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Building Blocks of the European Union's Strategy for Climate Neutrality

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2.1 Introduction

Since the early 1990s, when the international community became openly aware of the climate problem, the European Union (EU) has nurtured an ambition to be a leader in the fight against climate change. So far, it has succeeded in its intent, although admittedly competition for this distinction has generally been low. The EU has consistently played a positive role in the definition of a global climate regime, from the Kyoto Protocol to the Paris Agreement. Equally relevant, the EU has been a pioneer in the implementation of ambitious and innovative policies for the reduction of greenhouse gas emissions domestically. In this respect, the EU Climate and Energy Package, which was adopted in 2009, can be considered a turning point given the scope of its targets and policies as well as its integration into a broader policy agenda. Notably, the '20–20–20' targets, which stood for a 20% reduction in greenhouse gas emissions (relative to 1990 levels), a 20% share of renewables in energy consumption and a 20% reduction in energy consumption (relative to business as usual), all to be achieved – as indeed they were – by 2020, have shaped the framework of EU climate and energy policies in subsequent years. The same targets became part of the Europe 2020 Strategy (2010), with which the EU pursued improved international competitiveness and sustainable growth. In 2019, after many other EU initiatives in the climate–energy domain and in response to an ever more real climate emergency, the European Commission (EC) led by President Ursula von der Leyen launched the European Green Deal ('Green Deal').

As stated in the original Communication by the EC, the Green Deal is 'a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use'.[1] In the Green Deal, more clearly than ever before, the EU's pursuit of environmental and social sustainability is not subordinated to that of economic growth. Rather, it is a condition and even a driver of economic growth. Focusing on the Green Deal's item that is most relevant to this

[1] Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, The European Green Deal, COM/2019/640 final, 11 December 2019.

chapter, the goal of net-zero greenhouse gas emissions – or climate neutrality – by 2050 was put forward for the first time in the Green Deal Communication itself. For this goal to be meaningful, the EU needs to continue working in parallel: at the international level and domestically. Human-induced climate change is caused by global anthropogenic greenhouse gas emissions, of which today less than 10% originate in the EU. The EU, therefore, will continue to foster international climate co-operation. Moreover, it will influence climate action abroad through its own achievements and failures in moving toward net zero. The challenge is to demonstrate that a reformed economic system can thrive while greenhouse gas emissions are quickly reduced and eventually eliminated. The EU today looks like a laboratory where economic, climate, and energy policies are experimented with and will ideally be replicated elsewhere.

At the time of writing, namely, autumn 2022, the EU laboratory for climate neutrality was in full swing. In 2021, the EC presented a comprehensive package of legislative proposals, dubbed 'Fit-for-55', which seeks to enable the EU to meet a more ambitious emissions reduction target for 2030 than the one previously set: a reduction of 55% instead of 43% (relative to 1990 levels). The Fit-for-55 package provides for many existing and new policy instruments to be updated and introduced, respectively.[2] Important reforms of existing instruments concern the EU Emission Trading System (ETS), energy taxes, emission efficiency standards for vehicles, energy efficiency standards for buildings, and the regulation of greenhouse gas emissions and removals in the land use, forestry and agriculture sector, among others. Important novelties include, inter alia, the carbon border adjustment mechanism (CBAM), a second ETS covering greenhouse gas emissions from road transport and buildings, and new regulations on hydrogen and renewable gases as well as on methane emissions in the energy sector. Most if not all of the Fit-for-55 proposals are currently working their way through the EU legislative process, which by law can only successfully end with an agreement between the European Parliament and the Council of the EU. In any case, net of the changes that will be introduced during the legislative process, the general direction that these proposals have already traced is not in question.

Achieving climate neutrality on a large scale requires deep structural changes in the energy system and in the wider economy. It also implies that all sectors of society are involved and that only a large set of ambitious, well-co-ordinated, and innovative policies can be effective. With the Green Deal, the EU is aiming to accomplish this massive socio-technical transition by mid-century. In this chapter, we examine a few critical components of the EU's strategy for achieving climate neutrality. Of the many such elements that could be considered, we have chosen four: (a) carbon pricing, (b) electrification, (c) 'clean molecules', and (d) sustainable finance. Crucially, EU policy stands at the global frontier in each of the corresponding domains. Carbon pricing implemented through the EU ETS has characterised EU climate policy over the past 20 years. The EU ETS will remain central in the policy mix and new instruments are being developed to address the undesirable effects of high carbon prices. Meanwhile, as part of a vision of a future integrated and

[2] L. Hancher, L. Meeus, A. Nouicer, V. Reif (eds.), The EU Green Deal: 2022 Edition (EUI, Technical Report 2022/06, 2022). https://cadmus.eui.eu/handle/1814/75156.

decarbonised energy system, two major technological developments are being promoted, each with its own technical and economic challenges. First, the EU aims to maximise the share of electricity in final energy consumption. Second, alternative energy vectors, including notably green hydrogen and biomethane, also known as clean molecules, will be used to decarbonise energy-intensive activities not suitable for electrification. Last but not least, the EU is trying to radically ramp up the volume of private capital channelled towards sustainable investments. This too requires the adoption and implementation of a host of new specific financial capacities and regulatory tools.

The chapter is structured as follows. The first section describes carbon pricing in the EU, focusing on the EU ETS and on the forthcoming CBAM. Sections 2.4 and 2.5, respectively, discuss the roles of electrification and clean molecules in the future European energy system. Finally, Section 2.6 reviews the sustainable finance priorities, capacities, and regulatory instruments put forward by the EU, before a brief conclusion.

2.2 Carbon Pricing: Gearing Up for Net Zero

In June 1992, literally on the eve of the United Nations Earth Summit in Rio de Janeiro, and only one or two years after carbon taxes were first adopted by a few northern European countries, the EC presented a legislative proposal for an EU carbon tax. The proposal eventually failed because Member States did not reach unanimity, which is a requirement for fiscal matters under EU law. Eleven years later, the EU succeeded in adopting the EU ETS: a novel instrument chosen by the Union to meet its long-term greenhouse gas emissions reduction target under the Kyoto Protocol (a reduction of 8% relative to 1990 levels, over 2008–2012) and potentially other similar targets in the future.

Just as with carbon taxes, ETSs incentivise the reduction of greenhouse gas emissions by putting a price on carbon. However, the two forms of carbon pricing fundamentally differ in certain respects. It suffices to mention two features of ETSs that are not shared with carbon taxes. In an ETS, carbon prices are market prices of emission allowances issued by a regulatory authority. Moreover, ETSs such as the EU ETS, which more specifically are so-called ‘cap-and-trade’ systems, set upper limits on the total volume of regulated emissions. Simply described, the ‘cap’ of an ETS is given by the supply of emission allowances that are distributed to regulated entities within multi-year trading periods (called ‘phases’ in the EU ETS). The demand for allowances depends on output levels and emission intensity of regulated entities, among other factors. The interplay of demand and supply determines allowance prices.

In principle, the main strength of carbon pricing is cost-effectiveness, meaning the ability to cut greenhouse gas emissions at minimum cost. On the other hand, ‘carbon leakage’ and inequitable distributional effects are potential side effects of carbon pricing that need to be addressed. Carbon leakage is the phenomenon whereby emission reductions achieved in a jurisdiction (or sector) are to some extent offset by emission increases elsewhere. In the absence of a global uniform carbon price, higher carbon prices in a country can result in carbon leakage due to the deteriorated international competitiveness of domestic firms in certain sectors – which is in itself an economic problem, of course. Depending on which sectors are regulated, carbon pricing can also result in undesirable distributional effects across households. Poorer households are typically more affected than richer ones, in relative terms, by price increases of energy goods such as electricity, natural gas, and motor fuels. The higher carbon prices are, the greater the need for measures that can effectively counter these side effects. Today, the main challenge for the EU in leveraging carbon pricing relates to the design and implementation of such measures.[3]

2.2.1 The European Union's Emissions Trading

In operation since 2005, the EU ETS has imposed a linearly declining cap on greenhouse gas emissions from about 10,000 heavy energy-using and electricity-generating installations and aircraft. The total volume of emissions covered by the EU ETS currently accounts for slightly over 40% of the EU's total greenhouse gas emissions. Given increased climate ambition under the Green Deal, the current reform of the EU ETS mandates a steeper cap trajectory whereby the cap will reach in 2030 a level 61% below that of 2005 emissions.

