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Industrial Climate Neutrality in the EU: Outline of an Integrated Industrial Green Deal

The transition to climate neutrality is the defining challenge of our century. Over the next 30 years, global energy systems, mobility, logistics and agriculture will have to transform dramatically in order to reduce greenhouse gas (GHG) emissions to almost zero and give us a fighting chance of keeping the average temperature rise on earth below two degrees Celsius or even 1.5 degrees Celsius.[1]

Industry, and in particular the energy-intensive extraction and production of basic materials such as chemicals, cement, steel, non-ferrous metals, ceramics, and so on, is responsible for approximately 50% of global greenhouse gas emissions.[2] These energy-intensive industries (EII) form the constructs of our modern economy which is based on the presence of a large and diverse amount of such materials.

Decarbonising EIIs is complex. EII value chains not only link to each other, but also link to every possible economic sector forming a dense and intricate system.[3] Moreover, they are crucial in the transition to climate neutrality, given that no contemporary climate technology can be built without such basic materials – for instance, a new wind turbine contains dozens of tonnes of steel and cement and considerable amounts of copper, zinc, aluminum, fiberglass and materials from the chemical industry.[4] No matter how we turn it around, future human civilisation and economics will have to rely on all of these materials.

In the European Union, the industrial transition is well underway. Since 1990, EU EIIs have reduced their emissions and energy intensity profile significantly – GHG emissions dropped by 36%[5] while final energy consumption fell by 20%.[6] Globally, the EU is also at the forefront of industrial decarbonisation solutions.[7] If EU industry makes a successful low-carbon transition, it can be a model for other regions, proving that there are numerous pathways which can help reconcile a climate-neutral society with the large consumption of materials. However, challenges still exist for EU EIIs to reach climate neutrality.

This article seeks to highlight the constructive and solution-oriented role that EU EIIs have been playing, determine a combination of possible key solutions that will help EIIs to significantly reduce their emissions, as well as stress the need to address the necessary conditions to ensure that Europe is at the forefront of the low-carbon energy and industrial transformation.

The article first presents a coordinated profile of 11 EIIs through an assessment of GHG emissions, energy consumption, raw materials use, economic profiling and value chains.[8] Further, it highlights the essential role of the EIIs in the low-carbon economy through their quality of enablers. It looks at sector-specific and collaborative solutions from the EIIs which demonstrate that EIIs have already been very active in researching and developing technological solutions towards lower CO_2 emissions. It explores key areas in which EIIs can play an enabling role, including the likely application of ten different technological pathways across the different energy intensive sectors, prospects for industrial symbiosis and synergies with non-industrial sectors, the circular economy and material efficiency, and the synergies between the EU's energy transition and the EIIs' low-CO_2 transition. Finally, this contribution presents a set of framework conditions emerging from the previous section that will become elements of an industrial transition strategy: R&D challenges,

1 United Nations Convention on Climate Change: Paris Agreement, 12 December 2015, available at http://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf.
2 IPBES: Global Assessment Report on Biodiversity and Ecosystem Services, 2019.
3 T. Wyns, G. Khandekar, I. Robson: Industrial Value Chain: A Bridge Towards a Carbon Neutral Europe, Europe's Energy Intensive Industries contribution to the EU Strategy for long-term EU GHG emissions reductions, IES-VUB, 2018, available at https://www.ies.be/node/4758.
4 Ibid.
5 Emissions Data from sector associations.
6 Eurostat: Energy Balance, May 2018, available at https://ec.europa.eu/eurostat/web/energy/data/energy-balances; WBCSD: Cement Industry Energy and CO_2 Performance, Getting the Numbers Right (GNR), Cement Sustainability initiative Emission report, 30 December 2016, available at https://www.wbcsd.org/Sector-Projects/Cement-Sustainability-Initiative/Resources/Cement-Industry-Energy-and-CO2-Performance Glass Alliance Europe, EULA.
7 T. Wyns et al., op. cit., Addendum "Industrial Value Chain: A Bridge Towards a Carbon Neutral Europe".
8 Iron and steel, cement, chemicals and fertilisers, refineries, non-ferrous metals, ferro-alloys and silicon, pulp and paper, ceramics, lime, and glass.

