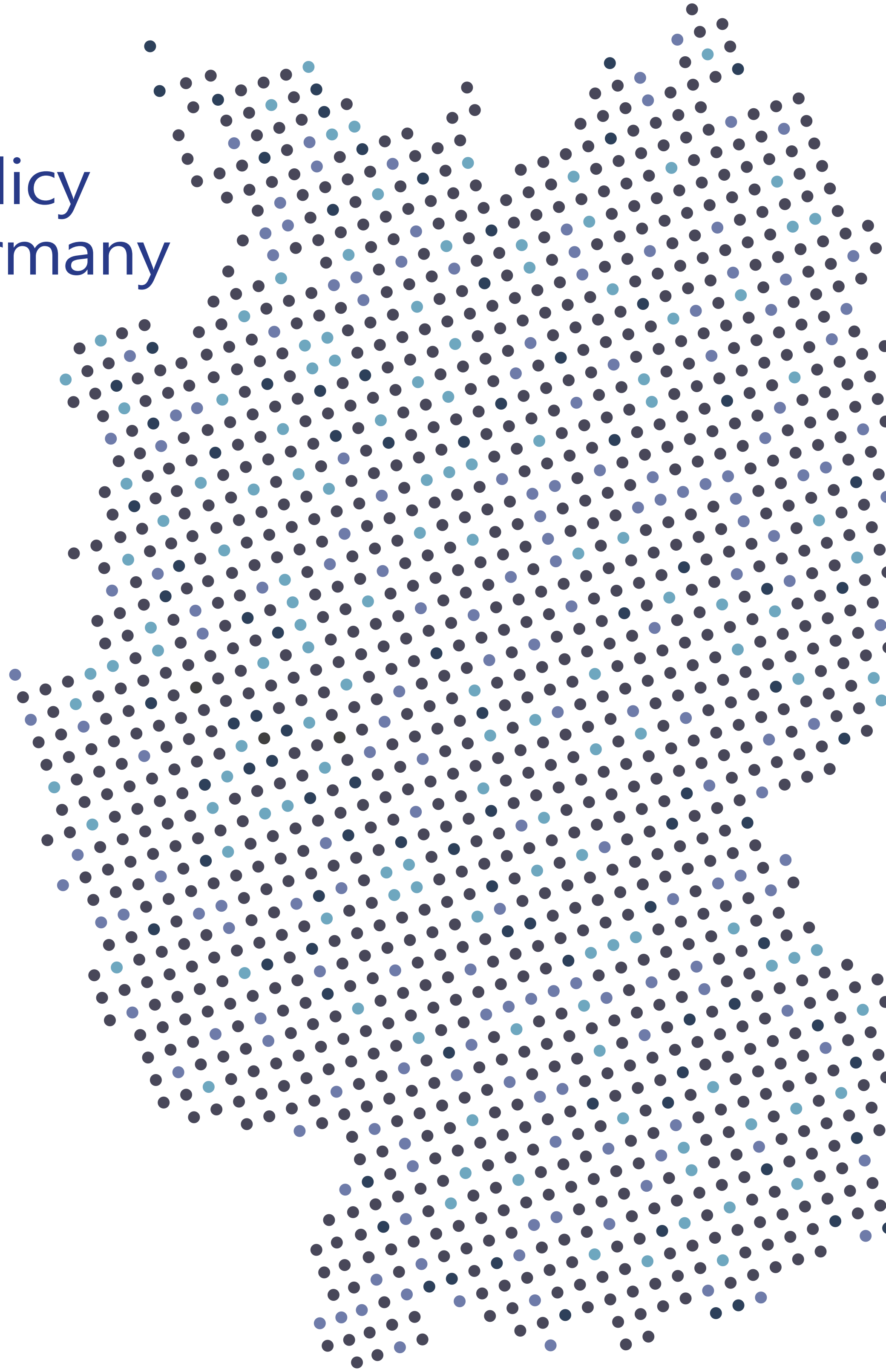
Industrial policy trends in Germany



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Introduction

The discussion about industrial policy has recently undergone radical changes. Until the turn of the century, industrial policy had been under severe criticism from orthodox economists, arguing that unfettered markets were more efficient at allocating investments than "bureaucrats". Structuralist authors (Amsden, 1992; Stiglitz, 1996; Wade, 2003; Cimoli, Dosi and Stiglitz, 2009) had always rejected the underlying assumptions. First, highlighting the pervasiveness of market failures and the fact that societal objectives matter, some of which may require compromises with private sector investments (such as mitigating climate change or balancing living conditions across regions; Altenburg and Lütkenhorst, 2015); second, conceptualising industrial policy as a coordinated process of public-private search for realistic and desirable techno-economic trajectories and associated policy interventions rather than top-down "picking winners" by bureaucrats (Evans, 1995; Rodrik, 2008). While the neoliberal discourse dominated economic policymaking in many Latin American and African countries, policymakers and practitioners in other parts of the world, especially in East Asia and Europe, remained largely immune to the ideological aberrations and pragmatically continued to apply industrial policies to protect and upgrade specific parts of their economies.

The ideological rejection of industrial policy gradually gave way to a more evidence-based and pragmatic consensus in the first decade of the 21st century. Rodrik's (2004, 2008) and Lin and Monga's (2011) work —even though it not fully embraced the structuralist's views (Chang and Andreoni, 2020)— convinced large parts of their colleagues in neoclassical economics and many governments that interventions in structural transformation processes are just as "normal" as regulatory guidance in other, less contested fields of much policymaking. Rodrik's description of "industrial policy for the 21st century" (2004) has been particularly influential in creating acceptance of a pragmatic version of industrial policy. This can be called the *first 21st century industrial policy paradigm change*.

Since then, however, the global economy has changed considerably, with deep implications for industrial policies. Technological change is accelerating, especially driven by the digital revolution. The emergence of platform economies, factory automation and the digital integration of value chains ("internet of things") all have deep implications for the structure of economies and international trade.

Additionally, big data and artificial intelligence are expected to have deep effects in the coming decades (Hallward-Driemeier and Nayyar 2017; Lütkenhorst, 2018). These trends are overlaid by increasing tensions between the main economic blocs, in response to which countries are linking industrial policies to national security issues, erecting trade barriers and protecting national industries they deem strategic. A recent, unprecedented wave of supply chain disruptions, triggered by the COVID pandemic and Russia's invasion of Ukraine, further accentuated concerns with industrial independence. Last, but not least, growing awareness about the impacts of climate change and other environmental threats led to a new set of industrial policies aimed at transforming economies towards decarbonization and circularity.

Two trends deserve major attention as they are strongly challenging the previous consensus on industrial policy: the greening of industries and the geopolitical rivalry, techno-nationalism and supply chain disruptions. Both stem from very different logics, but have important commonalities when it comes to industrial policy: they require a much deeper involvement of the state and societal stakeholders in shaping the economy, thereby shifting even further away from the initial understanding of markets as the key institution guaranteeing productive efficiency. In fact, we see an astonishingly rapid and radical shift in the major economies, both in terms of discourse and action, towards market intervention. This is referred to as the *Second 21st century industrial policy paradigm change*:[1]

(i) **Greening of industries**. The need to decouple economic development from resource consumption and emissions has now climbed to the top ranks of political targets worldwide. Projections on global warming call for a profound economic transformation towards decarbonisation and, more broadly, decoupling of economic activity from resource consumption. This transformation requires strong government intervention, firstly because of pervasive environmental externalities requiring interventions to internalize them (prices, bans, standards); secondly the need to transform entire economic subsystems, such as the energy and the transport systems, which entails augmented coordination and information failures; and thirdly, because new international agreements are needed to harmonise international greening efforts, employing energy partnerships, carbon border adjustment taxes and technology transfer commitments, amongst others. Efforts to green industries become manifest in national and regional Green Deals, decarbonization and circular economy action plans.

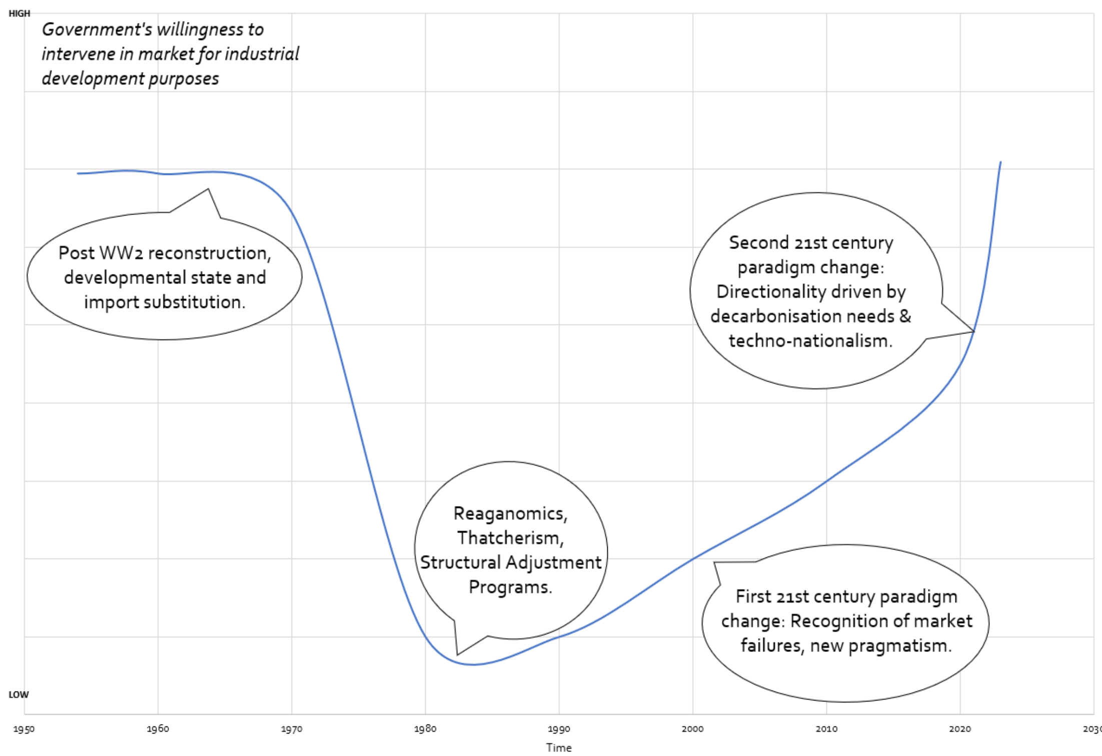
(ii) **Geopolitical rivalry, techno-nationalism and supply chain disruptions.** There is increasing emphasis on securing national supplies and protecting national industries in times of imperfectly functioning international markets. Two recent developments have clearly shown the limitations of free trade-based national supplies and triggered a round of protectionism and national industrial policy responses. First, political tensions between the big economic blocs, especially between China and the West and more recently between Russia and the West. The increasing geo-political and economic rivalry created a real threat of using trade embargos against the rivals, leading politicians and national industries to return to mercantilist policies to restructure their trade relations, supporting national champions in strategic industries, (such as semiconductors), banning foreign acquisition of strategic technologies (e.g., industrial robotics) and prohibiting the use of foreign technologies that are considered relevant for national security (Huawei case, 5G). Second, global supply chain disruptions at an unprecedented level, due to the COVID pandemic, the Ukrainian war and other events. The temporary energy and food shortages has disastrous knock-on effects (food crises, global inflation); the shortage of critical medical supplies in times of a pandemic showed the need for more distributed production capacities and

[1] One might see the digital acceleration as an additional game-changer, but the analysis of industrial policy responses in Germany (see chapter III) shows that these are more in line with the previous paradigm of light-handed market interventions.

greater national controls over supplies. All these trends created a new political legitimacy for putting national interests first and intervening in markets to become more independent. Mercantilism is back on the agenda, partly for good reasons, but also with all its risks of inefficiency, arbitrary interventions in markets and political capture.

These trends add up to a radical departure from previous assumptions about markets as the main drivers of structural transformation, especially when compared to the neoliberal paradigm of the late last century. Figure 1 illustrates how governments' willingness to intervene in markets for industrial policy purposes changed over time: from the Post-WW2 situation when reconstruction in post-war countries and import-substituting industrialisation in developing countries implied active industrial policy, to the neoliberal wave of the 1980 and early 90s, to an emerging consensus on pragmatic, light-handed interventions and most recently, the new wave of heavy-handed interventions to enhance technological sovereignty and accelerate decarbonisation.

Figure 1
Phases of industrial policy thinking and practice, 1950–2023



Source: Own elaboration.

This study explores these changes with a special focus on Germany, but it embeds the analysis in a discussion of trends in the major economic blocs of the world economy —China, the US and Europe—, considering that German policy changes are to a considerable degree direct responses to trends within the increasingly dominant economic blocs, the US and China, and their relationship. German industrial policies respond to global challenges in terms of climate change mitigation, geopolitical rivalry, securitization of industrial policy and increasing oligopolistic markets in strategic industries.

This study aims to make two contributions to the debate in Latin America and the Caribbean (LAC). Firstly, to draw attention to the need for the region to cope with the same trends in the world economy and, much like Europe and Germany, to define its position in an international economy that is increasingly dominated by two super powers and their mounting efforts to build or retain hegemony via interventions in trade and global value chains. Secondly, to document the recent industrial policy experience in Germany, which is an interesting case that may hold lessons for other countries, including those in the LAC region. Three factors stand out in the German case. First and foremost, it is a manufacturing industry powerhouse with a long-standing tradition in industrial policymaking and embedded autonomy; second in line, it is quite influential (together with France) in European policymaking; and finally, it is a trendsetter on some of the aspects of the recent industrial policy paradigm change.

The remainder of this study consists of four chapters. Chapter 1 provides a brief history of industrial policy in Germany and brings out certain features that make its national approach to industrial policy unique (and overall relatively successful), such as its corporatist structure, its pragmatism across all major political parties and industries, and its solid foundation in R&D and applied research institutions. This chapter also briefly explains the interrelations between national and EU-wide policies, as European nation states have delegated important competencies to the supranational level. Chapter 2 then zooms into the most recent phase of industrial policymaking that emerged in the last ca. 5-10 years, marked by the complex interplay of efforts to build and retain competitive industries, transitioning to green economies and coping with geopolitical rivalries in an increasingly mercantilist and hostile world economy. These new trends are analysed from a global perspective before zooming into Germany's industrial policy responses to the global challenges. Chapter 3 offers exemplary deep-dives into some specific German industrial policy initiatives, which illustrate the diversity of experiences in terms of challenges, policy designs, successes and failures of German industrial policymaking. Chapter 4 then briefly reflects upon implications for Latin America and the Caribbean, both in terms of addressing the new rules of the world economy and in terms of learning from German success and failure.

