Federal Ministry
Republic of Austria
Labour and Economy

FIW
Research Centre
International Economics

Policy Brief No. 59, June 2023

Advancing the European Green Deal with Industrial Policy

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The case for green industrial policy is strong and it is the obvious instrument to induce the structural transformation towards an emission-free economy. At the core of such a transformation lies the decarbonisation of the energy system. The industrial policy effort required to achieve the ambitious net zero objective in the European Green Deal (EGD) can be divided into three policy tasks: expanding renewable energy sources, raising energy efficiency across sectors and developing new technologies for industrial production processes where clean technologies are not available yet. While the first two tasks can rely on cost-competitive technologies and the required investment costs could in the long run pay for themselves, the third task constitutes formidable technological challenges that need to be tackled with a mission-oriented industrial policy. The industrial policy package employed ought to be a mix of public investments, green subsidies coupled with appropriate environmental regulations and an industrial mission for developing net zero industrial technologies. Importantly, with investment costs estimated at 1.75% of GDP per year, achieving the objectives of the EGD seems feasible also from a financial perspective. Despite this optimistic tone, the EGD is far from being a safe bet, and its success can easily be threatened by a plethora of factors, including opposition by vested interests or geopolitical confrontations.

1. Introduction – The policy context

1.1 The European Green Deal and industrial policy

First things first – the positive message is that achieving the ambitious goal in the European Green Deal (EGD) of transforming the EU into a climate-neutral, circular economy by 2050 seems absolutely feasible.[1] For sure, the transition from the current, predominantly fossil-fuel-based energy-system to an emission-free economy is a formidable challenge. It calls for major structural changes across all sectors of the economy, including first of all the energy sector but also industrial production, the transport sector and private households. Addressing this challenge requires appropriate policies which are guided by climate protection as the biggest societal challenge of our times.

The obvious policy tool for initiating such a process of structural change is industrial policy (see also Rodrik, 2009). For the purpose of this contribution, industrial policy is defined as the selective intervention or government policy that attempts to alter the production structures of an economy toward sectors, technologies or tasks that are expected to offer better prospects for economic growth or societal welfare (Pack and Saggi, 2006; Warwick, 2013). Industrial policy for the ecological transformation, that is, green industrial policy, is then the part of environmental and energy policies which pushes for structural change towards a less resource, energy and emission-intensive economy (Rodrik, 2012; Altenburg and Rodrik, 2017). Many of the principles of industrial policies apply to green industrial policies as well but there are also important differences. Notably, green industrial policies are not technology-neutral, as by definition, they favour sustainable, emission-free technologies. Moreover, green industrial policies are less likely to result in beggar-thy-neighbour policies and thus to lead to destructive subsidy races or trade wars. The reason is simple: even if an economy, say the EU, were to lose out in the development of a certain environmental product, for example solar panels or batteries for electric cars, and European companies were unable to sell in international markets, the EU would still benefit. It would benefit because in this scenario the foreign solar panels and car batteries, available at lower prices

[1] In addition to the ultimate objective to arrive at zero emissions by 2050, the EGD sets an interim objective of reducing emissions by at least 55% compared to 1990.

and/or higher quality, would still support the EGD (see Altenburg and Rodrik, 2017).[2]

1.2 Regulatory framework and finance for green industrial policies

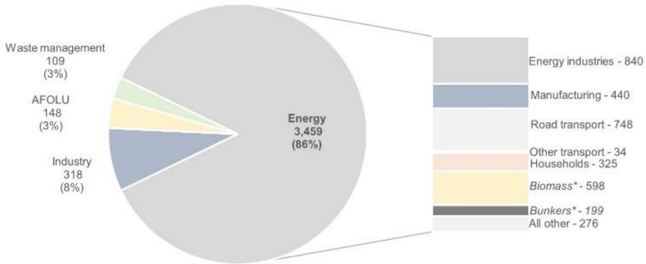
The EGD is complemented by a number of additional plans and legislation such as the Green Deal Industrial Plan (European Commission, 2023a). This plan calls for a simplified regulatory framework; faster access to finance; an enhancement of the skill base; and resilient supply chains within an open, rule-based global trade system[3]. Centrepiece in the efforts for improving existing regulations is the Net Zero Industry Act (European Commission, 2023b), proposed by the Commission in March 2023. The Net Zero Industry Act (NZIA) aims at enhancing the competitiveness of Europe's 'green' industries. The specific objective is to scale up the EU's manufacturing capacity for emission-free and environmental-friendly technologies and products such that 40% of the EU's annual deployment needs can be met internally. To reach this objective, the NZIA also calls for facilitating access to funding, inter alia, by extending the *Temporary State Aid Crisis and Transition Framework* and a revised *General Block Exemption Regulation*. Focusing on wind, solar photovoltaics, heat pumps, batteries, and electrolysers as important parts of net-zero technologies, the NZIA puts the accumulated investment needs at EUR 92 bn over the period 2023-2030 to fulfil the set objective.[4] Unfortunately, the NZIA does not include a financial envelope. It only mentions possible financing options, such as InvestEU, the Innovation Fund and important projects of common European interest (IPCEI). The lack of actual financial allocations for such an ambitious initiative is characteristic of EU industrial policy and one of its main weaknesses. And it is a major weakness because the best industrial policy will fall short of its objectives if the political process does not ensure the necessary funding. We argue that the objective of the EGD can be achieved by addressing and funding three policy tasks.