The EU ETS is often referred to as a 'cornerstone' and a 'flagship' of EU climate policy. The use of these terms is warranted. First, the EU ETS has contributed to reducing emissions by imposing significant carbon prices or, just as importantly, by determining the expectations of significant carbon prices in the future. Second, the cap alone has ensured consistency of regulated emissions with long-term emissions reduction targets. Third, the EU ETS, which at the time was the first instrument of its kind to be used for climate mitigation, has represented a model to follow and improve on for many countries. Partly inspired by the EU ETS, many other ETSs have been established around the world, including China's ETS, with many more likely to be established in the future.[4]

From a regulatory point of view, the EU ETS has changed substantially over the years. This is no surprise, as the EU ETS itself can be considered a 'grand policy experiment'.[5] Not only that, its evolution accelerated in response to major external events such as the Great Recession (2007–2009) and, more recently, the Green Deal. Major reforms were carried out in 2009 (Reform for Phase III, 2013–2020), 2015 (Market Stability Reserve),[6] and 2018 (Reform for Phase IV, 2021–2030). The current reform is no less relevant than the previous ones. In fact, it may be considered the most relevant so far in that it is the first to amend the system with a view to reaching net-zero emissions. The proposed reform comprises five main elements:[7] (1) a reduced cap, in line with the climate neutrality target; (2) revised rules

[3] S. F. Verde, W. Acworth, C. Kardish, S. Boghesi, Achieving Zero Emissions under a Cap-and-Trade System (EUI, Policy Brief 2020/26, 2020). https://cadmus.eui.eu/handle/1814/67510.

[4] ICAP, Emissions Trading Worldwide (ICAP, 2022). https://icapcarbonaction.com/en/publications/emissions-trading-worldwide-2022-icap-status-report.

[5] Back in the 1990s, this is how Robert Stavins described the U.S. sulphur dioxide (SO_2) allowance trading system (R N. Stavins, What can we learn from the grand policy experiment? Lessons from SO_2 allowance trading. *Journal of Economic Perspectives* 1998, 23(3): 69–88).

[6] The Market Stability Reserve introduced flexibility in allowance supply. It is a rule-based mechanism for addressing the imbalances of the allowance market caused by unanticipated changes in regulated emissions and, therefore, allowance demand.

[7] Proposal for a Directive of the European Parliament and of the Council Amending Directive 2003/87/EC Establishing a System for Greenhouse Gas Emission Allowance Trading within the Union, Decision (EU) 2015/1814 Concerning the Establishment and

on free allocation and on the Market Stability Reserve; (3) extension of the EU ETS to maritime transport; (4) a separate, brand new ETS for buildings and road transport; and (5) increase of the Innovation and Modernisation Funds as well as new rules on the use of auction revenues. Below is a description of the EU ETS that is focused on three of its fundamental dimensions touched by the reform: scope, cap trajectory, and allowance allocation.

2.2.1.1 Scope

Since 2005, the perimeter of emissions covered by the EU ETS has occasionally widened as a result of countries joining the system or extensions to previously exempt greenhouse gases or sectors. The current proposed reform of the EU ETS includes its extension, as of 2023, to emissions from maritime transport, specifically from ships above 5,000 gross tonnage. The volume of emissions involved makes this a significant step in the evolution of the EU ETS. At the EU level, maritime transport represents 3–4% of total carbon dioxide (CO_2) emissions. Globally, CO_2 emissions from this sector are projected to increase between 90% and 130% by 2050 compared to 2008 levels.[8] Given the lack so far of adequate measures to decarbonise maritime transport, the extension of the EU ETS to cover these emissions is an expedient development. The proposed extension concerns all emissions from intra-EU voyages, 50% of emissions from extra-EU voyages (that is, starting or ending outside of the EU), and all emissions occurring when ships are at berth in EU ports. To ensure a smooth transition, the requirement to surrender allowances covering 100% of emissions would be phased in over 2023–2025.

2.2.1.2 Cap Trajectory

In the regulation of cap-and-trade systems, setting the long-term cap is obviously a critical task. If an environmental target has already been identified, the task may seem straightforward: the cap just has to be consistent with that target. In actual fact, estimating business-as-usual emissions is needed to evaluate emissions abatement and the resulting levels of allowance prices, that is, carbon prices. Even if the market of emission allowances was perfectly efficient, both excessively high carbon prices and excessively low carbon prices can be problematic. Therefore, carefully calibrating the climate policy mix so that it results in a desirable combination of carbon prices and other climate policies (for example, subsidies for renewable energy, for energy efficiency, energy standards, etc.) is of the essence.

The cap of the EU ETS is indeed related to the broader targets for the EU's overall greenhouse gas emissions, hence including emissions not covered by the system. To align the cap with increased emissions reduction targets set in the European Climate Law,[9] the EC

Operation of a Market Stability Reserve for the Union Greenhouse Gas Emission Trading Scheme and Regulation (EU) 2015/757, COM(2021) 551 final, 14 July 2021.

[8] International Maritime Organisation, Fourth Greenhouse Gas Study 2020 (2021). www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx.

[9] Regulation (EU) 2021/1119 of the European Parliament and of the Council Establishing the Framework for Achieving Climate Neutrality and Amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'), PE/27/2021/REV/1, 30 June 2021. https://eur-lex.europa.eu/eli/reg/2021/1119/oj.

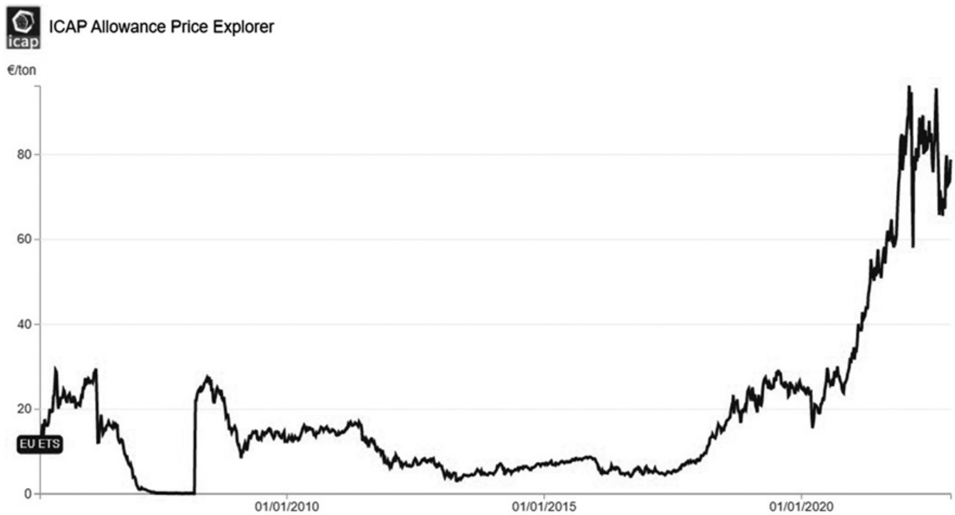

Figure 2.1 Prices of European Union allowances (2005–2022). *Source*: International Carbon Action Partnership, Allowance Price Explorer.

has proposed to cut regulated emissions by at least 61% relative to 2005 levels by 2030. This is a major tightening of the cap, which under current legislation would reach a reduction of ‘only’ 43% instead. Accordingly, the linear reduction factor, which measures the annual reduction in newly issued allowances, would almost double from the current 2.2% to some 4.2%. Carbon prices can be expected to rise in the future as a result of increased cap stringency. An interesting question, however, is to what extent they have already adjusted as a result of the market having discounted this announced development. As Figure 2.1 shows, prices of EU allowances have more than tripled since the Green Deal was announced in late 2019.

2.2.1.3 Allowance Allocation

The rules on the allocation of emission allowances are also an essential element of any cap-and-trade system. These rules are likely to be revised in a more or less substantive way on the occasion of any broad reform of a system. In the history of the EU ETS, some trends in the evolution of the allocation rules can be noted: (a) expansion of auctioning to the expense of free allocation; (b) targeting of free allocation with a view to minimising carbon leakage risk while avoiding windfall profits; and (c) use of free allocation as a tool for incentivising emissions abatement in investment decisions. These trends continue with the current reform.

As the cap declines over time, the total volume of allowances that can be given away is going to shrink. Indeed, this is the fundamental reason why the CBAM will gradually replace free allocation as the main approach to carbon leakage prevention. At the same time, allowance auctioning will be phased in for the aviation sector and, as already established by the previous reform for Phase IV, it will continue to expand (up to 100% in 2030) for the industrial sectors not deemed at risk of carbon leakage. Careful distribution of increasingly scarce allowances available for free allocation is also reflected in the space for more stringent emission efficiency benchmarks proposed by the EC. The maximum annual update of these (product) benchmarks, which are used for determining individual allocations of free allowances and which in the EU ETS correspond to the average of the 10% most greenhouse gas-efficient installations, would rise to 2.5% from the current 1.6%. Moreover, it has been proposed that free allowances will be partly granted conditional on proven decarbonisation efforts by firms so as to further incentivise the uptake of low-carbon technologies. Finally, the parameters determining mandatory participation of industrial installations in the EU ETS will be revised to remove unintended (dis)incentives. Notably, firms would not exit the EU ETS, which entails giving up valuable free allowances in excess of emissions, as a result of adopting effective abatement technologies (for example, through electrification). Not only will this remove a barrier to the adoption of break-through technologies, but – by keeping innovative installations in the EU ETS – it will also improve emission efficiency benchmarks and thus encourage greater emissions reductions in turn.