I. A brief overview of the genesis and special characteristics of industrial development and policy in Germany

A. Germany's industrial competitiveness – an overview

Germany's economy is overall very competitive. It ranks 15th in the Global Competitiveness Report (IMD/ World Competitiveness Centre, 2022). Germany's economy is highly export-oriented; its share of exports in GDP (50.3% in 2022) is among the highest worldwide.[2] Germany ranks third on the global Economic Complexity Index,[3] which measures a country's productive capabilities. Highly diversified productive capabilities make it easier to recombine capabilities in order to enter new sectors and drive future economic development (Hidalgo and Hausmann, 2009). Manufacturing value added (MVA) contributes 19.9% to German GDP, far beyond the percentage of other large economies,[4] with the notable exception of China. Main exports are in knowledge-intensive industrial products: motor vehicles and parts thereof (15.6% of total exports), machinery (13.3%) and chemical products (10.4%).[5] These in turn are strongly associated with high-value service activities, such as engineering and sophisticated logistics.

What is striking in comparison with other major industrialised economies is the diversity of firm sizes, with an exceptionally competitive *Mittelstand* (medium-sized enterprises). Many Mittelstand companies (called the "hidden champions" (Simon, 2009)) are world market leaders in specific niche technologies, others are specialized suppliers to large firms, for example in the automotive industry. As a general pattern, small and medium-sized companies *complement* large firms in activities where economies of scale are less important, rather than trying to compete with them. The latter is often the

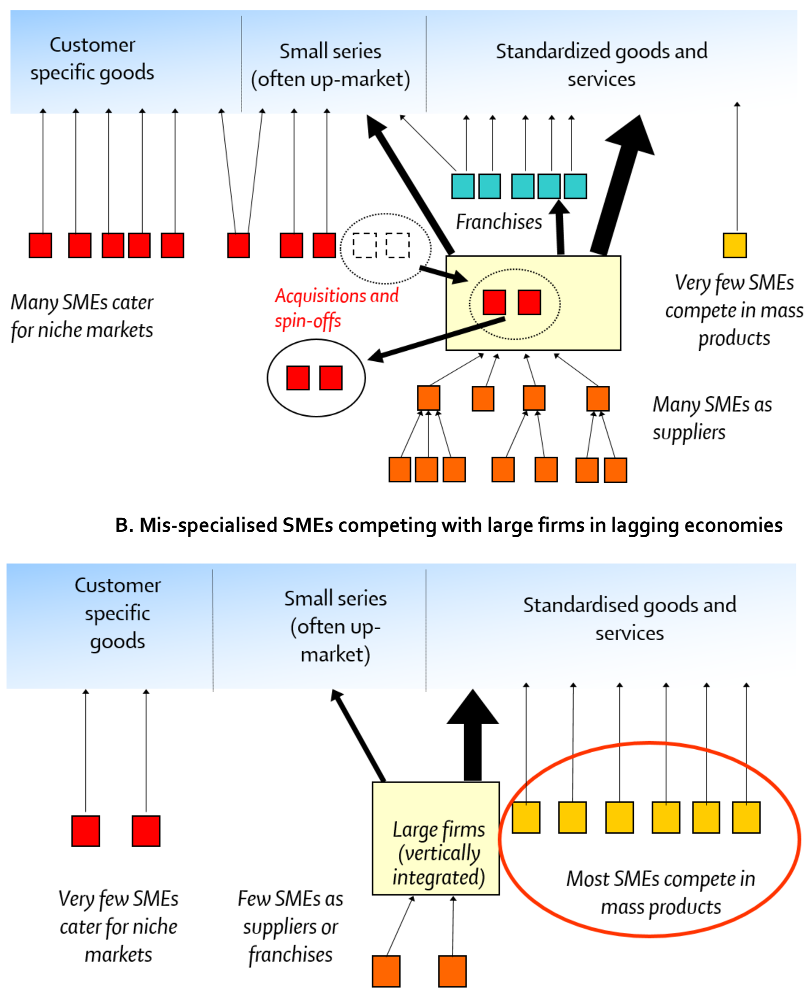
[2] https://data.worldbank.org/indicator/NE.EXP.GNFS.ZS?locations=DE.
[3] https://atlas.cid.harvard.edu/rankings.
[4] The US, United Kingdom, France and Spain are all in the range of 10 or 11%. https://w3.unece.org/SDG/en/Indicator?id=129.
[5] https://www.destatis.de/EN/Themes/Economy/Foreign-Trade/trading-goods.html.

case in countries with large shares of necessity entrepreneurship and whose technical and vocational training systems are not strong enough to build the capabilities required by a specialised and efficient SME sector (Altenburg and Eckardt, 2006; see also Diagram 1).

Diagram 1
Germany: Patterns of small and medium vs. large firm specialisation in economically advanced and lagging economies

A. Specialised SMEs complementing large firms in advanced economies

B. Mis-specialised SMEs competing with large firms in lagging economies



Source: Updated from Altenburg and Eckhardt (2006).

Germany's strong industry performance is underpinned with a strong national innovation system (Allan, 2015) and high investments in R&D (3.1% of GDP). Germany has a wealth of specialised researchers in dedicated institutes such as the Fraunhofer Society, one of the world's leading institutions for application-oriented research comprising 76 institutes with more than 30,000 employees. These explore future-relevant key technologies in close collaboration with industry. Similarly, there are Technical Universities and Polytechnics all over Germany (Fletcher and Fasteau, forthcoming).

Yet, the country's economy also has weaknesses, which explain why Germany has fallen back to rank 15 on the Global Competitiveness Index. One is its relative neglect of digitalisation both in the economy and the society more broadly (see also chapter III.A). On the European Commission's Digital Economy and Society Index 2022, Germany is close to the EU average, clearly behind Europe's most advanced digital economies, which include Finland, Denmark, the Netherlands and Sweden (European Commission, 2022).

Another weakness is the country's deficient start-up culture. Entry of new firms is considered to be important for innovation and competitiveness, as new market entrants challenge incumbent firms; even if many start-ups fail, the surviving ones bring new business ideas that may outcompete existing ones or force incumbents to adapt to them. Firm entry, exit and adaptation thus drive innovation, yet this "churning" happens much less than in other major industrial economies. As a result, while the USA and China are continuously producing "unicorn" companies (privately held start-up companies valued at over US$1 billion), these are rarely developing in Germany —even less than in other European countries.[6]

B. Genesis of Germany's industrial policy

Historically, Germany was a latecomer vis-à-vis England, hence when it started to industrialise, it had to do so against a technologically much more advanced competitor who in addition had used its decade-long monopolistic position to create enormous economies of scale in production. In the 19th century, Germany set out as a loose confederation of competing regions, yet some of them, especially Prussia, started using trade protection to systematically build industries, following the ideas of Friedrich List (1841). In addition, state support was given for big firms, or cartels of firms, and applied research was promoted. In 1871, Germany was unified in the "Deutsches Reich" (German Empire), which soon adopted a developmental approach to nurturing big industries, not least with military interests in mind. German industry started to thrive in steel, coal, chemicals, glass and other big industries. It also started to lay the foundation of its strong national innovation system, with the formation of technical universities with close links to industry as well as a unique technical and vocational training system. A banking system emerged that was strongly embedded in regions and also maintained close ties with industry (Fasteau and Fletcher, forthcoming).

Post-war industrial policy was ideologically market-oriented, yet with many pragmatic deviations, both to mitigate the socio-economic effects of sunset industries and to nurture strategic new industries. The most prominent examples of industrial policy efforts to cushion industrial declines targeted the coal and steel complex and shipbuilding:

- When Germany's coal mining industry fell into crisis due to cheaper imports of fossil energy sources in the late 1950s, it was heavily subsidised to mitigate the loss of employment and deindustrialisation of the coal-mining regions and to maintain national energy sovereignty. From 1958 to 1967 alone, this industry was subsidised to the tune of DM 17.1 billion (Grabbas and Nützenadel, 2013, 39 f.).[7]
- Since the 1960s, the competitiveness of the German shipbuilding industry declined vis-à-vis East Asian shipyards. German shipbuilding received DM 2.44 billion between 1966 to 1975 (ibid., 40).

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[6] https://www.cbinsights.com/research-unicorn-companies.
[7] This was in the order of 4.3 billion US$, author's own calculation.

Both subsidy schemes were unable to maintain the respective industries. Coal mining was given up, and shipbuilding only survived in small market niches.

In contrast, support for new industries as well as transitions of competitive industries were often successful. Nuclear energy technologies were developed in the 1960s with a strong mission-oriented approach. The Airbus project, a joint undertaking of four European countries, allowed to create a new industry and catch up with the American rival Boeing (Neven and Seabright 1995; Ahrens, 2020). Essentially all sectors that had to adapt to new challenges —such as the automotive industry transition to electric drives— have received industrial policy support, and most sectors managed to adapt fairly well. Only few sectoral policies can be considered failures. This includes Germany's support for Maglev trains and the fast breeder nuclear technology, which despite heavy support never reaches a commercial scale.[8]

C. Key characteristics of Germany's industrial system and policy

Over time, Germany's industrial system and policy have developed some specific characteristics, which are summarised below:

- A clear and pragmatic commitment to sector-specific industrial policy. This has been maintained regardless of the respective government coalition, party affiliation of Ministers of the Economy, and prevailing ideologies.
- Germany has a specific "corporatist" industrial governance, with cooperative relations between employers and workers, both at the firm level and in terms of institutionalized collective bargaining between employer organisations and unions. This results in very low levels of labour turnover and relatively few labour conflicts.
- There is a strong system of Technical Universities, Polytechnics and dedicated industry research institutes. All these institutions maintain close ties with industry and incentive systems rewarding industry collaborations, e.g. professors are appointed based on industry exposure, and public funding increases with the amount of industry-financed projects.
- An efficient technical and vocational training system —publicly funded, but closely co-managed with the private sector— is another key feature. Trainees get instructions at the firm level during three to four days a week and up to two days at vocational school. The companies bear the costs of the in-company training.

Overall, Germany's industrial policy systems is a prime example of what Peter Evans (1995) called "embedded autonomy": public institutions continuously engage with private firms and business associations to understand sector-specific trends and where, what kind of, and how much public support may be needed for how long to enhance national competitiveness; they are *embedded* in the enterprise sector. At the same time, public institutions have safeguards to prevent lobby groups from abusing of public support, hence they try to maintain the required *autonomy* in order to be able to enforce regulations and provide just the level of support that is required and justifies to compensate for market failures. The optimal balance of embeddedness and autonomy is arguably not easy to find and requires experimentation and adaptation; yet it is important for financial institutions, investment promotion and similar economic support agencies, technical universities, vocational training institutes and other institutions working with firms with a national development agenda.

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8 It should be noted that it is very challenging to prove success or failure of industrial policy for lack of counterfactual; moreover, industrial policy is about governments deliberately taking risks to create new market opportunities where the private sector does not, due to a range of market failures, chiefly the markets' limited ability to ensure coordinated investments. As Rodrik (2014, 472) argues, "mistakes are an inevitable and necessary part of a well-designed industrial policy programme; in fact, too few mistakes are a sign of *underperformance*. What is needed, instead, is a set of mechanisms that recognizes errors and revises policies accordingly.

Another important characteristic of German industrial policy is its multi-level governance. Germany is a federal republic consisting of 16 (federal) states —the "Länder". The German constitution grants them far-reaching competences. "Improvement of the regional economic structure" is a shared responsibility of the federal and State governments. The focus here is on strengthening the economic development of lagging regions and their ability to cope with economic transformations, thereby contributing to equal living conditions in the federal territory. Hence, support schemes exist with funding from the federal government as well as the states ("Länder"). Below the level of *Länder* are the municipalities, which have additional competencies for the promotion of the local economy, mainly the development and brokerage of industrial development zones, location marketing and the promotion of business start-ups.

D. Embeddedness in the European Union policy frameworks

At the same time, German industrial policy is increasingly embedded in European Union (EU) policy frameworks. With increasing economic and monetary integration of the EU, many industrial policy decisions have been delegated from the nation states to the European Commission and the European Parliament. National policy space has thus voluntarily been reduced, recognising the need for harmonisation of trade and industrial support policies of European integration. The Lisbon Programme of 2005, a "policy framework to strengthen EU manufacturing" set out the EU's first ever integrated approach to industrial policy. Since then, an increasing part of the legislation shaping the regulatory environment for industry has been created at the European level.

The EU can develop general policy frameworks that are not fully binding, but also "directives" that oblige member states to adapt national legislation within a defined period of time, and "regulations" that member states must apply exactly as defined at the EU level.

When tensions arise between national industry interests and European policymaking, national lobbying and complex negotiations start. For example, national energy systems differ considerably across Europe, and national industry interests in exploiting coal, gas, nuclear or renewable energy are thus very different; similarly, many tensions arise between countries that are mainly importers of certain technologies and those with export industries: for example, auto-manufacturing countries are lobbying against stricter environmental norms supported by the majority of those member states that do not have a significant national auto industry but an interest in clean air.

Hence, compromises have to be negotiated. Large countries typically have more bargaining power than small countries, and big industries deploy considerable resources to lobby EU institutions. In any case, European policies affect national industry interests, and policymaking becomes more multi-layered and complex. Some of the more ambitious green industry initiatives started at the EU level, which then led to subsequent changes in national policies.

After the Lisbon Programme, many other joint European policy frameworks followed.[9] Some of those address general approaches to strengthening European industrialisation and competitiveness, such as "A Stronger European Industry for Growth and Economic Recovery" (2012), which stated the need to reindustrialise, setting a target to raise the share of industry in GDP from 16% to 20% by 2020 and returned to a more targeted approach, identifying six priority action lines; and the "European Industrial Strategy" (2021). Others focus on specific global or regional challenges, such the 2008 'Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan' and the

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[9] https://www.europarl.europa.eu/factsheets/en/sheet/61/general-principles-of-eu-industrial-policy. Also: President von der Leyen's Political Guidelines; European Council's Strategic Agenda 2019-2024; Commission's Strategy on Shaping Europe's Digital Future.

"European Green Deal" on greening European industries as well as the Critical Raw Materials Act.[10] Also, there are plans and schemes for developing specific key enabling technologies, such as the space, the rail and the steel industry (Tagliapietra and Veugelers, 2023). A particularly relevant new development is the Important Projects of Common European Interest (IPCEI) framework, which funds specific strategic industries, the first two targeting battery cells and European production and use of climate-neutral hydrogen (Krebs, 2023). Also worth mentioning are the European Regional Development Fund (ERDF) whose purpose it is to reduce disparities between the levels of development of European regions and improve living standards in the least-favoured regions, and the Research and Development Programme Horizon Europe.