2. Major tasks of green industrial policy

2.1 The policy tasks ahead

The net zero objective of the EGD means that within a period of less than 30 years, the EU has to eliminate 4 bn tonnes of greenhouse gas (GHG) emissions.[5] The energy accounts reveal that more than four fifths of the total emissions involve the energy sector (Figure 1). It is therefore clear that the rebuilding of the energy sector is at the very core of the EGD. As illustrated by the bar on the right hand-side of Figure 1, the largest share of the emissions in the energy sector (21% or 840 mn tonnes) stem from 'energy industries', that is, from energy generation (including power plants, refineries and coking plants). They are closely followed by emissions from transport activities (19% or 748 mn tonnes).[6] Here it is worth mentioning that what really matters is road transport.

Figure 1: EU greenhouse gas emissions (GHG) by environmental sector, 2021 (in mn tonnes).



Note: *biomass and international bunkers are memo items. The circle shows the main sectors in the energy and environmental accounts as per the common reporting format (CRF), including the memo items biomass and international bunkers. The bar shows the breakdown of emissions from the energy sector. AFOLU = Agriculture, forestry, land use, which comprises the emissions in agriculture and the emissions from land use, land use change, and forestry.

Source: Eurostat Environmental Accounts; author's own calculations.

Two more sectors are of relevance when it comes to energy consumption: the household sector, mainly the heating of buildings (8%), and manufacturing and construction. The latter contributes to emissions in two ways. First, through industrial processes and product use (for example chemical reactions) covered in the separate industrial sector (318 mn tonnes, see pie diagram in Figure 1) and second, through the combustion of fuels during the production process (440 mn tonnes). Taken together 'industry', comprising mining, manufacturing and construction, accounts for about 19% of GHG emissions in the EU.

International bunker fuel and biomass facilities are also important emitters. The former could be a quick fix and could easily be dealt with appropriate regulation by simply prohibiting the use of heavy fuel oil throughout the territory of the EU and not allowing bunker-fuelled bulk carriers in EU ports. Biomass facilities are less problematic because plants capture almost the same amount of CO2 while growing as they later emit.

In view of the distribution of emissions across individual environmental sectors and sub-sectors, we argue that

[2] This assumes that an open trade and investment architecture is maintained, and geopolitical blocs are not decoupling technologically (see also Fabry and Veskoukis, 2021).

[3] This refers to maintaining and strengthening existing rules within the WTO and additional EU trade agreements as well as new initiatives such as 'Clean Tech/Net-Zero Industrial Partnerships'.

[4] The estimate refers to the 'NZIA policy scenario' in the Staff Working Document on the Net Zero Industry Act (European Commission, 2023c).

[5] Last available emission data are for the year 2021.

[6] Excluding international aviation and international navigation.

green industrial policies need to target three major tasks (Figure 2), which are

(i) accelerating investment in renewable energies thereby re-building the economy's energy system;

(ii) energy savings through efficiency improvements in existing technologies across sectors, including the household sector; and

(iii) using the potential of the entrepreneurial state to create new markets and products needed to make emission-free industrial production possible.

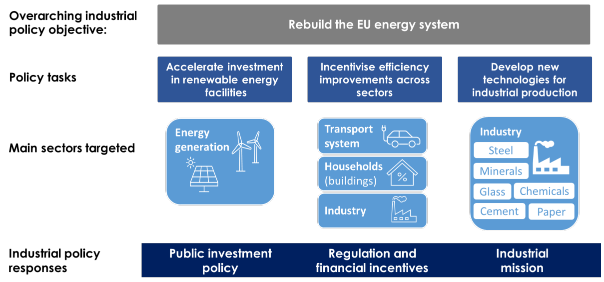
To properly address these tasks, a stronger and more systematic industrial policy is needed. This holds true even if state aid spending by member states has already been shifting to subsidies for environmental protection including energy savings ('green aid').[7] That current efforts are insufficient becomes evident when looking at the EU's GHG emission track record: since 1990, the benchmark year for emission reduction obligations under the Paris Agreement, GHG emissions declined by only 1.1% per year.[8] At current cruising speed, GHG emissions would still amount to 2.5 bn tonnes in 2050, implying an accumulated reduction of emissions against 1990 of 48% which means that the EU would not even reach the 55% objective by 2050.

