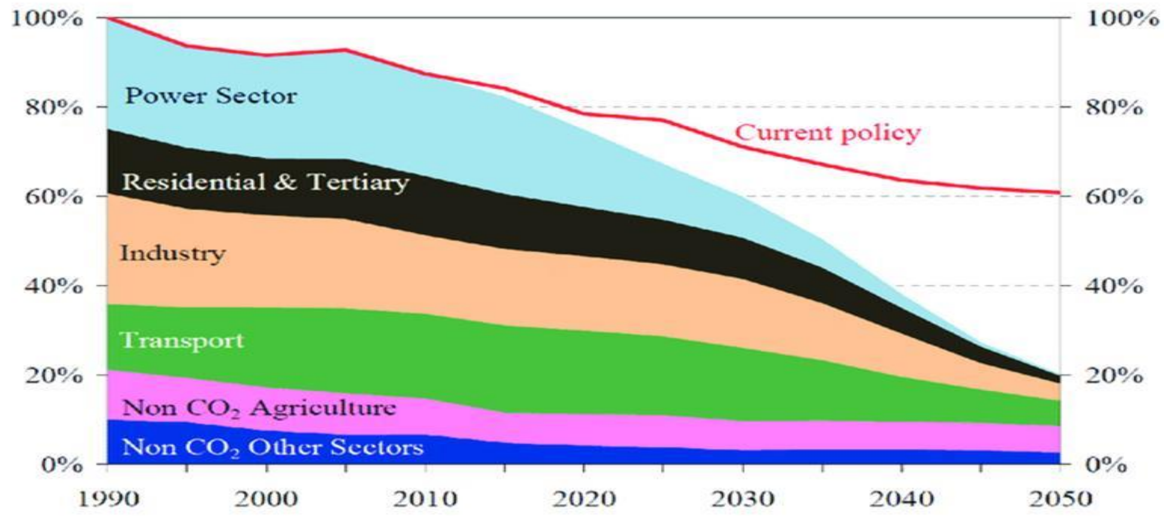


Source: Calculated from IEA (2018b).

2.4. European Commission – November 2018 scenarios

On 28 November 2018, the Commission presented its strategic long-term vision for 'a prosperous, modern, competitive and climate-neutral economy by 2050 – A Clean Planet for all'.[32] It published some accompanying scenarios using Primes and Forecast models,[33] which focus on the total energy demand in the EU28 region. The Commission has studied eight different pathways (see discussion below for descriptions of these pathways). These all include a wide range of technological and organizational options aimed at reducing emissions in all sectors (**Figure 8**). There is some breakdown by fuel and by sectors, so we can extract results for natural gas demand in the industrial sector.

Figure 8: Scenario for GHG emission reduction in Europe by 2050 (1990 = 100%)



Source: European Commission '2050 low-carbon economy'.

Some pathways focus on specific technologies or options (electrification, hydrogen, 'clean gas and biomass', power to X (P2X)), while others focus more on demand-side measures (energy efficiency and circular economy[34]). Some also combine various of the previous solutions. **Table 2** below provides an overview of the main drivers, targets, and assumptions for each of them.

The total final energy demand is expected to decline up to 2030 and continue on this trend up to 2050 (except in the P2X scenario). As seen in **Figure 9**, the role of fossil fuels (including natural gas for energy use) decreases in all scenarios, from above 70 per cent in 2015 down to potentially 15 per cent in the most ambitious scenarios.

The share of gas remains relatively flat in the baseline scenario,[35] against which the other (more aggressive) scenarios are compared; it drops from 21 per cent in 2015 to 7–9 per cent in the various scenarios which target a reduction of 80 per cent of GHG emissions (electrification, hydrogen, P2X, EE, and CIRC). In combination scenarios with stronger reduction targets (95 per cent and above) the share of gas drops even more, to 3–4 per cent of the mix.

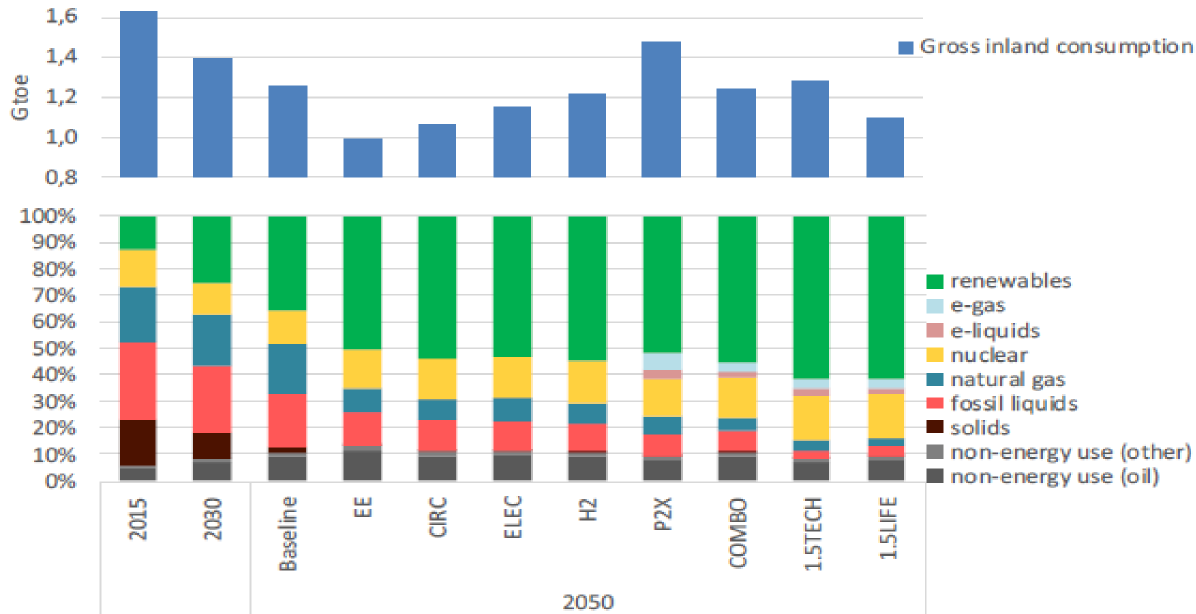
[32] European Commission (2018b).
[33] PRIMES includes interactions between the industry sector and other sectors. FORECAST follows a bottom-up approach, which is more detailed but sector-specific and therefore isolated from the other sectors.
[34] See definition in section III footnote 46.
[35] The baseline scenario is based on agreed EU policies and on policies that have been proposed by the Commission but which are still under discussion in the European Parliament and Council.

Table 2: Overview of the main assumptions for each scenario building block

	Electrification (ELEC)	Hydrogen (H2)	Power-to-X (P2X)	Energy efficiency (EE)	Circular economy (CIRC)	Combination (COMBO)	1.5°C technical (1.5TECH)	1.5°C sustainable lifestyles (1.5LIFE)
Main drivers	Electrification in all sectors	Hydrogen in industry, transport and buildings	E-fuels in industry, transport and buildings	Pursuing deep energy efficiency in all sectors	Increased resource and material efficiency	Cost-efficient combination of options from 2°C scenarios	Based on COMBO with BECCS, CCS	Based on COMBO and CIRC with lifestyles changes
GHG target in 2050	-80% GHG (excluding sinks) ["well below 2°C" ambition]					-90% GHG (incl. sinks)	-100% GHG (incl. sinks) ["1.5°C" ambition]	
Major common assumptions	* Higher energy efficiency post 2030 * Deployment of sustainable, advanced biofuels * Moderate circular economy measures * Digitilisation * Market coordination for infrastrcuture deployment * BECCS present only post-2050 in 2°C scenarios * Significant learning by doing for low carbon technologies * Significant improvements in the efficiency of the transport system							

Note 1: The European Commission uses the term 'E-fuels' for fuels derived from electricity: power-to-X.
Note 2: BECCS means bio-energy with CCS (as a way to obtain negative emissions).
Source: European Commission (2018b), p.56.

Figure 9: EU28 energy demand by fuel for various scenarios, 2015–2050 (Gtoe and %)



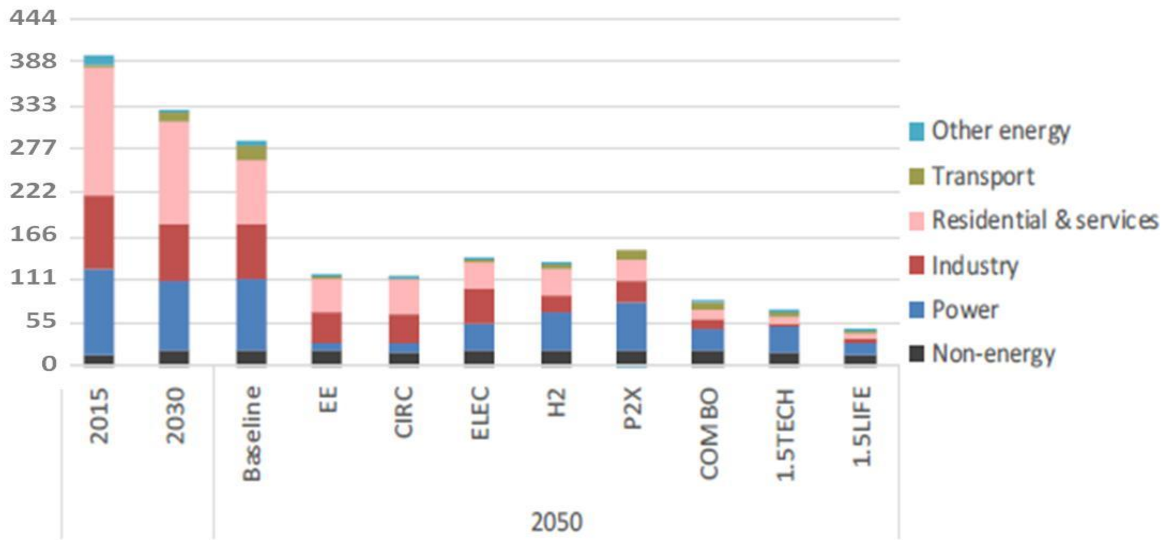
Source: European Commission (2018b), p.69.

As a result, the consumption of natural gas is expected to decline by 2050 in all scenarios, as seen in **Figure 10**, from about 390 billion cubic metres (bcm) in 2015 to about 330 bcm in 2030. In 2050, gas demand ranges between about 110 bcm (EE, CIRC) and about 145 bcm (P2X) in scenarios achieving 80 per cent GHG reductions, and to less than 85 bcm in scenarios achieving higher GHG reductions.[36] In most cases, except in the EE and CIRC scenarios, the power sector is the main driver for the remaining natural gas demand (associated with CCS in the scenarios with stronger emissions reductions).

[36] Estimates for total gas demand from this author (data in the original document –European Commission (2018b), p.81- given excluding 'non-energy use'). Original data in Mtoe and converted from Mtoe to bcm using 1 Mtoe = 1.111 bcm.