The various levels —EU, federal government, state governments and municipalities— thus add up to a multilevel governance system for industrial policy. German industrial policy needs to be understood as the outcome of a complex interplay between these levels. This is why the European dimension is considered in the following chapters as well.

[10] https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en.

II. A new era of more interventionist industrial policy: responding to interrelated mega-challenges

A. Recent trends in industrial policymaking

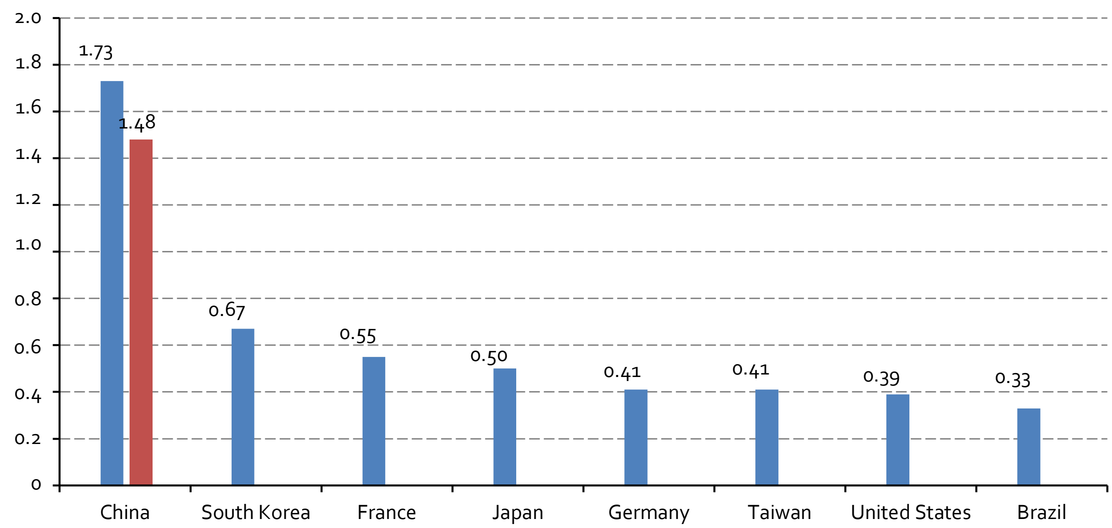
The global conditions for industrial development have changed drastically within a few years. The following two trends are standing out:

(i) **Greening of industries:** environmental challenges oblige societies to profoundly change their industrial structures, decarbonising industries and reducing consumption and waste of materials;

(ii) **Geopolitical rivalry, techno-nationalism and supply chain disruptions:** tensions between main economic blocs are rising, especially between the US and China and since the invasion of Ukraine also between Russia and the West. Especially the US-China rivalry reshapes the world economy and industrial policies, as both countries aspire for technological and market leadership which in many industries is closely related with national security; hence, all major economies are now nurturing and protecting strategic national industries.

Both trends have one thing in common, even though the underlying motives are very different: They all trigger a strong return of industrial policy, and a fairly heavy-handed, interventionist form of it, that constitutes a radical departure from a free market ideology and goes far beyond the industrial policy approaches that had become mainstream in the early 2000s. Figure 2 shows how much major industrial economies spend on industrial policy.

Figure 2
Industrial policy spending in key economies, 2019
(*As percentages of GDP*)



Source: diPippo, Mazzocco and Kennedy (2022).
Note: Estimates only consider instruments with sufficient data for quantification. China estimates are conservative. The right China column excludes some China-specific factors that are not comparable to other countries.

At the same time, both trends are interdependent —which further increases the complexity of industrial policy strategies: Green Deals are designed as protectionist policies for domestic value creation and thereby lead to a subsidy race and increased tensions between economic blocs; geopolitical rivalry is fierce when it comes to scarce inputs for the green transformation, such as lithium and rare earths. Policymakers need to account for such interdependencies and trade-offs.

The following two sub-sections discuss the two main game-changers in greater detail. In each section, the global trends are first characterised in general before Germany's (and, where necessary, Europe's) responses are analysed.

B. Greening of industries

1. Global trends towards green industrial policy

Environmental pollution (IPCC, 2023) and depletion of natural resources (UNEP, 2011) have reached alarming levels. This has now been recognised by the international community, and agreements have been signed to curb climate change (*United Nations Framework Convention on Climate Change*), protect the biodiversity (*Convention* on *Biological Diversity*) and tackle many other environmental challenges, from the protection of the ozone layer to combating desertification. Strict implementation of these agreements, especially the required deep decarbonisation, would have far-reaching implications for the structure of economies. Entire economic subsystems need to change in the transition towards a resource-efficient low carbon economy, one that decouples natural resource use and environmental impacts from economic growth: The way energy is produced, distributed and used; how transport systems are organized; and essentially all agricultural and industrial processes. While there is typically a considerable time lag between the agreement on environmental targets and implementation (and progress is not fast enough to safeguard human life on earth!), the move towards greener economies is accelerating and seems to be irreversible.

Greener practices are proliferating in all parts of the global economy, as exemplified, among others, by rapidly growing market shares of renewable energy, electric vehicles, organic farming, green certificates, green standards in international agreements and the coverage of emission trading.

Climate change is the single most important environmental challenge affecting economies, as industries need to transform from fossil to renewable energy inputs. Decarbonising the energy system is a prime concern. As fossil fuels are replaced with renewable energy, other economic sectors can be electrified without generating many additional greenhouse gases. For example, the automobile industry shifts from internal combustion to electric engines, houses can be heated using heat exchangers. Then there are the so-called energy-intensive hard-to-abate industries that cannot be directly electrified, such as aviation, steelmaking and the production of fertilisers and other chemicals. Here, renewable energy is used to produce intermediate energy carriers, such as hydrogen or ammonia, which can then be used to decarbonise the hard-to-abate sectors.

In parallel with decarbonisation, consumption of materials needs to be reduced (UNEP, 2011). The objective is to reduce material throughput and resource depletion and to recycle and reuse as many resources as possible. Overall, political pressure for resource efficient practices and establishment of circular, closed-loop systems is still less intense compared to decarbonisation, yet new regulations are also coming up in this domain, especially in the Global North —such as the EU Circular Economy Action Plan. Circular economy regulations in the leading economies necessarily induce changes in global value chains, thus impacting on all trading partners (To, 2022).

Managing the overall green transition requires new forms of industrial policy. Green industrial policy has a number of characteristics that distinguishes it from "business as usual" industrial policies (Altenburg and Rodrik, 2017; Lütkenhorst et al., 2014). Among others, given that markets do not sufficiently pay attention to environmental externalities, governments need to create economic incentives for cleaner production. These can be price-based, such as carbon pricing and emissions trading, or regulatory, such as bans and mandatory minimum or maximum standards. Green industrial policy makes a normative distinction between desirable and undesirable technologies, and typically entails not only measures to phase cleaner alternatives in, but also roadmaps and incentives to phase polluting ones out. Moreover, green industrial policies are typically very ambitious, firstly because they aim at profoundly changing whole sectors (from fossil to renewable power plants and grids; from individualized combustion-engine transport systems to electric and public transport; from plastics packaging to bio-based materials and return systems, etc.), which in all cases requires manifold coordinated interventions; secondly, because systemic change needs to be achieved within short periods of time, especially when global warming is concerned, hence time for market-driven experimentation is limited and acceleration becomes a key concern. Last but not least, new forms of international coordination are needed to harmonise national efforts and avoid undesirable distortions, for example due to differences between national environmental regulations and subsidy regimes. Moreover, the Paris Agreement calls for low carbon technology sharing, which, however, conflicts with national interests to exploit early mover advantages in green technologies. Also, shifting to greener global supply chains alters international trade relations, and governments enter into all sorts of bi —and multilateral trade agreements, energy— and hydrogen partnerships and the like (see e.g. IRENA (2022)).

Green industrial policy is about managing the transition to resource-efficient low carbon economies in a way that creates new economic opportunities for national economies and reduces the unavoidable transformation costs. As greener technologies become the "dominant design" (Utterback and Suarez, 1993) in many industries, the economic opportunities related to green technologies are increasing rapidly. According to the International Energy Agency's estimates, the "global market for key mass-manufactured clean energy technologies will be worth around USD 650 billion a year by 2030, more than three times today's level, (European Commission, 2023a, p. 1). Industrial policies around the world are increasingly targeting these industries, aiming to maximize the national gains from the newly emerging industries and exploit economic co-benefits (Pegels and Altenburg, 2020). Examples include the US Inflation Reduction Act and Europe's Green Deal Industrial Plan (2023).[11] EU President von der Leyen's statement summarises this new perspective: "We have a once in a generation opportunity to show the way with speed, ambition and a sense of purpose to secure the EU's industrial lead in the fast-growing net-zero technology sector. Europe is determined to lead the clean tech revolution,"[12] including a range of direct subsidies for strategic industries and ambitious targets for value creation within the EU. Such interventions have increased around the globe. Taking the case of Local Content Requirements for renewable energy, Lewis (2021) documents an increase of Local Content policies from 4 (2008) to 56 in 2020, regardless of the fact that they are often violating the World Trade Organization's (WTO) principles.

Green industrial policy however is not without trade-offs. Many countries possess competitive advantages in industries developed during the fossil-fuel age, which, in their current form, are highly carbon-intensive —most obviously the oil, gas and coal industries. The more incentive systems go green, the more it erodes these industries. Moreover, energy costs increase at least temporarily as energy systems shift to renewables, negatively affecting the competitiveness of energy-intensive industries, from steel and cement to the auto industry and aviation, as long as not all countries agree on the same energy policies. Sequencing, compensations and transition management are thus needed with a view to societal acceptability.

Also, there is considerable disagreement with regard to the necessary speed of the transformation and thus the degree of market intervention, with regard to technologies that are considered environmentally sustainable and the risks involved in certain technologies (nuclear energy, gene editing, carbon capture and storage) and concerning the choice of policies. For example, many economists consider carbon pricing schemes as the single most important (Linsenmeier, Mohammad and Schwerhoff, 2023) policy instrument, arguing that market actors would develop the most efficient environmental solutions once previously externalised emission costs have to be internalised, whereas others point to additional market failures and/ or favour other, regulatory or subsidy-based approaches (Krebs, 2023). Overall, the importance of green industrial policy is mounting, but the topic remains fraught with political controversies.

2. Green industrial policy in Germany

Germany has been a trendsetter in greening its economic policies, even though with backlashes, as lobby interests from established industries have created delays and backlashes for the green transformation. The National Strategy for Sustainable Development (2002) established sustainability as a guiding principle for national policies and set concrete targets, which are evaluated via progress reports. With regard to renewable energy, Germany was one of the early movers. The feed-in-tariffs, by which governments guarantee renewable energy producers off-take of the renewable energy produced at an above-market price, where first implemented in Germany and then applied at an almost worldwide scale. This created a market for renewable energy projects and a thriving start-up environment. In parallel, dedicated R&D institutions, for example for solar and wind energy research were created. Some renewable energy industries are now internationally very competitive, yet China's massive low-cost competition has created severe problems, especially in solar energy technologies (see section III.A for a detailed account).

Germany was also an early mover in terms of environmental fiscal reform. Already in 1999, a tax reform was introduced that increased taxes on fossil energy and decreased the taxation of labour. This

[11] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_510.

[12] ibid.

created an incentive to steer investments towards cleaner alternatives while at the same time boosting labour demand in times of high unemployment.

In other green technologies, Germany was not among the early reformers. In the automotive industry, enormous success in traditional combustion engine technology discouraged investments in hybrid and battery-electric powertrains. Japanese advances in hybrid engine technology and especially progress on lithium traction batteries then put German carmakers in a difficult situation, as Germany had almost no expertise in battery research and technology. America's Tesla, Japan's Toyota (in mild hybrid technology) and later Chinese, Japanese and Korean battery manufacturers expanded without Germany being able to compete. Still, the auto industry managed to largely close the technology gap in electric vehicles and also made major investments in battery technology. This catching up was supported by a well-coordinated electric vehicle sector policy (national platform electromobility) that, in Germany's corporatist traditions, integrated big industry, ministries and research institutes in efficient task forces (Altenburg, 2014). It was further facilitated by the fact that automotive Original Equipment Manufacturers (OEMs) and other big industry players, such as Bosch and BASF, have enormous R&D budgets and a long-standing experience with technology alliances with foreign firms that offer complementing capabilities. At the same time, automotive policy is one of the few examples where German business and national policymakers (due to vested interests in the internal combustion engine technology) lobbied against an environmentally more progressive European Commission.

On the other hand, Germany's federal government has committed itself by law to achieve climate neutrality by 2045, going beyond the EU's 2050 target. This puts decarbonisation pressure on all German industries. The latest big push policy aims to accelerate the transition to green hydrogen in a way that hard-to-abate industries can achieve their decarbonisation targets, and German industry can exploit early mover advantages in the emerging green hydrogen industry. This industrial policy approach is discussed in detail in the section below.

3. Green industrial policy in the European Union

The European Union has been greening its industrial policy in parallel, with the 2019 European Green Deal as its key document, introduced by the Commission the EU's New Growth Strategy. It sets the target of achieving climate neutrality by 2050, thereby becoming the first economic bloc to achieve this. This is then further specified and complemented with more detailed policy documents, most importantly the Fit for 55 package which makes the goal of reducing EU emissions by at least 55% by 2030 a legal obligation. The package includes a reform of the EU Emissions Trading System (ETS), the most important building bloc of EU climate policy and sets binding emissions targets for member states in sectors not covered by the ETS, such as aviation. It toughens vehicle emission standards and energy efficiency targets and regulates a range of other industry-specific climate aspects. Other important plans specify the industrial policies (such as the Industrial Plan for the Net-Zero Age (European Commission, 2023a)) or related aim, such as accelerating the energy transition (REPowerEU Plan) and advancing towards material-saving closed cycles (Circular Economy Action Plan).

Complementing the European nation states, the EU thus fulfills a number of important roles in green industrial policy. It sets bindings targets and standards, which are then translated into national policies among the member states and ensures a unique carbon price within the region. In doing so, the EU contributes to harmonizing European national policies and building consensus among the diverging interests of the nation states.