2.3 The Carbon Border Adjustment Mechanism

In real-world climate policy, the introduction of the EU CBAM represents a disruptive innovation and potentially a game changer depending on the responses that it might trigger internationally. From a theoretical point of view, the CBAM is a climate policy tool that falls under the category of border carbon adjustments (BCAs). Given climate mitigation policies with different levels of stringency across countries, the purpose of BCAs is to minimise carbon leakage occurring via the competitiveness channel. The logic of BCAs is to level the playing field for domestic and foreign producers competing in the same markets. Countries with a domestic carbon price may impose levies on the carbon embodied in imports from regions where carbon prices are lower or nil; by the same token, rebates on exports to regions with lower or no carbon prices could offset embodied carbon payments.[10] This way, firms subject to more stringent climate policies would not be penalised by higher production costs, either in domestic markets thanks to import charges or in foreign markets thanks to export rebates. As a result, net of expectations about the future, production activities and related greenhouse gas emissions should not shift abroad – not owing to climate policy, at least.

The idea of BCAs is not new. Over the past 15 years, they have been the subject of many studies and debates on international climate policy. Yet to date we have hardly any experience with actual BCAs. The only existing BCA we know of is applied in conjunction with California's ETS: it taxes electricity imports from neighbouring U.S. states on the basis of

[10] C. Böhringer, C. Fischer, K. E. Rosendahl, T. F. Rutherford, Potential impacts and challenges of border carbon adjustments. *Nature Climate Change* 2022, 12: 22–29.

emissions intensity.[11] The CBAM will be the first BCA affecting international trade. It thus raises several issues concerning country relations, including its very compatibility with World Trade Organisation (WTO) rules, the impacts on other economies and the related consequences. Up until the Green Deal, fears of retaliatory trade measures proved effective in inhibiting any international BCA initiative.

The reason why the time for the CBAM seems to have come today is a genuine need of the EU to strengthen its arsenal against carbon leakage. It is a need that has emerged stronger than ever with the Green Deal. The further tightening of the EU ETS cap entails a faster reduction in the number of emission allowances issued in the future. All else being equal, this implies faster growth in allowance prices and a faster reduction in the number of free allowances. Therefore, free allocation as a tool for limiting carbon leakage is bound to lose effectiveness. A second reason why the EU decided to adopt the CBAM is the possibility of inducing other countries to increase their emission reduction efforts. In this sense, along with the benefits offered to other countries – for example, through technological transfer and financial aid – the economic costs threatened by the CBAM should help. Countries with less-stringent climate policies as compared to the EU might decide to narrow the gap in order to minimise national welfare losses or, better, take the opportunity to put the economy on a more sustainable path. Indeed the greatest success of a BCA would be removing its own *raison d'être*, that is, different levels of climate policy stringency. As such, the measure of the CBAM's success will be the responses, in terms of policies and emissions abatement, by foreign governments and firms.

In the following, we describe the workings of the CBAM as proposed by the EC and discuss its compatibility with WTO rules. Other relevant questions, which are not addressed here for reasons of brevity, include the expected effectiveness of the CBAM in limiting carbon leakage and the CBAM's expected economic impacts on both EU and other countries, especially developing ones.

2.3.1 How Will the Carbon Border Adjustment Mechanism Work?

The proposed CBAM will be phased in gradually and will initially apply to five categories of imported goods: iron and steel, cement, fertilisers, aluminium, and electricity.[12] While a reporting system already applied in 2023, EU importers will start paying financial adjustments for differences in carbon prices only in 2026. European Union importers will first buy CBAM certificates from national authorities at a price equal to the weekly average auction price of the EU ETS allowances. Subsequently, every year, they will have to surrender CBAM certificates in amounts that match the volumes of imported emissions. As it stands, surrendered certificates will only have to cover direct emissions embodied in

[11] C. Kardish, J. Elbrecht, W. Acworth, Carbon Leakage and Competitiveness: California's Treatment of Imported Electricity and New Zealand's Synthetic Greenhouse Gas Levy (International Carbon Action Partnership, 2021). https://icapcarbonaction.com/en/publications/carbon-leakage-and-competitiveness-californias-treatment-imported-electricity-and-new.

[12] Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 May 2023 Establishing a Carbon Border Adjustment Mechanism, OJ L 130/52, 16 May 2023.

imported goods. By the end of the 2023–2025 transitional period, however, the EC will re-evaluate whether to extend the scope of the CBAM to indirect emissions (that is, emissions caused through electricity use) as well as to more products down the supply chain. To ensure equivalent treatment between EU importers and EU producers, the CBAM will apply only to the proportion of emissions that does not benefit from free allowances under the EU ETS. For the CBAM sectors, this proportion will reach 100% in 2035: the year free allocation will cease entirely. If non-EU producers can show that they have already paid a price for the carbon used in the production of the imported goods, the corresponding costs can be deducted for EU importers. This provision introduces an incentive for non-EU countries to align their carbon prices with those under the EU ETS.

2.3.2 Compatibility with World Trade Organisation Rules

The EC has always stressed that the CBAM needs to be compatible with WTO rules. This implies the fulfilment of two main requirements. First, the CBAM must comply with the General Agreement on Tariffs and Trade (GATT)'s non-discrimination principle, which relates to how imports of CBAM products into the EU are treated *vis-à-vis* different countries of origin ('most-favoured-nation treatment') as well as like European products ('national treatment'). Second, the CBAM must comply with the WTO rules on subsidies, which are relevant to how European exports of CBAM products may be safeguarded with a view to minimising carbon leakage.

The prevailing view among trade experts is that, overall, the CBAM proposed by the EC appears to be WTO-compatible.[13] The argument whereby the non-discrimination principle is deemed fulfilled is twofold. The application of different carbon prices to imports from different countries is justifiable on the basis of two of the admitted derogations from the non-discrimination principle (GATT article XX). These exceptions concern 'measures necessary to protect human, animal or plant life or health' and 'measures necessary for the conservation of exhaustible natural resources'. Besides, the criteria established to quantify imported emissions subject to the CBAM guarantee equal treatment of foreign and European producers. As regards EU exports of CBAM products, how to avoid market share losses abroad is obviously a key question. As a general rule, export subsidies as such, which are contingent on export performance, are prohibited under the WTO Agreement on Subsidies and Countervailing Measures. By way of derogation, export rebates on indirect taxes, such as VAT, energy taxes and carbon taxes, are allowed. However, the same exception does not extend to export rebates for regulations, such as ETSs.[14] Accordingly, the proposed CBAM provides for a full phase out of free allocation by 2035. As EU exporters seem set to face increasing international competition, supportive policies for deep domestic decarbonisation as well as convergence of climate policy stringency

[13] See, for example, P. Lamy, G. Pons, I. Garzon, L. Kauffmann, GT8 – Domestic and International Aspects of the EU CBAM: Two Sides of the Same Coin (Europe Jacques Delors, 2022), www.europejacquesdelors.eu/publications/domestic-and-international-aspects-of-the-eu-cbam; C. Galiffa and I. G. Bercero, How WTO-consistent tools can ensure the decarbonization of emission-intensive industrial sectors. *American Journal of International Law* 2022, 116: 196–201.

[14] A. Cosbey, S. Droege, C. Fischer, C. Munnings, Developing guidance for implementing border carbon adjustments: Lessons, cautions, and research needs from the literature. *Review of Environmental Economics and Policy* 2019, 13(1): 3–22.

internationally will be critical for limiting the relocation of energy-intensive activities to other world regions and consequent carbon leakage.

2.4 Electrification: Leveraging Wind and Sun

Electricity is an extremely versatile energy vector that can be used to deliver (almost) any type of energy service, from lighting to heating, from cooling to mobility, normally with negligible local negative environmental consequences or safety hazards. Electricity can be generated from many different energy sources, including modern renewable energy sources, such as wind and solar photovoltaic (PV), which have seen major cost reductions in the first two decades of the twenty-first century. The combination of these characteristics explains why electricity will play a central role in the transformation of the energy system necessary to deeply decarbonise the economy in the coming decades.

In 2021, electricity satisfied almost 23% of final energy consumption in the EU, a share that has been relatively stable in recent years.[15] Except for a few captive uses, the main one being represented by electronic and electrical appliances, electricity competes with other energy sources and vectors. In the heating and industrial sectors, competition is mostly with natural gas, while in transport electricity competes against oil derivatives, such as gasoline, diesel, and kerosene. Several factors explain why the share of electricity in final energy consumption has remained relatively stable over the years. First, natural gas and oil derivatives have specific characteristics, such as a higher energy density and their being easier to store than electricity, which make their use with current technologies more convenient, especially for certain applications. Second, the existing infrastructure for the transport and use of energy is still mostly centred around gas and oil derivatives (think of the current fleet of passenger cars, which are generally equipped with internal combustion engines, and the petrol stations for refuelling them). On the contrary, consumers do not generally have an infrastructure in place that can support a much larger distribution and use of electricity to satisfy their demand for energy services. Third, the existing structure of energy taxation and sector regulation often penalises a broader use of electricity beyond what is captive (think of increasing-block electricity tariffs that still exist in some jurisdictions or tax rebates on fuels that specific classes of consumers frequently benefit from).