Looking at natural gas demand by sector: in the baseline scenario, the residential sector takes the largest hit, while demand in the power sector is the most resilient. The industrial sector declines up to 2030 and seems to plateau after that. In specific scenarios, the results are very different. Gas demand in the industrial sector declines at least by half in all the scenarios (and potentially more if emissions targets are more stringent) compared to the baseline scenario, due to higher efficiency, circular economy, and electrification. In scenarios with an emphasis on hydrogen and P2X, gas demand also declines, but seems to get displaced to the power sector. Gas demand remains high for non-energy needs.[37]

Figure 10: EU28 natural gas demand by sector for various scenarios, 2015–2050 (bcm)



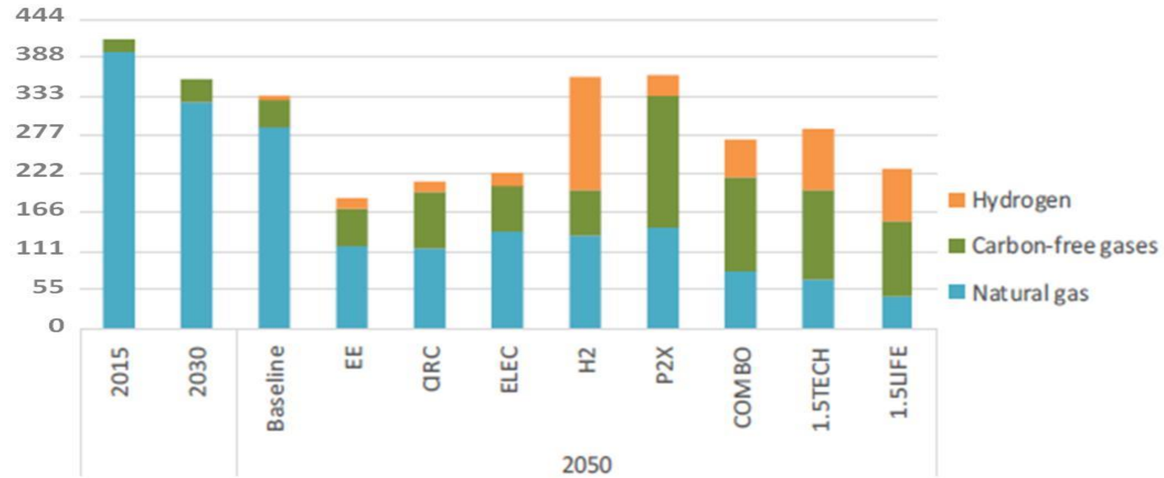
Note: Converted by this author from Mtoe to bcm using 1 Mtoe = 1.111 bcm.
Source: European Commission (2018b), p.81.

In the scenarios for total energy demand, the evolution of gaseous fuels is interesting, with a rapid growth of (and replacement of natural gas by) decarbonized gases, as seen in **Figure 11**. Hydrogen increases in the H2 scenario, which is logical, but this is also the case in scenarios with stronger emission target reductions. Biogas / 'e-gas'[38] also show a strong increase in P2X and in scenarios with stronger targets. This happens across all sectors, but industry increasingly sees a bigger role for hydrogen in its decarbonization strategies, except in the scenarios EE, CIRC, and ELEC where it remains a niche market (see **Figure 12**).

When the use of hydrogen increases, the assumptions are for large-scale deployment 'as soon as the technology is available competitively'. This is ambiguous, because of course we do not know when the technology will be available economically and at scale. 'E-gas' also increase for energy use in processes for which natural gas cannot easily be replaced by other fuels. If this happens, the current model of gas markets transporting a homogenous product through a unified network will change significantly post-2030.[39]

[37] European Commission (2018b)
[38] The European Commission uses the term 'e-gas' for carbonized derivatives of hydrogen produced from electricity (P2X)
[39] See Stern (2019) for a discussion on the issue.

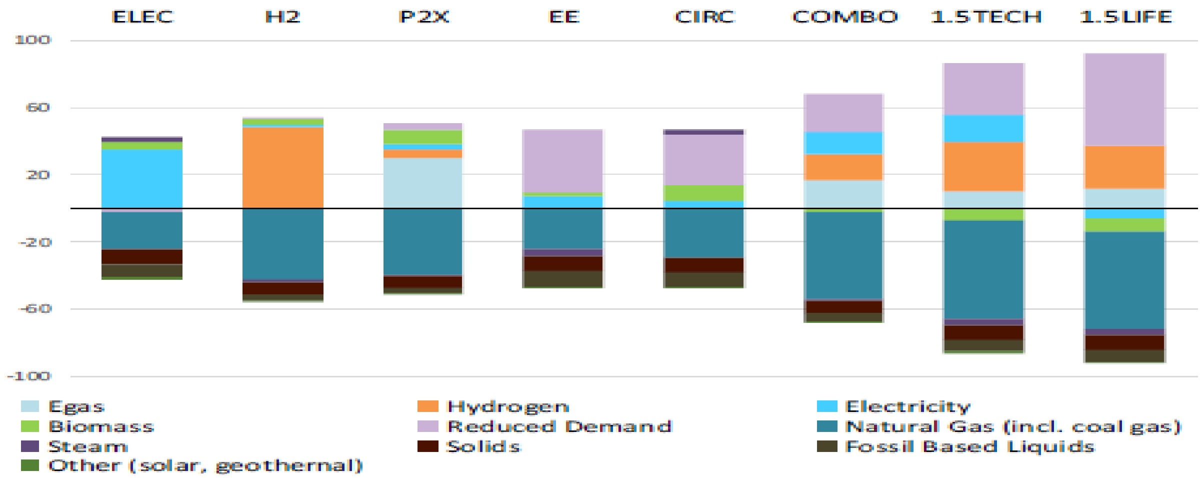
Figure 11: EU28 gaseous fuels demand in various scenarios, 2015–2050 (bcm)



Note 1: Converted from Mtoe to bcm using 1 Mtoe = 1.111 bcm.
Note 2: carbon free gases are 'e-gas', biogas and waste gas.
Source: European Commission (2018b), p.84.

All in all, there are significant differences in the energy mix by 2050, depending on the scenario considered. **Figure 12** provides a summary for the industrial sector. In the baseline scenario, all fossil fuels are expected to decline but the natural gas share remains at 24.5 per cent (about 61 million tonnes of oil equivalent –Mtoe- or 68 bcm[40]). Coal and oil account for an additional 9 per cent (23 Mtoe), while roughly half of the energy comes from electricity and heat.[41] In the scenarios achieving 80 per cent GHG reduction (ELEC, H2, P2X, EE, and CIRC), the share of fossil fuels is approximately cut in half and, depending on the scenario, it is replaced by electricity (in ELEC), hydrogen (in H2), hydrogen, 'e-gas' and biomass (in P2X), or a reduction of demand and some electricity or biomass (in EE and CIRC). In more ambitious scenarios, further reductions in industrial emissions come from clean gas-based solutions (such as hydrogen and 'e-gas') but not from the usually expected electrification option. These solutions are combined with energy efficiency and circular economy, but also with significant investments in CCS to capture process emissions.

Figure 12: Differences in final energy demand in industry compared to the baseline scenario in 2050 (Mtoe)



Source: European Commission (2018b), p.151.

[40] Conversion 1 Mtoe = 1.111 bcm.
[41] European Commission (2018b), p.150

2.5. Industrial gas demand in decarbonization scenarios: a summary

These scenarios show that various options can be considered and, depending on when (or if) they materialize in the future, they could have dramatic impacts on gas demand. Despite the projected increase in overall industrial output, the general view about the industrial sector is that gas demand is expected to decrease between 2015 and 2050 across all scenarios, as seen in **Table 3.** The energy mix will be very different depending on the pathways chosen due to diverse assumptions on targets, policies, and technologies. However, on the basis of these results, it seems that the role of gas declines most rapidly in scenarios with strong policy intervention to fight climate change and in scenarios where the gas industry makes insufficient progress toward decarbonization. This would lead to a push for other fuels – such as electricity in low-temperature applications in the 2020s and beyond – and for alternatives in other uses from the 2030s – such as the generation of hydrogen (using renewable electricity) which can be used for higher temperatures. These scenarios also show that, despite uncertainties around the path(s) chosen to decarbonize the industrial sector that may continue for some time, it seems difficult to find *credible* scenarios that meet the 2050 carbon targets that have no gas in the industrial energy mix, although some switching to decarbonized gases such as hydrogen, biogas, and 'e-gas' will need to happen.

Table 3: Summary on industrial gas demand variations up to 2050 compared to 2015 in Shell, Equinor, IEA, and the EU's scenarios (%)

		2030	2040	2050
Shell				
	Sky scenario*	-10.2%	-37.5%	-69%
Equinor**				
	Reform	-10%		-20%
	Renewal	-20%		-58%
	Rivalry	-12%		-40%
IEA -WEO				
	New Policy	-4%	-11%	
	Current Policy	1%	-2%	
	Sustainable dvlp	-14%	-32%	
EU **				
	Baseline	-22%		-22%
	EE			-59%
	CIRC			-63%
	ELEC			-52%
	H2			-78%
	P2X			-69%
	COMBO			-86%
	1.5TECH			-98%
	1.5LIFE			-94%

*In the Sky scenario, the European region is larger than the EU28 region.

** Author's estimates.

Sources: Calculated or estimated from Shell Sky scenarios 2018, Equinor Energy Perspectives 2018, IEA WEO 2018, and European Commission (2018b).

These scenarios offer some interesting insights regarding decarbonization and industrial gas demand trends up to 2050 in Europe. However, these models tend to simulate the industrial sector in an aggregate way that obscures the sectoral diversity of the sector, and as a result, the capacities for (or the constraints on) replacing fossil fuels to abate emissions are also obscured. They do not provide much detailed information about the evolution by country and by sector. Despite the considerable uncertainty concerning the way in which goals can be reached and a transition governed, the following sections consider the main characteristics, options (section III), and challenges (section IV) for a low-carbon transition, in order to propose a simple analytical framework (section V) to get some granularity into the possible evolution of industrial gas demand in Europe up to 2050.

III. Overview of the main options for decarbonizing the industrial sectors

There is no denying that the question of industrial decarbonization is complex. There is not yet a shared vision and there are no clear directions or widely accepted pathways for achieving deep reductions in industrial sector emissions. We don't know how many pathways there are or which ones are going to be picked up, but to follow through on the commitments made at the Paris COP21 agreement in 2015, many things have to happen,[42] major changes need to be made in the way industry consumes energy and produces its products between now and 2050.

There are a plethora of decarbonisation options for industry, but as already mentioned, this research was not aimed at getting into the technological details of industrial processes in the 28 EU markets, and it by no means claims to cover all the possible or potential scenarios that could be taken in each of the sub-sectors. To summarize the main options, it seems that reducing carbon emissions in the industrial sector and reaching the 2050 targets will essentially depend on a combination of a number of key measures and technologies which are:

- energy efficiency and circular economy,
- electrification of heat from zero-carbon electricity supply (and heat recovery techniques),
- fuel switching (to biomass or hydrogen as feedstock and/or fuel),
- carbon capture utilization and storage (CC[U]S).

3.1. Decarbonization options for heating purposes: efficiency improvements and switching to low-carbon energies

Industrial GHG emissions from heating purposes (space heating and hot water, but also low- and high-temperature applications) can be reduced through further efficiency improvements and by moving away from fossil fuels by switching to low- or zero-carbon energy sources. The following paragraphs provide an overview of the main decarbonization options, which have the potential to affect the outlook for gas demand in Europe in our timeframe (2050).

Efficiency improvement, energy savings, and reuse

Energy efficiency improvements in the production phase (to cut down on both heat demand and heat waste wherever possible), together with energy savings, are often the first cost-effective measures in GHG emissions reduction. However, most of the low-hanging fruits have already been harvested in Europe[43]; and as a result, efficiency improvements in the 2020s are expected to come from waste heat recovery and the development of highly efficient heat pumps[44] for lower-temperature heat applications.[45] The next phase would be the development of new models (such as re-use and recycling through circular economy[46] and sector coupling) at scale. This would probably take place near the end of the period (2040s and beyond), with wastes and biomass gradually replacing crude oil in industrial processes and in the cement industry,[47] or the gradual integration of hydrogen from

[42] See Stern (2019) for a discussion on the issue.
[43] See section I
[44] According to the IEA, 'the efficiency of a heat pump can be more than three-times that of a conventional gas boiler at the end-use level. Even after allowing for losses in the generation, transmission and distribution of electricity, a heat pump can reduce primary energy use by an average of more than 35% relative to a conventional gas boiler'. Source: IEA (2018b), p.275.
[45] European Commission (2018b).
[46] 'Circular economy' in the energy system consists of designs, processes, and solutions that maximize the efficient use of natural resources for energy production, end use of energy, excess energy, and side streams. Energy is an essential part of a sustainable economic system, as it enables the re-use of materials. Circular economy in the energy industry is promoted by cooperation between industries and companies, as well as by services that decrease the overall consumption of energy.
Circular economy in the energy industry can be categorized into:
- the circular economy of energy production (renewable energy, waste-to-energy, recycling the materials from energy production plants),
- circular economy established through cooperation with other actors (utilization of the energy industry's and other industries' excess energy and side streams, municipal and industrial cooperation),
- circular economy of the customer interface (demand response, two-way district heat, energy-as-a-service, energy efficiency of the end user).

