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Green industrial policy for climate action in the basic materials industry

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Abstract

Historically, the basic materials industry has had relatively low R&D expenditure levels, raising concerns about meeting 2050 climate targets given the crucial need for innovation and technology advancement in this industry. Decisive government intervention and active support for key technological pathways are required to address significant market failures and catalyse industrial decarbonisation. This Essay lays out the economic justification for an active green industrial policy and proposes key policy design principles, with the aim of striking a balance between facilitating the green industrial transition and maintaining cost efficiency in meeting climate targets.

Keywords Green industrial policy · Basic materials industry · Industrial decarbonisation

1 Introduction

Despite ongoing climate mitigation efforts, the realisation of net-zero greenhouse gas (GHG) emission targets represents a daunting task. Emissions associated with industrial processes, which amount to approximately one-third of the total global CO_2 emissions, pose a particularly significant challenge. In recent decades, these emissions have grown, both in sheer volume and as a proportion of total emissions (Lamb et al. 2021; Bashmakov et al. 2022). The basic materials industry, here encompassing iron and steel,

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cement, and chemicals, is responsible for roughly 60 percent of these industrial emissions (Bashmakov et al. 2022). These industries are characterised by high resource and emissions intensities, large production units, long turnover times in capital stock, high investment costs and non-standardised process designs (Rissman et al. 2020; Bataille 2020). Production is primarily directed towards upstream markets and combined with other inputs before it reaches end consumers (Rootzén and Johnsson 2017). In addition, traditionally, the basic materials industry has invested relatively little in research and development (R&D) (Galindo-Rueda and Verger 2016). Figure 1 illustrates that this trend of relatively low R&D spending, compared with other industrial sectors, has continued in recent years and is present even in several of the most innovative countries. This pattern raises serious concerns, given the pivotal role of innovation and the advancement of technologies currently at the demonstration level in achieving the 2050 climate targets (IEA 2021). While there are a few near-zero carbon emissions industrial projects close to final investment decision or under construction, there exist, to date, no full-scale, fully built and operating near-zero emissions iron and steel, cement, or chemicals plants anywhere in the world (Bataille et al. 2024). Transforming the basic materials industry to net zero GHG emissions will require concurrent efforts towards improving resource efficiency, promoting circular flows and practices across value chains for basic materials, phasing out existing emission-intensive capital, and phasing-in new net-zero emission production capacity (Vogl et al. 2021; Bataille et al. 2018, Bataille et al. 2023). The objective of this Essay is to present the economic rationale for implementing green industrial policies in the basic materials industry, and to suggest strategies for designing policies that balance promoting the industrial transition with the achievement of climate goals in a cost-effective manner.