2.2 Industrial policy responses

Given this track record, we suggest propping up the industrial policy efforts in the aforementioned tasks with three major types of industrial policy (see Figure 2). First, industrial policy in the form of public investments (investment policy) is needed for the EU-wide roll-out of renewable energy installations, mainly wind parks and photovoltaic facilities. While this constitutes also a form of investment policy, they have clear structural implications and therefore qualify as industrial policies. The Russian invasion of Ukraine in February 2022 and the associated turbulences on energy markets illustrate the necessity to reduce the EU's foreign energy dependence, not only from an environmental but also from a geopolitical perspective. This is particularly true if the EU wants to bring its Open Strategic Autonomy to life.

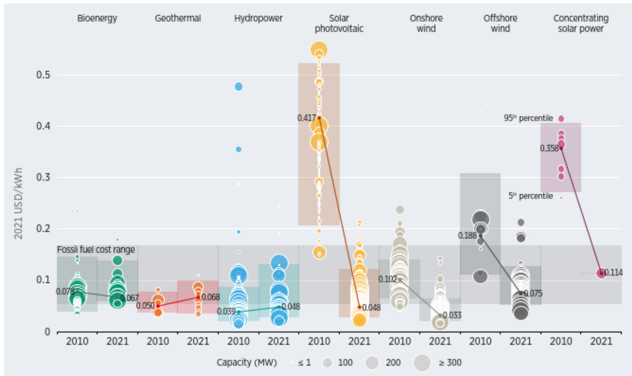
Notwithstanding remaining challenges regarding the stability and capacity of energy grids and energy storage technologies, the deployment of renewable energy is facilitated by the impressive decline in cost of installing renewable energy facilities (Figure 3).[9] Cost comparisons between different sources of electricity generation in investment planning are typically based on levelized cost of electricity (LCOE).

Figure 2: Major tasks of the EGD and policy approaches



Source: Author's own elaboration.

Figure 3: Global levelised cost of electricity (LCOE) across renewables technologies, USD per kWh, 2010-2021



Note: The LCOE is a measure for the net present cost of electricity generation from an energy source over its lifetime. Data refer to the year of commissioning. The LCOE is calculated with project-specific installed costs and capacity factors. The grey band represents the fossil fuel-fired power generation cost range, while the bands for each technology represent the 5th and 95th percentile bands for renewable projects.

Source: IRENA (2022) based on IRENA Renewable Cost Database.

According to data from the International Renewable Energy Agency (IRENA), an intergovernmental organisation for the promotion of renewable energy, the average LCOE of (onshore) wind fell below the level of the cheapest new fossil fuel-fired alternative for electricity generation in 2018, with solar photovoltaics (PV) following in 2020.[10] Adding hydropower to the list, there are several sources of renewable energies which are cost-efficient at the global level.

Second, in order to push efficiency improvements in transport systems ("better batteries"); in the household sector (heating systems, insulation of buildings) and in industrial processes, appropriate regulations and financial incentives are needed. The ban on the sale of new petrol and diesel cars from 2035 onwards, as part of the Fit-for-55 package, is a good example for such regulations. Financial incentives will have to take the

[7] Expressed in per cent of GDP, green aid amounted to less than 0.5% of GDP in 2021.

[8] Calculations based on Eurostat data (series "TOTX4_MEMO").

[9] According to IRENA (2022), solar photovoltaics (PV) could realise the most rapid cost reductions between 2010 and 2021 with costs of newly commissioned projects declining by 88% (global weighted averages). Impressive cost reductions were also recorded for onshore wind (-68%) and offshore wind (-60%) during the same period.

[10] In the EU, renewable energy sources have become cost-competitive vis-à-vis fossil-fuels several years before that (Trinomics, 2020).

form of (further) subsidies which can be provided either by member states or via EU funds. At the EU level funding for energy efficiency measures is supported by the REPowerEU plan/the Recovery and Resilience Fund (RRF).[11] As mentioned, the provision of 'green' state aid by member states is facilitated by the NZIA. Measures to increase energy efficiency are crucial because the higher the energy savings, the stronger will be reductions in total energy consumption. An expansion of renewable energy sources will be nevertheless necessary because the decarbonisation of the energy system will raise the demand for electricity (see e.venture, 2023 for the Germany).[12]

The third task is the most difficult one. While investments in renewable energies can rely on mature technologies and the incentives for improving energy efficiency can at least build on 'infant' technologies[13] (e.g. electric cars, air-source heat pumps, etc.), in numerous industrial production processes it is not yet possible to replace fossil fuel combustion with emission-free technologies. The development of yet non-existing technologies is a case for a mission-oriented industrial policy (Mazzucato, 2013; 2018; 2022), in which the state has an extremely important and equally challenging role to play. In view of this challenge in the industrial sector, we suggest "Net zero technologies in industrial production" as the most pressing industrial mission in the context of the EGD.