Promoting the electrification of final uses whenever technically feasible and economically efficient is a fundamental building block of the European strategy for climate neutrality by 2050, as it enables leverage on the recent successes in the decarbonisation of electricity generation. Over the past two decades, technological development and policy support have pushed the share of renewables in the European electricity mix. From the early 2000s to 2021, annual electricity generation from renewables more than doubled, surpassing 1,100 terawatt hours (TWh) in absolute terms and reaching a share of almost 38%. Wind, solar,

[15] The share of electricity in final energy consumption is normally considered a measure of the electrification of an energy system. For a comprehensive overview of the concept of electrification and its role in the energy transition, see P. Aalto (ed.), *Electrification:Accelerating the Energy Transition* (Academic Press/Elsevier, 2021). Unless when differently specified, data in this section refer to EU27 and were taken from Eurostat, Shedding Light on Energy – 2023 Edition, available at https://ec.europa.eu/eurostat/web/interactive-publications/energy-2023#.

and, to a more limited extent, bio-based energies have experienced remarkable growth and reached, under certain circumstances, grid parity with electricity generated from fossil fuels or nuclear. Their still largely untapped potential, in particular for solar and wind, suggests they will likely continue to grow and feed the European energy system with significant additional volumes of electricity in the coming years.[16]

The EU Strategy for Energy System Integration issued by the EC in July 2020 considers a greater electrification of end-use sectors as one of three complementary and mutually reinforcing concepts upon which energy system integration can be built. The other two are a more 'circular' energy system, with energy efficiency at its core, and the use of renewable and low-carbon fuels, including hydrogen, for end-use applications where direct heating or electrification are not feasible.[17] The central role of electrification in supporting a climate-neutral economy at the least cost across sectors is confirmed by the action plan included in the same strategy, which features an acceleration of the electrification of energy demand, building on a largely renewables-based power system, as one of its six fundamental pillars. In the strategy, the EC foresees the possibility to reach a share of renewables in electricity generation around 55–60% and a share of electricity in final energy consumption around 30% by 2030. According to the scenarios developed by the EC, these numbers would be consistent with a trajectory ensuring climate neutrality in 2050.

However, in order to achieve those targets and be in a good position to reach climate neutrality 20 years later, several actions are needed in the decade to 2030. Notably, the EU must tackle the barriers to the expansion of renewable electricity supply, the accelerated electrification of energy demand, and the development of the necessary infrastructure linking supply and demand within and beyond the electricity sector. In what follows, we will first describe the main policy measures that the EC proposed in the Fit-for-55 package, which followed the Strategy on Energy System Integration. Then, we will provide a more critical overview of the opportunities and the challenges that electrification raises in the current transformation of the European energy system.

2.4.1 European Union Regulation Promoting Electrification

The Fit-for-55 package proposed by the EC in July 2021 contains several measures that try to accelerate the electrification of energy demand while building a renewable-based power system. As it is not possible to describe all of them in this text, an overview of the main measures, highlighting the obstacles to renewable-based electrification which they aim to remove, will suffice.[18]

[16] For an overview of the characteristics and potential of renewable energy sources for electricity generation, see N. May, K. Neuhoff, New technologies on the supply side, in J.-M. Glachant, P. Joskow, M. Pollitt (eds.), *Handbook on Electricity Markets* (Edward Elgar Publishing, 2021), p. 332; and C. Jones, J. Kneebone, A. Piebalgs, Cost-effective Decarbonisation Study (European University Institute, 2022).

[17] European Commission, Communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Powering a climate-neutral economy: An EU Strategy for Energy System Integration, COM(2022) 299 final, Brussels, 8 July 2020.

[18] The interested reader may find a comprehensive overview of the relevant European policy framework and the recent legislative proposals in L. Hancher et al., The EU Green Deal: 2022 Edition (EUI, Technical Report 2022/06, 2022). https://cadmus.eui.eu/handle/1814/75156.

First, the package contains measures that promote an expansion of the supply of renewable electricity, a necessary condition to ensure that electrification is consistent with the long-term objective of decarbonising the European economy. In this context, the most relevant piece of the Fit-for-55 package is the revision of the Renewable Energy Directive (RED III), which raises from 32% to 40% the targeted share of renewables in the EU energy mix by 2030. This target is binding at the European level and is complemented by indicative national targets. The revised directive foresees specific targets for the various sectors as well. Significant attention is given to transport, industry, and the heating and cooling sector. To achieve these targets, EU Member States are allowed to adopt support measures. Reinforcing a trend initiated with the previous revision of the Renewable Energy Directive in 2018, the so-called RED II, bio-based energies and biofuels must satisfy increasingly stringent requirements in order to be eligible for support or even be allowed to be used.

Second, the package contains measures that promote electrification by removing existing rules that penalise electricity use or by introducing new rules that favour its use over other energy vectors. The revision of the Energy Taxation Directive (ETD) is a notable example of the former, while the revision of Regulation 2019/631, setting emission performance standards for new passenger cars and new light commercial vehicles, is an example of the latter. The ETD aims to ensure that the level of taxation of an energy product reflects its energy content as well as its environmental impact, with cleaner energy products such as electricity or renewable fuels being taxed less than more polluting energy products such as heavy fuel oil or coal. In order to achieve this result, the proposal by the EC foresees a set of minimum tax rates that Member States must respect and the abolition of several exemptions that have so far incentivised the use of fossil fuels. The revision of Regulation 2019/631 strengthens the emission performance standards for new cars and vans, and foresees that from 2035 onwards it will be possible to sell only new zero-emission vehicles. Under this requirement, electric vehicles seem one of the few technological options that will remain viable after that date.

Third, the package contains measures that promote a reduction in overall energy consumption and the use of more efficient technologies, such as heat pumps and electric vehicles. This is essential given the physical and economic limits to the expansion of renewable-based electricity generation, both in the short and the long term. In this regard, an important piece of the Fit-for-55 package is the revision of the Energy Efficiency Directive, which foresees a 9% reduction of energy consumption in 2030 compared to a 2020 reference scenario. This target is binding at the European level, with only indicative national contributions. The revised directive also promotes electrification via the definition of efficient heating and cooling systems based on minimum shares of renewable energy sources, with requirements for a gradual increase in these shares over time. Heat pumps clearly benefit from this measure. The revision of the Energy Performance of Buildings Directive, proposed in December 2021, provides another relevant example. It introduces the concept of zero-emission buildings, that is, buildings characterised by very high energy performance which can cover the very low amount of energy they need via renewable energy produced locally. According to the proposed revision of the directive, all new buildings must be zero-emission from 2027 onwards, while renovated ones will have to reach that standard from 2030. At that level of efficiency, electricity-based heat pumps represent an efficient and effective way of heating and cooling a building under most of the conditions.

Fourth, the package contains measures that promote the roll out of the necessary infrastructure to satisfy a larger and more differentiated electricity demand, including for new uses such as mobility. In this regard, the package contains a proposal for a regulation replacing the Alternative Fuel Infrastructure Directive (AFID). This directive, adopted in 2014, aimed, inter alia, at promoting the deployment of an adequate public recharging infrastructure for electric vehicles and the installation of shore-side electric supply for inland waterway vessels and seagoing ships, but did not foresee any mandatory target. The proposed regulation tries to fill what turned out to be a weakness of the AFID by introducing mandatory national targets for the deployment of alternative fuel infrastructure and other obligations. Together with RED III and the revision of Regulation 2019/631, the proposed regulation is expected to induce a paradigmatic shift in the transport sector.

2.4.2 Opportunities and Challenges

In the EU, electricity is currently mostly used to satisfy energy demand by the residential and commercial sector (in 2021, 31.7% of the energy consumed in those sectors was in the form of electricity) and by industry (33.2%), while it still plays a negligible role in transport (less than 2%). New technologies that are rapidly becoming mature promise to enable a much larger use of electricity in the coming years. In particular, the deployment of heat pumps can foster the use of electricity for the heating and cooling of buildings,[19] while electric vehicles may reduce the current supremacy of oil derivatives in road transport.[20] Electricity is also making its way for the production of process heat in the industrial sector, while it is still lagging behind in feedstock production.[21] Similarly, the role of electricity in maritime transport and aviation is expected to be limited for several years to come.

A larger use of electricity to cover final energy consumption presents several opportunities for the EU. First, as mentioned above, it allows taking advantage of the remarkable progress achieved in wind and solar PV generation technologies and the wide resource base available in Europe.[22] This progress and such resource base are hardly comparable with less satisfactory results in biofuels and direct heat generation from renewable sources, both in terms of technological development and production potential within the EU. Currently, electricity generation from solar and wind has a cost that is comparable to, if not lower than,

[19] M. Fajardy, D. Reiner, Electrification of residential and commercial heating, in J.-M. Glachant, P. L. Joskow, M. O. Pollitt (eds.), *Handbook on Electricity Markets* (Edward Elgar Publishing, 2021), p. 506.

[20] B. Clinton, C. Knittel, K. Metaxoglou, Electrifying transport: Issues and opportunities, in J.-M. Glachant, P. L. Joskow, M. O. Pollitt (eds.), *Handbook on Electricity Markets* (Edward Elgar Publishing, 2021), p. 463.