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securing competitive low-CO_2 electricity, infrastructure needs, financing challenges, circular economy and material efficiency challenges and regulatory challenges. The conclusion stresses the way forward through a new EU industrial strategy and a Green New Deal for carbon-neutral EIIs and their value chains.

The energy-intensive industry in the EU

The energy-intensive industrial sector in the EU holds strategic importance given that around 80% of the goods produced by the EII are consumed all over Europe.[9] In 2015, total aggregate production value for EIIs stood at nearly 1.3 trillion euro[10] while gross value added (GVA) was 378 billion euro,[11] with direct employment provided to 1.5 million people.[12] EIIs were seriously affected by the 2007 economic crisis and the aftereffects are still visible as scar tissue. Between 2000 and 2016, output fell in all sectors (except the chemicals sector and pulp and paper industry) while in some EIIs, like steel, cement, refining, glass, ceramics and lime, large industrial closures ensued.[13] To date, with the exception of only the chemical sector, no other EII has achieved pre-crisis level production. While GVA among the EII as a whole grew by 19% (2000-2016),[14] the rest of the EU economy grew faster.

The total direct GHG emissions from EIIs in the EU stood at 665 Mt CO2-eq in 2015,[15] representing 15% of EU total GHG emissions (18.4% in 1990).[16] Between 1990 and 2015, EIIs reduced direct emissions by 36% (-375 Mt) contributing 28% of the total economy-wide emission reductions by the EU (-1331 Mt).[17] These reductions have ensued due to a combination of factors such as improvements in energy efficiency, fuel switching including increased use of biomass, closures and lower production levels or capacity utilisation in some sectors, in particular, following the economic crisis of 2008, deep reductions of non-CO_2 GHG emissions in chemicals and fertilisers production (N_2O and fluorinated gas emissions reduced by 93% between 1990 and 2015 in these sectors).[18]

Total final energy consumption of EIIs in 2016 stood at 9.4 Exajoules (EJ) having dropped by almost 20%, or 2 EJ from 11.7 EJ, since 1990.[19] Between 1990 and 2016, the share of EIIs in the EU's final energy consumption fell from 23% to 19%. This reduction happened most noticeably in iron and steel production (-41%), cement production (-37%) and chemicals (-26%).[20] Most importantly, energy intensity declined by 39% across all industrial sectors together in the same period with the chemicals industry, reducing its energy intensity by 60%.

The period 1990-2016 also registered an important fuel shift away from solid fuels (from 23% of final energy consumption in 1990 to 14% in 2016) towards higher use of renewable fuels (from almost 3% in 1990 to 7% in 2016) and electricity (19% to 22%).[21] Oil products' share dropped slightly (24% to 22%) while the share of gas remained stable at 28%.[22] Overall, solid fossil fuel use dropped by 49%, use of renewable fuels (e.g. solid biomass, biogas, biofuels and municipal waste) increased by 123%, and the use of industrial and (non-renewable) municipal waste increased dramatically by 331%. The drop in solid fossil fuel use happened across all industries between 1990 and 2016: refining (-96%) iron and steel production (-40%), chemicals production (-61%), non-ferrous metals (-81%), non-metallic minerals (-65%), and pulp and paper (-61%).[23]

European EIIs have made important headway into circularity. For instance, next to virgin raw material use, recycled materials form a high share of EII raw material inputs.[24] Such strategies have helped to reduce European EII trade dependency and increase supply security. Moreover, the vast majority of the output is consumed within the EU internal market and imports outweigh exports in a number of sectors like steel, refining, glass, and ferroalloys and silicon.[25] Only in the chemicals, pulp and paper and ceramic sectors do exports exceed imports (EU ce-