As already pointed out, the case for green industrial policy is particularly strong. A key argument are market failures in the form of negative externalities. While environmental externalities are an important motive for industrial policy, it is important to go beyond a market-fixing approach and move to a market-creation approach (Mazzucato, 2013; Mazzucato and Kattel, 2023). Market creation of this kind requires an entrepreneurial state. At the core of the entire concept of the entrepreneurial states is the conviction that innovation activities are intrinsically uncertain. The state alone is capable of financing the entire set of projects whose joint realisation could lead to the accomplishment of a mission (Mazzucato, 2022). Its deep pockets and long planning horizons enable the entrepreneurial state to take great risks and to deal with uncertainties, something that profit-maximising firms are struggling with.[14] Essential vehicles to 'create new markets' (Mazzucato, 2013) are public agencies providing research grants, expertise and coordination among stakeholders, as well as financing institutions for early-stage funding ('seed finance'). Importantly, all efforts by the state, agencies, financial institutions (such as venture capital funds), universities and firms need to be aligned and geared towards the objective of the mission (Mazzucato, 2022).

As should be the case with any industrial policy, the objective of a mission is crucial. This objective must be operational, in the sense, that the question of whether the mission was accomplished can be answered with a clear yes or no. In our case, the objective is net zero emissions in industrial production by 2050 (Figure 4). By then, it will be crystal clear whether this was achieved: either clean technologies to produce steel, cement, paper and other manufacturing products exist and are operational at an industrial scale, or industrial firms still have to rely on fossil-based technologies. The mission *net zero technologies in industrial production* is directly linked to climate protection, as a major societal challenge.

Going down the level of granularity, the mission consists of a critical mass of innovation-oriented projects that aim at finding technological solutions, such as producing steel with 'green' hydrogen. Any of these projects could be a success or a failure. Importantly, though, all technological bottlenecks must be eliminated to make the industrial mission a success. A large number of projects is crucial in order to ensure cross-fertilisation between them.

For example, it could be the case that green hydrogen as an energy source in blast furnaces for steel can also be used in the glass industry or in a more 'distant' fields such as oceanic transport.

Making this mission a success is the most challenging task from an industrial policy perspective. It requires, inter alia, an aligned set of policies and effective coordination between major stakeholders such as innovation agencies, venture capital funds and public development banks (Mazzucato, 2022). Importantly, any public support to private firms ought to come with conditionalities attached to it, in order to ensure discipline and avoid favouritism (Mazzucato, 2022; Altenburg and Rodrik, 2017).[15]

[11] The REPowerEU plan earmarks EUR 300 bn of finance for investment in energy saving, clean energy production and the diversification of energy supplies. It was presented as a major initiative to ramp up investments in these areas. Unfortunately, the plan does not really inject new money because the EUR 300 bn are taken from the existing RRF, the EU's temporary recovery instrument which supports reforms and investments by member states for their environmental and digital transition with grants and loans amounting to EUR 723.8 bn.

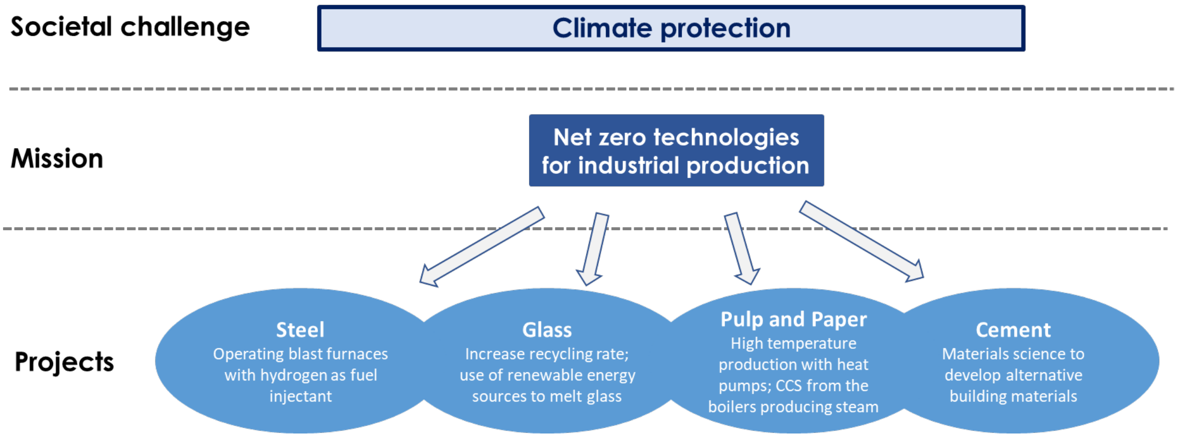
[12] The decline in total energy demand and the increase in the electricity generation are also reflected in the energy projections of the IEA (2021).