[21] G. Zachmann, F. Holz, A. Roth, et al., Decarbonisation of Energy: Determining a Robust Mix of Energy Carriers for a Carbon-neutral EU, Study Requested by the ITRE Committee (European Parliament, 2021).

[22] Additionally, EU companies have an advantage in some of these technologies, one of the most visible examples being offshore wind, where the EU still plays an important role both in terms of manufacturing and deployment. However, this is not true of other technologies, namely solar photovoltaics. See International Energy Agency, Energy Technology Perspective 2023 (IEA, 2023).

that of conventional technologies, at least if measured in terms of the levelised cost of electricity. This cost-competitiveness has not yet been achieved for biofuels and direct renewable heat, except under certain conditions.

Second, electrification enables the use of more energy-efficient technologies that reduce the need for primary energy, facilitating in this way the transition of the energy industry from fossil fuels to renewables. As an example, an electric vehicle can turn most of the electricity stored in its batteries into motion, while traditional cars based on internal combustion engines waste 70% or more of the energy contained in the fuel they burn. Obviously, the more efficient final consumption is, the lower the amount of clean primary energy the system must produce, with significant savings both in environmental and economic terms.

Third, an expanded use of electricity in final uses offers the possibility to add flexibility to the electricity system, an increasingly valuable resource in the transition from an electricity generation fleet based on dispatchable technologies such as fossil fuel-fired power plants to an electricity generation fleet based on intermittent technologies such as wind and solar PV. Several of the new uses of electricity are not necessarily time-constrained and may be shifted, at least to some extent, to the hours of the day when intermittent technologies are producing at capacity, while batteries, including those of electric vehicles, can inject electricity in the grid when those intermittent technologies do not produce, such as at night or when the wind does not blow. In this sense, a flexible electricity-based energy demand is a natural complement to a more variable energy generation.

Fourth, in an electrified energy sector it is easier to engage final customers and develop consumer-centred energy markets, where electricity constitutes the integrating element of the various sectors and vectors. Electricity-based technologies, such as rooftop solar PV, electric vehicles, heat pumps, and domestic batteries, are relatively efficient at small scale and together with other controllable loads represent the physical asset base upon which innovative energy services and flexibility products can be developed and traded, with the fundamental support of digitalisation.[23] New markets can emerge at the local level and adapt to the specific local conditions. Even more disruptively, electricity can become the platform upon which all the energy vectors (that is, electricity, heat, and fuels) and sectors (that is, buildings, industry, and transport) can interact and be integrated, breaking the legacy silos that have characterised so far the energy industry.[24]

Nonetheless, electrification of EU energy faces important challenges that question the optimism sometimes expressed by European policymakers and that perhaps warrant a bit of extra cautiousness. First, to be compatible with the decarbonisation of the European economy, electrification must be matched by a significant growth of renewable electricity generation. Between 2000 and 2020, the wind and solar generation capacity in the EU has increased by more than 25 times, reaching 315 gigawatts (GW). This is a remarkable result; however, in order to be able to cover the needs of mobility and buildings, the EU will have to

[23] N. Rossetto, V. Reif, Digitalization of the electricity infrastructure: A key enabler for the decarbonization and decentralization of the power sector, in J. Montero, M. Finger (eds.), *A Modern Guide to the Digitalization of Infrastructure* (Edward Elgar Publishing, 2021), p. 217.

[24] J. Vasconcelos, EU Electricity Reform (NEWES, 2022).

speed up the deployment of wind farms, solar parks, and other renewable-based power plants. The energy resource base and the technologies might be there, but still this is a daunting task for industry and society alike.[25] Four aspects are particularly critical: the manufacturing capacity of technology suppliers, the availability of sufficient financial and human resources to fund and deploy the initial investments in new-generation assets, the expansion and strengthening of the existing electricity grid, and the acceptability of new infrastructure by the local population. None of these aspects can be taken for granted, even more after the start of the war in Ukraine and the tightening of monetary policy in the EU.

Second, even if sufficient renewable-based power plants were to be installed, the existing organisation and regulation of the electricity system and markets may represent a barrier to the full exploitation of the opportunities behind electrification. Indeed, the operation of the electricity system and the market design developed in Europe since the 1990s were built around very different assumptions, such as the centrality of large and dispatchable power plants, the relative passive behaviour of final consumers, and a clear distinction between the three fundamental end-use sectors, namely electricity, transport, and heating and cooling. Today, those assumptions are less and less justified, requiring a reform of system operation and market design. How big such reform should be is a matter of intense debate among academics and practitioners, which goes far beyond the purpose of this text.[26]

Third, an expansion in the use of electricity in final consumption requires a profound renovation of the energy equipment of consumers.[27] Households and firms are called to replace their existing assets based on fossil fuels with new assets running on electricity. They are also called to improve the efficiency of their buildings and adjust their consumption patterns, to make them compatible with the efficient deployment and use of electricity-based technologies. This is a far from negligible task, especially given the relatively low replacement or renovation rate that characterises those assets. The strongest inflation wave in decades, the exceptionally high prices for electricity, and the uncertainty regarding the future state of the economy in Europe are likely to limit, at least in the short to medium term, the ability and willingness of households and firms to implement those renovations and replacements. While this may change in the longer term, less-affluent families and firms with limited financial means are likely to continue to struggle unless adequate public policies are put in place.

2.5 Clean Molecules: The Challenge of Market Uptake

In the European vision for a carbon-neutral economy by 2050, the evolving role of natural gas in the future EU energy mix is a central element, and to some extent an innovative one.

[25] For a back-of-the-envelope calculation of the needed expansion of renewable generation see R. Belmans, P. C. dos Reis, P. Viengerhoets, Electrification and Sustainable Fuels: Competing for Wind and Sun (European University Institute, 2021).

[26] In addition to Vasconcelos' work cited above, the interested reader may look at L. Meeus, C. Batlle, J.-M. Glachant, et al., The 5th EU Electricity Market Reform: A Renewable Jackpot for All Europeans Package? (European University Institute, 2022); J.-M. Glachant, Reforming the EU Internal Electricity Market in the Middle of a Huge Energy Crisis: An Absolute Short-Term Emergency or Preparation for the Future? (European University Institute, 2023).

[27] Some studies estimate that the ratio between the expected investment by final users and by energy producers is close to 5:1. See G. Zachmann et al., Decarbonisation of Energy: Determining a Robust Mix of Energy Carriers for a Carbon-neutral EU, Study Requested by the ITRE Committee (European Parliament, 2021), pp. 98–99.

For decades, natural gas has constituted the energy backbone of European industrial and household consumption. Nowadays, more than 20% on average of the European primary energy consumption is still covered by natural gas. In recent years and more convincingly since the mid-2010s, Europe has embraced its no-regret conversion towards renewable energies and has at the same time embarked on a slow but progressive phasing out strategy of natural gas and the other fossil fuels from the EU energy system. In an effort to reach the EU climate goals, the overall European decarbonisation strategy has envisaged, already since 2016, a considerably smaller role for natural gas in the energy mix by 2050, as well as its gradual replacement with renewable electricity and a mix of clean molecules such as renewable hydrogen, biogas, biomethane, and synthetic methane.[28]

However, the presence of these clean molecules in the EU energy mix is currently minor if not negligible. Biomethane is already present in the existing natural gas network and is widely considered among the most commercially viable alternatives to replace at least part of current natural gas consumption, due to similarities in chemical composition and therefore compatibility with existing infrastructure. Still, only 3 billion cubic metres (bm^3) of biomethane and 15 bm^3 of biogas are currently produced in the EU,[29] approximately 1% of overall gas consumption (fossil gas and clean molecules combined). According to the European Biogas Association,[30] biogas and biomethane in 2021combined covered about 200 TWh. Although biomethane production is envisaged to increase massively in the coming years due to ambitious national initiatives, sustainable biomethane is not an infinitely scalable energy vector (as the feedstock from which is produced is limited), which prevents it from being able to displace fossil methane. Furthermore, there is a risk of creating perverse incentives whereby strong support for biomethane may lead to more animal agriculture and consequently higher overall emissions.[31]

While hydrogen is also likely to play a significant role in the EU energy mix by 2050, its demand is still modest (257 TWh, or just over 8 megatons, in 2020). The total hydrogen currently used in Europe amounts to approximately 6 GW as its use is currently restricted to feedstock in specific industrial clusters in Europe. Different to biomethane, the availability of hydrogen is potentially unlimited, because hydrogen is the most common element present in nature. Rather, the difficulty relates to its exploitation as a large-scale energy source, due mainly to the still infant stage of the technology which can enable its generation. Further obstacles to a fast upscale of hydrogen concern its transport. Indeed, while biomethane is not that different in chemical terms from natural gas, and can therefore be transported via the same infrastructure, hydrogen molecules have a different chemical composition, strongly limiting the possibility of utilising the existing gas infrastructure to transport, compress, or store hydrogen. Nevertheless, the EU has reiterated on many occasions its

[28] These are the specific renewable and low-carbon gases that are here defined as 'clean molecules', regardless of the modalities and feedstock involved in their generation.