Source: Deloitte (2018).
[47] Material Economics (2018).

renewable electricity as an industrial feedstock.[48] These processes show important potential for deep industrial decarbonization, but much research and further investment are required to attain commercial scalability. In addition, the options of efficiency improvement, energy savings, and reuse measures are often site- and process-specific, which will complicate the elaboration of support policies and the analysis of possible impacts on energy demand.

Improving energy efficiency and re-use is a cost-effective way of lowering CO_2 emissions, but it is far from sufficient on its own. Once the need for energy has been reduced, the next step is to focus on how this energy is supplied as moving away from fossil fuels in favour of low-carbon options will improve GHG emissions.

Electrification of heat

The decarbonization of the electricity supply offers opportunities to use electricity to replace fossil fuels in industrial processes. The electrification rate[49] of the industry sector is already fairly high at about a third of total energy demand,[50] although there are important differences between sectors and countries, as seen in **Table 4**.

Table 4: Total direct electrification rates in Europe in the industrial sector, 2015 (%)

	France and Benelux	Germany and Central Europe	Iberia	Italy	Nordic and Baltics	Poland	Southeast Europe	UK and Ireland	Europe (total)
Industry	**29%**	**34%**	**35%**	**36%**	**41%**	**25%**	**30%**	**35%**	**33%**
Iron &Steel	18%	28%	54%	37%	45%	31%	36%	21%	32%
Other industry	33%	36%	33%	36%	40%	24%	32%	34%	35%
Chemicals	24%	31%	33%	36%	42%	28%	17%	47%	30%

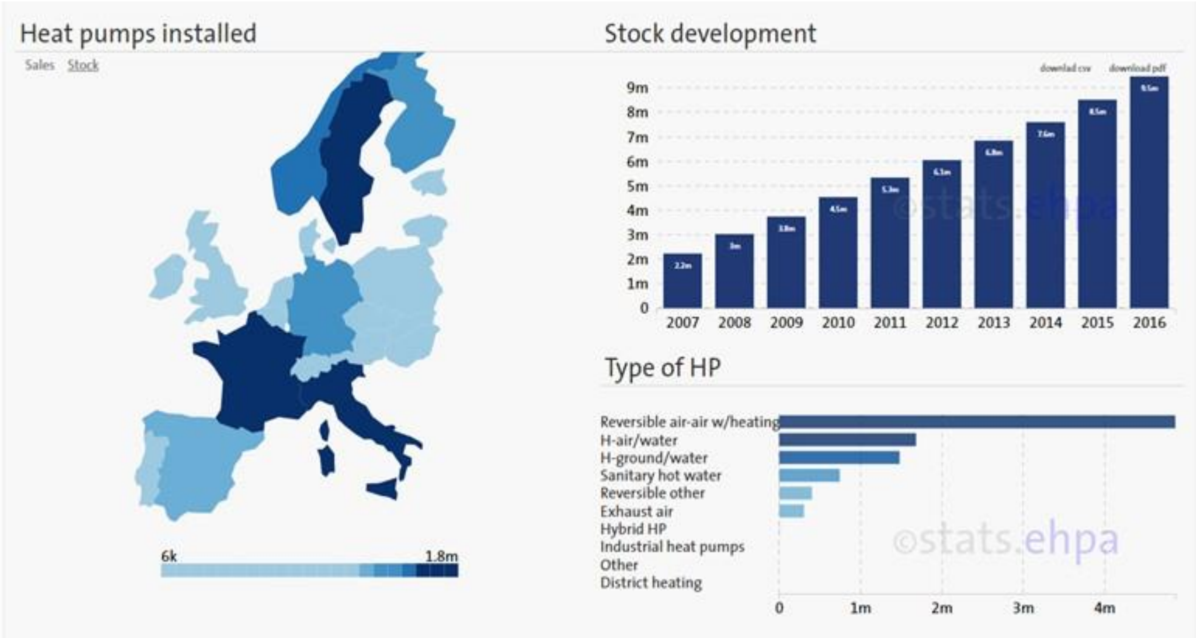
Source: Eurelectric (2018).

Further electrification potential of the industrial sector exists. In its scenarios, Eurelectric expects the direct electrification rate to rise from 33 per cent in 2015 to 38–50 per cent by 2050 (while the share of 'emitting fuels' would drop from 52 per cent to 36–21 per cent), depending on the emission reduction target.[51]

This electrification is likely to come essentially via increased dissemination of heat pumps for low-temperature heat (up to approximately 100° C[52]) and electric boilers (below 300° C). In the IEA 'Future is electric' scenario for instance, the role of heat pumps for low-temperature heat is expected to take off after 2025 when they become competitive with conventional natural gas-fired boilers.[53] This is an important assumption, as heat pumps need to overcome commerciality problems, as well as acceptability ones. Out of 893,000 heat pumps sold in 2016 in Europe, only 577 were industrial heat pumps[54] as most of the market seems to be focusing on the residential sector (**Figure 13**).

[48] European Political Strategy Centre (2018).
[49] 'Direct electrification' is defined as the share of electricity consumption within total final energy consumption.
[50] In 2015, the electrification rate of the industry was about the same level as in the building sector (34%) and far above that in the transport sector (1%). Source: Eurelectric (2018), from IEA data.
[51] Eurelectric (2018).
[52] New projects seem to be able to reach 150° C. However, the use of heat pumps often requires a waste or excess heat stream as input to achieve temperatures up to 100 °C efficiently; the lack of waste or excess heat stream could be another limiting factor in addition to equipment retrofit. Source: IEA (2017)
[53] IEA (2018b).
[54] Data from European Heat Pump Association website – Examples of industrial uses of heat pumps include drying processes, washing processes, heating of process water with waste heat from a refrigeration system, or pasteurization. For more information on these uses, see: Industrial Heat Pumps website.

Figure 13: Stock of heat pumps in Europe by country and end-user market, 2015 (millions)



Source: European Heat Pump Association (website).

According to Eurelectric, a series of industrial processes can, technically, be directly electrified, accounting for up to 50 per cent of total energy consumption by 2050,[55] with the electrification of ethylene production and electric arc furnaces (EAF) in iron and steel production given as the most prominent examples of this potential. However, even if a wide range of possibilities[56] does exist, most technologies have not yet been demonstrated at commercial scale and/or they are not expected to become competitive in our timeframe (2050) (except in locations where a cheap supply of renewable electricity is – or becomes – available).[57 & 58] Direct switching to zero-carbon electricity in high-temperature heat processes would also require significant changes to the design of furnaces.[59] As a result, the use of electricity in (very) high-temperature applications, while possible, is probably going to be limited.

Further potential from electrification comes from indirect electrification, via producing hydrogen from electrolysis and using it to replace carbon-based feedstock such as in steel and ammonia production, as seen in the next section.[60]

Switching to decarbonized gases (and the role of CC[U]S)

If electrification is not commerciality possible or not technically desirable because of the chemical and physical properties needed, another option is to substitute particular fossil fuels with other fuels having a lower carbon content, such as decarbonized gases. The options are:[61]

- biogas,[62]
- biomethane,[63]

[55] According to Eurelectric, 'market-mature electro-heating technologies such as induction, resistance, infrared, electric arc and radio frequency as well as microwave heating are available today, while promising innovative technologies such as laser, electron beam and plasma arc heating are emerging and need to be further developed. Source: Eurelectric (2018).
[56] For more information, see IEA (2018b).
[57] Ricardo-AEA (2013).
[58] Small modular reactors (SMRs) for industrial uses are also considered, especially in the USA.
[59] McKinsey (2018).
[60] Eurelectric (2018).
[61] For more information, see Lambert (2017), Lambert (2018a), Lambert (2018b), and Stern (2019). Detailed analysis of these options and projects, which are both operating and planned, can be found in other publications, see Fischer (2018).
[62] Biogas can be produced from anaerobic digestion or solid biomass gasification.
[63] Biomethane is treated and purified biogas. It has the advantage of being able to be injected into the existing natural gas grid.

- bio-SNG (or syngas) via gasification,[64]
- hydrogen and/or syngas made using renewable power ('e-gas'),
  - power to gas (P2G),[65]
  - power to methane (methanation[66]),
- hydrogen from methane via:
  - steam reforming (SMR),
  - auto-thermal reforming (ATR) with carbon capture, utilization, and storage (CC[U]S),
  - methane cracking with storage/utilization of solid carbon.[67]

Hydrogen is already commonly used in some industrial processes, for instance in ammonia production, low-carbon methanol, other chemicals, and in the iron and steel industry.[68] It can be produced by the utilization of a wide array of fossil fuel and sustainable energy sources, meaning that GHG emissions could be released, depending on the type of production process. About 68 per cent of all of the hydrogen in Europe is produced by the steam reforming of methane; this breaks down natural gas using steam, and results in CO_2 emissions.[69] A low-carbon future would need to switch to hydrogen produced by electricity (essentially by electrolysis). Hydrogen produced in this way would thus, in turn, require additional electricity, but this would make the production process less carbon intensive, or even carbon neutral, provided that the electricity is generated from low-carbon sources. However, the commercialization of power-to-gas technology is at an early stage of development; it is not yet ready for large-scale deployment even though progress is being made.[70] The production costs are thus still high compared to the low production costs of technologies utilizing fossil fuels. Additional research is needed to decrease its production costs and further develop the associated processes.[71]

Synthetic natural gas from gasification is also still at an early stage of development but many biogas and small-scale biomethane plants are already operating. In 2016, 16.1 Mtoe (about 18 bcm) of biogas primary energy were produced in the EU28 and less than 2 bcm of biomethane.[72]

So what are the expectations?

- Significant growth rates of biogas production are expected in the next 10–15 years with the potential to reach 50 bcma by 2030 (or about 10 per cent of the EU28's current gas demand)[73] and, potentially, 100 bcma by 2050.[74]
- The most optimistic of estimates show about 98 bcm of biomethane production from biomass sources up to 2050.[75] The ENTSOG scenarios for 2040 are very substantially lower, showing only 20–50 bcm of biomethane production in 2040.[76]

[64] Synthetic natural gas (SNG) can be produced from gasification of waste via a thermo-chemical process using biomass and/or other waste as a feedstock. Lambert (2017), pp.3–4 explains the process in detail.
[65] Power to Gas (P2G) relies on the principle of electrolysis: using electricity to separate water into its component parts of hydrogen and oxygen.
[66] Methanation is the reaction by which carbon oxides and hydrogen are converted to methane and water. This is was the European Commission calls 'E-gas'.
[67] This is an additional method of hydrogen production. Methane cracking splits methane into hydrogen and a solid carbon residue – carbon black – which can then be used in a range of industrial processes. This process is currently at the laboratory testing stage and it remains to be seen how quickly it will develop. Source: Stern (2019). For further information see Karlsruhe Institute of Technology (2018) and Fincke et al. (2002).
[68] See Hydrogen Europe website for more information.
[69] DNV GL estimated the following shares for European hydrogen production in 2017: gas 68%, oil 16%, coal 11%, and electricity (electrolysis) 5%. Source: DNV GL (2018), Slide 12.
[70] Experimental pilot plants were developed in the late 1990s and early 2000s, and potential for widespread commercial deployment is increasing due to the availability of renewable power generation in excess of immediate electricity demand. See Lambert (2018a).
[71] Note that because it can be blended with natural gas, it would give the possibility to offer gas with lower emissions, while at the same time making use of the existing gas transport infrastructure. See Lambert (2018a).
[72] Data for biogas production in EU28: EurObserver'ER website, Biogas barometers.
Data for biomethane production for nine main countries (Germany, the UK, France, Switzerland, Austria, Sweden, the Netherlands, Denmark and Finland): 15.6 TWh. Source: EurObserver'ER website, Biogas barometers. Converted by this author from GWh to bcm using 1 GWh = 0.00009 bcm.
[73] ENTSOG/TNYDP (2018), p.41.
[74] Ecofys (2018).