[13] We define mature technologies as technologies which are cost-competitive. Infant technologies are technologies which are not cost-competitive yet but where learning effects are present so that the technology has the potential to become cost-competitive.

[14] The difference between risk and uncertainty is that in the former case there is sufficient experience and data to derive probabilities which can be used to calculate expected profits, while such probabilities are not available when uncertainty is involved.

[15] In addition to discipline, the implementation of industrial policy requires embeddedness and accountability on the part of policy makers (Altenburg and Rodrik, 2017).

Figure 4: Industrial mission: Net zero technologies in industrial production



Note: The projects shown are non-exhaustive. Several projects reflect entries in the IEA's Clean Energy Demonstration Projects Database.

Source: Author's own elaboration based on the illustration of industrial missions in Mazzucato (2018).

3. Green industrial policy in numbers

The most ingenious and well-designed industrial policy is bound to fail (in the sense of not achieving its objectives) if the finance for the measures necessary to implement the policy is not provided. Therefore, it is imperative to look at the numbers. More precisely, we shall look at the available estimates for the cost of achieving the net zero objective in the EGD and furthermore to evaluate whether making the funding of the EGD available seems plausible or at least realistic. After all, the success of the EGD will depend much more on the political priorities of EU institutions and member states than its technological feasibility.

However, modesty is warranted in this endeavour because the complexity of policy tasks needed for realising the EGD and the long-time horizon imply that any forecast of the associated costs can merely be considered as rough estimates. This is true for all three policy tasks but in particular for the additional R&D investment in new technologies.

3.1 Putting a price tag on the EGD

The impact assessment report of the European Commission (2020) provides an estimate for the cost of the climate targets of the EGD. The costs are divided between supply-side and demand-side investments, with the latter being responsible for the major part of the total costs estimated at EUR 995 bn for the period 2021-2030 and at 1.2 trillion for the period 2031-2050 (Table 1).

Table 1: Estimated average annual investment in the energy system by the European Commission, in EUR bn

Investments	2011-2020	2021-2030	2031-2050
Supply-side	56.7	105.2	207.8
Power grids	*24.0*	52.7	84.1
Power plants	*30.9*	48.1	94.4
Boilers	*1.8*	3.4	1.6
New fuels	-	1.0	27.7
Demand-side	626.6	890.2	979.2
Industry	*9.0*	19.4	14.7
Households	*83.7*	166.6	156.7
Services	*41.7*	83.4	81.4
Transport	*492.2*	620.8	726.4
Total	683.3	995.4	1,187.0
Additional investment		*312.1*	*503.7*
(in % of GDP)		*2.10%*	*2.82%*

Note: Based on the 'mix' scenario the European Commission's Impact Assessment on the - Stepping up Europe's 2030 Climate Ambition.

Source: Table 46 in European Commission (2020).

Taking into account the average expenditures for energy investments in the period 2011-2020, this implies additional investment needs of EUR 440 bn annually, or 2.61% of GDP.[16]

While these are significant amounts, the order of magnitude of the estimated funding requirements means that it is realistic and even plausible that the EU and member states will be able and willing to provide the necessary financial means to cover these costs.

[16] This is the weighted average of the annual additional investments in the period 2021-2030 and 2031-2050 in Table 1.

3.2 An alternative estimate for the investment cost of 'net zero'

The numbers of the European Commission for the cost of financing the EGD have been criticised as too low (Wildauer et al., 2020).[17] In order to get an alternative estimate for the expected cost of achieving net zero emission, we employ the 'broad brush' approach of Pollin (2020) and Pollin et al. (2014). This approach divides the green deal into two tasks, i.e. investments in the expansion of renewable energy and investments in energy efficiency to realise energy savings. The former corresponds to the supply-side investments in the impact assessment reported in Table 1 while the latter is related rather to demand-side investments. Our approach refrains from a sectoral break-up of the demand-side investments and is naturally less sophisticated than the model-based impact assessment study. The upside is that it is very transparent in terms of both assumptions (see Appendix 1) and calculation.

The major drawback of the 'global' approach of Pollin (2020) is not its lack of detail but rather the omission of the cost of additional investments in new technologies. To compensate for this shortcoming, and in line with Wildauer et al. (2020), we include a 'guestimate' for the possible cost of the additional R&D effort needed to develop the new technologies needed to accomplish the industrial mission.

The cost estimates for the three policy tasks of realising the EGD in our suggested approach – expansion of renewable energy supply, increasing energy efficiency and scaling up green R&D efforts – rely on several assumptions regarding, inter alia, GDP trends, renewables energy supply and final energy demand, for the period 2023 to 2050.