[29] S. Alberici, W. Grimme, G. Toop, Biomethane, Production Potentials in the EU: Gas for Climate Report 2022 (European Biogas, 2022). www.europeanbiogas.eu/wp-content/uploads/2022/07/GfC_national-biomethane-potentials_070722.pdf.

[30] EBA Statistical Report 2022 (Brussels, November 2022). www.europeanbiogas.eu/wp-content/uploads/2022/12/EBA-Statistical-Report-2022_-Short-version.pdf.

[31] European Commission, Communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Hydrogen Strategy for a Climate-Neutral Europe, Brussels, COM(2020) 301 final, 8 July 2020.

strong belief that renewable and low-carbon gas will play a determinant role in the transition to a climate-neutral economy and in the future EU energy system. As we will see in the next section, at the regulatory level, this message has translated into specific measures aimed mainly at facilitating market uptake of clean molecules, namely biomethane and renewable hydrogen.

2.5.1 European Union Regulation for the Development of Renewable and Low-Carbon Gases

The very first mention of renewable and low-carbon gases appears in the Communication on an EU Strategy for Energy System Integration (ESI).[32] The third fundamental pillar of the ESI strategy, after the ‘energy efficiency first’ principle and the greater direct electrification of end-use sectors, consists in ‘promoting renewable and low-carbon fuels, including hydrogen, for hard to-decarbonise sectors’. The strategy promotes the use of renewable or low-carbon gases as they are considered a suitable energy vector in hard-to-abate sectors, where electrification with current technology is not possible due to technological immaturity.

On the same day of the Communication on an ESI, the very first EU Hydrogen Strategy (Communication on a Hydrogen Strategy for a Climate-Neutral Europe[33]) was also published. Hydrogen is therein defined as a ‘key priority to achieve the Green Deal and Europe’s clean energy transition’ and renewable hydrogen in particular is labelled as ‘the most compatible option with the EU’s climate neutrality and zero pollution goal in the long term and the most coherent with an integrated energy system’. The Hydrogen Strategy provides a roadmap to a fully fledged EU hydrogen market in 2050, with targets for the progressive development of renewable hydrogen (6 GW of electrolyser capacity by 2024, and 40 GW by 2030)[34] in the EU and neighbouring region.[35] In 2021, the 35th meeting of the European Gas Regulatory Forum (‘the Madrid Forum’) addressed the subject of clean molecules in detail, concluding that efforts should be made to facilitate the certification of renewable and low-carbon gases and the growth of a dedicated market and corresponding rules and regulations.

Building on these outcomes and on the ambitions of the Fit-for-55 package, the EC released its Hydrogen and Decarbonised Gas Market Package (HDGMP) in December 2021.[36] Not comparable in terms of volumes and importance to the previous

[32] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Powering a Climate-Neutral Economy: An EU Strategy for Energy System Integration, COM(2020) 299 final, 8 July 2020.

[33] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Hydrogen Strategy for a Climate-Neutral Europe, Brussels, COM(2020) 301 final, 8 July 2020.

[34] The EU hydrogen strategy targets for ‘renewable hydrogen’ refer to hydrogen produced via electrolysis. Electrolysis is the process of splitting water into hydrogen and oxygen molecules; if the process is fuelled by renewable electricity, the hydrogen obtained can be considered ‘renewable hydrogen’.

[35] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Hydrogen Strategy for a Climate-Neutral Europe, Brussels, COM(2020) 301 final, 8 July 2020.

[36] European Commission, Hydrogen and Decarbonised Gas Market Package. https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/hydrogen-and-decarbonised-gas-market-package_en.

ESI and Hydrogen Communications, the HDGMP aimed to develop the pre-existing regulation applying to natural gas since 2009 (the so-called Gas Directive and Gas Regulation) into a configuration that can incorporate a higher diversity of actors, a wider range of gases, and a different role for natural gas in the energy mix. The new package of measures proposes a new regulatory approach to market and infrastructure, which does not betray the existing set-up for natural gas and on the contrary builds on its core principles, such as third-party access (TPA), unbundling, and tariff regulation. In parallel, a gradual implementation is envisaged for renewable and low-carbon gases, taking into account the still immature stage of development of their value chain, and for which exemptions and a certain degree of flexibility in the application of these regulatory provisions are allowed until 2030. This two-stage regulatory approach is conceived of as tailor-made for the nascent clean molecules markets and is meant to facilitate their uptake in the initial stage of development. Importantly, the HDGMP also provides greater (albeit still partial) clarification on the definitions of renewable and low-carbon gases, and more specifically renewable and low-carbon hydrogen – which had been expected for a long-time, particularly by investors and market operators.

With the outbreak of war in February 2022, caused by the Russian invasion of Ukraine, the EC's new priority suddenly became replacing Russian energy supply to Europe with reliable alternatives. REPowerEU, which was published in two steps between March and May 2022, provides an action plan aiming at this target. Alongside the measures aimed at demand reduction and diversification of supply, REPowerEU introduced ambitious targets for an increased availability of 'clean electrons', first and foremost wind and solar energy, as well as clean molecules. Specifically, the REPowerEU plan doubles the target for biomethane production to 35 bm^3 by 2030 (it was set at 17 bm^3 in the Fit-for-55 package)[37] and elevates the already ambitious target of 5.6 million tons for renewable hydrogen, set only a few months before by the Fit-for-55 package to 20 million tons in 2030 (of which 10 megatons reflects imported capacity). Moreover, REPowerEU urges that all new cross-border infrastructure should be hydrogen-compatible, so as to support a faster development of an integrated gas and hydrogen network, including storage facilities and port infrastructure.

2.5.2 Opportunities and Challenges for Renewable and Low-Carbon Gases

Natural gas currently covers approximately 40% of overall energy consumption in residential heating in the EU, followed by industrial use (about 20%) and electricity generation (about 15%). As per the ESI strategy, a significant amount of this energy demand is likely to be electrified. Significant volumes of molecular energy will, nevertheless, be needed. This is due in part to the physical properties of energy in this form which make molecular energy more advantageous compared to electrical energy: first, gases such as methane and hydrogen are more effective than electrical energy in certain applications where high

[37] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, 'Fit for 55': Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality, COM(2021) 550 final, 14 July 2021.

temperatures are required such as steel production. Second, molecular energy can be stored for extended periods of time at very low marginal cost relative to electricity. For this reason, clean molecules can have a role in an integrated energy system as an energy vector, helping to balance the electricity and gas grids by providing medium to long-term storage and dispatchable power. This balancing component is likely to grow in importance as the EU electricity mix becomes increasingly characterised by intermittent renewable sources.

Furthermore, clean molecules could have an increasingly important role in achieving greater energy independence and overall security of energy supply in Europe, which has become the top energy policy priority in the current energy crisis. As previously mentioned, in the context of Russia's invasion of Ukraine, in February 2022, the EU has proposed measures to aggressively divest from Russian gas imports, and also oil and coal, for which the EU is also heavily dependent on Russia.[38] Clean molecules can play a central role in these efforts as they are typically produced locally or at least can be supplied by a large number of parties.

A number of obstacles and bottlenecks could significantly limit or slow down the growth of clean molecules in the EU energy mix. These challenges mainly relate to their upscale, in terms of cost and efficiency. We already mentioned the limitations linked to the upscale of biomethane, in terms of maximum generation capacity. A second consideration to be made relates to the fact that its generation process is not greenhouse gas-free, as anaerobic digestion – the process through which about 90% of biomethane is globally produced – does involve CO_2 and methane emissions, hence making it a not-100% greenhouse gas-free gas. Therefore, although boosting biomethane generation is a logical choice in terms of diversification and economic opportunity terms, in the long term there might be greener solutions to reach the Green Deal objectives.

The greatest uncertainties, however, regarding future clean molecules' development at scale concern hydrogen, with the main critical points being high costs and low efficiency. Hydrogen can be produced starting from different feedstocks (ranging from water and biomass to oil, coal and natural gas) and, therefore, costs, efficiency (and also safety) concerns depend, first and foremost, on the production process (steam methane reforming, pyrolysis, electrolysis, photocatalysis, etc.) and corresponding conditions. For the sake of simplicity, we will only focus here on hurdles linked to the development of renewable hydrogen, which is the preferential choice according to the EU regulation, but also the most problematic type of hydrogen to be produced at the moment.

As a first consideration, the massive planned investments in research and development and innovation – both at the EU and national level – are likely to reduce hydrogen generation costs while improving efficiency (meaning more volumes and fewer energy losses) at the same time. This could happen in a relatively short time, regardless of the technology choices that will be made. As a precedent, the levelised cost of energy (LCOE) – a metric indicating the average costs of generation per unit of electricity – for solar panels halved between 2009 and 2011 and continued on a more gradual downward trend, thanks to

[38] Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions REpowerEU: Joint European Action for More Affordable, Secure and Sustainable Energy, COM/2022/108 final, 8 March 2022.

economies of scale and international competition. Something similar is likely to happen for hydrogen with the cost of electrolysers that are used to produce renewable hydrogen.