- As for power-to-gas, progress in both technology and projects suggests relatively small volumes, unless a very large surplus of low/zero-cost renewable electricity is available.[77] High estimates for European power-to-gas production up to 2050 suggest 24 bcm of renewable hydrogen from wind and solar power in 2050,[78] although this is two and a half to five times higher than ENTSOG's scenarios for 2040.[79]

Estimates show good potential, but decarbonized gases will be used in all sectors, not just in industry. As a result, even the highest estimates of biogas, biomethane, and power-to-gas suggest that these low-carbon options will need to be supplemented with the reforming of methane into hydrogen accompanied by CC[U]S.[80] CC[U]S could be a technically viable option for most large combustion industrial plants and would allow them to keep their existing production processes while still reducing their GHG emissions (from both energy and process emissions).[81] However, the application of CC[U]S to smaller industrial facilities, especially existing ones, is more complicated and it would potentially be very expensive due to the smaller volumes of emissions. An industrial plant has more diverse sources of emissions at each plant with differing concentrations while the physical space for post-process capture CO_2 scrubbers may be limited.[82] In order to have CC[U]S commercially available by 2050, demonstration plants and transport infrastructure must happen in the 2020s. The lack of any successful CC[U]S demonstration project,[83] negative public perception (in particular for underground storage of CO_2 onshore), and the requirement for significant subsidies and regulatory constraints in many countries are all likely to limit the large-scale deployment of CC[U]S in Europe (although some countries including the UK and Norway have pledged funds to launch CCS projects in industrial sectors[84]).[85] Nonetheless, if it did happen, some demand for natural gas would be maintained well into the 2030s and probably beyond, even in a scenario of a highly decarbonized industrial sector.

Switching to renewables

The choice of a renewable, low-carbon energy carrier is still mostly limited to the use of biomass,[86] which is already a central element in the paper and pulp industry (where it is readily available). Its use is highly concentrated in three countries: Sweden (19 per cent of the total), Finland (16 per cent), and Germany (12 per cent).[87] An interesting feature is that biomass can be used for high-temperature heat applications (up to 500 °C), contrary to other renewables options (see section IV). It has therefore significant potential to substitute fossil fuels for process heat generation. IRENA notes that switching to biomass as a fuel (or feedstock) is financially attractive for cement plants and for newly built steel plants as existing technologies are available for biomass in these sectors.[88]

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[75] The 98 bcm figure is comprised of 63 bcm from anaerobic digestion and 35 bcm from thermal gasification. The largest single biomethane contribution is from maize silage and triticale produced as sequential crops, based on an optimized Italian concept 'Biogasdoneright'. Ecofys (2018), pp.13–21.
[76] ENTSOG/TNYDP (2018), p.41.
[77] Stern (2019), p.7.
[78] Ecofys (2018), p.9.
[79] ENTSOG/TNYDP (2018), p.43.
[80] CC[U]S could play an important role during the transition to low-carbon energy carriers by helping the development of hydrogen, but it could also prolong the use of natural gas in the mix. See Leeds City Gate H21 (2016) project for a UK example.
[81] IEA (2014).
[82] Bataille C. et al (2018).
[83] There are only two operational natural gas-based carbon capture projects in Europe, both of which are at Norwegian gas fields (Sleipner and Snohvit) with CO_2 injection directly into offshore reservoirs, although there is a range of other projects at the feasibility study or test stage in six other European countries (Belgium, France, Netherlands, Sweden, Republic of Ireland, and the UK). In central and southern Europe, lack of access to offshore storage structures means that the methane reforming option is logistically problematic and therefore less commercially viable. Source: Stern (2019), see also IOGP (2018).
For more information on CCS, see CCS Institute (2018).
[84] Argus Direct, 25 April 2019, End free ETS permits to cut industry emissions: NGO
[85] European Political Strategy Centre (2018).
[86] See Honoré (2018b).
[87] Calculated from Eurostat data for 2016.
For instance, in Finland, the share of renewable heat is over 70%, with the biggest user of industrial heat being the forest industry, which uses its own fuels in production, such as black liquor and other wood fuels. Source: IEA (2018a).
[88] IRENA (2014).

However, the supply potential for biomass may be limited when it originates from crops.[89] Resource sustainability will therefore be an important factor and may set a limit to using biomass energy resources for producing heat. The use of biomass for high temperatures will also be in competition with its non-energy uses (feedstock for producing bio-based chemicals and materials) and also with its other energy uses in power generation and transport (in other words, the available land and biomass will go to the highest-value economic activities, which may not be industry).

Despite all these challenges, biomass seems to be the most important technology to increase industrial renewable energy use. Other renewables, such as solar thermal and geothermal technologies, can play a role but are not necessarily a straight replacement for fossil fuel heat options. For example, solar thermal systems can support space heating but may require another system, such as a gas boiler, for back-up. There can be other issues facing renewables, such as:

- they can be more costly,[90]
- their deployment could be constrained by the maximum temperature of the steam they can deliver,
- the applicability of renewable heat sources may depend on the geographical location (this is the case for solar thermal and even more so for geothermal heat – although this is usually directed to power generation rather than industry).

Combination of options: example of industrial sector decarbonization pathways for the UK

In 2011, the European Commission published a 'Roadmap for moving to a competitive low-carbon economy in 2050' combined with an 'Energy Roadmap 2050', which had a focus on the energy sector.[91] Since mitigation options and challenges are specific for each industry sector, the European Commission expressed the need for roadmaps to be developed in cooperation with the industrial sectors concerned, who would present their views on the technical opportunities and challenges as well as on the policy implications. **Table 5** provides a summary of the action plans published by the UK in 2017.[92] These plans were elaborated in conjunction between government and industry 'to identify voluntary commitments from all parties to enable sectors to decarbonise and improve their energy efficiency'. They cover seven energy-intensive sectors: cement, ceramics, chemicals, food and drink, glass, oil refining, and pulp and paper. They show that for the design of a decarbonization strategy, combinations of options are possible although not all the options have the same efficiencies and not all will be available or desirable for all industrial processes.

[89] See Lambert (2017).
[90] IRENA (2014).
[91] European Commission (2011).
[92] See DBEIS (2017) for more information.

Table 5: Industrial sector decarbonization pathways for the UK

Sector	Pathway	Base year (2012) - Emissions (MtCO2eq)	Relative emissions reduction in 2050 (relative to 2012)	Examples of technology groups (in descending order of relative contribution)
Cement	BAU	7.5	12%	Energy efficiency
	Max tech - with or without CCS		33-62%	(CCS), fuel switching to biomass
Ceramics	BAU	1.3	27%	Energy efficiency, material efficiency, fuel switching, biomass
	Max tech		60%	Electrification of heat, CCS, energy efficiency, biomass, material efficiency, fuel switching
Chemicals	BAU	18.4	31%	Biomass, energy efficiency, CCS, fuel switching, clustering
	Max tech - with or without biomass		79-88%	CCS, (biomass), energy efficiency, clustering, fuel switching
Food and drink	BAU	9.5	40%	Energy efficiency, biomass, electrification of heat, material efficiency, CCS, fuel switching
	Max tech - with or without electrification of heat		66-75%	(Electrification of heat), energy efficiency, biomass, material efficency, CCS, fuel swithcing
Glass	BAU	2.2	36%	Energy efficiency, material efficiency, fuel switching
	Max tech - with or without CCS		90-92%	CCS, electrification of heat, fuel switching, material efficiency, energy efficiency
Iron and steel	BAu	23.1	15%	Energy efficiency, material efficiency, fuel switching
	Max tech		60%	CCS, energy efficiency, clustering, material efficiency, fuel switching
Pulp and paper	BAU	3.3	32%	Energy efficiency, electrification of heat
	max tech - clustering and electrification		98%	Energy efficiency, clustering, electrification of heat
	Max tech - biomass		98%	Biomass, energy efficiency, electrification of heat

Source: Based on DBEIS (2017), p.4.

3.2. Emissions from feedstocks

Around a quarter of industrial emissions consist of process-related emissions[93] (in other words, emissions from chemical reactions other than combustion), which are more difficult to reduce as it is technically difficult, or even impossible, to switch to other energy carriers; the solution will therefore be mainly a change of process. As industrial processes evolve, some fossil fuel use could also be replaced by non-emitting alternatives such as biomass (for example, the use of bio-based feedstock in chemicals production) and hydrogen (in the steel industry, ethyl or ammonia production, among others).[94] As a result, as for high-temperature process heat, CC[U]S is likely to be needed to allow for the non-energy use sector to transition to a low-carbon sector.

[93] European Commission (2018c)
[94] IRENA (2014), Eurelectric (2018).

IV. Main challenges to industrial decarbonization: a complex, costly and long process

There is no shortage of options, or of combinations of options, to decarbonize the industrial sector, but the implementation of these low-carbon options faces critical energy challenges with few simple answers. The paragraphs below highlight some (far from all) of the main challenges facing industrial decarbonization in Europe:

- the limited choice of low-carbon options due to calorific content, characteristics of the fuels, and the equipment used;
- the economic factors: trade exposure and the lack of a 'business case' for investing in these high cost projects;
- the magnitude of the transformation needed, and
- the time it will necessarily take.

4.1. Industrial processes require heat at different temperature levels

While heating requirements for buildings are fairly standard (space heating, water heating, and cooking), the industrial sector requires a wide variety of temperature levels to be achieved for diverse processes and end-uses, ranging from low-temperature heat below 100 °C to high temperatures far beyond 1000 °C.[95]

- Industrial process heat with temperatures below 100 °C (9 per cent of the industrial heat demand) is used mainly in the food, chemical, paper and print, textile, and wood industrial sectors (the last two work almost solely at this temperature level) as seen in **Figure 14**.
- Industrial process heat with temperatures between 100 °C and 500 °C represents 30 per cent of the total, and essentially concerns paper and print production, but also food and chemical production (some low- and medium-temperature heat is also required in energy-intensive sectors, such as aluminium oxide refining).
- Industrial process heat with temperatures between 500 °C and 1000 °C is essentially needed in the chemical industry, but also for steel and minerals.
- Temperatures above 1000 °C essentially concern the production of metals and non-metallic minerals (blast furnace pig iron production requires temperatures up to 1,300 °C, cement production around 1,400 °C, and aluminium smelting about 1000 °C) and represent the largest share of industrial energy demand for heat production (42 per cent).[96]

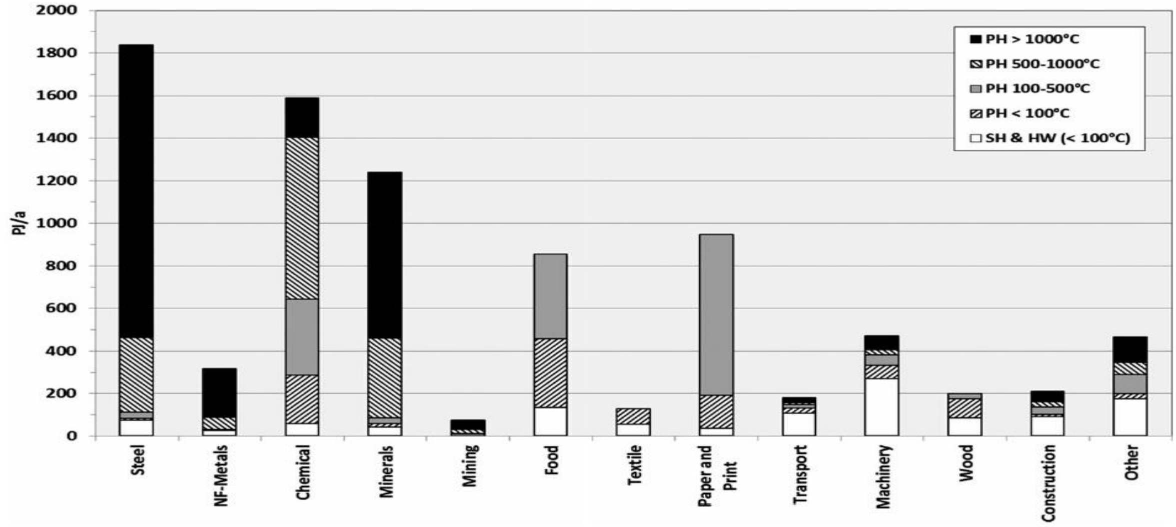
Data available on energy demand classified by temperature needs is limited. **Figure 15** provides some information in the ranges: below 100 °C, 100–200 °C, 200–500 °C, and above 500 °C. Renewables (essentially biomass) are used in processes requiring temperatures below 200 °C, while industrial process heat with temperatures above 200 °C is traditionally provided by fossil fuels. Coal is found primarily in processes that require temperatures above 500 °C, as is electricity. Natural gas is also used essentially for high temperatures, but is also present in other segments.[97]

[95] Processes are specific to sectors, and even to sub-sectors (production methods and purpose), but heat demand above 500 °C is typically provided by industrial furnaces, while heat demand below 500 °C is mostly provided by steam boilers and CHP units.