Based on these assumptions, the cost of realising the net zero objective of the EGD is estimated at EUR 285 bn per year which adds up to EUR 7,740 bn for the period 2024-2050 (Table 2).[18]

Table 2: Average annual costs of realising the EGD, own estimates, in EUR bn

Policy task	Total costs 2023-2050	Annualised costs	Cost in % of GDP
Renewable energy	2,677.2	99.2	0.61%
Energy efficiency	530.2	19.6	0.12%
New technologies	4,537.2	166.6	1.02%
Total	7,744.6	285.4	1.75%

Note: Assumptions as described in the text. The methodology is similar to that of Pollin (2020) with the exception of the increase in R&D efforts, which follows Wildauer et al. (2020).

Sources: IEA (2022), Eurostat SNA database, Eurostat STI database, 2022 European Commission (2022), European Commission (2020), European Court of Auditors (2022), Trinomics (2020), IRENA (2022).

With 1.75% of GDP, this estimate is considerably lower than that of the European Commission (2.6%). However, more striking than the difference between the two cost estimates are the differences in the composition of the costs.[19] A crucial point to be emphasised is that the investments in the expansion of renewable energy sources should be strongly facilitated by the fact that many renewable energy technologies, notably solar power and onshore wind parks, have become cost-competitive vis-à-vis carbon-based technologies in the production of electricity.

4. Sources of revenue for financing the EGD

The discussion of the EGD-related investment costs involves the question of how this investment effort should be financed. Following the literature, such as Pollin (2020) or Heimberger and Lichtenberger (2023), one can assume that about half of this financing gap will be covered by the private sector, leaving the other half to be funded by the EU budget and member states. According to our estimates, this implies a public-sector contribution of EUR 143 bn annually (Table 3).

Incorporating some of the suggestions for funding a global green deal by Pollin (2020), Table 3 lists several potential sources of revenue. A definite stream of revenue will come from the EU emission trading system (ETS).

An additional EUR 1 bn is estimated to come from the carbon border adjustment mechanism (CBAM)[20] which complements the EU ETS and is scheduled to become operational in October 2023. Another important source of revenue would be the phasing-out of fossil-fuel subsidies. A report by Enerdata (2022) for the European Commission puts the current EU subsidies for fossil fuels at EUR 52 bn per year. Since such subsidies thwart the net zero objective, eliminating such subsidies seems an obvious policy measure.

The three revenue items mentioned add up to EUR 84 bn, leaving a funding gap of EUR 58.7 bn per year – or 0.36% of EU GDP. This could be the lower limit for the necessary additional annual funding contributions. These are currently envisaged to be channelled through existing financing instruments, such as InvestEU or the Innovation Fund. Providing this amount over a period of 27 years (from 2024 to 2050) would add up to EUR 1.59 trillion. This is the amount of *new* funds that will have to be factored in for the EU's next long-term budgets.

The funding gap of EUR 58.7 bn per year can be considered as the lower limit because the estimates in

[17] Their estimates rely strongly on data for gross fixed capital investments and amounts to about 6%.

[18] The details of the calculations are available on demand.

[19] This is not surprising, given that the two methodologies are not comparable.

[20] See: https://meijburg.com/news/revenues-eu-ets-and-cbam-eu.

the impact assessment report by the European Commission would, taking into account the same sources of revenue, leave an annual funding gap of EUR 136 bn (0.83% of EU GDP. Anything between EUR 60 and EUR 140 bn of new annual funding would therefore be the order of magnitude needed for the EGD's net zero objective.

Table 3: Sources of revenues for financing the EGD

Expenditure/revenue	Amount in EUR bn
Net zero investment cost (total funding requirement)	285.4
Private sector contribution (50%)	142.7
Public sector contribution (50%)	142.7
Sources of revenue	
EU emission trading system	31.0
*EU budget**	*6.0*
Member States	*25.0*
CBAM	1.0
Phase-out of fossil fuel subsidies	52.0
Additional funding	58.7
Total public funding	142.7
Memo item	
Reduction in military spending (10%)	21.4

Note: * Assigned to the Innovation Fund and the Modernisation Fund. CBAM=Carbon border adjustment mechanism.

Source: Table 2, Enerdata (2022), EEA

These considerations ignore a potential reduction of military spending by EU member states, which is shown in Table 3 as a memo item. A reduction of member states' military budgets by 10% – suggested, for example, in Pollin (2020) – would free up EUR 21.4 bn annually. In the face of the Russian invasion of Ukraine, redirecting funds from EU military spending to the green transition seems impossible politically and is therefore omitted from the calculations.