Moreover, the cost of renewable hydrogen generation highly depends on the cost of the energy input. The exceptionally high prevailing electricity and gas prices in 2021–2022 have completely rewritten the economics of this sector. Under those high gas prices conditions (100 euro per megawatt hour (MWh) or more), green hydrogen is cheaper than fossil hydrogen or any methane-based hydrogen, provided electricity is purchased on a long-term power purchase agreement (PPA) established prior to the energy crisis or afforded through a dedicated supply.[39] Similarly, at a price of roughly 70 euro per MWh biomethane has historically struggled to be cost-competitive with imported fossil methane, which has averaged roughly 20–30 euro per MWh in recent years.[40] However, biomethane is comparatively very cheap, with fossil gas prices in the hundreds of euros per MWh as it was the case in 2022.

Focusing on efficiency, renewable hydrogen is produced through electrolysis, a process of passing renewably produced electricity through water, splitting it into hydrogen and oxygen. Roughly 25% of the energetic value of the renewable electricity input is lost in converting it into hydrogen, with a further 25% loss if it is subsequently reconverted back into electricity. For the limited applications of hydrogen envisaged in the next couple of decades, efficiency losses add to cost but not in a prohibitive measure and can be offset by other benefits such as reducing load on grids. Different considerations need to be made for a future where renewable hydrogen is used on a much larger scale. In an energy-abundant scenario, losses are not problematic, but with the current REPowerEU plan and projections, renewable electricity will probably be anything but abundant.

Different EU initiatives aimed at decarbonisation may thus end up competing for the same renewable electricity; for example, electrification of road transport and electrolyser capacity for hydrogen production. Where fossil-based electricity is generated to make up for renewable electricity that is diverted from the grid to serve electrolysers, the resulting green hydrogen may de facto cause higher emissions than hydrogen obtained from fossil fuels.[41] With this in mind, it will be important for the overall decarbonisation of the sector for clean molecules to be deployed strategically where they are the most effective, giving consideration to the overall decarbonisation approach.

2.6 Sustainable Finance: An Ambitious European Union Agenda to Develop New Markets

Sustainable finance is a relatively recent policy priority of the EU. It can be retraced to the original agenda setting work of the High-Level Expert Group on Sustainable Finance

[39] J. Stones and J. Hamilton, Renewable PPAs and a review of the commodity price spike on renewable hydrogen production costs (2022). https://s3.eu-west-1.amazonaws.com/icis.ada.website.live/wp-content/uploads/2022/10/10183635/Renewable-PPAs-and-a-review-of-the-commodity-price-spike-on-renewable-hydrogen-production-costs.pdf.

[40] IEA, World Energy Outlook (IEA, 2020). https://iea.blob.core.windows.net/assets/a72d8abf-de08-4385-8711-b8a062d6124a/WEO2020.pdf.

[41] Belmans et al., Electrification and sustainable fuels: competing for wind and sun (EUI, Energy Working Paper, 2021). https://fsr.eui.eu/publications/?handle=1814/71402.

(HLEG). Created in 2016, the HLEG was following the momentum built in Europe after the Paris Agreement around the mobilisation of private capital towards sustainability purposes. Although greatly amplified lately by the Green Deal drive, virtually all the recently adopted and pending EU legislative initiatives that aim at fostering sustainable finance by better channelling private capital towards green financial instruments can be traced back to the ideation work performed as part of the HLEG.

Sustainable finance has reached the status of a dedicated EU policy area with the release of its Action Plan on Sustainable Finance.[42] Largely side-lined due to the COVID outbreak and the resulting health crisis management needs, the EU sustainable finance agenda was facing a significant risk of ending up in the EC's drawers, like many regulatory initiatives before that. Yet as sustainability concerns came back to the fore of EU agenda-setting already in the summer of 2020 as EU policymakers, stakeholders, and the wider public showed a renewed concern to preserve our environment. After the first waves of COVID receded and the EU's flagship response to COVID (Next-Generation EU, or NGEU)[43] was agreed and implemented, the European Commission invested yet further time and energy to come up with an attempt at revitalising its sustainable finance agenda through the publication of its Renewed Sustainable Finance Strategy in July 2021.

Sustainable finance now has solid roots in the Green Deal agenda, but has in many ways also spilled out of it. It has gained its own traction, especially ever since the new programmatic work elaborated and set out under the Renewed Sustainable Finance Strategy. In what appears to be the most operational definition of EU sustainable finance, one can assume that sustainable finance is a 'Commission workstream that supports the European aim of channelling private investment towards the transition to a climate-neutral economy'.[44] For recollection the EC committed to mobilise at least one trillion in sustainable investments over the period 2020–2030. Sustainable finance in the EU can be narrowed down to three central building blocks, which will be explored in turn in the following sections: (1) a set of EU financial capacities; (2) a two-legged approach to definitional standards; and (3) regulatory initiatives on disclosure. Taken together, these blocks are thought to contribute to significantly increasing the amount of private capital poured into European sustainable investment.

Sustainable finance in the EU takes many shapes and forms. All instruments will have effects on their own. Yet they will also interact and can therefore best be described as a mix of mutually reinforcing carrots and sticks. The virtuous circle is indeed at play to ensure that new and more rigorous sustainability standards are both supported by a host of newly injected funds as well as new data. Figure 2.2 illustrates this dynamic.

[42] European Commission Action Plan on Sustainable Finance released on 8 March 2018. https://finance.ec.europa.eu/publications/renewed-sustainable-finance-strategy-and-implementation-action-plan-financing-sustainable-growth_en.
[43] NGEU is covered in further details in a subsequent section.
[44] European Commission, Sustainable Finance, 2023. https://commission.europa.eu/business-economy-euro/banking-and-finance/sustainable-finance_en.

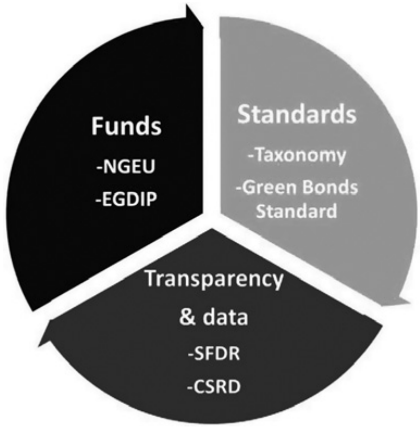

Figure 2.2 European Union sustainable finance key building blocks.

2.6.1 A Set of European Union Financial Capacities

On the carrot side two key instruments stand out: the NGEU plan, and the European Green Deal Investment Plan (Green Deal IP). While the two instruments speak to different target groups as we shall see, they all aim at the same objective of ensuring a macro-significant impact on the development of sustainable finance markets in the EU. They all derive from a market-making logic.

Next-Generation EU was adopted in principle in 2020 as a temporary instrument/ economic package running from 2021 to 2026 in order to enhance Europe's recovery from COVID. It consists of a total envelope of 750 billion euros provided to EU Member States in either grants or loans. It will be largely financed through the issue of EU debt on capital markets for which the Commission has been granted a mandate. De facto, the Commission extensively relied on the issuance of green bonds to finance NGEU. The Commission aims at raising up to one-third of NGEU funds via NGEU green bonds,[45] thereby implementing itself its sustainable finance agenda of scaling the size of sustainable finance markets.

The European Green Deal Investment Plan should be looked at as the real investment pillar of the European Green Deal. Rather than being an articulated instrument, the Green Deal IP should best be regarded as an overall umbrella plan with a strong headline target of 1 trillion euros of funds mobilised for sustainable investments by 2030.[46] These funds come partly from the EU budget (directly and indirectly through a complex system of leverage and guarantees) and partly from the European Investment Bank Group. Two strategic instruments of Green Deal IP are worth mentioning: the InvestEU Programme,

[45] European Commission, Next Generation EU Green Bonds. https://ec.europa.eu/info/strategy/eu-budget/eu-borrower-investor-relations/nextgenerationeu-green-bonds_en.

[46] For more details on the complex EU sustainable finance landscape, see European Commission, The European Green Deal Investment Plan and Just Transition Mechanism Explained, 2020. https://ec.europa.eu/commission/presscorner/api/files/document/print/en/qanda_20_24/QANDA_20_24_EN.pdf.

a 250 billion euros programme financed by the European Investment Bank, and the Just Transition Mechanism, which totals 100 billion of investments from 2021 to 2027 for EU citizens and workers adversely impacted by the energy transition. Because of partial overlaps between the above instruments and NGEU, it will be very difficult for external analysts to track progress made on the one trillion euro objective.

2.6.2 A Two-Legged Approach to Definitional Standards

Besides funding capacities, the EU also launched a series of strategic initiatives to accompany the EU Green Deal following a market-shaping approach. We will focus here only on two of the most salient EU legislative initiatives in this field.

The much-maligned EU Taxonomy is a classification exercise that defines with a set of criteria which economic activities are sustainable. Taxonomy Regulation 2020/852 therefore provides uniform definitions, but focuses mostly so far more on the environmental dimension of sustainability and less on its social and governance dimensions. According to the Taxonomy, 'environmentally sustainable economic activities should comply with the following criteria (cumulatively) (per article 3): contribute substantially to one or more of the environmental objectives; not significantly harm any of the environmental objectives;[47] [be] carried out in compliance with minimum social safeguards; comply with technical screening criteria established by the Commission'. With a view to facilitating transition investments but at the risk of blurring lines between what is sustainable or not, the Taxonomy also includes two other types of economic activities: transition activities, that is, 'economic activity for which there is no technologically and economically feasible low-carbon alternative' and enabling activities, that is, 'activities which enable other activities to make a substantial contribution to one or more of the environmental objectives' but not in their own right.