[96] Calculated from Heat Roadmap Europe (2017),. See also Honoré A. (2018b) for more information.

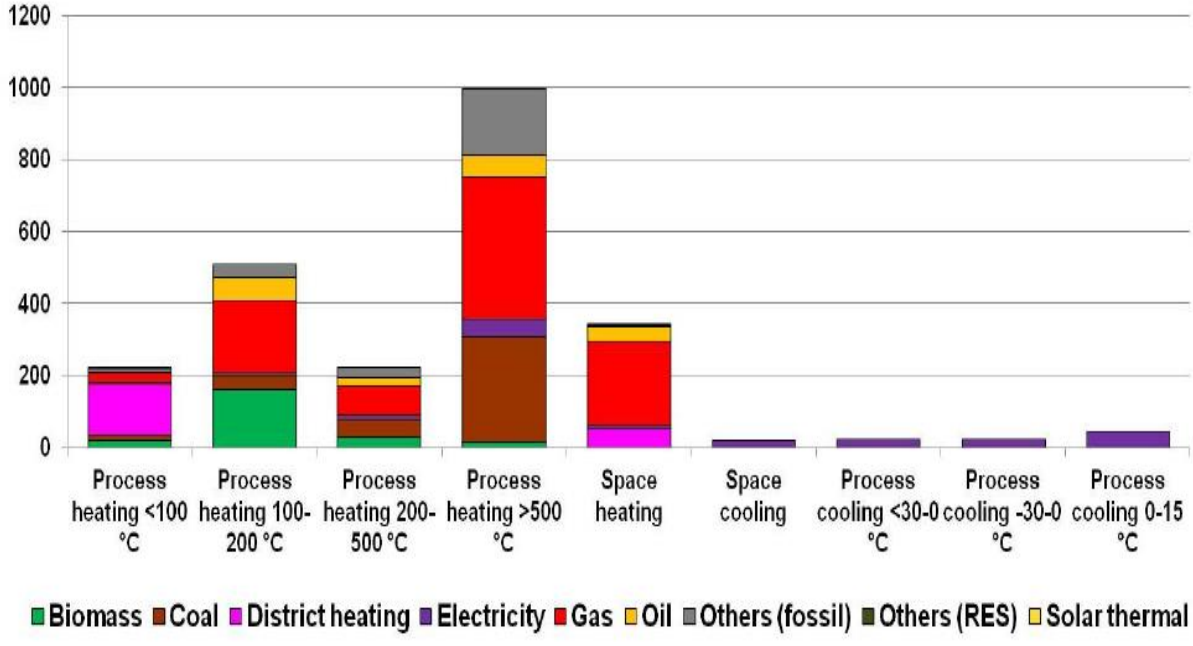
[97] See Honoré (2018b) for more information on heat supply and demand in Europe.

Figure 14: Estimate of the distribution of energy consumption in terms of process heat demand across the EU28 industrial sub-sectors, by temperature level, 2012 (Pj/a)



Note: PH: process heat, SH: space heating, HW: hot water.
Source: Naegler T., Simon S., Klein M., Gils H.C. (2015).

Figure 15: EU28 final energy demand in the industrial sector by temperatures and fuels, 2015 (TWh)



Source: Calculated from Heat Roadmap Europe (2017), in Honoré A. (2018b).

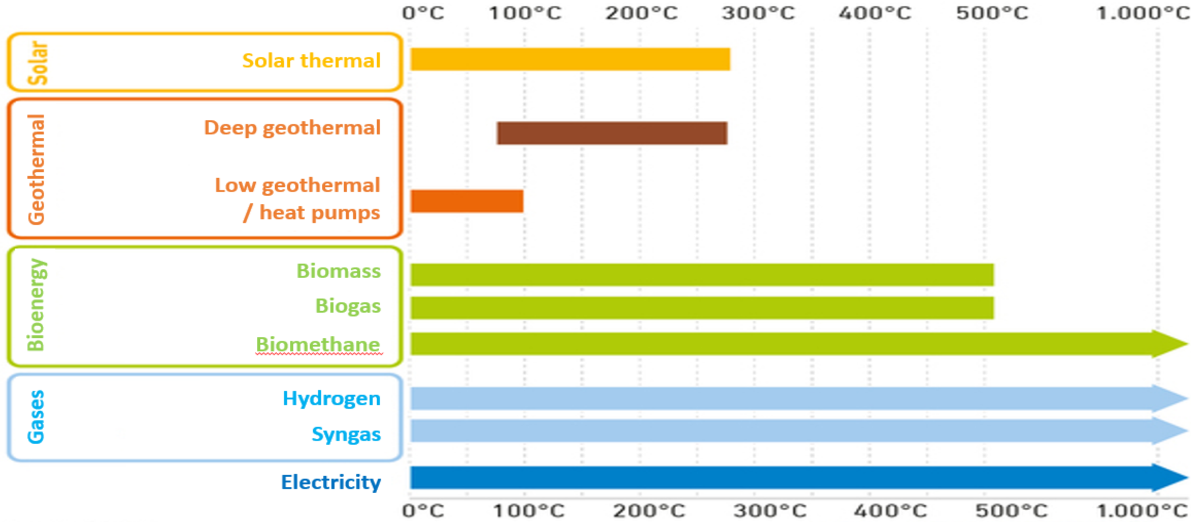
The concentration of renewables in the non-process heating sector and for industrial process heat with low temperatures occurs because these ranges are easily accessible for solar thermal energy, deep geothermal energy, and heat pumps (which can be air-source, ground-source, or water-source based systems), as seen in **Figure 16.**

However, most industrial GHG emissions arise from high-temperature process heat, but achieving temperatures above 300 °C can pose a challenge, as not all technologies and fuels are capable of achieving high temperatures, especially those associated with traditional renewables.[98]

Low-carbon options which can achieve high temperature are mostly limited to:[99]

- biomass and biogas, which can reach 500 °C (and might be a feasible option in the (petro) chemical industry and the food and beverage industry, where it could be generated from by-products of the operations in these sectors),
- biomethane, which has the dual advantage of being able to be injected into the existing natural gas grid and of reaching much higher temperatures (1000 °C and above),
- hydrogen and syngas/'e-gas', which can also achieve temperatures similar to natural gas,
- electricity.

Figure 16: Examples of temperatures accessible to various forms of renewable energy (°C)



Note: Within the technology there are big differences: for example, vacuum tube collectors in solar thermal energy can reach up to 200 °C, while concentrated solar thermal energy can reach up to 300 °C.
Source: Agentur fur Erneuerbare Energien (in German, author's translation).

To sum up, natural gas (and fossil fuels in general) can be more easily displaced by traditional renewable energies (and heat pumps) for low-temperature applications. Higher temperatures in energy-intensive industries, which cover about half of the total industrial gas demand, are likely to be more complicated to decarbonize but also cost more and take more time.

4.2. How to justify the (private) risks investments in low-carbon technologies?

Reducing emissions to near zero in the industry sector means that significant investments need to be made in new low-carbon technologies. However, the route (or routes) toward low-carbon options in the industrial sector is (are) somewhat less advanced than in other sectors (power, buildings). It is therefore extremely difficult to make accurate cost estimates. Some published industrial roadmaps have given an idea of the scale of the process, and it is likely to cost many billions of euros over the next 30 years and beyond. For instance, the European Commission mentioned annual investments of more than €10 billion in its 2011 Roadmap for moving to a competitive low-carbon economy in 2050.[100] In the UK, the 'Industrial decarbonization and energy efficiency action plans' that concern eight sectors[101] estimate a cost of about £22.5 billion to decrease GHG emissions by 73 per cent by

[98] Heat Roadmap Europe (2017).
[99] Other options are also considered but are not discussed in this paper, such as nuclear (specifically small modular reactors [SMRs]) for instance, which would certainly face limitations due to site and licensing restrictions in Europe. More information on plans in the USA can be found in McMillan et al. (2016).
[100] European Commission (2011).
[101] Cement, ceramics, chemicals, food and drink, glass, iron and steel, oil refining, and paper and pulp. Source: DBEIS (2017).

2050. In Germany, the cost of decreasing industrial GHG emissions by 80 per cent could rise to €120 billion, and even €230 billion for a reduction of 95 per cent, with investments essentially concentrated in steel, cement, chemicals, and refineries.[102]

Economics will contribute to determining which low-carbon technologies are deployed. Any investment in new processes is likely to result in substantially higher production costs. Higher costs would indicate a potential for the subsequent loss of competitiveness of European industries during the transition phase (at least). This would be especially relevant for key internationally traded goods sectors such as ammonia/chemicals, cement, ethylene, paper products, and steel which are commodities, so cost is the decisive consideration in purchase decisions. Companies that increase their costs by adopting low-emission processes and technologies will have a price disadvantage to others that do not. This may have a negative influence on any decision to invest in low-carbon technologies, but any delay in investment may hamper the chances of meeting the emissions-reduction targets and would prolong the use of existing fuels (including natural gas) for longer.

New technology deployment requires large investments, but there is currently no 'business case' for investing in research and innovation and creating pilot projects. Even investment in energy efficiency in the industry sector fell by 8 per cent in 2017 compared to 2016 with the biggest share spent in one manufacturing sector (food and beverage) rather than in energy-intensive sectors (steel, cement).[103] Even more risky and expensive investment may be very difficult to justify to shareholders.[104] This problem will need to be addressed through policy and regulation.[105] Strong support will be needed to reduce cost gaps compared to existing industrial processes; from initial pilot projects based on emerging technologies, to demonstration projects, and then to the scaling up and dissemination of the technologies throughout the industry.

Some technologies will not become competitive without carbon pricing or other interventions. There is a wide range of policies aimed at reducing GHG emissions, both at a national and at an EU level. Putting a price on CO_2 emissions via the EU Emissions Trading Scheme (ETS)[106] is one, but there are also air quality regulations via the Industrial Emissions Directive (SO_x, NO_x, PM), and the Best Available Technique (or BAT) Reference (BREF) documents, which stipulate the BATs (such as binding limits on SO_x, NO_x, dust, and mercury) for large combustion plants.[107]

Carbon pricing is the main instrument that facilitates the use of new technologies and discourages carbon-intensive activities, but with limited effect on inducing the required longer-term technology shifts. One of the reasons is that the industrial sector has largely been sheltered from the carbon price. The EU gives industrial emitters free ETS allowances to protect them against carbon leakage, which is the risk that companies will relocate their operations outside Europe, where carbon costs are lower. More than 90 per cent of industrial emissions were covered by free allocations in 2018.[108] In order to force the industrial sector to reduce its emissions, the EU is expected to reduce the number of sectors which will receive free allowances in phase four (from 2021 to 2030) and only 63 sectors will be eligible, down from 175, and the allocation is also expected to get tougher. As a result, bigger constraints on the industrial sector can be expected from the EU ETS from the early 2020s, although it may not be sufficient to deliver the necessary investment in low-carbon solutions on its own. For instance, the Global CCS Institute (GCCSI) hinted in April 2019 that the cost of first-of-a-kind CCS projects in the fertilizer sector was at \$23–33 (about €20–29) /t of CO_2, but other industries would have much higher costs, for instance in the cement sector CCS projects could cost around \$102–192 (about €92–172) /t of CO_2, while for iron and steel production, it was at about \$59–105 (about €52–

[102] BCG and Prognos (2018).
[103] IEA (2018c).
[104] Wesseling et al. (2017).
[105] For further discussion, see Stern (2019), p.11.
[106] The EU ETS puts a cap on emissions within the EU and forces firms to buy permits to cover each tonne of CO_2 they emit.
[107] There is even an Industrial Policy Strategy, published in 2017, which is essentially a wish list of what would need to take place to decarbonize the industry, but without any major indication on what is going to happen. Source: European Commission (2017).
[108] Argus Direct, 25 April 2019, End free ETS permits to cut industry emissions: NGO.