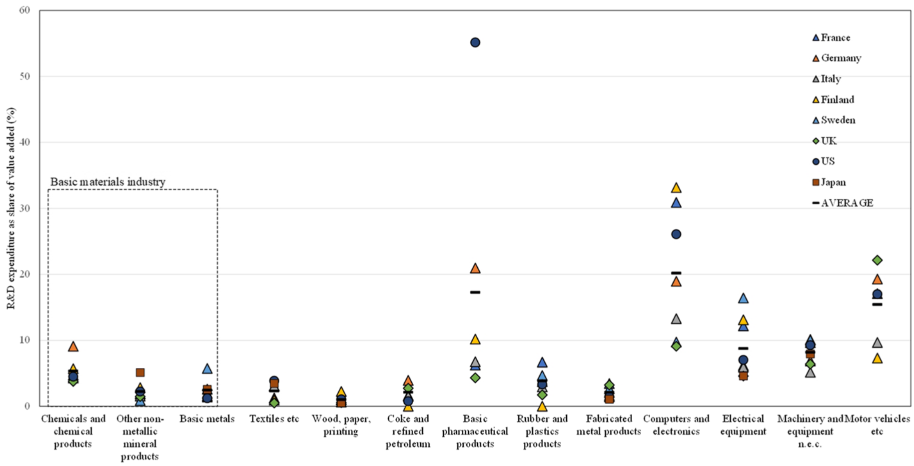

Fig. 1 Enterprise expenditure on R&D as a share of gross value added. Focus of this essay is on the basic materials industry here encompassing iron and steel, cement, and chemicals (included in the basic metals (iron and steel), other non-metallic minerals (cement) and chemicals and chemical product (chemicals) categories). Note: The ratio of R&D enterprise expenditure and value added is calculated by dividing R&D enterprise expenditure in millions of national currency by value added in millions of national currency. Data on R&D enterprise expenditure by manufacturing sector are obtained from Eurostat's 'Science, technology, digital society' database. Data on value added were obtained from the OECD's 'Value added and its components by activity, ISIC rev4' dataset. Observations are for the year 2018 for all countries except France and Sweden, whose data are for 2017

The need to accelerate the green transition in industry has been recognised by policy makers across the globe. This is exemplified by initiatives like the EU Innovation Fund, the EU Net-Zero Industry Act, the US Inflation Reduction Act, Japan's Green Innovation Fund, and China's 14th Five-Year Plan, which will together make billions of dollars available to stimulate innovation, demonstration, and investments in enabling technologies such as direct or indirect (via hydrogen) electrification processes, carbon capture and storage (CCS), and zero-emissions electricity supply (IEA 2023). On the surface, these types of policy interventions appear to run counter to conventional policy recommendations, which generally caution against favoring specific technological solutions for achieving decarbonisation goals (Jaffe et al. 2005; Juhász et al. 2023). However, such recommendations are based on models that disregard the specific market failures relevant to sectors such as the basic materials industry, which become particularly prevalent as more radical emission reductions are required. Acknowledging these market failures, this Essay commences with laying out the economic rationale for green industrial policy targeting the basic materials industry. Similar to the broader concept of industrial policy, there is no commonly accepted definition of what *green* industrial policy entails (Altenburg and Rodrik 2017). Here, we define green industrial policy as a policy that actively steers the transformation of the structure of domestic economic activity, and hence the technological pathways, of selected sectors or industries with the goal of achieving net-zero GHG emissions.[1] The targeted nature of green industrial policy distinguishes it from broad-based decarbonisation policies, such as carbon pricing, while the goal of net-zero GHG emissions differentiates it from traditional growth-oriented industrial policy.

The question whether or not governments should engage in active green industrial policy, has been the subject of extensive debate in the academic literature. For instance, Nilsson et al. (2021) argue for the pursuit of multiple policy strategies to support industry decarbonisation, Mazzucato et al. (2020) advocate for a mission-oriented approach in favor of desired societal goals, with a proactive role for the government in shaping markets, while Karlson et al. (2021) argue against such an 'entrepreneurial state', pointing at the limited empirical support for effective industrial and innovation policies. While the necessity of green industrial policy is increasingly recognised, many scholars remain hesitant due to the risks of rent-seeking, corruption, and misallocation of resources that can arise when governments attempt to steer economic development through targeted policies (see, e.g., Nahm and Urpelainen 2021 and Wen et al. 2021). In response, we seek to contribute by elaborating on the rationale for green industrial policy from an economics perspective, akin to Hallegatte et al. (2013) and Rodrik (2014). Next, acknowledging the reservations of many scholars, our analysis turns to the crucial question of *how* to effectively shape a green industrial policy in the coming decades, a key aspect highlighted in Aiginger and Rodrik (2020). We provide important considerations for policy design, articulated through three principles detailed in Section 3, which aim at balancing the enabling of a green industrial transition with cost efficiency. These principles could be relevant beyond the basic materials industries, and more broadly provide important insights into the debate on the appropriate equilibrium between government intervention and market forces.

[1] This definition, which stresses targeted, structural transformation and a decarbonisation goal, is similar to the definition of green industrial policy outlined in Hallegatte et al. (2013) and Juhász et al. (2023).