Even so, the provision of less than 0.8% of GDP in public investment funding for the three types of industrial policies needed to advance the green deal appears totally realistic. This is all the more true given that several sources of revenue could be mobilised so that only 0.36% of GDP would have to be debt financed. Missing out on this, would be regrettable not only from an environmental but also from an economic perspective. In the longer term, the investments in the energy transition will pay for themselves through the positive spillovers from learning-by-doing dynamics in the expansion of renewable energies and associated GDP expansion, even without considering the environmental benefits (Arkolakis and Walsh, 2023).[21]

[21] Arkolakis and Walsh (2023) show this for the renewable energy subsidies foreseen in the US Inflation Reduction Act (IRA) in a growth model.

5. Caveats and challenges

The appallingly slow pace of reducing GHG emissions in the EU over the past decade illustrates that achieving the net zero objective, even if a realistic scenario, is anything but a safe bet. To avoid the impression of an overly optimistic depiction of the situation, we shall, without claim to completeness, mention a number of caveats and complications which may derail the agenda of the EGD.

Special-interest groups. The risk that vested interests use their leverage to influence political decisions, especially on the use of subsidies and the strictness of regulations, in their favour (but to the detriment of the general public) is real enough (Grossman and Helpman, 1994). In particular, well-established industrial lobby groups from energy-intensive sectors will defend 'brown' subsidies, that is, subsidies where the environmental costs exceed the environmental benefits. Overcoming such obstacles and shifting resources from 'brown subsidies' to green subsidies, public investments in renewable energies and mission-oriented policy support will be decisive for the success of the net zero objective (see Wagner, 2023). Transparency and accountability of political decision makers as general principles of industrial policy are of paramount importance in this context. The success of the industrial policy tasks will therefore depend strongly on the quality of institutions and the political system.

Technological challenges to net zero emissions. Given that many industrial processes are still dependent on CO2-emitting technologies, it may be the case that the suggested mission will fail. As mentioned, from an industrial policy perspective, this is the most challenging and most uncertain part of the policy tasks. Nevertheless, we would consider the scenario of a failure of the industrial mission as less likely than the political economy problems associated with special-interest groups. Obviously, the increase of R&D efforts to develop clean technologies will play a key role. The agreement on additional IPCEIs, ideally lifted from the member state to the EU level, could be one puzzle piece in the wider effort to make the clean industrial production mission a success.

'Bad' technological fixes. Technology choices entail another risk. While green industrial policy is by definition not technologically neutral, decision makers can choose among a wide range of emission-free and/or emission-binding technologies. However, several technologies which do not emit GHGs and are therefore climate-friendly are nevertheless problematic because of other environmental risks which are still not fully controlled by humans. Nuclear energy is probably the most illustrative example since the looming dangers are revealed by the fact that as of today the EU has no final disposal site for highly radioactive nuclear waste. Carbon capture and storage technologies (CCG) are another example of a problematic technology approach which should only be used as a solution of last resort in exceptional cases, that is, for industrial production processes for which no emission-free technologies are available. Finally, geo-engineering must be seen as an extremely high-risk technology because of its potentially disastrous systematic impact on the planet's climate.

Retaliation, subsidy races and trade wars. Industrial policy has always been a contentious issue. As evidenced by the concerns about the US Inflation Reduction Act (IRA), this also holds for green industrial policies. If tensions over distortions of competition in international markets grow – which is likely, given the expansion of industrial policy worldwide (Wade, 2012; UNCTAD, 2018) – this may well result in retaliatory measures and subsidy races, as observed already in the 1970s, or even in trade wars. The probability of outright subsidy races will depend on the details in the design of the subsidy programmes and other support measures (for example innovation support and public procurement rules). Obviously, discriminatory provisions to the detriment of foreign firms will increase the risk of disputes. A problem in this context is that discrimination is not always easy to define. For example, many developing countries consider the introduction of the EU CBAM as green protectionism, while the EU argues that it complements the EU ETS and that both are economically meaningful because they internalise externalities associated with GHG emissions. While state interventions will necessarily increase if green industrial policies are propped up around the globe, one can hope that major trading partners remain committed to a transparent and rule-based world trading system. Such a system need not aim at eliminating all state interventions or even tariffs but should maintain the principle of Most-Favoured-Nation Treatment established in the GATT which served countries quite well.[22] Regional trade agreements (RTAs) can be useful, but the EU should be careful that such agreements do not undermine the objectives of the EGD. The environmental provisions in such RTAs appear to be less relevant in this context than efforts to bring transport prices closer to the true cost of transport. Hence, while expanding international trade is not an objective in itself, the exchange of goods tends to be environmentally advantageous, as new products and technologies will be diffused globally. Again, a precondition for this to materialise is that transport costs reflect the true costs, including negative environmental externalities. Similarly, and notwithstanding provisions on investment screening introduced by several countries, foreign direct investments (FDI) are a major vehicle for technology transfer. Moreover, with a view to the investment needed in renewable energy sources, multinational firms are important contributors. Greenfield FDI into renewable energy and alternative power projects are on the rise. For example, in the first half of 2022, investors announced more than 300 renewable energy projects with a total capital expenditure of about USD 130 bn[23]. While these are global figures, this capital expenditure figure is clearly important when compared to the total investment funding required for the EU's EGD.