While its key role so far has been to set environmental standards for the internal market, including a common carbon price, proactive support for industries has been limited. This, however, is now changing as a reaction to green industrial policy elsewhere, especially in China and the USA (see section below). The Net Zero Industry Act (European Commission, 2023b) explicitly aims at strengthening "the European manufacturing capacity of net-zero technologies and overcome barriers to scaling up the manufacturing capacity in Europe." These technologies are then clearly specified, in another move to overcome the previous focus on sector-neutrality. The Act defines a set of strategic zero carbon industries that are eligible for special benefits: solar photovoltaic and solar thermal technologies; onshore wind and offshore renewable technologies; battery/storage technologies; heat pumps and geothermal energy technologies; electrolysers and fuel cells; sustainable biogas/biomethane technologies; carbon capture and storage as well as grid technologies. The Act furthermore sets a "benchmark" to manufacture at least 40% of the EU's annual deployment needs by 2030 in the region. This is complemented with a new Carbon Border Adjustment Mechanism that imposes taxes on imports from regions where producers pay nothing or less for their emissions.

C. Geopolitical rivalry, techno-nationalism and supply chain disruptions

1. Global trends towards techno-nationalism

Recent years have seen a rapid deterioration of the relationship between China and the Western market economies and even more between Russia and the West since Russia's invasion of Ukraine.

China-US tensions have been triggered by a combination of Chinese economic catching up and a more self-confident Chinese foreign policy. On the one hand, Chinese firms started to threaten America's dominance in many industries. Chinese firms are the world's most successful exporters, increasingly outcompeting US and European firms, not only in low-, but increasingly also in high-tech markets (Atkinson and Foote, 2019). This led to an increasing deficit in the US trade with China —from 84 bn US$ in 2000 to 382 bn in 2022 (United States Census Bureau, 2023). Moreover, in its 14^{th} five-year plan (2021-2025), China aims to establish itself as an innovation-driven high-tech superpower. These aspirations are accompanied by strong political intervention in markets, including huge government subsidies for firms (diPippo et al., 2022), mandatory technology sharing, export controls and other measures that Western competitors perceive as unfair market distortions. For example, "the Chinese Development Bank committed sixty-two billion dollars in 2021 lending to support strategic emerging industries and advanced manufacturing —investing in both upstream and downstream firms."[13] This also comprises investments in green technologies. China accounted for nearly half of the world's low-carbon spending in 2022, surpassing US investments four times (Schonhardt, 2023).

At the same time, China pursues an increasingly active diplomacy to achieve a mix of international political and economic objectives. This includes heavy government investments in international infrastructure corridors under the Belt&Road Initiative (Huang, 2016) as well as securing access to critical raw materials, for many of which China now holds almost monopolistic shares of the global mining and processing capacities (Kalantzakos, 2020). Moreover, China is more and more aggressively claiming hegemony in the Pacific and threatening Taiwan, which it considers a Province of China. This creates conflicts with US hegemonic claims in the region, and especially the prospect of a Chinese invasion of Taiwan would have disastrous knock-on effects in the works economy, not least because Taiwan is the world's leading manufacturer of semiconductors, a strategic input to all major global industries including military uses (Miller, 2022).

The combination of these trends triggered strong protectionist reactions in the US. President Trump markedly increased trade protectionism, imposing a series of tariffs and tariff increases, mostly on China, but also on other trading partners. This was meant to protect national manufacturing

[13] See [online] https://www.atlanticcouncil.org/commentary/transcript/the-biden-white-house-plan-for-a-new-us-industrial-policy/.

industries and workers, but also to safeguard national security.[14] A number of other protectionist industrial policies followed, both under President Trump and his successor Biden:

- the Endless Frontier Act (2019) supporting investment in high-tech research vital to U.S. national security; this was later (2021) transformed into the Innovation and Competition Act aimed at confronting the multiple supply chain crises during the pandemic;
- the Defense Production Act, a law dating back to 1950, was activated in 2020 to oblige companies to produce medical goods for the national market and restrict exports of COVID-19 vaccines;
- the Chips and Science Act from 2022[15] offers a $280 billion support package to fund domestic research, enhance workforce training and lure investors to the US with tax credits. Support is targeted at specific key technologies, especially semiconductors, but also other industries that are considered strategic, including energy storage, and advanced computing. As one observer puts it: "Strategic public investment to shelter and grow champion industries is a reality of the twenty-first century economy. We cannot ignore or wish this away."[16] The Act is explicitly presented as a response to Chinese aspirations;
- the Inflation Reduction Act, also from 2022, adds a range of new incentives, especially targeted at investments in climate protection, including $369 bn tax credits and subsidies for firms conditional upon a high US-American local content or local assembly (Aghion, 2023) —with the effect that many multinationals relocated production sites to the US.

Many of these —American as well as Chinese— subsidies, tariffs and other protectionist measures are challenging the WTO's principles and the rules-based international trade system more generally. Yet, the US has through its veto power de facto suspended the WTO Appellate Body whose role is to resolve trade disputes. Hence there are currently hardly any international means for those suffering from the subsidy race between the US and China (Altenburg, Berger, Brandi, 2023).

In addition, the US government took action against several Chinese multinationals, for alleged security reasons, banning the sale and import of communication devices from Chinese smartphone manufacturers and network equipment suppliers Huawei and ZTE and legislating to achieve that no US-technology be supplied to Huawei. Similarly, there are attempts to ban the Chinese social media platform (the first law was just passed in Montana). While it is difficult to judge to what extent the alleged national security concerns are justified (and to what extent they may be motivated by the desire to harm a competitor), it is clear that securitization has become a key element of the national policy agenda. Many of today's key technological innovations, from semiconductors to rare earths and artificial intelligence, are dual-use – they are strategic for military as well as civil industries —which "further elevates the national security dimensions of industrial policy" (Johnston, 2023).

The COVID pandemic with its severe global supply chain disruptions and international competition for undersupplied goods —from vaccines to semiconductors— as well as Russia's invasion of Ukraine further eroded the previous belief in the benefits and reliability of free trade and the global

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14 See [online] https://www.brookings.edu/articles/did-trumps-tariffs-benefit-american-workers-and-national-security/#:~:text=While%20tariffs %20benefited%20some%20workers,or%20significantly%20improve%20national%20security.

15 For a more detailed analysis of the context in which this law is enacted, see [online] https://research.hinrichfoundation.com/hubfs/Capri%20Report%20-%20Jan%202020/Hinrich%20Foundation%20report%20-%20US-China%20tech%20war%20and%20semiconductors%20-%20January%2031%202020.pdf.

16 *National Economic Council Director Brian Deese's speech on US industrial policy as prepared for delivery at the Atlantic Council on June 23, 2021. The event transcript can be found* at https://www.atlanticcouncil.org/commentary/transcript/brian-deese-on-bidens-vision-for-a-twenty-first-century-american-industrial-strategy/.

division of labour, accelerating a "new cycle of escalation over protectionist or nationalist industrial policy trade and investment restrictions" (Johnston, 2023).

This has severe international implications. On the one hand, the subsidy escalation accelerates investments in socially desirable, especially green, technologies. Also, countries struggling to increase their policy space are now less restricted to do so. Even nationalization of industries is back on the agenda. While proponents of industrial policy may welcome this paradigm change, there are substantial concerns as well. The subsidy race between China, the US —and increasingly the EU, see below— greatly distorts markets in different undesirable ways:

- it creates imbalances between those who can subsidise (essentially China, the US and to a lesser degree Germany and France) and those who cannot;
- it hollows out the remainders of a rules-based international system;
- it may distort investment decisions by firms, making rent capture more lucrative than striving for efficiency, innovation and competitiveness; and
- it increases big corporations' leverage of politics, potentially undermining democratic control of government-industry relations.

These geopolitical tensions, the "new era of techno-nationalism" (Capri, 2020) and the securitization of industrial policy have also led to a rethinking of industrial policy in Germany and the EU.

2. The rise of techno-nationalism in Germany

In Germany, the Ministry of Economy published a new "Industrial Strategy 2030" (BMWI, 2019) that broke with some of the previous ideological foundations. The new strategy marked "the first time in decades that German officials openly contemplated a significantly augmented role for the state in promoting and protecting its industrial base, technological lead, and economic independence" (Germann, 2022). The strategy introduces the term "technological autonomy" and calls for measures to protect and retain control of the "relevant industrial substance" in Germany and Europe, to "avoid losses of expertise, and to retain self-determination in key fields of technology" (BMWI, 2019). The strategy foresees a stricter control of foreign acquisitions of "strategic" firms and even creates the option of a temporary state shareholding in companies to avoid unwanted foreign takeovers. The initial version also called for nurturing large industrial OEMs in order to be able to compete with US and Chinese rivals in scale-intensive economies, but this was watered down in the final version. The strategy further sets, for the first time, a specific target to increase the share of manufacturing value added to "25% of gross output in Germany by 2030" (ibid.). All these new, fairly heavy-handed interventions are justified by competition "with economic systems which rely more on state subsidies, protectionism and intervention" (ibid.). Bofinger (2019) therefore speaks of a "paradigm change in economic policymaking" —which, interestingly, was initiated by a conservative government and pushed through against strong criticism from the German Federation of Industries.

Since then, both the conservative government and the following coalition under social-democratic chancellor Scholz (and with a Minister of Economy from the Green Party) pursued interventionist legislative action. The government "has progressively tightened its oversight of foreign direct investment (FDI) to guard against Chinese acquisitions, and consistently pushed for greater discretion in applying EU and national competition rules to target US digital giants, foster inter-corporate alliances, and pour state money into selected growth industries" (Germann, 2022). In Summer 2023, two unprecedented subsidy packages were granted to foreign semiconductor firms investing in Germany: 10 bn € to Intel and another 5 bn to the Taiwan Semiconductor Manufacturing Company TSMC, arguing that this would increase the German economies resilience and dependence on semiconductor imports from Asia, amidst fears that China might use its market power against Europe or even invade Taiwan. Again, these subsidies evoked criticism from all corners of Germany society. The most relevant critique from an industrial policy perspective is that subsidies should be targeted at indigenous semiconductor R&D and local start-ups, or attracting R&D activities from foreign multinationals, rather than mass-manufacturing plants.

3. Techno-nationalism in the European Union

As in Germany, the discourse changed in the European Union. "Strategic autonomy" has become a new key concept, with implications reaching from defence policy to redefining Europe's approach to global value chains. The European Commission's "New Industrial Strategy for Europe" (2019) emphasised the need to become less dependent in the new geopolitical context, with China as a "systemic rival". The Commission also proposed a European Chips Act (2022), paving the way for subsidies to attract chip manufacturers to Europe. The EU also created a new instrument, the "Important Projects of Common European Interest (IPCEI)", to increase European technology sovereignty in critical industries. Eligible projects need to contribute to strategic EU objectives, be jointly implemented by several Member States and have very ambitious research and innovation objectives and be co-funded by consortia of firms. Such projects can then be subsidised beyond the otherwise existing state aid rules. The six IPCEI that so far are being supported relate to microelectronics, battery research and hydrogen, all critical technologies with significant spillover effects across industries. Another area of strategic interest for the EU is access to critical raw materials, such as lithium or cobalt, that are essential for the shift to a net-zero industry. The "Critical Raw Materials Act" (2023)[17] sets benchmarks for domestic capacities in extraction, processing and recycling of strategic raw material as well as to diversify international source of EU supply, again with a view to "strategic autonomy", here specifically from China's dominant role in raw material supply chains.

Overall, European economies are relatively small (compared to the US and China) open economies and depend on foreign trade to a very high degree, especially in the case of Germany, and most do not have substantive means to enter a subsidy race or deploy foreign policies to secure global supplies. Hence, Europe's and Germany's response to techno-nationalism and protectionism has to be balanced —also because member state governments have different views on protectionism vs. free trade. The "New Industrial Strategy for Europe" states that "Europe's response cannot be to erect more barriers, shield uncompetitive industries or mimic the protectionist or distortive policies of others. Being competitive requires competition —both at home and in the world" (European Commission, 2020). Similarly, all German strategies stress the adherence to free trade principles and a rules-based WTO. On the other hand, new European and German policies are increasingly designed to counterbalance the renaissance of "industrial policy nationalism" (Johnston, 2023) in China and the US.

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[17] See [online] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1661.

III. Case studies of specific industrial policies

This chapter provides three examples of sector-specific industrial policy-making. These have been selected to illustrate some of the specific features and challenges of industrial policy-making in Germany, hence they complement the bird's eye perspective of the previous chapters.

The three case studies have a common structure. They all:

(i) Start by analysing the specific societal challenges they address,

(ii) then discuss the concrete policies employed,

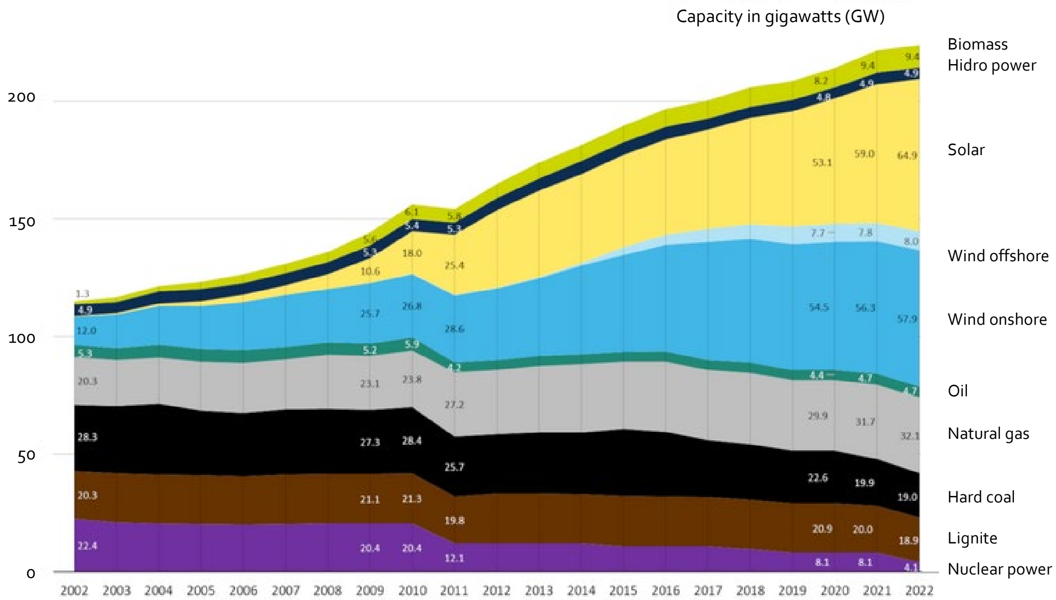
(iii) and finally assess to what extent Germany has succeeded or failed.