9 T. Wyns et al.: Industrial Value Chain…, op. cit.
10 Eurostat: Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E), 2018, available at https://data.europa.eu/euodp/data/dataset/hVEPsB0XIdBfx9oXmOPg; 2013 figure was used for manufacture of refractory products.
11 Eurostat: National accounts aggregates by industry (up to NACE A*64), 2018, available at:https://ec.europa.eu/eurostat/web/products-datasets/product?code=nama_10_a64.
12 Different industrial sector federations.
13 T. Wyns et al.: Industrial Value Chain…, op. cit.
14 Eurostat: National accounts…, op. cit.
15 Excluding Land Use, Land-Use Change and Forestry.
16 See sector data and European Environment Agency: Greenhouse gas – data viewer, 2018, available at https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer; European Environment Agency: Annual European Union greenhouse gas inventory 1990–2016 and inventory report, 2018, available at https://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2018.
17 Ibid.
18 T. Wyns et al.: Industrial Value Chain…, op. cit.
19 Excluding auto-generation of electricity (e.g. CHP and use of blast furnace gas for power generation). For refining, energy data from 'consumption of the energy branch' was used from the EU energy balances. see – Eurostat: Energy Balance…, op. cit. For refining, the energy data from section 'consumption of the energy branch' was used.
20 Eurostat: Energy Balance…, op. cit.
21 Ibid.
22 Ibib.
23 Ibid.
24 T. Wyns et al.: Industrial Value Chain…, op. cit.
25 United Nations: UN Comtrade Database.

ramics sector had a positive trade balance of 4.4 billion euro in 2015).[26]

Industry-led solutions

EIIs have been active in developing solutions towards lower CO_2 emissions both in relation to their own emissions (footprint) and emissions in other sectors of the economy through their products and activities (handprint).

In recent years, research into new climate-friendly innovations in industry has increased sharply, often with support from European science policy. For each sector, multiple technology options towards significant GHG reductions are being developed. In the steel sector, this includes new types of CO_2 and energy efficient blast furnaces which will also have the option of capturing and storing CO_2.[27] At Tata Steel in Ijmuiden, the Netherlands, this technology has been successfully tested on a pilot scale.[28] The Swedish SSAB is planning to reduce iron ore use through hydrogen instead of the traditional CO_2-emission intensive process that uses coal.[29] ArcelorMittal Gent is working on the use of residual gases from the steel production process (in particular carbon monoxide) for the production of ethanol – a liquid that can be used in the chemical industry to produce plastics instead of oil as input material.[30] Interesting technologies are also being developed in the petrochemical sector, e.g. the use of biomass to extract high-quality chemical products.[31] Many important chemical processes could use hydrogen, in combination – or not – with CO_2 to replace fossil fuels and raw materials.[32] A whole series of such processes are now being developed.

The most prominent technological pathways are presented in Table 1 while Table 2 provides an assessment across the main pathways identified in terms of technology status, impact on energy use, capital expenditure (CAPEX, relative to investments in the current state of the art), operating expenses (OPEX, relative to current operations), infrastructure needs and possible co-benefits.[33]

The technology assessment above indicates that industrial symbiosis where companies and sectors cooperate more with each other to optimise material, raw material, waste and energy flows will become more prominent as sectors seek to reduce GHG emissions. Waste gases from primary steel production can become the feedstock for the production of high value added chemicals.[34] Steel slag, a waste product from blast oxygen furnaces, can be used as the main constituent in cement for use in bricks.[35] The pulp and paper and chemical sectors will likely also align more with forest fibre derived bio-based products, becoming feedstock for a wide range of chemical products. Industrial symbiosis is also already used extensively at site level with multiple production installations (e.g. exothermal processes delivering heat to processes requiring additional energy). There are examples of EIIs delivering waste heat to other industries or sectors of the economy (e.g. paper production to automotive or waste heat used for district heating). In Belgium, for example, the refining sector and petrochemical industry are even physically integrated through large process installations (e.g. naphtha crackers). Silica fume, which is a by-product of silicon and ferro-silicon, is added to concrete in construction, which helps reduce cement use while providing better performances. Lime forms an essential raw material for steel, paper and glass production and has played a vital role in reducing damaging emissions of sulphur dioxide. Cement and fertilisers contribute to recycling and recovering waste and by-products from other EIIs.