2 Effective green industrial policy implies abandoning technology domain neutrality

The superiority of a policy approach that relies on multiple instruments to simultaneously address environmental and innovation market failures is well-established (e.g., Aldy et al. 2010; Acemoglu et al. 2012; Aghion et al. 2016). A critical decision policymakers subsequently face is whether to adopt technology-neutral or technology-specific strategies to accelerate the development and deployment of green technologies (Fabra and Montero 2023). Technology-neutral policies include broad-based policies, such as pricing environmental externalities through emissions taxes or emissions trading schemes, as well as general subsidies for R&D or technology deployment (Lehmann and Soderholm 2018).

Beyond creating the right incentives, technology-neutral policies allow markets to select technological pathways to achieve climate targets, promoting the development and deployment of the least costly technologies first. In contrast, technology-specific policies promote particular technological fields, sectors, or even individual projects through tailored support mechanisms, such as feed-in tariffs or targeted R&D subsidies.

Technology-neutral policies avoid several pitfalls of technology-specific policies. These include concerns that public support might crowd out private investments, that information asymmetries and lack of relevant expertise may lead policymakers to endorse mitigation strategies that either underperform or prove costlier than expected, and concerns about the risk of regulatory capture and increased lobbying by industry leaders. Yet, the promotion of technology-neutral policies rests on the assumption that market failures associated with the development and diffusion of technologies are absent or are properly addressed by other policies. However, such market failures are particularly prevalent in the basic materials industry, posing considerable barriers to the innovation and deployment of green technologies (Löfgren and Rootzén 2021).

First, innovation in the basic materials industry is highly path-dependent and can be expected to generate spillover effects (Aghion et al. 2016; Popp et al. 2019; Noll et al. 2023).For example, advancements in low-carbon steel production techniques, such as hydrogen-based direct reduction, build upon decades of research in metallurgical processes (Pei et al. 2020). Policy interventions to encourage investments in hydrogen-based direct reduction within one country can create first-mover advantages for national industry, while also contributing to reducing future costs and risks across the globe.

Second, investments in innovative low-carbon technologies within the basic materials industry depend on coordination among actors within the industries as well as along supply chains. Network effects — where the value of a technology increases as more market participants adopt it (Greaker and Midttømme 2016; Heijmans 2023) — can lead to technology lock-in, thereby hindering the adoption of new technologies. This is illustrated by the case of CCS, where a cement factory investing in carbon capture relies on other actors to invest in energy, transport, and storage infrastructure (Golombek et al. 2023). According to the International Energy Agency, attaining the necessary adoption of hydrogen and CCS mandates a significant increase in investments in supporting infrastructures (IEA 2021). The importance of supply chain coordination is further emphasised by Dugoua and Dumas (2021), who demonstrate that green innovation in industrial networks requires producers to coordinate with suppliers. Without such coordination, shared suppliers can become bottlenecks to green innovation. Importantly, Dugoua and

Dumas (2021) show that when innovation is complementary across firms, price-based policies, such as carbon taxes, may not be sufficient to achieve deep industrial decarbonisation at the lowest cost.

Third, substantial financial barriers exist for investments in both existing and novel green technological pathways, as markets may be overly myopic and lack complete information about which technology will ultimately prevail (Nemet 2009; Armitage et al. 2024). For the basic materials industry, where capital intensity is high, project lead times are long, and where commodity and policy risks are significant, this means that private investors and lenders, in the absence of policy interventions, tend to be particularly hesitant. Cordonnier and Saygin (2023) describe how there is a general lack of tailored financing instruments to de-risk and improve the economic viability of industrial decarbonisation projects. They also describe how annual investments in new production plants compatible with net-zero pathways for chemicals, steel, cement and aluminium production is much too low to be consistent with net-zero pathways. They estimate that investments in such near zero production plants need to increase from USD 15 billion globally today to USD 70 billion by 2030 and USD 125 billion by 2050.