At the same time, they are all very different with regard to objectives, international repercussions, level of intervention in markets, etc.

A. Solar and wind energy: successful market development, less successful industrial development

Solar and wind energy are crucial to replace environmentally harmful and unsustainable energy carriers that dominated the German energy mix in the past: hard coal, lignite, natural gas and nuclear power. Figure 3 shows how the energy mix changed within only 20 years.

Figure 3
Germany: installed net power generation capacity 2002-2022



Source: Fraunhofer ISE, 2022 (https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts).

The challenge of renewable energy projects, and thus the case for public policy, is that the true social costs of fossil (in terms of global warming and air pollution) and nuclear energy (melt-down of reactors, radioactive pollution, final disposal of nuclear waste, weapons proliferation) are not internalised in firms' investment decisions. This allows energy utilities to offer low-priced electricity against which renewable energy projects could, at least in the beginning, not compete. The task for policymakers was then to enact reforms to a) price externalities and b) support the desirable clean technologies through a range of industrial policies, thereby enabling technological learning and economies of scale that would bring costs down and make renewables cost-competitive.

There is an ongoing debate among policymakers whether pricing externalities would be sufficient to steer investment towards clean and safe technologies —from an economic perspective the most market-friendly first-best option. Imposing the true social cost on producers, however, can only work if the respective pricing mechanisms are applied to all competitors worldwide; otherwise, energy-intensive industries (for tradable goods at least) would shift to locations where policies are not enforced to the same degree (carbon leakage). Since such international harmonisation could not be achieved, German policymakers opted for combination of proactive support of clean technologies and gradual introduction of pricing policies.

To support solar and wind technology, Germany was the first country to enact a green electricity feed-in tariff scheme in 1991. This was later developed into the Renewable Energy Sources Act (Erneuerbare Energien-Gesetz) that obliged grid operators to connect and preferentially dispatch renewable energy, plus the guaranteed a fix feed-in tariff for 20 years (Renn and Marshall, 2016). These fixed long-term subsidies proved to be extremely successful in boosting investments, but also became very costly, as prices of renewable energy technologies came down which meant that guaranteed prices were far above market prices. This led to a reform in 2017, ending the fixed funding rates and introducing an auction scheme to determine more realistic funding rates.

In addition to renewable energy pricing schemes, dedicated research and development and technology demonstration programme were set up.[18] The German federal states also supported renewable energy through a variety of policies. For example, there are support schemes for creating regional value chains in the wind turbine industry in northern state of Schleswig-Holstein and solar energy cluster programs for Freiburg in the South and in the central region (Solar Cluster Mitteldeutschland). This is helpful to account for different resource endowments and political priorities, but it also comes at a cost as "the present multi-level governance structure does not provide for the necessary integration of national and subnational energy policies" (Ohlhorst, 2015).

In 2022, after the Russian invasion of Ukraine which exposed German dependency on Russian gas imports, the 2030 target for the share of renewables in power consumption was increased to at least **80%. Onshore wind capacity should be doubled and solar capacity more than tripled by 2030.** This would be achieved via a package of new policies, including more generous subsidies for offshore wind projects, the obligation to make 2% of Germany's land area available for onshore wind turbines[19] and higher feed-in tariffs for solar rooftop installations.[20]

In parallel, pricing of externalities was introduced gradually, albeit slowly. First, the environmental tax reform of 1999-2002 taxed fossil energy, and second, Germany lobbied for a European Union's Emissions Trading Scheme (ETS), to ensure a level playing field in Europe. This scheme was introduced in 2004, but European governments allocated too many free certificates to effectively incentivise emissions reductions. This changed significantly with a reform in 2018 that reduced the number of certificates and thereby induced a sharp increase of emission costs for firms, finally making the ETS an efficient instrument to steer investments towards low carbon. Consequently, the price went up from 5 €/ton in 2017 to fluctuating around 80 €/ton in 2023 (Sandbag Carbon Price Viewer, 2023).

While this is the purpose of the ETS, it obviously undermines the competitiveness of European producers in energy-intensive tradable goods and services. This then led to efforts to introduce a Carbon Border Adjustment Tax to shield European producers from unfair competition.

The packages to support renewables and discourage greenhouse gas emissions created a strong demand push for renewable energy technologies and incentivised technological innovation in Germany. Especially the early adoption of the Renewable Energy Sources Act made production economically attractive in Germany at a time when incentives for renewables were negligible in the world economy. Energy became more expensive for German industry and households, but the policies created a strong early-mover advantage for industry. As a result, especially the solar panel and the wind turbine industries recorded a phase of phenomenal growth, starting in the mid-1990s in the onshore wind turbine industry, around 2000 in solar photovoltaics (PV), and around 2010 in the offshore wind industry. During this golden age, the onshore wind industry's net electricity generation grew from 1,500 (1995) to 56,000 GWh in 2014, the solar PV industry from a negligible production level in 2000 to 35,000 GWh in 2014 (German Environment Agency, 2014). This made Germany the world's largest solar PV producer at that time (Lütkenhorst and Pegels, 2014). The emergence of renewable energy markets triggered efficiency improvements and created economies of scale that brought production costs down[21] at an

[18] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2013/GWEC/GWEC_Germany.pdf?la=en&hash=DD3A50E77910814C87F7E9B783273289F64F0F76.

[19] https://www.energypartnership.cn/home/current-changes-in-germanys-energy-and-climate-policy/.

[20] https://www.cleanenergywire.org/factsheets/germanys-2022-renewables-and-energy-reforms.

[21] …."between 2006 and 2012, prices fell by roughly two thirds, from € 5,100 to € 1,750 per kWp. In 2012 alone, solar module prices tumbled by 45 per cent" (BSW-Solar, 2013).

unexpected and relatively unprecedented speed, hence installations became much cheaper while feed-in-tariff prices remained at the guaranteed high price. Renewable energy projects thus became ever more lucrative, which further boosted demand.

In both the wind and solar industries, complex industrial eco-systems emerged, and German producers were among the leaders at almost any stage of the value chain (Grau, Huo, and Neuhoff, 2012). The solar industry requires production of silicon wafers, further processing into cells (crystalline or thin film technologies) and modules (which in turn demands specialised glass and frames) as well as system components such as converters, connectors and cables. Equipment is needed for laser processing, thermal management, wet chemistry and others. The wind industry comprises producers of towers, tubes, foundations, blades, wind energy converters, mechanical (such as hydraulic equipment, generators, gearboxes, bearings and brakes) and electronic components (automation, controls, power converters, transmission systems, etc.). Offshore wind is even more sophisticated, requiring larger wind turbines, steel and cement structures and underwater grid connections. In addition to manufacturing value added, many services are required services both in wind and solar, such software solutions to optimise systems for solar and wind systems efficiency, project development and finance, site selection, maintenance and repair. In parallel, many specialised research institutions emerged, including Fraunhofer ISE, Europe's largest solar energy research centre, today employing some 1,400 employees.

After 2012/13, however, the solar photovoltaics industry went into a crisis. Firstly, China had learned to produce solar cells and modules and, with significant government subsidies and low production costs, quickly outcompeted most other producers worldwide, including those in Germany (Quitzow, Huenteler and Asmussen, 2017). In 2023, Germany imported 87% of its solar cells and modules from China.[22] Moreover, feed-in-tariffs in Germany were reduced, shrinking the domestic market. Many German producers (including Q-Cells, previously the global leader in solar cell production, Solon, Conergy and SolarWorld) declared bankruptcy, ceased production or were taken over by competitors. 70,000 jobs were lost in the German solar industry, according to industry experts.[23]

Despite this overall loss of international competitiveness in the international market for solar panels, the story of solar energy development is at least a partial success. Firstly, German firms are still competitive in some high-tech segments of the industry, such as solar inverters and integrated solutions for energy storage at home. Secondly, the internal market is now again flourishing, and with it the creation of firms and employment. There is now a renewed policy impetus on climate change mitigation. More ambitious renewable energy targets have been set, and more favourable support schemes were again introduced. The German government has set the target of an 80 % share of renewables in the national electricity mix by 2030, up from about 50% in 2022. Total national solar energy capacity is planned to reach 215 GW by 2030, up from about 63 GW in 2022. This is expected to revive the solar industry and boost employment. Today, solar employment is essential in providing services for the internal market and developing advanced software solutions.

Given the fact that cells and modules are almost entirely imported, there is very little employment creation in solar manufacturing (as compared to installation and maintenance). Yet, this again may change with Germany's and Europe's renewed interest in reducing import dependence on China. The European Union's Net-Zero Industry Act, proposed by the European Commission in March 2023 (but not yet ratified), foresees that 40% of all solar panels installed in Europe be produced in Europe by creating import protection and other support for manufacturers in the region.

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22 https://taiyangnews.info/markets/germany-imported-e3-6-billion-solar-pv-systems-in-2022/.

23 https://www.npr.org/2023/05/02/1173247358/germany-aims-to-revive-its-solar-power-industry-which-was-booming-a-decade-ago.

While energy generation is rapidly expanding in both types of renewable energy in Germany, the wind turbine industry has performed better than the solar photovoltaics industry in terms of employment, innovation and international competitiveness. As in solar, Germany had an early mover advantage when it started investing in wind energy 40 years ago. Only few other countries anticipated this industry's growth potential at that time, including Denmark, Spain and the USA. Germany's renewable energy policies provided opportunities for investment and technological learning. Several German companies became world market leaders and successful exporters. Today, 25% of Germany's electricity demand is covered by wind energy; employment in this industry stand at 130,000 in 2021 (BWE, 2022).

Yet again, the industry is now in a difficult situation, mainly for two reasons:

(i) Firstly, Chinese firms rapidly caught up with the pioneering nations and built internationally successful companies. While the Chinese market initially provided considerable export opportunities for German wind turbine manufacturers, the Chinese home market is now largely served by national firms, and these also compete in the global market.

(ii) Secondly, Germany's internal market lost its initial dynamism. Local communities increasingly reject the construction of infrastructure of supra-regional importance, such as wind parks and energy transmission lines, in their neighbourhood, even though in principle they are in favour of the energy transition. This has been called the NIMBY ("not in my backyard") phenomenon. Conservative state governments in particular often sided with local protesters to block renewable energy investments. Hence, there are ongoing disputes, especially with regard to the minimum distance between wind parks and residential areas. This led to a shift towards offshore wind parks, yet these are located in the North of Germany, in the Northern and Baltic Seas, whereas most electricity is consumed in the South, calling for long-distance transmission lines, which in turn are blocked by local citizen groups.

Due to these two developments, industry growth slowed down, employment went down to 130,000 and manufacturers started accumulating losses.

Despite these difficulties, the German wind turbine industry has been much less affected than the solar photovoltaics industry. Three German-based companies (now partly international joint ventures) are still among the global top 10 of the wind turbine industry (Siemens Gamesa, Nordex Group and Enercon). Pegels and Lütkenhost (2014) compared performance indicators of both industries showing that the wind turbine industry performs better on all dimensions: cost per Kwh, revealed comparative advantage, share in global patents and employment creation. While competitive advantage has been lost with regard to smaller size inshore wind turbines, Germany is still at the technological frontier in more sophisticated market segments, namely large-scale turbines and offshore technology.

Germany's current government coalition, with a Minister of Economy and Climate from the green party and in light of the need to decrease dependence on gas imports from Russia, enacted a policy package to revitalise the wind energy sector. As one measure to accelerate the roll-out of wind parks, it adopted a law requiring Germany to set aside 2% of its total land area by 2032 for wind energy use. As a measure to increase acceptance of wind parks in communities, the instrument of "citizen wind farms" was created, whereby the local population is offered a share in the project. In addition, land use planning procedures were streamlined to speed project implementation up, and financial support to offshore wind parks was increased.

Overall, the case study shows the importance of early market creation for green technologies, given that such technologies start with strong disadvantages compared to polluting incumbent technologies. The Renewable Energy Sources Act has been the most important instrument here, providing an early mover advantage to German industry. Although much of the early mover advantage has now vanished, with other nations taking market shares, both the solar and the wind industry are now important parts of the German industry structure. Yet, it also shows the importance of proactive industrial and innovation policy to fully exploit the opportunities provided by market-creating instruments —and this is where German policy has been less supportive and successful. A former director of Germany's leading solar energy research institute stated that "Germany's energy policy has created a market for photovoltaics – not an industry".[24]

B. Green hydrogen: ramping up a nascent industry

Green hydrogen refers to hydrogen produced with renewable energy. It is indispensable for the decarbonisation of economies, especially for the so-called "hard-to-abate" industries that cannot be decarbonised using green electricity directly. This includes high-temperature heating for the production of steel, feedstock supply for chemical products (for example, ammonia for the production of fertilisers) as well as heavy-duty freight transport, maritime shipping and aviation. Renewable energy is used to split water into hydrogen and oxygen ("electrolysis"), and the energy-intensive hydrogen is then used directly to generate electricity in fuel cells or to produce chemical derivatives, such as ammonia and methanol (which can be used as feedstock for a variety of industrial processes) and sustainable aviation fuel (SAF). Hydrogen and its derivatives make renewable energy storable and enable long-distance transport. Competing with green hydrogen is blue hydrogen as another low carbon alternative. This is hydrogen produced from natural gas with carbon capture and storage, which is less sustainable, but widely accepted as a bridge technology.

Given ambitious decarbonisation plans in the hard-to-abate industries, demand for green hydrogen is booming. Deloitte (2023) expects the global "clean" hydrogen market to reach a capacity of 170 million tons (MtH2eq) in 2030 and 600 MtH2eq in 2050, corresponding with US$642 billion in annual revenue in 2030 and US$1.4 trillion per year in 2050.

Currently, green (and blue) hydrogen are more expensive than fossil fuel-based alternatives, but major initiatives are underway to develop a global green hydrogen market and bring costs down through economies of scale and technological learning. IRENA estimates that green hydrogen will become cost-competitive with less sustainable alternatives by the mid-2030 (IRENA, 2020). More specifically, "the breakeven point can be reached by 2030 for ammonia, 2035 for gaseous hydrogen, 2045 for methanol, and 2050 for SAF" (Deloitte, 2023).