Likewise, future demand for electricity can rise significantly (if higher levels of electrification, use of hydrogen, valorisation of CO_2 and capturing of CO_2 are deployed across the EIIs) reaching almost 3,000 TWh or half of final EU electricity consumption in 2050 (under a -95% scenario).[36] To be consistent with the economy-wide carbon neutrality objective, this electricity will have to be generated without emitting CO_2. Industry is already play-

26 T. Wyns et al.: Industrial Value Chain. . . , op. cit.

27 T. Wyns et al.: Addendum, op. cit.

28 See https://www.tatasteel.nl/nl/over/organisatie/in%E2%80%93ijmuiden.

29 Hybrit Fossil-Free Steel, http://www.hybritdevelopment.com/.

30 Arcelor Mittal: Project "Steelanol" First commercial project for advanced bio-fuel production from waste gas, 2015, available at http://www.vlaamseklimaattop.be/sites/default/files/atoms/files/Arcelor-Mittal%20-%20project%20Steelanol.pdf.

31 H. Chen, L. Wang: Technologies for Biochemical Conversion of Biomass, Science Direct, Chapter 1 – Introduction, 2017, Academic Press, pp. 1-10, available at http://www.sciencedirect.com/science/article/pii/B9780128024171000016.

32 DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V.: Results of the BMBF funding measure Technologies for Sustainability and Climate Protection – Chemical Processes and Use of CO_2, 2019, available at https://dechema.de/en/energyandclimate/_/CO2_Buch_engl.pdf.

33 T. Wyns et al.: Industrial Value Chain. . . , op. cit.

34 The amount in Europe would suffice to supply the production of 55 Mt methanol (see DECHEMA: Low carbon energy and feedstock for the European chemical industry, 2017, available at https://dechema.de/dechema_media/Downloads/Positionspapiere/Technology_study_Low_carbon_energy_and_feedstock_for_the_European_chemical_industry.pdf) or the majority of ethylene production in Europe (Acelor-Mittal – Steelanonal).

35 Vito: Annual report: Steel waste recycled into new construction materials, 2014, https://jaarverslag2014.vito.be/en/highlights/steel-waste-recycled-into-new-construction-materials.

36 Eurelectric: Decarbonization pathways, EU electrification and decarbonization scenario modelling – synthesis of key findings, 2018, available at https://cdn.eurelectric.org/media/3172/decarbonisation-pathways-electrificatinopart-study-results-h-AD171CCC.pdf.

Table 1
Overview of low-CO_2 technology potential for energy-intensive sectors

	Electrification (heat and mechanical)	Electrification (processes: electrolysis/ electrochemistry excl. H2)	Hydrogen (heat and/ or process)	CCU	Biomass (heat and feedstock)/ biofuels	CCS	Other (including process integration)
Steel	xxx	xx	xxx	xxx	x	xxx	Avoidance of intermediate process steps and recycling of process gases: xxx Recycling high quality steel: xxx
Chemicals/ fertilisers	xxx	xxx	xxx	xxx	xxx	xxx(*)	Use of waste streams (chemical recycling): xxx
Cement Lime	xx (cement) o (lime)	o (cement) x (lime)	x (cement) xx (lime)	xxx	xxx (cement) x (lime)	xxx	Alternative binders (cement): xxx Efficient use of cement in concrete by improving concrete mix design: xxx Use of waste streams (cement): xxx
Refining	xx	o	xxx	xxx	xxx	xxx	Efficiency: xxx
Ceramics	xxx	o	xx	x	x	o	Efficiency: xxx
Paper	xx	o	o	o	xxx	o	Efficiency: xxx
Glass	xxx	o	x	o	xxx	o	Higher glass recycling: xx
Non-ferrous metals/alloys	xxx	xxx	x	x	xxx	x	Efficiency: xxx Recycling high quality non-ferrous: xxx Inert anodes: xxx

Notes: o: Limited or no significant application foreseen, x: Possible application but not main route or wide scale application, xx: Medium potential, xxx: High potential, xxx: Sector already applies technology on large scale (can be expanded in some cases), (*) in particular for ammonia and ethylene oxide. CCU – Carbon Capture and Utilisation, CCS – Carbon Capture and Storage.