Overcoming these market failures requires targeted policies that involve selecting specific technologies. This implies that, contrary to the principles of technology-neutral policy, which advocates for policy that does not favor certain technologies, full technology neutrality will not be attainable, or even preferred. In this approach, carbon pricing would address the emissions externality, while targeted policies—such as targeted investment support and targeted R&D subsidies—would tackle the specific market failures that hinder innovation and the deployment of green technologies in the basic materials industry. These targeted interventions are crucial because market failures related to technology path-dependence, coordination, and financial barriers arise not only from insufficient market incentives, but also from uncertainties surrounding technological pathways. This underscores the need for government involvement in technology selection, making a strong case for a proactive and targeted green industrial policy.

But how should an active targeted green industrial policy be designed? We argue that such policy should identify and commit to what we term as 'technology domains'. A technology domain, as we define it, is a broad technological pathway that enables a collection of specific technologies or, as we call them, 'technology families'. To decarbonise the basic materials industry, there are a limited number of technology domains available to choose from. These domains include direct electrification, indirect electrifica tion (via hydrogen), biogenic carbon as a fuel and feedstock, carbon capture and storage, among others. These technology domains are not mutually exclusive, and may be combined. The successful implementation of these technologies requires parallel development of various interconnected technological systems and business models, along with corresponding modifications to regulatory frameworks and support systems. Figure 2 depicts several principal domains and corresponding examples of technology families pertinent to the decarbonisation of the basic materials industry. While green industrial policy can be designed to target specific technology domains, the development of certain markets and infrastructure, such as those that expand the supply of clean electricity, may benefit multiple domains. This interconnection is represented by the dotted arrows between the technology domains in Figure 2.

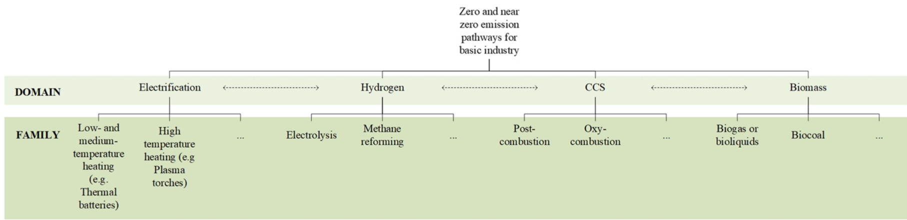

Fig. 2 Taxonomy. Key technology domains and examples of technology families with relevance for the decarbonisation of the basic materials industry

3 Technology family neutrality and market incentives remain key

As described above, green industrial policy must move away from technological neutrality as a guiding principle at the level of technology domains and instead actively support key technological pathways to achieve climate targets. Yet, the main pitfalls of industrial policy – failure to pick winners, influence of interest groups and potential crowding out of private investments – remain. While abstaining from active government intervention could circumvent these pitfalls, it could also risk a second type of error — underinvestment in technologies with the potential to substantially contribute to industrial decarbonisation.

We formulate three key principles that can guide policymakers in the design of effective green industrial policy for the basic materials industry, aimed at mitigating the pitfalls mentioned above:

Principle 1. Use experts to systematically and transparently identify pertinent market failures and select technology domains.

Requiring governments to provide documentation regarding the rationale for intervention enhances the likelihood of accurately selecting the right technology domains to support. Key market failures in the decarbonisation of the basic materials industry that justify targeted subsidies or regulatory interventions include technological spillovers, path-dependence in technology development, network effects, as well as financial and informational barriers. Targeted policies that focus on promoting specific technology domains are necessary to address these market failures. However, since selective support can be vulnerable to regulatory capture, ensuring transparency is essential to minimise the influence of special interest groups.

Principle 2. Maintain neutrality across technology families within supported technology domains.

Market actors hold more information than policy makers concerning effective solutions for emission reductions and their costs. To harness this information and keep the door open for possible future innovations, the government should maintain a level playing field within technology domains, avoiding support for specific technology families or tailored to individual firms. For instance, the government could steer its green industrial policy to specific technology domains (e.g. electrification) but make sure that selection processes treats competing firms and technology families within that domain equally.

Principle 3. Maintain and strengthen market-based climate policy instruments, such as carbon taxes and emissions trading, as the cornerstone of climate policy.