The green hydrogen market is nevertheless already starting to unfold, as some industries (for example, aviation and steel) are willing to pay high prices to start their technological learning processes, and some governments (including Germany's) are willing to subsidise the price differential between production costs and offtake prices. With these incentives for market ramp-up, big hydrogen investments are now undertaken, with many more at the feasibility stage. For Europe alone, the European Clean Hydrogen Alliance assembled a list of 840 investment projects ranging from hydrogen production and transmission and distribution to applications in industry, transport, energy systems, and buildings.[25]

As stated in the previous section on the specificities of green industrial policy, the market for green hydrogen is almost entirely policy-driven —by politically-set decarbonisation objectives, and employing subsidies at various levels to start the industry off. The aim of governments, in coordination with leading industry players, is to ramp up an industry that is considered indispensable for the future of various other industries. This comes with enormous uncertainties and risks, and thus hesitance on the part of investors. Green hydrogen requires large-scale expansion of renewable energy generation, which can only be scaled up if it is either lucrative relative to energy from fossil fuels, or subsidised. The

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24 Eicke Weber, Director of Fraunhofer ISE, in: Paris Tech Review (2012:5).

25 https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/european-clean-hydrogen-alliance/project-pipeline_en.

fossil-renewable cost differential depends on many factors that are hard to predict, such as war, cartels, international carbon pricing, economies of scale and technological improvements. Moreover, upfront costs of electrolysers are high, as this technology is still nascent and has not yet been massively scaled up. Technological learning and economies of scale will drive costs down, but there is uncertainty about how much and how fast, which affects deprecation time and cost-competitiveness of related investments. Moreover, hydrogen is a very flammable gas and requires special methods for transportation in pipelines or tank ships, in most cases it needs to be converted to intermediate products such as ammonia and Liquid organic hydrogen carriers (LOHC). It also presupposes availability of water, which in many locations can only be provided using seawater desalination. All the related infrastructure still needs to be technologically improved and built.

Industrial policy for green hydrogen (Cammeraat, Dechezleprêtre and Lalanne, 2022; Stamm et al., 2023) thus has two main tasks. Firstly, creating a level playing field with polluting alternative technologies by tightening CO2 pricing and helping to build economies of scale for green technologies through R&D and pilot schemes. Secondly, coping with the massive and multiple hen-and-egg problem through integrated sector policies. Investors interested in any specific element of the *hydrogen production* system —a wind park, a dedicated pipeline, and an ammonia conversion plant, an electrolyser, a dedicated tank vessel, a desalination plant— or any *hydrogen use* technology —hydrogen-based steel technology, low carbon aviation fuel, fuel-cell vehicles— face big risks and are likely to underinvest as long as a range of complementary upstream and downstream industries has not been set up. This requires sufficient market coordination as well as investment guarantees, and start-up subsidies provided by governments.

Hydrogen policy is further complicated as it pursues a range of different objectives. The Germany government, first of all, aims to ensure the decarbonisation of hard-to-abate industries, without which it is impossible to reach its decarbonisation target of net-zero emissions by 2045. Moreover, it wants to maintain competitiveness in these industries, many of which are key pillars of the German economy (e.g. chemicals and steel). Given increasingly tighter industry-specific targets and increasing costs of carbon emissions under the ETS, supply of sufficient green hydrogen is essential. Yet, renewable energy resources in Germany (and Europe) do not suffice to produce the required amount, hence an import strategy is needed to scale up production in renewable energy-rich countries, establish transport infrastructure and tie producers to the German market. At the same time, Germany policymakers want all the investments to pay off in terms of early mover advantages for technology producers for the green economy —from electrolyses to green steel. This calls for proactive innovation policies.

Securing imports furthermore requires technology partnerships with potential supplier countries. These countries, in turn, in most cases wish to also use hydrogen domestically —which is also in Germany interest because decarbonisation of emissions-intensive industries needs to be promoted globally. Hence, there are inherent tensions between the goals of securing imports into Germany and Europe and assisting partner countries to use hydrogen locally; and between the wish to position German firms as hydrogen-technology market leaders and the recognition that partner countries aspire for local value added and technological learning and therefore mostly do not see their role as exporter of basic energy carriers, such as ammonia. Dealing with these trade-offs requires international hydrogen diplomacy and a range of bilateral partnerships with potential hydrogen exporting countries, where conflicting interests are negotiated. In fact, Germany is developing such bilateral partnerships with a number of renewable-rich potential hydrogen-surplus countries, including Egypt, Morocco, South Africa and Namibia, often underpinned with technical cooperation programmes.

Overall, German hydrogen policy is a typical example of the complexities and the inherent trade-offs as described for the emerging field of green industrial policy in section A. The following paragraphs summarise the most important policies.

Germany's federal government agreed on a first National Hydrogen Strategy in 2020 (BMWI, 2020) which was updated in 2023 (Die Bundesregierung, 2023).

The updated strategy identifies four pillars of the strategy:

(i) Ensuring the availability of sufficient hydrogen.

(ii) Expanding the hydrogen infrastructure.

(iii) Establishing hydrogen applications (industry, transport, electricity, heat).

(iv) Creating good framework conditions.

Following, these four pillars are discussed one by one, distinguishing between objectives and measures (table 1, below, provides an overview):

Pillar 1: ensuring the availability of sufficient hydrogen. This pillar has two main elements, the incentivation of renewable energy and electrolysers in Germany; and a strategy for securing imports of hydrogen and derivatives.

To further incentivate renewable energy generation, a more ambitious national target was set, and the Renewable Energy Sources Act updated, with additional incentives and streamlining of procedures (see section C.1). In terms of national electrolyser capacity, the 2023 strategy lifted the previous objective of 5 GW to a minimum of 10 GW installed capacity by 2030, including investments on land as well as combined with offshore wind projects. A number of tenders are being prepared which are considered in the strategic national interest to achieve energy security and therefore contain subsidy elements that are higher than normally allowed by the European Union.

Additional demand —which is the bulk of projected demand— will be imported. A specific import strategy is currently being developed. The strategy aims to open up broadly diversified import channels and avoid new dependencies. It includes the creation of international partnerships with exporting countries. Imports will use pipeline as well as ships. Pipeline-bound imports are the preferred low-cost option, but connections are only possible with European and near-by North African countries. Ships can transport derivatives from remote regions, yet this requires conversion to derivatives. Some of the promising options, e.g. using LOHC as a transportable derivative, are still at a pre-commercial stage, and Germany supports research on such solutions.

An important and innovative policy instrument is the H2Global auction mechanism, "the first international trading platform for green hydrogen and its derivatives" (Die Bundesregierung, 2023). As stated earlier, due to uncertainty and coordination failure, the supply of green hydrogen is not taking off, thereby preventing hard-to-abate industries from implementing their decarbonisation roadmaps. To overcome this market failure, H2Global created an intermediary company that concludes long-term purchase contracts on the supply side and short-term sales contracts on the demand side, both organised via tenders. The tendering mechanism helps to determine prices of a not-yet-existing market.[26] Supply prices will be considerably higher than demand prices. This difference will be covered by grants from the German government. The mechanism aims to jump-start a green hydrogen market and thereby de-risk hydrogen investments. As such, it is considered a temporary measure. The German government has allocated €900 million for the first funding window and is currently preparing further tenders worth € 3.5 billion.[27]

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[26] https://www.h2-global.de/project/h2g-mechanism.

[27] https://www.bmwk.de/Redaktion/DE/Pressemitteilungen/2023/06/20230601-bundesregierung-und-eu-kommission-machen-h2global-zum-europaeischen-wasserstoff-projekt.html.

Pillar 2: expanding the hydrogen infrastructure. This comprises the development of national infrastructure as well as European initiatives to support Europe-wide infrastructure.

Hydrogen infrastructure includes a network of pipelines connecting places of generation (electrolysis), import and storage with major consumers. It also comprises hydrogen filling stations for road transport. As hydrogen is an aggressive agent, special pipelines are needed, or existing natural gas pipelines need to be converted for hydrogen use. The 2023 strategy aims to establish a pipeline network more than 1,800 km of converted or newly built hydrogen pipelines by 2027/2028 and an additional 4,500 km throughout Europe —the "European Hydrogen Backbone" (Die Bundesregierung, 2023). By 2030, all major generation, import and storage centres shall be connected to the relevant consumers. The government also started to build new import terminals along the German coast, not least under impression of a gas shortage when Russian natural gas imports were stopped in 2022 due to the invasion of Ukraine. It also envisages hydrogen storage capacity to enhance national energy sovereignty.

Pillar 3: establishing hydrogen applications. Hydrogen is essential for decarbonisation in activities that cannot be directly electrified at reasonable costs or for which no alternative technical solutions exist for achieving climate neutrality. Many of the new applications require considerable technological innovations —for example, the current form of steel production based on blast furnaces needs to be replaced with a new production mode, direct reduced iron with hydrogen. Likewise, production of sustainable aviation fuels is still at an experimental stage, as is the development for fuel-cell heavy-duty vehicles. Energy-intensive industries thus need to cope with a dual challenge: they face increasing costs for emission certificates, while at the same time requiring major investments in new technologies and industrial infrastructure.

Industrial policy responses focus on three aspects:

- First, offering temporary subsidies to mitigate the dual financial challenge and thereby accelerate the transformation. Subsidies are provided for research, pilot plants as well as investment in industrial-scale plants. Moreover, the establishment of carbon contracts for difference (CCD) is under preparation. CCD are a government subsidy covering the extra cost of not yet competitive low carbon production processes compared with conventional procedures.
- Second, measures are adopted to develop "green lead markets", shifting demand patterns to low carbon standards. This is pursued using product standards and labels and defining criteria and quota for public procurement. In the case of aviation, a mandatory share of hydrogen-based kerosene has been introduced.
- Third, research, development and pilot testing are promoted for a range of emerging technologies. This includes the National Innovation Programme Hydrogen and Fuel Cell Technology, a future programme to support demonstration projects for hydrogen-based drives and fuels for marine shipping as well as funding under the Important Project of Common European Interest (IPCEI) programme.

Pillar 4: creating good framework conditions. Coherent and enabling regulatory frameworks are needed at all levels of the hydrogen economy: for sustainable production, transport, storage, import, provision and use of hydrogen and its derivatives. This applies to national as well as European and international laws and regulations. Technical and environmental standards need to be agreed and certification systems established. Planning and approval procedures need to be streamlined while safeguarding legitimate environmental and social concerns. Furthermore, carbon pricing schemes need to be advanced to tilt the balance in favour of low carbon solutions, and European producers need to be protected from competition imports from countries with less ambitious carbon pricing using carbon border tax adjustments. Good framework conditions also include schemes to ensure technical and vocational training of experts in the various new capabilities required for the hydrogen economy.

Table 1
Key objectives and main policies in Germany's National Hydrogen Strategy 2023 update

Pillars	Objectives	Main policies
Ensuring the availability of sufficient hydrogen	Upscaling national renewable energy generation. Incentivation of 10 GW domestic electrolyser capacity by 2030. Increase secure and reliable import.	H2Global Subsidised tenders, R&D support, pilot schemes. Forging of international hydrogen partnerships H2Global dual tender with grant element.
Expanding the hydrogen infrastructure	1,800 km of hydrogen pipelines established in Germany by 2027/2028. 4,500 km added throughout Europe. Generation, import and storage centres connected to consumers.	Integrated energy infrastructure planning and harmonisation of European plans. Revision legal requirements. Pipeline projects with select import countries in Europe (Norway) and North Africa.
Establishing hydrogen applications	Developing new technologies mainly for hard-to-abate industries and transport (fuel cells, aviation and maritime fuels). Making Germany a lead supplier of hydrogen technologies.	Industry subsidies for research, pilot plants and conversion of industrial-scale plants. Subsidies to cover cost differential between low carbon and incumbent technologies ("carbon contracts for difference"). Development of "green lead markets", via standards, labels and public procurement. Funding of research, development and pilot testing.
Creating good framework conditions	Establishing conducive regulatory frameworks. Reducing transaction costs via agree and harmonised standards. Avoiding unfair import competition and carbon leakage.	Simplification and acceleration of project planning und approval procedures. Development and harmonisation of technical and environmental standards. Technical and vocational training programmes. Further advancing CO_2 pricing while establishing effective carbon leakage protection via the EU's Carbon Border Adjustment Mechanisms (CBAM).

Source: Own summary, based on Die Bundesregierung (2023).

Overall, the German hydrogen strategy confirms a considerable commitment to national decarbonisation. The multiple market failures involved in this endeavour exemplify why the green transformation is entirely unthinkable without an active state that coordinates, facilitates, supports R&D and market ramp-up and de-risks investments. The German approach here is very comprehensive.

Given the early stage of the hydrogen economy it is impossible to assess the effectiveness of the strategy. Yet, the strategy takes a variety of good practices into account. It has been co-developed with a wide range of stakeholders and advised by an independent expert group, the National Hydrogen Council. The strategy strikes a negotiated balance between environmental and industrial competitiveness interests as well as between national import requirements and export countries' concerns with the risks of "export extractivism". It uses subsidies to compensate for market failures, and it uses tenders to elicit the necessary information to keep subsidies to the minimum. Revision mechanisms and continuous update are built into the strategy.

Still, certain issues remain relatively vague. Firstly, it is not clear how the government intends to achieve technological leadership. While the strategy states that "German suppliers are expanding their technology leadership and offer the entire value chain of hydrogen technologies, from production (e.g. (e.g. electrolysers) to the various applications (e.g. fuel cell technology)" (*own translation*), there is little mention of technology and innovation schemes to support technology development. The government seems to assume that market-creation subsidies will automatically translate into national competitiveness; yet, this is unlikely, not least because tenders are open to foreign competitors. Hence, the mistakes of the solar and wind energy support (section A) may be repeated here.