Source: Based on T. Wyns, G. Khandekar, I. Robson: Industrial Value Chain: A Bridge Towards a Carbon Neutral Europe, Europe's Energy Intensive Industries contribution to the EU Strategy for long-term EU GHG emissions reductions, IES-VUB, 2019, available at https://www.ies.be/node/4758.

ing its part in the transition nexus. One such example is corporate power purchase agreements (PPAs) between renewable energy and industry sectors which are growing in success.[37] PPAs enable industry consumers to secure a supply of green electricity at a competitive price with long-term price visibility while financial certainty for utilities brings down the cost of capital and thereby the price of electricity generated while adding renewable capacity online. Indeed, long-term PPAs have been part of the industry's strategy for decades as both investors and financial institutions alike seek to diversify long-term market, price and risk (e.g. 20 years). In addition, the industry will play an increasingly important role in managing the electricity system through demand control (whereby the industrial electricity demand is flexibly aligned with supply) and through storage of energy and electricity (for example via hydrogen and ammonia).

Deep emission reductions will only be possible if the value chains of the EIIs are closely involved in the transition to a climate-neutral society.[38] All of the above activities together can indeed lead to very deep emission reductions in the industry. But this alone does not guarantee decarbonisation. There are important preconditions that must be met before a successful industrial transition can take place.

The big climate paradox: Producer versus consumer

Shifting the cost (for the time being) of more expensive climate-friendly technologies from the producer to the consumer could help protect the competitiveness of industry while ensuring a market for low-carbon products. At the start of the value chain, such climate-friendly technologies can represent a 20% to 80% increase in production costs, which can harm competition and eventually shift production abroad.[39] But at the end of the value chain, for example when purchasing a car, plastic bottles or building a house, the final consumer will notice very little of those additional costs of basic materials, even if they are fully charged.[40] Research shows that the prices for these

37 T. Wyns, G. Khandekar: Metals for a Climate Neutral Europe: A 2050 Blueprint, IES-VUB and Euometaux, 2019, available at https://www.ies.be/files/Metals_for_a_Climate_Neutral_Europe.pdf.

38 T. Wyns et al.: Industrial Value Chain..., op. cit.
39 Material Economics: The Circular Economy, op. cit.
40 Ibid.

Table 2

Assessment of main technology options vis-à-vis technology status, energy use, CAPEX, OPEX and infrastructure needs

Technology status	Energy use – compared to current operations	CAPEX – relative to conventional technologies	OPEX – compared to current operations	Infrastructure needs	Possible co-benefits
Electrification heat					
High technology readiness level except for high temperature furnaces (glass, cement)	Higher electricity demand but primary energy use can be lower	Depends (replacement of boilers relative low additional CAPEX, (high temperature) furnaces major investment)	Depends on (favourable) electricity vis-à-vis natural gas prices and efficiency improvements from electrification	Medium	Higher potential for electricity demand response; Possible energy savings
Electrification processes					
In most cases not reached demonstration stage	Higher electricity demand but primary energy use can be lower	High	Highly dependent on electricity prices	Low/medium (possible need for more/ upgraded high-voltage connections)	Higher potential for electricity demand response
Process integration					
Move towards pilot and demonstration plants	Medium/high	Medium (unless combined with CCU or CCS)	Higher	Medium (unless combined with CCU or CCS)	Recycling/ process internal use of generated process gases
Hydrogen					
Move towards pilot and demonstration plants	High electricity consumption for electrolysis based production	High	Higher (dependent on electricity prices)	High (unless hydrogen production happens on site)	Possibility of power storage (e.g. use of ammonia as carrier)
Biomass					
Diverse, move towards pilot and demonstration plants for newest technologies	Can be notably higher	High for feedstock applications (new process technologies) Low/medium for fuel applications (compared to e.g. natural gas based furnaces)	Higher for feedstock applications Higher for feedstock applications (depends on price of biomass)	Medium/high (need for new and reliable logistics chains for sustainable biomass from within and imported into the EU)	Industrial symbiosis (e.g. use of biomass waste streams)
CCU					
Moving towards commercialisation for carbonation and synthetic fuels; Other processes, besides the ones mentioned above, are expected to move towards development of process and demonstration plants over next years	Can be very high for hydrogen based routes; Limited for carbonation and mineralisation	High (but lower for some carbonation technologies)	Can be high (esp. when hydrogen from electrolysis is required; Depends on renewable electricity price); Limited for carbonation/mineralisation	High	CO_2 becomes resource instead of cost
CCS					
Move towards pilot and demonstration plants	Will be higher	High	Higher	High	Possible process integration benefits