93) /t of CO_2.[109] The organization noted that the EU ETS alone would not deliver the support needed to deploy CCS in the highest-cost sectors.

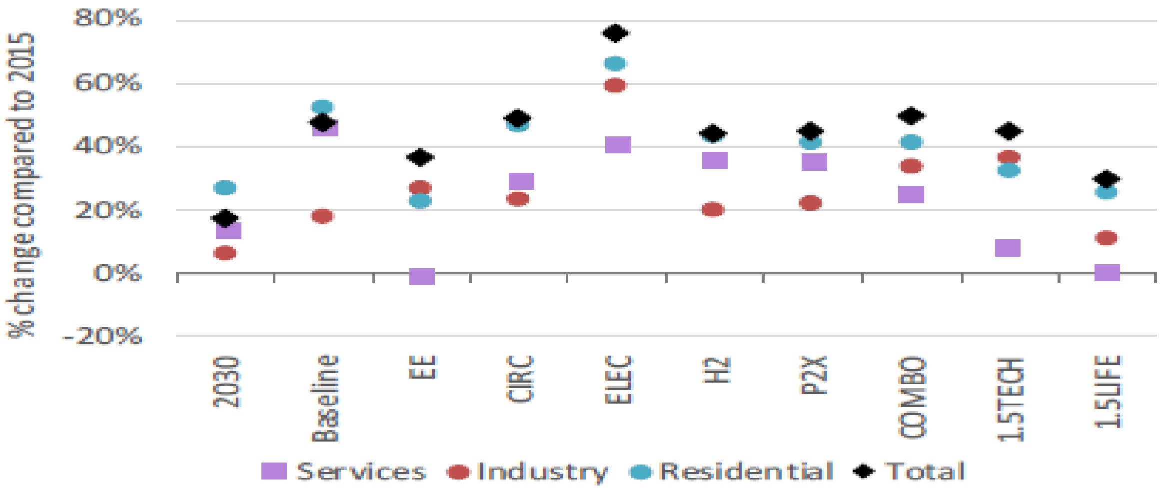
The majority of existing policies and measures address industry as a whole, rather than specific sub-sectors or even national or local specificities. However, industrial heat is often generated on-site and almost every facility worldwide is different, producing a wide array of product qualities and variations,[110] making the industrial sector more difficult to regulate than a more centralized sector such as large thermal power generation. As there is no 'one size fits all' solution, policies and options will need to be adapted to industry-specific and varied needs. They will also need to be coordinated with other sectors of the economy that will need to develop in parallel.

4.3. Investments will also need to happen in parallel in other sectors

The technology options chosen for industrial decarbonization could have implications for the overall energy system. For instance, switching the energy source of industrial processes to low-carbon sources will require a decarbonization of these energy carriers (electricity mix and/or decarbonized gas). Fuel-switching to electricity or hydrogen / 'e-gas' will only provide an improvement in emissions if they are produced from low-carbon sources, which implies the need for continued investment and growth in wind and solar power plants, which in turn would require a significant and costly transformation of the energy system.[111]

Interestingly, while total energy demand may decline as a result of decarbonisation policies, electricity demand may in turn increase due to large-scale development of heat pumps and the uptake of P2X (hydrogen and 'e-gas'). As seen in **Figure 17**, electricity demand in the industrial sector actually increases significantly in all the EU decarbonization scenarios between 2015 and 2050, from an additional 30 per cent to potentially close to 80 per cent, while the industrial sector could see increased electricity demand of 60 per cent in the electrification scenario.[112] Higher demand for electricity will necessitate investment and deployment of the necessary infrastructure, especially grid reinforcement. Similarly, the development of hydrogen and 'e-gas' will require suitable transport infrastructure, whether from upgrading the existing gas infrastructure or building a new one.

Figure 17: Changes in final electricity demand in EU28 for a range of scenarios, 2050 vs 2015 (%)



Note: see section II for a definition of the various scenarios.
Source: European Commission (2018b), p.74.

[109] Note: At the beginning of April 2019, the front year EU ETS contract closed at about €24/t of CO_2 Source: Argus Direct, 16 April 2019, 'CCS "feasible" at current EU ETS price'.
[110] Fischedick et al. (2014), pp.739–810.
[111] See Honoré and Sen (forthcoming 2019).
[112] European Commission (2018b).

Higher electricity demand may or may not impact the need for natural gas in the future generation mix, especially if CC[U]S gets developed.[113] CC[U]S would allow natural gas to continue to be used in a wide range of sectors, including power generation and industrial process output, but in order for hydrogen to be competitive, large quantities of methane reformers would need to be deployed[114] and pipeline infrastructure would need to be built and adapted to transport the CO_2 to the storage sites.

4.4. Uncertainty on the timeframe

Even with technologically proven low-carbon options, the procedure of switching fuel in industry will take time. Industrial production facilities tend to have long lifetimes and a slow turnover of capital stock, especially in energy- and capital-intensive industries where investment cycles of 20 to 40 years are not uncommon and technical life times for equipment may even extend beyond that.[115] Some capacity may have to be retired or retrofitted before the end of its technical lifetime to enable switching to low-carbon options. And due to the highly integrated nature of industrial processes, a change in fuel often requires a change in process, and changing one part often requires changes to other parts of a given process.

A number of industries have already voluntarily committed themselves to further reducing their emissions and are developing projects to identify sustainable and economically viable low-carbon business cases.[116] The choice between options will essentially depend on local circumstances (such as access to decarbonized electricity, CC[U]S availability, extent of gas grid, and applications), but available examples show that it will take time to transform to a low-carbon industry sector.

For instance in the UK, the Cadent HyNet NW project, which aims to deliver hydrogen produced by methane reforming with CCS[117] to industrial users, is expected to scale in various time frames, but a realistic time frame for this project is probably going to be at least another decade (early 2030s).[118]

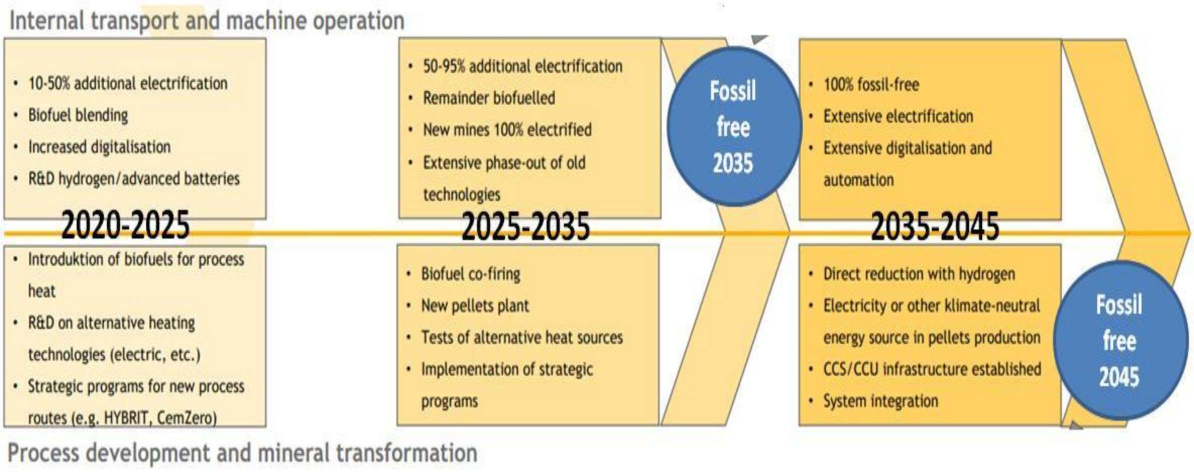
Other relevant examples can be found in Sweden, a country which has a zero emissions target by 2045 and access to relatively cheap and abundant renewable energy. In this country, the government and manufacturers are exploring various innovations to electrify the industrial sector. The main projects include:

- CemZero, a collaboration between cementmaker Cementa and power company Vattenfall to electrify cement kilns.
- HYBRIT, which aims to provide fossil-free steel production by replacing coking coal (in the traditional blast furnace method, large amounts of carbon are released) with hydrogen. While direct reduction with natural gas is now well-established in steel production, corresponding production methods based on hydrogen exist only on a pilot scale so far.[119] Construction of the pilot project started in 2018. This phase is expected to last until 2024[120] and then the demonstration project will take place from 2025. Developers expect to have fossil-free steel production by 2035.[121] The project is backed by about €50 million from the Swedish Energy Agency. This financial support is also complemented by costs on carbon.[122] While initial research suggests that HYBRIT's production costs will be around

[113] The impact of the decarbonization of the power sector on gas demand is not studied in this paper, but see forthcoming OIES paper by Honoré and Sen (forthcoming 2019), and Honoré (2018b) for additional information.
[114] As explained in section III. See also Pöyry (2018).
[115] In contrast, some sectors in light industries such as electronics tend to develop products with much shorter life-cycles (two to three years or less), which makes it easier and potentially faster to introduce low-carbon option. Source: Lempert et al. (2002)
[116] See examples: European Round Table website: https://www.ert.eu/.
[117] Autothermal reforming.
[118] Cadent, HyNet project website.
[119] There are other projects looking at hydrogen-based steelmaking in the EU, for instance SALCOS, H2Future, GrlnHy, SIDERWIN or Susteel. See bibliography for individual websites.
[120] The aim of is to have the pilot plant up and running by 2020, then to use the pilot facility for a few years up to 2024.
[121] Hybrit project website.
Production costs are currently 20–30% higher than normal steel production, but the cost gap 'will shrink' as carbon prices go up and green electricity prices fall. Source: Euractiv (2018).
[122] Most energy-intensive Swedish manufacturers are covered by the EU's Emissions Trading Scheme. Other manufacturers are subject to Sweden's carbon tax, meaning they must pay about 110 Euros (SEK 1,150) for every tonne of emissions. This high tax provides a very strong incentive to reduce emissions. Source: Beyond Zero Emissions (2018).

20 to 30 per cent greater than those of traditional steelmaking processes, that gap is expected to shrink over time, with the potential for raising the costs of CO_2 emissions through the EU ETS, and an expected decline in the cost of renewable energy.[123] This project is interesting because even in a well-placed location, where the project can access low-carbon electricity and with a project already underway, the estimated timeline is still quite lengthy (post 2035), as seen in **Figure 18**.

Figure 18: Lead-times to develop fossil free mining and mineral industry in Sweden



Source: http://www.energimyndigheten.se.

The key message is, that given the inertia associated with the economic lifetime of industrial facilities of 20 years or more (up to 50 years, with regular maintenance in energy-intensive industries[124]) and the large scale of investments required by industry, decisions need to be made now and action taken soon in order to reach the 2050 emissions targets (or at least to get closer to them). This is especially the case in energy-intensive industries, which are probably only one, or maybe at the most two, major investment decisions away from 2050. In other words, low-carbon technologies in the industry will need to be developed in the 2020s and be operational by 2030, in order to be deployed to scale across the EU by 2050.

These observations on the industrial sector, the low-carbon options and the challenges ahead provide important indications on how the decarbonisation process could affect the role of natural gas in the industrial sector in the coming decades.