Market-based climate policy instruments are critical tools to leverage the private information held by firms and industries. They sustain incentives for cost-effective emission reductions (Lewis 1996; Ahlvik and Liski 2022), promote innovation in the most promising technological solutions and accelerate the uptake of such new technologies within technology domains (Ahlvik and Bijgaart 2024). Therefore, green industrial policy should supplement broad market-based climate policies, not replace them.

4 Reflections on U.S. and EU green industrial policy in light of the three principles

In recent years, green industrial policies have been increasingly debated and adopted in the world's major economies (Juhász et al. 2022; Criscuolo et al. 2023). Below we offer some brief reflections on two of the most prominent green industrial policy packages implemented in recent years — the Inflation Reduction Act in the United States and the European Green Deal Industrial Plan — through the lens of our three principles. To provide context, we start with a concise description of the main elements of these green industrial policies.

Both the Inflation Reduction Act (IRA) and the Green Deal Industrial Plan are complex policy packages consisting of a broad range of climate provisions. The climate provisions of the IRA are primarily a combination of tax credits, grants, and loan programs with the aim of incentivising deployment of clean energy, innovation, and domestic manufacturing. The main focus of IRA is on promoting the energy transition through clean energy tax credits (either production-based credits or investment tax credits). Notably, by 2025 the credits will be technology neutral, creating a level playing field for technologies such as solar, wind, storage, hydrogen, carbon capture, and direct air capture (Bistline et al. 2023b). Compared to the subsidies to the power and transportation sector, the direct subsidies for innovation and the adoption of technologies specific to the industrial sector are still relatively scarce. The IRA earmarks only USD 5 billion out of a total of USD 392 billion for industrial decarbonisation (Bistline et al. 2023a). However, given the anticipated importance of both hydrogen and carbon capture technologies for the industrial sector, the overall subsidies to industry are likely larger, as these technologies are eligible for tax credits. In addition, there exist other programs that provide investment support and incentives that are complementary to the IRA tax credits. One example is the Infrastructure Investment and Jobs Act (IIJA), which supports hydrogen initiatives through USD 8 billion of support for hydrogen hubs (Krupnick and Bergman 2022). Finally, to encourage the domestic development of green industries, the IRA includes significant benefits for domestic production. This feature is internationally contentious, and has raised concerns about increased protectionism, which could negatively impact international trade and trigger global subsidy races (Kleimann et al. 2023). In March 2024, a first round of support targeting a range of industry decarbonisation projects was announced. The Industrial Demonstrations Program received USD 6.3 billion, combining funding from IIJA and the IRA, to support the advancement of transformational technologies across several basic material industries (e.g. steel, cement and petrochemicals) and across various technological families (U.S., Department of Energy 2024).

The Net-Zero Industry Act (NZIA) - a central pillar of the European Green Deal Industrial Plan - was adopted by the EU Council on 27 May, 2024. Often seen as the EU's response to the

IRA, the NZIA marks a shift from the EU's previous focus on extensively subsidising early-stage innovation to supporting green technologies closer to commercialisation and accelerating the market penetration of strategic net-zero technologies. This shift makes EU industrial policy more similar to the IRA that has a strong emphasis on technology deployment. Kleimann et al. (2023) compare the extent of subsidies and find that, aside from renewable energy production where EU subsidies are higher, EU subsidies were generally comparable to those under the IRA.

The NZIA aims to accelerate the green transition and deplyoment of green technologies by simplifying approval processes, improving market access for strategic technologies, enhancing workforce skills, and coordinating member states' efforts through the Net-Zero Europe Platform. The NZIA does not provide direct funding for strategic technologies at the EU level; rather, such support is anticipated to come from national policies implemented by member states and from sources like the EU Innovation Fund. The EU Innovation Fund is funded through sales of the EU Emission Trading Systems' (EU ETS) emission allowances and the total funding thus depends on the development of the carbon price. At the current carbon price of EUR 75/tCO_2, the 530 million allowances earmarked for the fund would make EUR 40 billion available from 2020 to 2030. The funding covers five areas: (i) energy intensive industries, (ii) renewable-energy technologies, (iii) CCS, (iv) energy storage, and (v) net-zero mobility and buildings (EC 2023). To date 124 projects have been rewarded EUR 6.7 billion. Almost half of the funding (EUR 3.2 billion) has so far been allocated to support investments in commercial demonstration of innovative zero-carbon and low-carbon technologies in the steel, cement and petrochemicals industries (EC 2024).

