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Addressing the regional dimension of open strategic autonomy and European green industrial policy

New perspectives and pathways for impact

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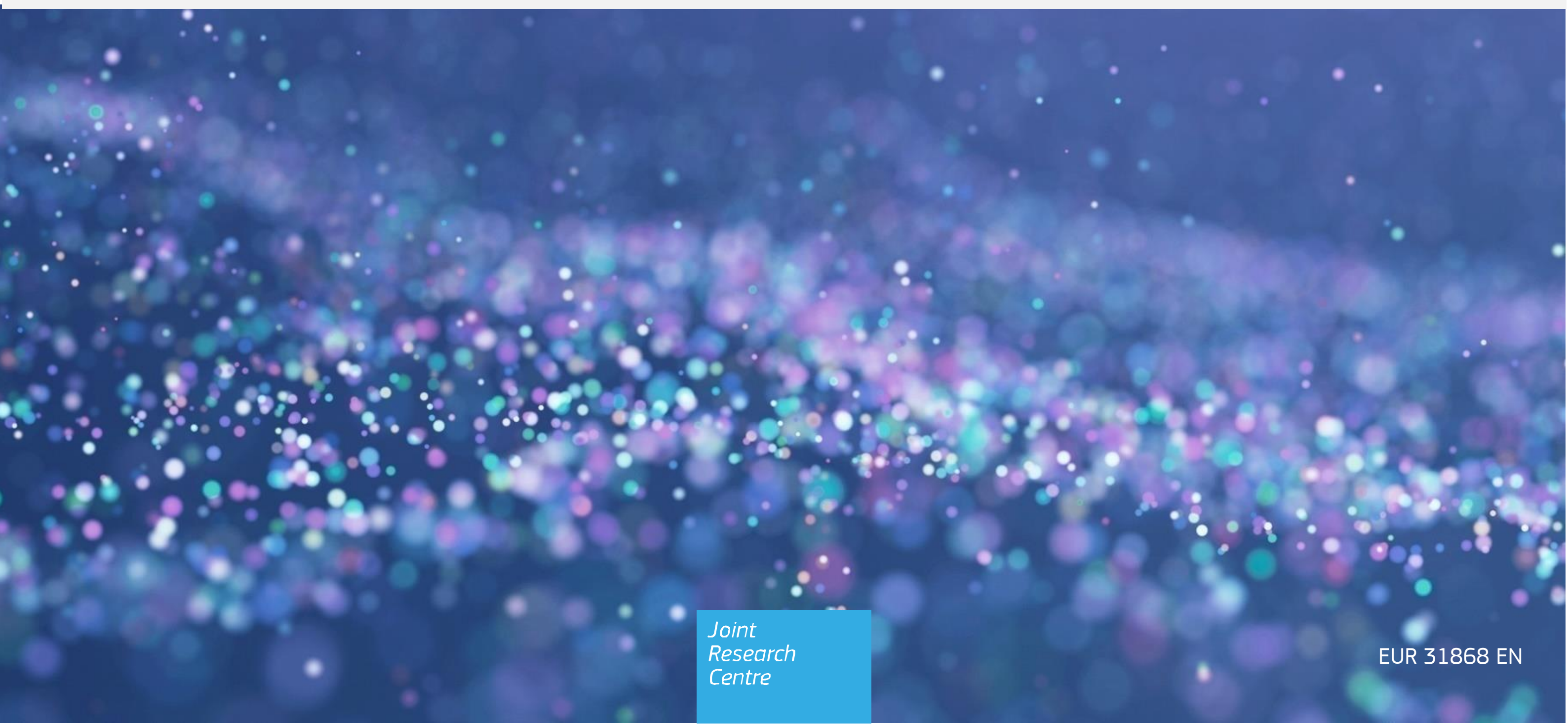

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Contents

Abstract

We explore the regional implications of the policy concepts of open strategic autonomy and technology sovereignty, examining how those policies may impact and interact with industrial development and the socio-economic and -ecological transformation of regions. We highlight that the effects of policies on promoting strategic autonomy and technology sovereignty can vary significantly across regions. We demonstrate that the effectiveness of such policies can depend with regional development and cohesion strategies under certain circumstances. To exemplify these arguments, we analyse several cases, including the territorial aspects of military security, energy transitions, microchip production, and critical raw materials. Achieving OSA related goals without compromising environmental and social sustainability requires a fundamental rethink of supply chains, material sourcing and use, radically different energy systems, and a new industrial policy centred on renewable energy sources and sustainable material use.

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1 Introduction

In this contribution, the Scientific Committee delves into recent developments in European policy making pertaining to strategic autonomy which has emerged as a direct reaction to escalating geopolitical tensions and uncertainties, and the rediscovery of industrial policy as a means to attain greater technological sovereignty. Strategic autonomy means the European Union's (EU's) capacity to act independently of other countries in strategically vital areas, including, for example, the economy, defence and energy. Technology sovereignty, a related concept, has been defined as sovereignty of government action: "the attempt to safeguard public agency in the domain of technology and innovation, i.e. the ability to act independently in the face of institutional and economic boundary conditions and, in some cases, third parties' adversarial actions" (Edler et al., 2023: p.2). The potential impacts of these policies on regional development have yet to be explored but it is clear these policy developments are important with respect to the EU's and its member states' industrial and innovation policies and the advancement of sustainability transitions in regions.