Notes: CCU – Carbon Capture and Utilisation, CCS – Carbon Capture and Storage.

Source: Based on T. Wyns, G. Khandekar, I. Robson: Industrial Value Chain: A Bridge Towards a Carbon Neutral Europe, Europe's Energy Intensive Industries contribution to the EU Strategy for long-term EU GHG emissions reductions, IES-VUB, 2019, available at https://www.ies.be/node/4758.

goods, produced in a climate-neutral manner, would increase by less than 1%.[41] This limited impact is also visible in the total social cost for sustainable steel, cement and plastics production, whereby a recent study by Material Economics indicates that this cost would amount to only 0.2% of European GDP.[42]

41 Ibid.

42 Material Economics: Industrial Transformation 2050. . . , op. cit.

Ingredients for a successful industrial transition

The transition to a climate-neutral industry will only be possible if industry is able to safeguard its competitiveness during that process. The cornerstone of the current industry-focused climate policy is the 15-year-old European Emissions Trading System (EU ETS), which set a price for CO_2 emissions throughout the EU. The ETS has not been without faults. For one, the emission ceiling was repeatedly set too high (due to a lack of knowledge within the government, handy industry lobbying and a major unexpected and long-term economic crisis) resulting in CO_2 prices that were too low to incentivise the structural reduction of emissions. Also, large parts of the industry remain partially exempted because they receive the bulk of the allowances free of charge unlike the energy producers. Moreover, the most low-hanging fruits have been picked (in terms of N_2O emissions in the chemical industry, for example). In the short term, emissions can decrease by 1% per year, but that is far from sufficient to achieve climate neutrality by 2050. These efforts are becoming increasingly difficult and more expensive. In other words, we can impose a CO_2 tax on a steel company of 200 euro per tonne of CO_2 tomorrow, but that will not automatically cause emissions to fall more quickly. There is a high degree of inelasticity in the short term. A new approach and new instruments are therefore needed in addition to the existing EU ETS carbon price that focus on, among other things, facilitating (transition) investments, a better link between sectors to accelerate the transition and abandoning linear consumption and business models.

Facilitate investment through moonshots

Current policy is based on the protection of the status quo (for example through compensation under the EU ETS). However, the question is no longer how we can prevent investments going abroad (i.e. protection against carbon leakage), but how we can have more (and even a doubling of) investments in this area. This will require a new and ambitious industrial policy in which the authorities must play a clear and supporting role.

The transition to net zero emissions in the industry will require large investments in order to replace virtually all processes with innovative technologies.[43] Many of the aforementioned technologies are promising, but still in development and only proven on a small scale. Moreover, these innovations have not yet had the time to become more efficient and therefore cheaper through years of improvements. So, they often (but not always) have a higher production cost compared to existing, mature technologies.[44] The most important task now is to scale up these innovative processes to industrial size. However, this is a very capital- and risk-intensive process. Companies alone will not be able to cope with this risk. That is why, through mission-oriented public-private cooperation, significant investment in industrial demonstration projects will have to be made.

A mission-oriented R&D industrial policy must be pursued, also known as moonshots. At European level, large research funds such as Horizon Europe will increasingly focus on missions and major societal challenges led by economist Mariana Mazzucato.[45] Such innovation programs must be steered from the specific challenges that industry faces and mandate sound coordination between research and educational institutions, the business community and governments. This can make the EU an innovation hub for industrial and circular low-carbon technologies.[46] It is therefore relevant to work across the entire innovation chain and to invest sufficiently in industrial demonstration projects.