In relation to our Principles, it appears that, while not always explicitly framed in terms of market failures, several elements of both the IRA, along with complementary acts like the IIJA, and the NZIA are consistent with our first and second principles. While the direct support dedicated specifically for decarbonisation of basic materials industries is a smaller component of the IRA, industry actors can benefit also from tax credits for domain technologies such as CCS and hydrogen. In addition, there is an acknowledgement of coordination failures as important impediments to industrial decarbonisation, and provisions to overcome these coordination failures, such as in the case of hydrogen hubs in the IIJA. In the EU, the NZIA targets market failures beyond emission and knowledge externalities, such as the need for coordinated zero-emissions electricity supply, expanded grids, and a skilled labor force. Furthermore, NZIA defines strategic net-zero technologies and the EU Innovation Fund supports investments in strategic net-zero technology ecosystems. Interestingly, these technologies translate to technology domains in the case of the basic materials industry, and hence is generally aligned with our Principles 1 and 2. The NZIA also permits the granting of state aid to strategic net-zero technologies, thereby relaxing state-aid rules. This aims to make it easier for individual member states to subsidise these technologies, accelerate the green transition, and reduce investment uncertainty through clear objectives and monitoring mechanisms.

Regarding Principle 3, it can be noted that while the EU has implemented carbon pricing to incentivise industrial decarbonisation through the EU EU ETS since 2005, carbon pricing plays a more limited role in U.S. climate policy.[2] In the U.S., carbon pricing is primarily evident through cap-and-trade programs in a limited number of states, including California's cap-and-trade program (since 2012), Washington's cap-and-invest program (since 2023), and the Regional Greenhouse Gas Initiative (RGGI) covering 11 states and only the power sector (since

[2] However, it is important to note that the IRA include the first price on greenhouse gases at the federal level in the US: a charge on methane emissions that exceed specific thresholds at selected facilities in the oil and gas industry. The charge starts at USD 900 per metric ton of methane, increasing to USD 1,500 after two years (corresponding to USD 36 and USD 60 per metric ton of carbon dioxide equivalent, respectively).

2009). An additional cap-and-invest initiative is expected to launch in New York State in 2025. However, it is important to note that the carbon prices in these programs are much lower than the social cost of carbon, which recent studies estimate to average well over 100 USD per tonne of CO_2 (Hänsel et al. 2020; Rennert et al. 2022; Moore et al. 2024). As pointed out in Principle 3, policy makers should work to strengthen these broad market-based policy instruments.

5 Conclusions

This Essay lays out the economic rationale for an active green industrial policy targeting the basic materials industry. It puts forth three key policy design principles, with the aim of striking a balance between facilitating timely green industrial transition and maintaining cost efficiency. We advocate for the adoption of a green industrial policy that addresses pertinent market failures and actively supports crucial technological pathways (domains). This policy should ensure a level playing field within selected technology domains, while also employing market-based climate policy instruments to incentivise cost-effective GHG emissions reductions. As laid out above, active governmental involvement in the transition of the basic materials industry definitively comes with its potential pitfalls. However, inaction risk a second type of error — underinvestment in technologies with the potential to substantially contribute to industrial decarbonisation. Such policy error may be less visible, but not less costly. Decarbonising the global basic materials industry will be a complex task, therefore experimentation and continuous evaluation should be key components of policy implementation. Insights from economics, in conjunction with a broadened recognition of relevant barriers and market failures in the industrial sector, offer a strong foundation for successful and timely green industrial policy aimed at achieving carbon neutrality.

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Data availability Data underlying Fig. 1 are from publicly available databases as described in the figure caption.

Declarations

Ethics approval and consent to participate Not applicable

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