V. Industrial gas demand and decarbonization: a simple analytical framework

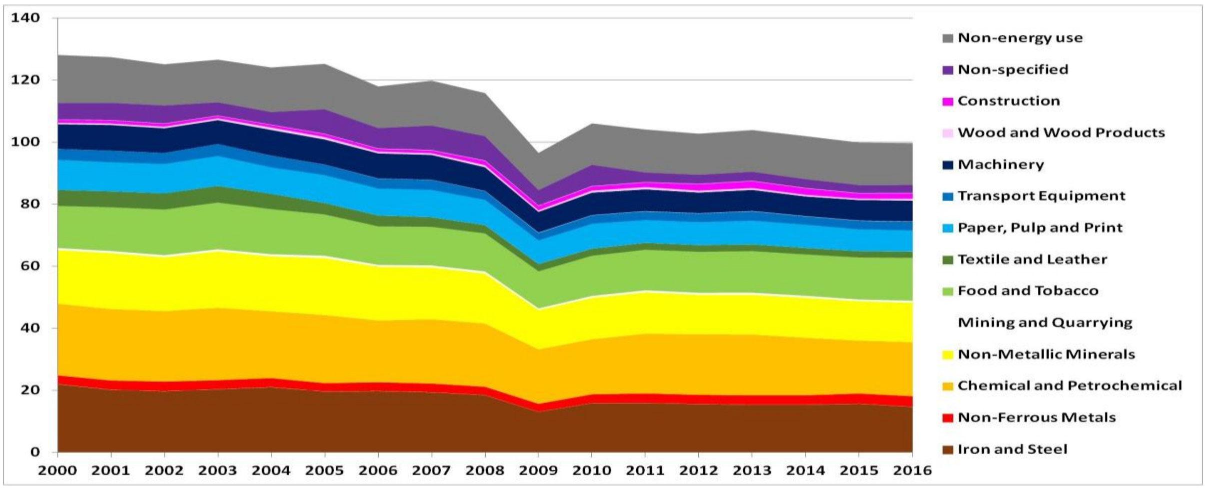
Despite the heterogeneity and complexity of the industrial sector and its decarbonisation routes, this section aims to present a simple analytical framework that draws from the previous findings – without advocating for any one solution, option, or pathway in particular – in order to understand the potential impacts of decarbonization on industrial gas demand in Europe up to 2050. The ambition was not to replace the more complicated scenarios (such as the ones presented in section II), but rather to work alongside them to add some explanations and granularity that were previously lacking. The first and the second sections (5.1 and 5.2) below provide a brief overview on industrial gas demand in Europe, before turning to the possible evolution of this demand (5.3). In the following paragraphs, all natural gas demand data that applies to a required level of heat are this author's estimates.

[123] World Steel Association website.
[124] McKinsey (2018).

5.1. Declining industrial gas demand in Europe

As seen in **Figure 19**, industrial gas demand has declined by 17 per cent since the early 2000s. This was due to energy efficiency improvements and shifts to less gas-intensive sectors (but with higher value added).[125] The largest losses (in volume) happened in Italy (–14 bcm[126]), the UK (–11.5 bcm), France (–8 bcm), and Spain (–6.5 bcm), while Germany and Austria registered the largest growth (3.4 bcm and 1.8 bcm respectively).

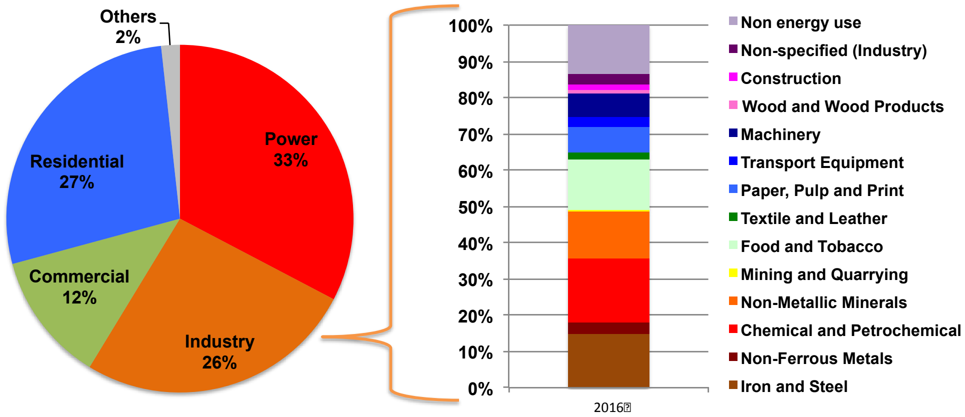
Figure 19: Industrial gas demand in EU28, 2000–2016 (bcm)



Source: Calculated from Eurostat.

The industrial sector still accounts for 26 per cent of all European gas demand and represents about 111 bcm.[127] Most of the gas is consumed for energy uses (86.5 per cent) as seen in **Figure 20.** The chemical and petrochemical sector has the largest share, with 17 per cent of the total (19 bcm), followed by iron and steel at 15 per cent (16 bcm), food and tobacco 14 per cent (15 bcm), non-energy use 14 per cent (15 bcm), and non-metallic minerals 13 per cent (14 bcm). Paper, pulp and print and machinery each represent about 7 per cent (8 bcm). The other sectors have shares below 5 per cent.

Figure 20: Industrial gas demand per industrial sector, 2016 (%)



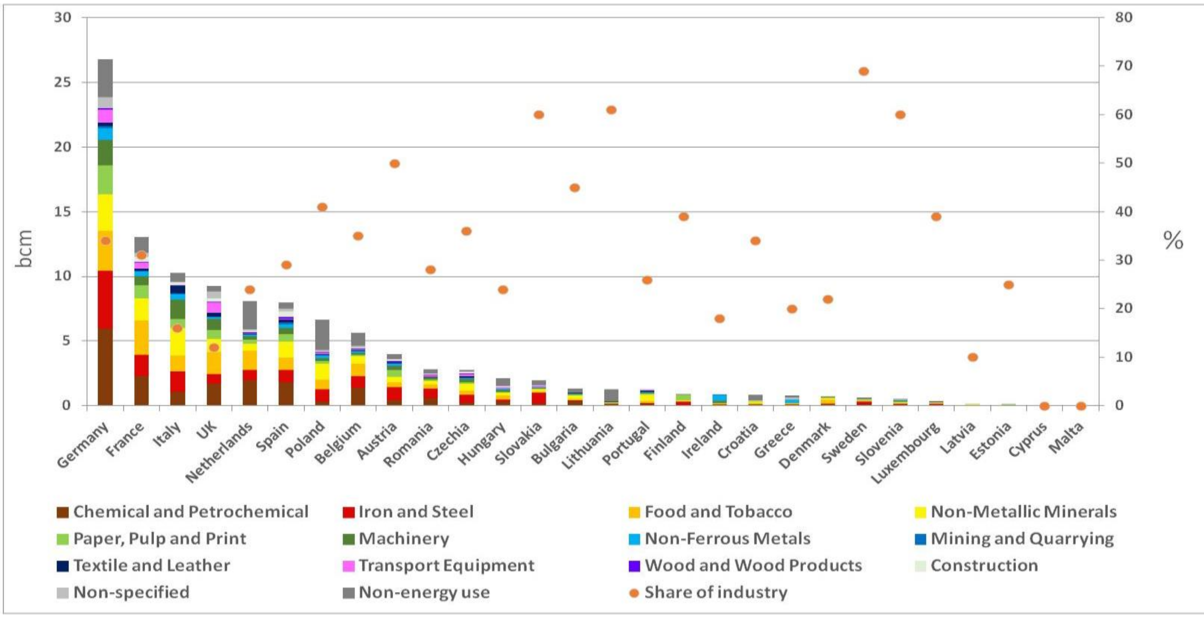
Source: Calculated from Eurostat.

125 Shifts mean changes to products (e.g. different chemicals produced), or changes in processes (e.g. less gas used in steel production, as it is replaced by coke).
126 Calculated from Eurostat data, data for the period 2000–2016.
127 Calculated from Eurostat data; data for 2016.

5.2. High concentration in a few countries

The share of industrial gas demand varies from country to country, from about 10 per cent in Latvia to 70 per cent in Sweden as seen as **Figure 21**.[128] One of the most important characteristics is the high concentration in a few countries. The main industrial gas users in Europe are Germany (24 per cent of regional industrial gas demand), France (10 per cent), Italy (9 per cent), and the UK (8 per cent). These four countries account for more than half of the EU's industrial gas demand, and eight countries account for 80 per cent of the total (the other major markets are the Netherlands and Spain (each 7 per cent), Poland (6 per cent), and Belgium (5 per cent)). What happens in these eight countries, and the efforts that they will make to transition their energy industries (especially the chemical and petrochemical and the iron and steel sectors) towards low-carbon solutions, will have a major impact at EU level.

Figure 21: Industrial gas demand per country and share of the sector in total gas demand, 2016 (bcm and %)



Source: calculated from Eurostat.

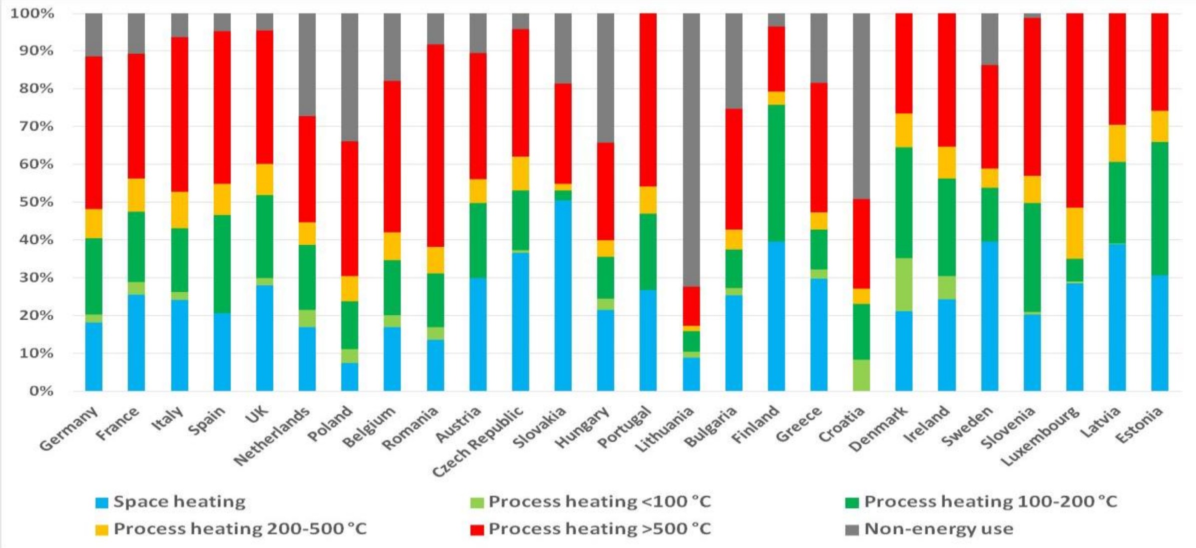
5.3. Decarbonization and industrial gas demand up to 2050

As previously mentioned in section IV, fossil fuels can be more easily displaced by traditional renewable energies and heat pumps for low-temperature applications. These technologies already exist and can be deployed in the coming years if adequate support is in place. Conversely, high-temperature heat processes are more complicated to decarbonize as most of the options would necessitate dramatic investments, changes and innovations which are going to take time.

Figure 22 below shows natural gas demand per level of heat required to be achieved for each of the EU28 market. The colours in blue or green (space heating, process heating <100 °C, process heating 100–200 °C) reveal shares of gas demand that may start to decline as early as the 2020s, while the colours in orange or red (process heating 200–500 °C, process heating >500 °C) show sectors where natural gas is used for high-temperatures processes and its use here could possibly decline from the 2030s, but most likely the 2040s. The grey colour represents the non-energy use of natural gas demand in industry, which is very hard to replace, and shifting to decarbonized options here may be even harder, potentially requiring whole new processes. This gas demand may be the last one to start to decline at scale.

[128] See Honoré (2018b).

Figure 22: Natural gas demand in the industrial sector by process heating temperatures and countries, 2015 (%)



Source: Author's estimates from Heat Roadmap Europe (2017).