An energy and industry pact

A coordinated industrial and energy transition plan will have to be drawn up that examines how industry can maximise its role in the energy transition (for example through demand management and storage) and how the energy transition can be organised and financed so that industrial competitiveness is preserved. Energy and industrial policy may no longer be viewed separately and will have to promote a more active role for industry in energy systems which could include better utilisation of residual heat, rewarding demand management and, in the long term, energy storage by industry.

Sector linking and infrastructure

New low-carbon processes will need new infrastructure for raw materials, energy and the realisation of more symbiosis between companies and sectors.[47] This means laying pipelines for the transport of CO_2[48] and hydrogen as well as providing reliable logistics chains that guaran-

43 T. Wyns et al.: Metals for a Climate Neutral Europe. . . , op. cit.

44 For a thorough overview of technology status and costs, see T. Wyns et al.: Addendum, op. cit.

45 M. Mazzucato: Mission Oriented Research and Innovation in the EU, A problem-solving approach to fuel innovation-led growth, European Commission, 2018.

46 T. Wyns, G. Khandekar, M. Axelson, O. Sartor, K. Neuhoff: Industrial Transformation 2050: Towards an Industrial strategy for a Climate Neutral Europe, IES-VUB, 2019.

47 Dechema: Low carbon energy… , op. cit. ; T. Wyns et al.: Industrial Value Chain. . . , op. cit.

48 CO2Europipe: Towards a transport infrastructure for large-scale CCS in Europe, 2011, available at http://www.co2europipe.eu/.

tee the supply of biomass and waste and materials to be recycled at a competitive price. Large industrial clusters can be targeted for new infrastructure and investments in new innovative processes to take advantage of possible economies of scale like Carbon Capture and Storage.[49] Here, the EU could provide budgetary flexibility to member states so that the latter can write off investments that help in the transition to a climate-neutral society over several years (rather than in one year as is currently the case).

Skills development

The development of new processes will have to go together with the development of skills to implement and operate those processes.[50] While it is unclear yet exactly how these new jobs will look, future job descriptions such as industrial symbiosis manager, plasma response engineer, feedstock purification expert, bioprocess engineer or hydrogen production operator can be considered based on the technologies under development.[51] Education and training initiatives at the EU level will therefore have to integrate these new skills in collaboration with the business community.[52]

From linear to circular business models

Without a high degree of efficient use of materials and circularity, achieving a climate-neutral society is virtually impossible. This means that policy will have to focus more on value chains, the efficient use of materials and how they are treated at the end of the life cycle.[53] For example, when plastics are burned at the end of the current product life cycle, almost as many GHGs are released as in the production phase.[54] The latter emissions, however, fall outside the current scope of EU ETS. The implementation of these three new policy pillars will also have to be accompanied by a new range of instruments.[55]

Standards for a material-efficient and circular economy

Due to the focus on a CO_2 tax, 'standards' are often underestimated but can be really useful. For example, the ban on incandescent light bulbs across Europe led to large energy gains with the switch to LEDs.[56] In the context of the transition to a circular economy, standards will be very important, such as the ban on disposable plastic, the introduction of a deposit or the obligation to use only plastic that (in the long term) consists of at least 80% recycled material.[57] With regard to increasing the efficient use of materials, similar instruments can be looked at in energy efficiency policy such as the standardisation of the efficient use of materials in the packaging and production of goods. Furthermore, the EU and/or member states can create and stimulate new markets for sustainable products by making smart use of government procurement policies by including more criteria with regard to sustainable production and efficient use of materials.[58] In this way, companies that innovate and invest in breakthrough technologies would have a reliable market for their low-carbon products.

Realising levers for green investments

Tax reforms for industry can prove transformative. Ideally, tax reforms can be introduced whereby tax reductions in the industry are linked to innovative and green investments unlike the current system based purely on accounting rules. The establishment of national investment banks can also ensure that (risk) capital finds its way to industrial low-carbon investments more easily. It is important that such investments are managed smartly so that they also flow back to society in the form of financial returns or as part of the proceeds of sponsored intellectual property.