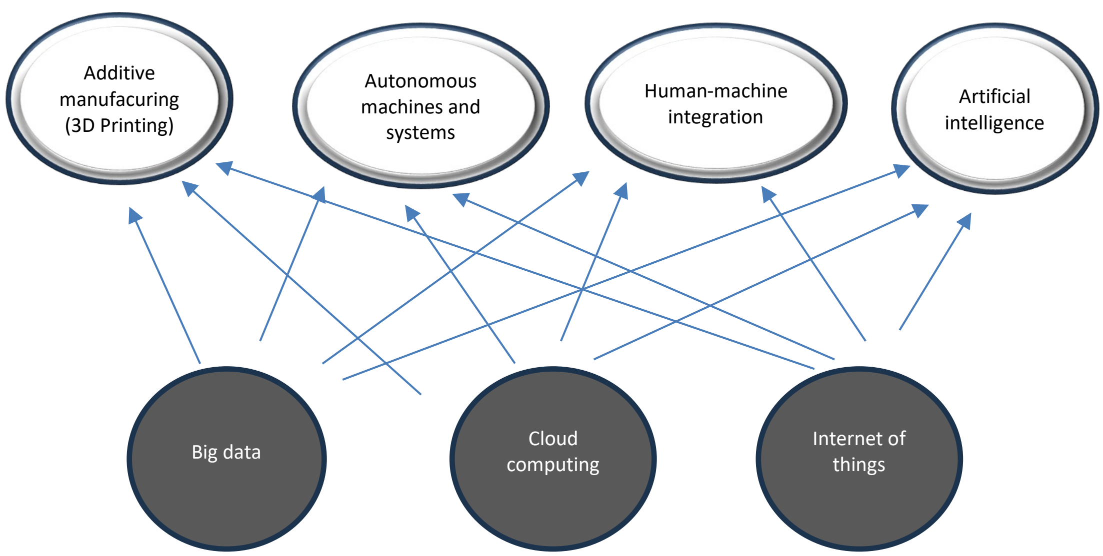
Secondly, the issue of green vs. blue hydrogen needs to be clarified. The 2020 strategy was clearly geared to green hydrogen, whereas the 2023 update also considers support for blue hydrogen. There is a statement that supply-side support programmes will prioritise green hydrogen, but demand subsidies do not differentiate —which can be considered an indirect supply side subsidy. Given major blue hydrogen investments in Europe and the MENA region, lack of clarity might create incentives to lock-in the long-term exploitation of gas fields.

C. Coping with the digital transformation —the German economy's Achilles heel?

Digital innovations are revolutionising the way our economies work. The combination of big data with artificial intelligence, blockchain technologies, digital printing, the internet of things and platform economies all create pressure to innovate or exit the market. Digital technologies are "general purpose technologies" (Jovanovic and Rousseau, 2005) that change the way economies work and citizens interact with society in practically all domains. In the last few decades, various digital technologies and business models have co-evolved and accelerated each other. There have been different attempts to disaggregate the main elements. Here we provide a brief summary based on OECD (2017) and Lütkenhorst (2018).

Diagram 2 shows the multiple drivers of digital change affecting industrial transformation and how they are interrelated in many ways.

Diagram 2
Key digital technologies and enablers of industrial transformation



Source: Adapted from OECD (2017).

OECD (2017) identified three main digital enablers:

(i) Big data: with digital technologies, unprecedented amounts of data can be gathered, stored, processed and transferred. Data can be gathered by trading platforms (for example, consumer profiles), but also by sensors (for example, driverless cars). Big data allows for manifold new uses, and big data companies are therefore highly valued on stock exchanges.

(ii) Cloud computing is related to big data, as it enables data storage and sharing by using a network of remote, internet-hosted servers. As big data, cloud computing requires enormous investments, providing cloud operators a very strong market power, with ramifications for the digital sovereignty of countries.

(iii) Internet of Things (IoT) refers to "a network of interrelated devices that connect and exchange data with other IoT devices and the cloud. IoT devices are typically embedded with technology such as sensors and software and can include mechanical and digital machines and consumer objects.[28] This connectivity enables data collection and use to improve the performance of entire systems.

These —strongly interdependent— digital enablers create unprecedented innovation opportunities for simulations, artificial intelligence and system integration which, in turn, revolutionised production technologies, such as:

- Additive manufacturing, or 3D printing, is a process by which an artefact is built up layer by layer on the basis of digital 3D design. This may in principle revolutionise traditional manufacturing systems, substituting trade and value chains with data exchange.
- Autonomous machines (such as industrial robots) are increasingly able to not only perform predefined tasks but also collect information through advanced sensing and cognitive capabilities, e.g. voice and pattern recognition, which enables them to learn and continuously improve.
- Human-machine integration refers to collaboration between semi-autonomous machines and humans in areas where artificial intelligence is not (yet) capable of replacing human creativity and decision-making. In such cases, humans train learning robots.
- Artificial intelligence is based on computer systems that are able to process big amounts of data and thereby perform tasks that were traditionally requiring human intelligence. It enables technological and business innovations such as search engines, visual perception, speech recognition, decision-making, translation between languages, text-writing tools and self-driving cars, with applications in industry, government and science.

Keeping abreast with these breakthrough innovations is crucial for the economic development perspectives of any nation. Yet, digital innovation also involves a number of risks, such as:

- Oligopolistic market power: some digital developments require enormous economies of scale and favour winner-takes-all dynamics, with the effect that so-called superstar firms (Autor et al., 2020) gain oligopolistic market power;
- Loss of employment: some digital innovations replace human labour. They also create new business opportunities. Most likely, semi-skilled routine jobs will be replaced (Frey and Osborne, 2013), whereas demand for e.g. advanced digital skills increases, which may widen societal inequality. Research shows that superstar firms have a low labour share of value added, hence oligopolies further reduce labour demand (Autor et al., 2020) —for example when Amazon replaces traditional retail. Net effects on labour markets are difficult to calculate and depend on the "analog complements" (World Bank, 2016) of digital innovations, such as reskilling programmes, competition policies and labour market regulations.

[28] https://www.techtarget.com/iotagenda/definition/Internet-of-Things-IoT.

- Loss of national sovereignty: some technologies are extremely scale-intensive and very strategic (e.g. semiconductors, cloud technology, 5G cellular network technology), hence dependence on foreign corporations may jeopardise national sovereignty;
- Information privacy issues: as firms collect big data for new business models, protection of personal data becomes an issue;
- Online transactions have incentivised ever new forms of cybercrime and corporate espionage.

Digital policy is therefore not only about promoting innovation, but also about regulating, protecting citizens and steering digital innovation towards societally useful solutions, such as inclusive business models, the decoupling of economic development from resource consumption, and increased market transparency.

Europe is lagging behind the USA and China in digital technologies (European Center for Digital Competitiveness, 2019), and within Europe, Germany is only average, lagging in particular behind the Scandinavian countries (European Commission, 2022). Given the fact that digital technologies affect competitiveness in practically all parts of the economy, this is a major threat. The digital lag is the Achilles heel of German competitiveness and probably the main reason for its fall in competitiveness rankings.

The lag affects many aspects of digital development, both in the economy and in the public sector, and it is underpinned by technological scepticism in large parts of the population. The value of platform economies is a telling example. Here, the stock market value of the Top 100 platforms increased from 4.3 bn (2016) to 16.6 bn US$ (2021), of which 78, % accrue to American firms such as Apple, Microsoft, Alphabet and Amazon, and 17.3% to Asia/Pacific, especially Chinese giants like Tencent and Alibaba. Europe only holds 2,8%, with software company SAP being Germany's only major player in this field.[29]

This reflects a weakness in digital innovativeness that is reflected in lags in digital infrastructure (low share of glass fibre connections), finance (for example, companies that started with venture capital later than 1994 have a share of 34% in US market capitalisation, but only 1.3% in Germany), R&D (investments in artificial intelligence, quantum computers), hardware (semiconductor production is concentrated in Asia and the USA), as well as in the digitalisation of public services (46% in Germany compared to 77% in the Netherlands).[30] As a result, digital standards are mostly set by the US and China, which in turn creates serious problems of digital sovereignty —in terms of cyber security, military sovereignty, privacy regulation, data storage in clouds etc.

The challenge of German digital policy is thus to catch up with USA and China in terms of infrastructure, industrial hardware and software applications, increase digital literacy and the digitalisation of public services, but also to regain digital sovereignty and set its own standards in ways that strengthen industrial competitiveness, exploit digital solutions for societal challenges (for example the decoupling of growth from materials consumption) while ensuring data security and avoiding monopolistic market power.

To cope with these challenges, Germany (and Europe) have developed a wide range of strategy documents. Within these strategies, the following paragraphs zoom into some programmes that are directly related with firm's competitiveness and structural change —and thereby can be classified as industrial policies in a narrower sense. Overall, there is an increasing trend, especially in EU documents, to address the two overarching megatrends discussed in chapter II —digital contributions to greening[31], and digital sovereignty[32] in response to geopolitics.

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[29] See [online] https://www.netzoekonom.de/plattform-oekonomie/, retrieved Nov 11, 2023.
[30] See European Center for Digital Competitiveness (2019).
[31] See [online] https://digital-strategy.ec.europa.eu/en/policies/european-green-digital-coalition.
[32] See [online] https://www.eu2020.de/eu2020-en/eu-digitalisation-technology-sovereignty/2352828.

For Germany, the Implementation Strategy of the Federal Government to shape the digital transformation[33] is an umbrella document, complemented with a large number of specific strategies and support programmes, such as the "mobile communications strategy", "digital infrastructure" support and "Digital Now", a support programme for SMEs.

In line with Germany's corporatist industrial policy, interactive stakeholder platforms have been created. Most importantly, the Digital Summit is an annual forum inviting participants from politics, private sector, academia and civil society to discuss with policymakers. The Summit establishes eight "platforms" developing solutions for specific challenges, such as digitalisation and the economy, digital skills, digitalisation and labour markets, all headed by the competent Ministries.

Following, and based on BMWK (2022), we zoom into three support programmes that are directly related with firm's competitiveness and structural change —and thereby can be classified as industrial policies in a narrower sense. Support for (i) "Industry 4.0" is presented more extensively, and programmes for (ii) "Artificial Intelligence" as well as support for (iii) "Innovations an Start-ups" are summarised. We thus exclude a wide range of policies that are only indirectly related to economic development, such as increasing overall digital literacy, digitising public services, and data protection. The following three activities should be seen as illustrative examples, as a full account of all strategies and support instruments is beyond the scope of this report.

Industry 4.0 refers to the intelligent networking of machines and processes in industry with the help of information and communication technology. All aspects of industrial production, industry-related services as well as the use of industrial products become more and more digitalised. This multiplies the number of interfaces between different players. Digital networking among industries and users —the "Internet of Things"— can potentially boost productivity and opens up space for new business models. Industry 4.0 is one of the areas where German firms are relatively advanced, especially the big, R&D-intensive firms. Yet, major challenges exist especially for SMEs, many of which lack the means to follow up on the latest digital trends.

Again here, a deliberation platform has been created with representatives from industry, Ministries, science and trade unions. The Platform Industry 4.0 consists of six working groups which prepare practical solutions, for example to develop and harmonise norms and standards for different industries to ensure interoperability between different companies and applications; to ensure IT security and data protection; to develop new business models; and to help SMEs adapt to the changes.

SMEs can apply for the "go-digital" funding programme, to get fit for Industry 4.0 and other digital challenges. Funding is provided for consultancy services, covering 50% of consultancy cost up to a certain amount. 30 days of external consultancy can be subsidised in a period of six months. In order to relieve SMEs of bureaucratic requirements, authorised consulting companies take over the application for funding, deliver the consultancy services and also take care of invoicing and submitting the proof of utilisation.

Among other support measures, regional 'Mittelstand 4.0 Centres of Excellence' have been created to offer information, training and opportunities to test their Industry 4.0 applications. "Demonstration and learning factories" provide space where companies can test innovations. Also, there are a number of "testbeds" at universities and research institutions where new production and logistics systems are being assessed, tested and enhanced under real-life conditions.[34]

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[33] See [online] https://www.bundesregierung.de/resource/blob/975226/1552758/c34e443dbe732e79c9439585b4fbade5/pdf-umsetzungsstrategie-digitalisierung-data.pdf?download=1.

[34] https://www.bmwk.de/Redaktion/EN/Dossier/industrie-40.html.

The **Artificial Intelligence (AI) strategy** underlines the relevance of AI as a general purpose technology and announces a budget of five billion euros by 2025 to implement the strategy in the following fields: to train, recruit and retain more AI specialists in Germany; to support research, with dedicated programmes for example for AI applications in life-sciences or autonomous driving; to support the application of research results in firms, to support start-ups and modernise regulatory frameworks.

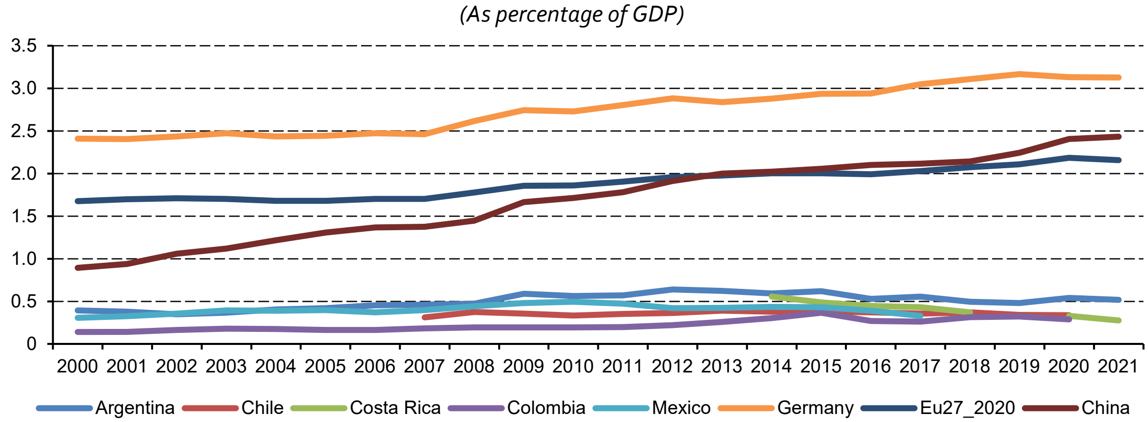
Support for innovations and start-ups comprises a number of instruments to improve the start-up ecosystem, including finance (especially subsidizing venture capital), 12-month grants for University graduates who intend to found technology-oriented firm, business plan competitions, and networking among start-ups.

Despite the large number and broad range of strategies, critique of digitalisation policies is widespread in Germany. This concerns lack of a strategic big push, despite the obvious risks of Germany's digital lag, as well as recent budget cuts for digital projects, especially in the domain of digitalisation of public services. The digital lag is thus likely to remain the Achilles heel of German competitiveness.

IV. Conclusions and lessons for countries in Latin America and the Caribbean

There is a strong revival of industrial policy globally. Many LAC countries have neglected industrial policy as well as investments in science, technology and innovation, in the past. This has long been criticised (Fajnzylber, 1990; Katz, 2001; Cimoli, Pereima and Porcile, 2018), yet little action has followed. Figure 4 shows gross domestic spending on R&D as a percentage of GDP for five Latin American countries in comparison to the OECD average, Germany and China. While OECD countries on average spend 2.7% of GDP, Chile, Colombia and Mexico are hovering around 0.3%; Argentina spends 0.5%. Moreover, the R&D share is increasing throughout the OECD world, yet Latin American economies' share is stagnating or even decreasing, thus falling even further behind in knowledge-intensive industries. This pattern contrasts sharply with that of East Asian economies, which, starting from a lower level of development than many LAC countries, are rapidly closing the R&D gap with the OECD average, in some cases even exceeding the OECD level (Cimoli, Pereima and Porcile, 2018).