More specifically, what does this tell us about the future of industrial gas demand? Natural gas use for space heating and in applications for process heat below 100 °C represents about 27 bcm in EU28.[129] It is especially important in the mix of Slovakia, Sweden, and Latvia but the larger markets were Germany (5 bcm), France (3.3), Italy, and the UK (3 bcm each). Because the technology exists, it would be possible for this gas demand to disappear fairly rapidly if gas becomes replaced by heat pumps and also, to a lesser extent, by solar thermal, geothermal (if location specifics permit it), and electric boilers. However, judging by the slow development of heat pumps across Europe (and potential technological restrictions [130]), additional incentives will probably be needed for this assumption to be realized. But even if this happens, the impacts are likely to be felt from the second half of the 2020s, at the earliest.

Applications for process heat between 100 °C and 200 °C consume about 21 bcm of gas. This medium heat demand could also decline in the 2020s and 2030s, and be replaced by electric boilers and renewable solutions, although this may not be as straightforward as for lower temperatures.[131] It will essentially concern the sectors of food, paper and print, and machinery and the major markets would be Germany (5 bcm), Spain (2.7 bcm), and France (2.2 bcm).

As a result, half of the industrial gas demand used for energy use (48 bcm out of 96 bcm) could, in theory, decline as soon as the 2020s, as gas is replaced by low-carbon options. If this happens, this could have some major impacts in Germany (10 bcm), France (5.5 bcm), but also in Italy, the UK and Spain. However, the main assumption behind this scenario lies in the rapid development of heat pumps. Judging by their rather low take off in most of Europe, the reality could end up quite differently from the theory on paper, unless some additional support is provided for the dissemination of heat pumps and renewables across low-temperature process heat industries.

The other half of industrial gas demand used for energy will probably not decline so fast. As explained in section III, higher temperatures and energy-intensive industries are likely to be more complicated to decarbonize and will therefore take more time. Options exist – such as hydrogen and other decarbonized gases and biomass – but these are at early stages of development, and/or their economics are uncertain, and/or their implementation may necessitate additional innovations and/or

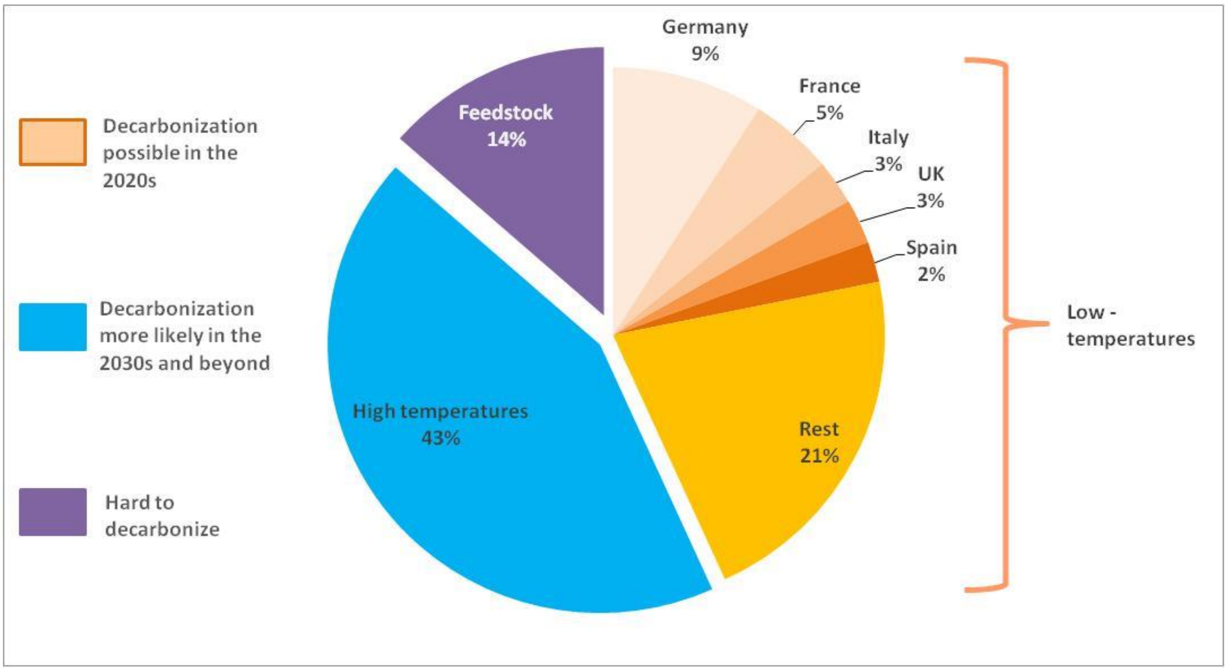
[129] Author's estimates, data for 2016.
[130] See footnote 52.
[131] IEA (2017), p.317.

infrastructure. Further electrification is technically possible, but it will increase electricity demand and costs (so thermal combustion seems to be more efficient for high temperatures). In addition, some industries need very high temperatures (above 1000 °C) which can only be reached by certain low-carbon options such as biomethane, hydrogen, syngas/'e-gas', and electricity (but not biomass or biogas[132]) which limits the available options even further. The main impacts on this type of gas demand, which represents about 48 bcm, are expected much later in the mid-2030s at the earliest, and most likely in the 2040s. Exactly what, where and when is too soon to tell as pathways on how to decarbonize the high-temperature energy-intensive industries only are in their early stages.

Natural gas used as a raw material in industry represents about 15 bcm, essentially in Germany (3 bcm), Poland (2.3 bcm), the Netherlands (2.2 bcm), and France (1.2 bcm). This portion is even more difficult to replace by a different energy carrier. On paper, both hydrogen and biomass could be used to replace both oil and natural gas in some sectors. However, low-carbon hydrogen[133] is still in the early stages of development and the economics are uncertain; as for biomass, constraints on available supply will limit its role in the future. Any decline in gas demand would probably come from lower levels of production, although in the past this mostly affected the demand for oil products as feedstock, while gas demand for non-energy use in the industry remained fairly flat (see **Figure 3** in section I).

Figure 23 offers a summary of these results showing industrial gas demand by energy use for combustion and for non-energy use, together with the possible timing of decarbonization.[134]

Figure 23: Industrial gas demand and possible timing of decarbonization (%)



Source: Author.

As for energy efficiency in general, the largest impacts can be expected on energy demand for space heating and low-temperature heat, as better insulation and heat pumps develop[135] possibly from the

[132] See section III.
[133] Power-to-gas or steam reforming of methane using CCS
[134] At the regional level, about 25% of industrial gas demand goes to space heating, 3% in applications for process heat below 100 °C, 21% in applications for process heat between 100 °C and 200 °C, 9% in applications for process heat between 200 °C and 500 °C, and 42% in applications for process heat above 500 °C. Source: Author's estimates from Heat Roadmap Europe (2017).
[135] See Honoré (2018b) for more details on decarbonizing heat in buildings.

2020s. It may then slow down until new models develop at scale – such as circular economy, probably in the 2040s.

One option that is considered in other sectors is coal-(or oil)-to-gas switching. Replacing coal and oil with natural gas would reduce emissions and have a positive impact on gas demand. With a fair amount of coal and oil still present in the industrial energy mix (39 per cent),[136] could that be an option for the EU28 industrial sector as well?[137] In a previous paper, this author estimated that such a move could –in theory- correspond to about 34 bcm of additional gas demand. However, the short answer to this question is 'no'. This is not really an option to be considered seriously in the EU28. Some US companies have looked at replacing coal with natural gas in steel making, as relative fuel prices there make this a possible option.[138] However, in Europe, the options being considered to decarbonize industry are more radical ones, with a shift toward low-carbon solutions. For instance, hydrogen is considered for fossil-free steel making but not natural gas. No major increase in gas demand can therefore be expected in the industrial sector from coal-(or oil)-to-methane switching.

The general conclusion of this section is that the road towards low-carbon solutions in industry suggests a (much) longer and (more) complex transition than that seen and anticipated in other sectors (power, buildings and even transport) and as a result, industrial gas demand will most likely not decline dramatically before well into the 2030s or even later in Europe.

Conclusions

In scenarios published by Shell, Equinor, the IEA and the EU, the general view about the industrial sector is that gas demand is expected to decrease between 2015 and 2050 across all scenarios although the energy mix will be very different depending on the pathways chosen due to diverse assumptions on targets, policies, and technologies. One problem is that these models tend to simulate the industrial sector in an aggregate way that obscures the sectoral diversity of the sector, and as a result, the capacities for (or the constraints on) replacing fossil fuels to abate emissions are also obscured. They do not provide much detailed information about the evolution by country and by sector. The objective of this paper was to propose a simple analytical framework to get some granularity into the possible evolution of industrial gas demand as a result of decarbonization policies in Europe up to 2050.

Industrial energy demand still relies mainly on fossil fuels and electricity, while renewable resources represent only a very small share of the mix and essentially come from biomass. Decarbonization will require a dramatic shift in how industrial heat is generated. There will be no simple solution and a combination of decarbonization options will have to be deployed and adapted to local circumstances. These options are essentially energy efficiency improvements, electrification of heat from zero-carbon electricity supply (and heat recovery techniques) together with fuel switching (to biomass or hydrogen as feedstock and/or fuel), and carbon capture utilization and storage. This transformation is still at its early stages and is facing many challenges. This brings uncertainties on what can be done, when, and at what cost.

Fossil fuels can be more easily displaced by traditional renewable energies (and heat pumps) for low-temperature applications, but not so much for high-temperature heat. In the next decade or so (up to 2030), it appears that the main mitigation options are to improve energy efficiency via the use of heat

[136] Energy used for combustion. Source: calculated from Eurostat, data for 2016.
[137] Coal is essentially used in Germany (28% of the total), Poland (11%), and France (10%), while oil is mostly used for non-energy use (74%), which is concentrated in Germany (23% of this use), the Netherlands (15%), and France (15%), while the other 26% is used for combustion to produce heat. Source: calculated from Eurostat, data for 2016.
[138] Coal (as coke) is: a reducing agent, a source of energy to drive the process, and a source of carbon to incorporate in the steel. Alternative processes need to meet all three functions.
Another possible option is wood or other biomass which can provide: the reducing function, a source of energy, and the minor carbon component in steel. Further heat would need to be obtained from electricity or natural gas (or biogas). However, this may have an impact on forests and sustainability may be a challenge.

pumps (provided that they can overcome commerciality and acceptability problems) and to increase the use of renewables (solar and geothermal). This represents about 48 bcm of natural gas demand, (essentially in Germany, France, Italy, the UK and Spain). However, even the development of relatively more mature options such as heat pumps is at risk; without additional support and/or regulation, any vast deployment might not take place.

Temperatures above 300 °C pose a challenge to decarbonization as not all technologies and fuels are capable of achieving high temperatures. Replacing fossil fuels will therefore require the development of breakthrough technologies with solutions that are neither technically mature nor cost-competitive – such as electrification, the use of decarbonized gases, and/or CC(U)S. Even with available funding and good conditions, it will take time to scale up to a commercial level, probably 10–15 years at least. As a result, the decarbonization of high-temperature process heat is likely to be more complicated and to take more time, with the main impacts on natural gas demand (another 48 bcm) expected in the mid-2030s at the earliest, and most likely in the 2040s and beyond.

Emissions from non-energy use or feedstocks will be even harder to tackle as it is technically difficult, or even impossible, to switch to other energy carriers, thus any solution will mainly be a change of process. As a result, natural gas used as a raw material in industry (15 bcm) is probably going to take even longer to replace and its use may remain high throughout the period (unless industries shut down or are relocated outside the region). As a result, as for high-temperature process heat, CC[U]S is likely to be needed to allow for the transition to a low-carbon sector.

These results show that dramatic changes and innovations will need to happen soon (from the 2020s) if the EU is to achieve a decarbonized industrial sector by 2050. Several projects are being developed across Europe, but it is still hard to get a clear indication of what will happen, at what scale, and by when. A follow up on the deployment (or delay) of heat pumps and other renewable sources for low-temperature usage in the 2020s would give an indication on how fast (or slow) industrial gas demand will decline. This paper also provides an important foundation for further research, especially in the area of high-temperature process heat, in order to understand the full impact of decarbonization on industrial gas demand in Europe up to 2050 (and beyond).

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