Another problem is that industry often reckons with very short payback periods (e.g. under three years) for investments in, for example, energy efficiency because it does not prefer to or cannot take risks in the longer term (e.g. market contraction during a crisis). This can be absorbed by the creation of so-called special purpose vehicles that make investments outside the company's accounts and thus safeguard the balance sheet.[59] Here too, a win-win

49 McKinsey & Co: Decarbonization of industrial sectors: the next frontier, 2018, available at https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/how-industry-canmove-toward-a-low-carbon-future.

50 FTI Consulting: Driving Technology and Business Models Innovation for Storage and Demand Response, 2016, available at https://www.eprg.group.cam.ac.uk/wp-content/uploads/2016/05/R.-Clover.pdf.

51 Council of the European Union: A Non-paper on the Competitiveness of the EU Energy Intensive Industries, 2017, available at http://data.consilium.europa.eu/doc/document/ST-8263-2017-INIT/en/pdf.

52 CEFIC: Skills for Innovation in the European Chemicals Industry, 2011, available at http://www.cefic.org/Documents/PolicyCentre/Skills-for-Innovation-in-the-European-Chemical-Industry.pdf.

53 Material Economics: The Circular Economy, 2018, available at http://materialeconomics.com/latestupdates/the-circular-economy.

54 E. Watkins, J.P. Schweitzer: Moving towards a circular economy for plastics in the EU by 2030, Institute For European Environmental Policy, 2018.

55 Material Economics: Industrial Transformation 2050 – Pathways to Net-Zero Emissions from EU Heavy Industry, 2019.

56 European Commission: New lightbulb rules will enable household energy savings and help reduce greenhouse gas emissions, 2018, available at https://ec.europa.eu/info/news/new-lightbulb-rules-will-enable-household-energy-savings-and-help-reduce-ghg-emissions-2018-aug-31_en.

57 T. Wyns et al.: Metals for a Climate Neutral Europe…, op. cit.

58 IISD: Low-Carbon Innovation For Sustainable Infrastructure The Role Of Public Procurement, 2016, available at http://i2-4c.eu/wp-content/uploads/2018/03/Low-Carbon-Innovation-for-Sustainable-Infrastructure-The-role-of-public-procurement_v2.2_web.pdf.

59 T. Wyns et al.: Metals for a Climate Neutral Europe…, op. cit.

situation can arise for both industry and the wider society. While a financial return of 15% from an investment in energy efficiency may not be attractive for some companies, it is very interesting for other investors as they generate a return that yields much more than savings.

Conclusions

The transition to a carbon-neutral industry will be a monumental task not short of a new industrial revolution. The challenges are numerous but come with opportunities for growth, circular and material efficiency, a low-carbon energy system through synergies with industry, and development of innovation hubs and global leadership. EU industry-led efforts have been aplenty thus far. Going ahead will require a dynamic EU industrial policy composed of an ambitious industrial strategy along with a mission-oriented 'Green New Deal' that supports industry efforts and multiplies them by creating a supportive framework that not only allows industry to survive but also thrive. Such an industrial policy would ensure that low-carbon technologies are developed and commercialised, that enough affordable low-carbon electricity is available for industrial consumption by 2050, that supply security of raw materials is ensured, that markets for low-carbon products are created and scaled, that sufficient transition-related infrastructure is developed, that greenfield development is supported and that basic materials producers are not penalised in the process, thereby forcing them out of Europe. In particular, this would be a policy that uses a wide range of instruments and aims to achieve sustainable value creation in a targeted manner to complete a climate-neutral and competitive industrial revolution. More importantly, this means a policy that protects employment and added value, and sets a global example that the pursuit of climate neutrality can go hand in hand with a thriving industry. A successful industrial transition in the EU would not only provide a credible pathway for the rest of the world but would also make a historical contribution to the global fight against dangerous man-made climate change.