Geopolitical decoupling/failure to form a climate club. Linked to the maintenance of a rule-based international trading system is the avoidance of a wider geopolitical fragmentation or even decoupling. A technological decoupling, in particular, would imply that the spillovers emanating from environmental technologies are severely curtailed. This is the worst-case scenario for a green deal at the global scale. Therefore, it is in the interest of the EU that a climate club (Nordhaus, 2005)[24] will emerge at the global level with a critical mass of participating countries. A carbon club would ensure cooperation in the field of climate protection, at least among like-minded countries.

6. Conclusions

Achieving the net zero objective of the EGD is feasible, both from a technological and financial perspective. Even if precious time has been wasted and progress at the mid-point between 1990 and 2050, the target date of the EGD, is disappointing, the main message is that the EGD remains a realistic endeavour. While the development of new industrial technologies in selected manufacturing industries may be the greatest technological challenge, the biggest risk for a derailment of the EGD does not stem from the technological side but from the lack of political commitment and determination. After all, the rebuilding of the energy system can rely on cost-competitive clean technologies which greatly facilitates the green transformation.

Equally important, the financial burden for the public sector associated with EGD investments, are of such a magnitude that finding sources of revenues does not constitute an insurmountable problem. Given the political will to advance the EGD, an additional annual budget of about EUR 60 to EUR 140 bn along with the already existing sources of revenue discussed and a reshuffling of fossil fuel subsidies, could finance the industrial policy push needed.

[22] Exceptions to this principle are the special and preferential treatment provisions for developing countries and regional trade agreements.

[23] Based on data from the fDi markets crossborder investment monitor. See: https://www.fdiintelligence.com/content/news/renewables-set-to-smash-fdi-record-in-2022-81463?saveConsentPreferences=success.

[24] A climate club refers to a coalition of countries which engage in reducing GHGs and implement corresponding measures, such as environmental regulations and carbon pricing. Carbon pricing can take the form of carbon taxes or of an emission trading scheme. The cross-border complement is a carbon border tax.

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8. Appendix

8.1 Assumptions underlying the calculation of the investment costs of achieving the net zero objective

1. **GDP growth trend.** Forecasts from the European Commission (2022) for the years 2023 and 2024, projections from the impact assessment report (European Commission, 2020) for the years 2025-2050.
2. **Renewable energy supply.** Data from Eurostat linked with projections from the International Energy Agency (IEA) in the "announced pledges" scenario for 2050, which in the case of the EU is the EGD.
3. **Total final energy demand.** Projections from the International Energy Agency (IEA) in the "announced pledges" scenario for 2050.
4. **Cost of renewable energy expansion.** Costs are calculated at the basis of levelised costs of electricity (LCOE) for the EU from Trinomics (2020) updated with data from IRENA (2022) and long-term projections for the cost evolution from the IEA until 2050. Average LCOEs of renewable energy sources are assumed to decline from EUR 65.5 per megawatt hour (MWh) in 2021 to EUR 39.7 per MWh.
5. **Cost of increasing energy efficiency.** The cost of increasing energy efficiency is taken from the European Court of Auditors (2022) who put the avoidance cost at EUR 56 per MWh for reducing energy consumption in industry.
6. **R&D investment in new technologies.** The cost of the additional R&D effort needed is approximated by the implied expenditure of increasing the EU-wide R&D intensity to 3.5% until 2050. This is lower than in Wildauer et al. (2020) who use 4% as the target rate but still above the R&D to GDP ratio of Sweden in 2021 (3.35%), which is the country with the highest ratio in the EU. The average R&D intensity of the EU was 2.48% in 2021.
7. **Starting point for stepping up EGD investments.** Given that the EGD is already underway, no further delay in stepping up the efforts to achieve net zero is assumed so that estimates relate to the period 2024-2050.

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Imprint:

FIW Policy Briefs are published at irregular intervals on current foreign trade topics. Publisher is the FIW - Research Centre International Economics. The authors are responsible for the content of the Policy Briefs.
FIW offers a research platform, information on topics relevant to foreign trade and access to economic databases. It is a cooperation project of the Vienna University of Economics and Business, the University of Vienna, the Johannes Kepler University Linz, the University of Innsbruck, the Austrian Institute of Economic Research, the Vienna Institute for International Economic Studies and the Computing Centre for Economics and Social Sciences and is funded by the Federal Ministry of Labour and Economy and the Federal Ministry of Education, Science and Research.

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