Figure 4
Latin America (5 countries) and other selected economies: gross domestic spending on R&D
(As percentage of GDP)



Source: Own calculations based on OECD data, https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htm, retrieved 4 July 2023.

The same seems to apply for government spending on industrial policy more broadly. Data on industrial policy spending as a percentage of GDP is lacking for LAC with the exception of Brazil. Figure 1 (in section II shows that even Brazil, the LAC country with the most ambitious industrial policy, trails all the comparator countries in this regard.

The lack of industrial policy is particularly worrisome, as the world economy becomes more and more knowledge-intensive, with breakthroughs stemming from artificial intelligence, semiconductors, software, biotech, energy storage and other industries, where firms in the LAC region have hardly any competitive advantage.[35] Here, barriers to entry are increasing in terms of R&D intensity, economies of scale, CAPEX requirements etc., hence catching up with these growth industries and generators of innovation rents will become ever more difficult the longer industrial policy investments are postponed.

While there is little doubt about the need to step up industrial policy efforts in the LAC region, the analysis has also shown that the consensus on the design of policies had increased with the first 21st century paradigm but again eroded with the transition to the second 21st century paradigm: on the balance between trade liberalisation and protectionism, on the role of subsidies, on the choice of strategic industries, etc. International practice is diverging, and LAC countries need to define their own approach for dealing with the new trends.

One of the lessons to be learned from Germany refers to the success of its embedded autonomy system. That is, knowledge institutions, vocational training and the financial system are all closely aligned with the private sector, and public and business associations are collaborating in a myriad of ways. For many challenges of structural transformation, Germany creates public-private platforms where strategies and policies are co-designed, and implementation often involves firms as well as business-minded flexible publicly funded institutions. Examples include the Digital Summit to discuss digital strategy more broadly, as well as specific platforms for specific challenges, such as the Platform Industry 4.0. Similar platforms exist for the ramp up of hydrogen, for the shift to electric mobility and for the socially acceptable phase-out of coal. Often, these platforms have a secretariat and specialised technical working groups to develop solutions. This close integration and trustful relationship has helped to overcome the typical coordination failures of market-based allocation and to minimise the misallocation of public funds. Mutual recognition and trust between industries and public agencies are deeply engrained in many institutional routines. This largely insulated the German system from the wave of neoliberal deregulations in the 1980s that eroded the foundations of competitiveness in Latin America and elsewhere. This is in stark contrast with many other countries, where firms ascribe incompetence and bad intentions to public institutions ("politiquería") and public servants mainly consider the private sector as exploitative.

The review of Germany's industrial policy also shows the importance of stable, reliable and thus predictable policies. Predictability is key to investor' confidence. In general terms, German industrial policymaking has been relatively reliable and predictable, with only limited adaptations when governments changed. The fact that public administration relies on a meritocratic civil service further helps to stabilise the policy environment, as does the fact that German policy is embedded in (partly binding) European frameworks. Yet in some cases, abrupt policy changes have created enormous costs, such as in the case of the solar industry.

Beyond these general lessons on good industrial policy, which are much in line with the policy lessons drawn e.g. by Rodrik (2008) and Altenburg et al. (2008), the recent megatrends described in the previous sections call for a reorientation of LAC industrial policies —as they do everywhere else.

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35 A google search for "globally leading companies" in these five categories found no LAC-based company among the top 20 in any category.

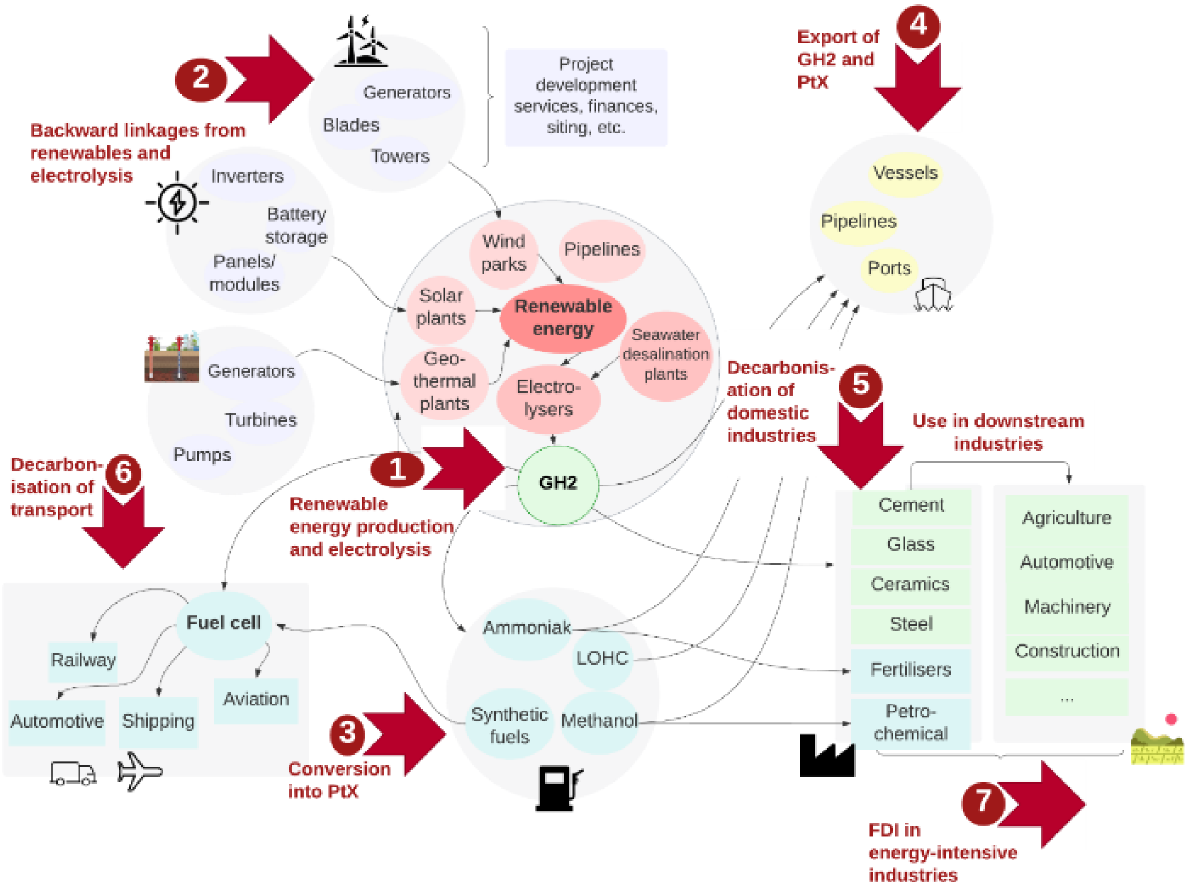
LAC economies will not escape the overall trend towards **greener economies**, especially in sectors that are trading with North America, Europe and Asia. Green product and process standards are becoming entry requirements for international markets, partly as mandatory standards, partly imposed by lead firms in global value chains or because they are tied to financial support or trade agreements. Reducing the environmental footprint of regional products and services (and certifying it) thus gives producers a competitive edge in essentially any global value chain.

In some industries, LAC countries are particularly well-positioned to take advantage of emerging "green windows of opportunity" (Lema, Rabellotti and Fu, 2020). Many countries can exploit the fact that they have a low-carbon energy mix to export energy-intensive products. Global corporations are increasingly striving to reduce the carbon footprint of their production. Hence, there is a strong incentive for "green-shoring", that is, to source energy-intensive products —such as steel, fertilisers, aluminium parts or carbon fibre products— from countries with a low-carbon energy mix. German carmaker BMW for example sources aluminium parts from a solar-powered site in Saudi Arabia and carbon fibres from a hydro-powered site in the US. This so-called "renewables-pull" (Samadi, Fischer and Lechtenböhmer, 2023) is expected to increase as international carbon prices go up.

Similarly, a low-carbon energy mix and abundant solar, wind, hydro or geo-thermal resources provide a huge potential for green hydrogen production. Chile, Uruguay, Brazil, Colombia and other regional economies are already planning major investments in this regard, taking advantage of high solar irradiation (Chile) or abundant hydro-power (Uruguay, Brazil). Importantly, hydrogen can not only be produced for exports —which bears the risk of enclave investments with only limited distributional effects and technological learning; instead, countries can try to add value locally and decarbonise existing domestic industries. Stamm et al. (2023) distinguish seven clusters of industries which countries may try to develop in relation to the emerging hydrogen market (see digram 3): (i) Renewable energy projects need to be rolled out at scale, and electrolysers need to be built, as well as seawater desalination plants when freshwater resources are limited. (ii) Renewable energy projects create demand for industrial inputs, such as solar panels, rotor blades and energy storage facilities, which may be built locally. (iii) For storage and transport and for use in certain industries, hydrogen often needs to be converted into derivatives, such as ammonia and methanol. (iv) Exporting hydrogen or derivatives requires specific infrastructure including pipelines, storage tanks and vessels, for which demand will grow enormously. (v) Hydrogen can also be used to decarbonise existing industries, such as mining, cement, iron & steel and pulp & paper, making them export-ready for a low carbon world trade and contributing to national decarbonisation plans. (vi) Similarly, new markets arise in the mobility sector, including fuel cell vehicles and the production of synthetic aviation fuels. (vii) Lastly, national provision of cost-competitive renewable energy and/or green hydrogen can be used to attract energy-intensive industries, such as steel, aluminium manufacturing and chemicals, which in turn may create spillover effects into downstream —e.g. autoparts— industries (see BMW's renewables-pull examples above). LAC countries with favourable renewable energy endowments should carefully scrutinize theses potentials, which of course have very different requirements for local industrialization.

Conversely, LAC countries that fail to green their energy systems are likely to weaken their position on global value chain. Mexico is a case in point. As the governments is strongly betting on oil and neglecting the renewable energy transformation, it may lose many of the opportunities that the nearshoring trend in the US economy offers (Melgar, 2023).

Diagram 3
Industrial linkage potential of green hydrogen



Source: Stamm et al. (2023).

Additional new economic opportunities stem from the increasing demand for mining products related to the green transformation, such as lithium, nickel, copper and rare earths. Countries hosting relevant mineral reserves can explore options for value creation. Forward and backward linkages from mining do not accrue easily. Previous efforts to develop linkages based on mining have often only limited success, for example exploiting some niche markets, but not challenging the supremacy of global mining corporations (Pietrobelli, Marin and Olivari, 2018). Both downstream beneficiation and upstream equipment manufacturing for mining are demanding in terms of technological sophistication and minimum scales. Still, minerals exporting countries should explore realistic options and develop roadmaps towards increased domestic value creation. The fact that some minerals are scarce and essential, and that the big industrial economies are desperately looking for secure suppliers provides exporting countries with a strong bargaining power to negotiate contracts by which access to minerals is linked to technology transfer and minimum shares of domestic value added. More generally, LAC can negotiate for greater (industrial) policy space in the emerging new rounds of EU-Mercosur trade negotiations.

As a general observation, in a globalised world market concentration tends to increase in commodity production and manufacturing, leaving only the largest global players in the market. This is no good news, especially for Latin America's smaller economies. Yet, firms can still thrive in services that are less dependent on scale and often responsive to local customers and national framework conditions. Overall, strengthening manufacturing industries remains an important objective for the region, given the opportunities for technological learning inherent in this sector, which in turn facilitate diversification into new activities. When entry barriers are extremely high, countries with limited innovation capabilities may be well-advised to focus their attention on value added in services (Rodrik, 2023). For example, site selection, project development services, maintenance and repair, environmental impact analysis, certification and engineering services for renewable energy projects may be easier to localise than the manufacturing of solar panels or wind turbines, where market concentration and technological sophistication are very high.

Likewise, the increasing **geopolitical rivalry, techno-nationalism and supply chain disruptions** involve opportunities and risks for the region. The subsidy race between the rich economies puts LAC at a serious disadvantage. Big multinationals have a strong bargaining position to locate their greenfield investments where they receive the most generous subsidies —which will not be the LAC region. LAC countries should therefore form coalitions with other countries that are not part of the "club" of the wealthiest nations to insist in a rules-based international trade and investment regime. The latter is increasingly hollowed out by the US and China in pursuit of their national interests (for example, the WTO Appellate Body is de facto blocked by the United States). LAC can, on the other hand, use its own space, e.g. applying local content requirements and technology sharing requirements, which are in principle inconsistent with WTO regulations but de facto used by more and more countries (see figure 2 in chapter II showing industrial policy expenditures for selected economies).

LAC countries, especially Mexico and Central America, may also benefit from the nearshoring and "friend-shoring" (Maihold, 2022) trends. Recent supply chain disruptions motivate US importers to shore from suppliers nearby, and geopolitical tensions with China create an additional incentive to source from countries that are considered political allies and/ or in the own area of influence. Hence, US manufacturers aspiring to reduce their dependence on Chinese supplies may shift investments to the neighbouring LAC region. In fact, FDI inflows from the US into Mexico have steeply increased, and Mexican exports are reaching record levels, driven e.g. by increased automotive shipments to the USA which grew 31% in the last year (Alvim and Averbuch, 2023).

Overall, new opportunities for industrial development are emerging for the region. Policymakers can either leave it to individual investors to exploit them or not, or they can adopt a more active stance, luring in strategic investors, investing in domestic capabilities, coordinating sectoral policies and nurturing domestic firms. Economies that are successful in knowledge-intensive industries, including Germany, have generally opted for the latter (Chang, 2008; Cimoli, Dosi and Stiglitz, 2009).

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Industrial policy is firmly back on the international agenda and it comes in new forms. The general attitude of governments around the world has gone through phases: from outright rejection in some countries during the neoliberal phase to light-handed interventions in the early 2000s, and, increasingly, to deeper interventions over the last 10 to 15 years. Two trends are driving industrial policymaking of late, especially in the United States, China and Europe: decarbonization, which requires deep, government-led restructuring of various industries; and increasing geopolitical rivalry and supply chain disruptions, which raise concerns about strategic autonomy and economic resilience. Both trends result in heavy-handed market interventions, including unprecedented subsidies to firms, protectionism and control of foreign direct investment (FDI) flows. This study explores how these trends are changing industrial policy in Germany by examining three industries: solar and wind energy, hydrogen and digital technologies. It concludes with a discussion of the implications of these shifts for Latin America and the Caribbean, in light of its need to position itself in a changing geopolitical environment. In doing so, the region can learn from the successes and failures of Germany and other countries.

E C L A C

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