The regulation establishing a voluntary EU green bond standard stems from the need to develop more trust and credibility in sustainable financial products and avoid green-washing. It defines clearer conditions on the use of proceeds (in terms of transparency but also in terms of alignment with the criteria of the EU taxonomy and external review) and on the contributions of second-party opinion providers, which if the proposal is adopted would be subject to approval and registration by the European Securities and Markets Authority (ESMA), the EU financial watchdog. The proposal thus suggests laying down 'uniform requirements' based on existing best market practices. The text is expected to enter into force in 2023–2024. When proposing the new standard, the Commission stressed its expectation that:

> [I]ssuers will have a robust tool to demonstrate that they are funding legitimate green projects aligned with the EU taxonomy. And investors buying the bonds will be able to more easily assess, compare and trust that their investments are sustainable, thereby reducing the risks posed by greenwashing.[48]

[47] The six environmental objectives (per article 9) are: 'climate change mitigation; climate change adaptation; sustainable use and protection of water and marine resources; transition to a circular economy; pollution prevention and control; protection and restoration of biodiversity and ecosystems'.

[48] European Commission, Proposal for a Regulation of the European Parliament and of the Council on European Green Bonds, COM/2021/391 final, 6 July 2021.

2.6.3 Regulatory Initiatives on Disclosure

Following the same concern to increase trust in sustainable financial products via enhanced transparency, the EU is rolling out an ambitious agenda in terms of disclosure obligations. The two flagship initiatives in this field are the sustainability-related disclosures in the financial sector (per the Sustainable Finance Disclosures Regulation) and the Corporate Sustainability Reporting Directive (CSRD). They both complement the Taxonomy work and legislative proposals made on EU labels such as climate and ESG benchmarks.

The Regulation on Sustainability-Related Disclosures in the Financial Sector (also called the Sustainable Finance Disclosures Regulation, or SFDR) was adopted in November 2019 and implemented in a Commission-delegated regulation in April 2022. Its key objective is to improve the quality of sustainability disclosure among both sustainable finance product manufacturers and advisers, ensuring stronger comparability across products as well as reducing sustainability abuses and greenwashing. As the Commission's delegated act stresses, it aims to 'bring further accountability and discipline to sustainability claims'.[49] Three examples are worth mentioning: the SFDR requires financial market participants to disclose their 'strategic handling of sustainability risks on their websites';[50] it also requires them to 'disclose their products' negative sustainability impacts on the business on their websites';[51] and finally it forces participants to 'explain advertised ecological or social aspects and sustainable investments'.[52]

The CSRD – which amends the non-financial reporting directive – aims at gathering reliable and extensive data on the sustainable conduct of listed companies, including listed small- and medium-sized enterprises. Its key goal is to enable more granular, reliable, and comparable data across companies involved in sustainability activities. The rationale is that the reporting required under CSRD would be provided in line with the new sustainability indicators foreseen under the Taxonomy regime. While the CSRD has yet to come into effect, the implementing technical standards have already been brought forward by the technical standard elaborating actor EFRAG (the European Financial Reporting Advisory Group), which is developing – in close consultation with European Supervisory Authorities – detailed sustainability standards. A crucial innovation of the CSRD is its digital angle: it aims to foster reporting using digital tools (for example, XHTML format).

2.7 Conclusion

With the Green Deal, the EU has accelerated the pace towards climate neutrality, which is to be reached by 2050, as well as towards other related environmental objectives such as those on biodiversity and local pollution. The EU today presents itself as the main live laboratory of policies for steering a capitalist economy onto an environmentally sustainable path. Recent signs of growing determination and efforts to fight climate change by the two

[49] European Commission, Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on Sustainability-Related Disclosures in the Financial Services Sector (Text with EEA relevance), PE/87/2019/REV/1, 27 November 2019.
[50] Bankinghub.eu, 2022.
[51] Bankinghub.eu, 2022; Sustainable Finance Disclosures Regulation article 4.
[52] Bankinghub.eu, 2022.

greatest greenhouse gas emitters and economic powers, namely China and the United States, gratify the EU's leadership in this field – even if accompanied by rising international competition in green industries – and above all they give us hope for a less-bleak future. For reasons of brevity, we could not possibly examine all the relevant aspects of the EU's strategy for climate neutrality. We thus focused on four of its building blocks that see the EU at the global frontier of policy: carbon pricing, electrification, clean molecules, and sustainable finance.

Carbon pricing has always been at the heart of EU climate policy by virtue of its expected cost-effectiveness and an enduring appreciation of this property by EU policymakers. Nevertheless, only after many years and multiple reforms does the EU ETS finally seem to be functioning as intended. Over the past year, the price of EU allowances has floated – not without some major oscillations – around 80 euro per ton of CO_2. While the functioning of a cap-and-trade system should not be judged solely by the price that it determines, that figure does fall within the 50–100 US dollar range for the period 2020–2030 identified by the High-Level Commission on Carbon Prices[53] as consistent with the achievement of the temperature target of the Paris Agreement. The EU ETS is undergoing reform again. However, this time the ultimate purpose of the reform is to start equipping the system towards net-zero emissions. In this same vein, the EU has decided to unilaterally introduce the CBAM. This is a difficult but necessary initiative to begin aligning international trade rules with the imperative of global climate neutrality.

The incredible cost reduction of certain technologies such as wind and solar PV over the past two decades has allowed the EU to achieve positive results in the decarbonisation of its electricity mix. Expanding the use of electricity in buildings, transport and industry looks like a promising choice to build on such a positive technological trend and reap the benefits of a highly versatile energy vector, which can be used efficiently and with negligible local polluting implications. Nevertheless, rapid electrification poses important challenges that must be addressed, if one wants to ensure an environmentally sustainable and secure supply of energy to European citizens and firms in the coming years. Electrification calls for a radical change of the capital stock in the energy sector, not only upstream (need to build new renewable-based power plants) and midstream (need to build new power lines at transmission and distribution level), but also downstream (need to replace fossil fuel-based appliances such as gas boilers and internal combustion engines with electric ones). Providing sufficient and co-ordinated incentives to the multiple actors at stake is not easy. Several rules, within and beyond the electricity sector, must be reassessed and potentially amended. With the proposals in the Fit-for-55 package, the EC has taken the first steps in this direction. Whether this will be sufficient in the turmoil that currently characterises energy markets is hard to tell.

Moving to clean molecules, the EU's action plan for decarbonisation outlined in the Green Deal involves the integration of renewable and low-carbon gases (so-called clean molecules) as a progressive replacement for traditional fossil fuels in some specific sectors

[53] CPLC, Report of the High-Level Commission on Carbon Prices. www.carbonpricingleadership.org/report-of-the-highlevel-commission-on-carbon-prices.

 https://doi.org/10.1017/9781009341493.003

and energy uses. The energy crisis and the outbreak of war in Ukraine has not led to any back step, at the European policy level, regarding the fundamental role that clean molecules are destined to play in the EU decarbonisation strategy. In fact, without a prompt and progressive deployment of renewable and low-carbon gases, the achievement of the Green Deal objectives is at risk. The EC has been working to facilitate the integration and market uptake of renewable and low-carbon gases with several initiatives in recent years and focusing in particular on facilitating the upscale of biomethane and the market uptake of renewable hydrogen in the future EU energy mix via the publication or the review of EU directives and regulations. The viability of satisfying meaningful portions of natural gas demand with biomethane and renewable hydrogen requires a number of key developments, including significant sustained demand for renewable hydrogen, an increase in the availability of renewable energy, and a further reduction in the cost of renewable electricity and in the cost of electrolyser manufacturing and the supply chain.

The expanding role of the EU in sustainable finance is puzzling because of the mutually reinforcing dynamics at play between its financial capacity instruments and its standard and regulatory instruments. In this policy area and more than in other policy areas the European Commission has acted both as a policy agenda developer and as a policy agenda implementer. Having access to a host of instruments to finance sustainable projects, the Commission can equally use these instruments to ensure that the definitional standards it promotes have a market uptake. This is abundantly clear in the cases of the green bond standard and of the Taxonomy, which has been made operational through the eligibility criteria of the NGEU. However, the Taxonomy also helps to structure the more detailed and broader reporting foreseen by the CSRD. This being said, at the time of writing the jury is still out as regards the effectiveness of the EU sustainable finance strategy that, if one were to simplify, can amount to the financial arm of the Green Deal. The loopholes of the EU Taxonomy have been flagged since the EC decided to include natural gas and nuclear as transitional activities. Also, and although it is perhaps too early to tell, several voices are questioning the incomplete nature of the framework, in particular when it comes to the highly opaque and unregulated ESG ratings markets. ESG ratings regulation and supervision appear as the new frontier of this vibrant policy area.