At first sight most of the ideas reflected in e.g. the four pillars of the EU's Green Industrial Plan[1], such as the Net-Zero Industry Act[2], the Critical Raw Materials Act[3] or the reform of the electricity market design[4], all aimed at reaping more benefits from the large single market. However, their implications for regional development and for place-based transformative innovation are likely to be significant. This is because regions possess different innovation and industrial capabilities, natural resources and contextual conditions, which affect their possibilities to benefit from these policy changes.

The EU has a long tradition in industrial policy. In many ways, the new belief in Europe in "technological sovereignty" is reminiscent of some of the old ideas from the 1980s and 1990s of creating European industrial champions through the Research Framework Programmes. Only few of those attempts succeeded, most failed particularly in some of the most technologically advanced areas such as digital technologies. One can, in other words, only hope that the new calls for strategic autonomy and technological sovereignty learn from past experiences. These calls are also made in a rapidly changing world, where China's role is growing in importance in the global economy (as well as in some regional economies in the EU as an investor), and where both geopolitical and regional instabilities and tensions have increased. These efforts are also placed in a world where the impacts of climate change and biodiversity loss are more visible and increasingly extreme.

In section 2, we discuss in general terms what the new concepts of open strategic autonomy and technological sovereignty imply for the new forms of European (green) industrial policy. Viewed through pragmatic policy lenses, the notion of "open strategic autonomy" (OSA) provides a framework for assessing risks affecting the EU's (geo)economic and societal security. It includes identifying sectors/products/technologies which could be considered critical to Europe's long-term security. Some of these sectors/products/technologies are discussed in more detail in section 3. We start with the defence sector: an area which traditionally has been kept outside of the European integration project, the latter being considered in first instance a peace initiative. The second sector we discuss is the energy sector: a sector which is today at the centre of an accelerated transformation process following the painful realisation of Europe's fossil fuel dependency on Russian oil and gas in the wake of the country's war on Ukraine. The third case is characteristic of traditional industrial policy: the manufacture in Europe of microchips considered today a strategic commodity in most of Europe's industry and in which Europe lacks domestic production and

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[1] See https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan_en

[2] https://single-market-economy.ec.europa.eu/publications/net-zero-industry-act_en

[3] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan/european-critical-raw-materials-act_en

[4] https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/electricity-market-design_en

technological capabilities. Finally, there is the case of access to “critical raw materials” many of which are today of strategic importance for both the renewable energy transition as well as for the manufacture of chips and batteries and where Europe appears now to be heavily dependent on China.

The sectors/areas discussed in section 3 are not exhaustive but rather illustrative of the different nature of possible dependencies which the new industrial policies of strategic autonomy and technological sovereignty seek to address. In section 4, we explore the potential regional development impacts of the industrial policy areas outlined in section 3. As already noted above, these impacts have hardly been addressed in policy debates concerning OSA and technological sovereignty, including the Green Industrial Plan. Essential questions, such as how these regional impacts can inform or guide the design and implementation of OSA industrial policies, and how place-based innovation and development policies can contribute to European technological sovereignty, remain unanswered but must be properly understood. OSA policies create opportunities for regional industrial development in some places while others might benefit less. We will pay close attention to the question of which conditions need to be (put in) place for regions to develop new industrial paths or transform established ones in strategic sectors. It is important to consider that these strategic sectors have varying location requirements, which necessitates a nuanced discussion. Finally, we assert that the drive towards OSA may result in regional industrial development with unintended negative economic, social, and environmental consequences within the region and beyond, highlighting the potential existence of trade-offs. The challenges and risks involved in facilitating industrial development in strategic sectors must be taken into account at the regional, national, and EU policy levels. Finally, section 5 concludes.

2 A changing global context and the advent of open strategic autonomy and technological sovereignty

The past years have seen significant changes in the global context. Global shifts in technological capacities (above all China's growing science power), increasing geopolitical tensions and uncertainties, growing effects of climate change, and a new competition between different political and value systems (Edler et al., 2023; OECD, 2023a) have been raising concerns. As Edler et al. (2023, p. 1) note: "The globalist assumptions of the post-Cold War era that reliable mutually beneficial agreements could be reached with all nations, regardless of ideology, have been shattered. A previously less visible, mostly political, risk dimension has been brought to the fore by recent geopolitical and geo-economic developments".

Against this background, notions such as (open) strategic autonomy (OSA) and technological sovereignty have gained prominence in policy debates in Europe (and elsewhere). They reflect a growing concern about Europe's multifaceted dependencies (and thus vulnerabilities). As Soete and Burgelman (2023) note, these dependencies cover a wide range, from Europe's reliance on the United States for military and digital technologies to its dependence on Russian fossil fuels for energy. The latter caused serious problems after Russia's invasion of Ukraine in 2022, but new solutions have been found (such as the expansion of renewable energy, energy efficiency investments and liquefied natural gas terminals) which require some time to have a full effect (Kuzemko et al., 2022). Moreover, Europe's economic and industrial dependency on China, as highlighted by the case of solar panels but is even more predominant in relation to several rare earth materials, has gained increased attention. The COVID-19 crisis, along with the resulting disruptions in supply chains, have further highlighted some of these dependencies, especially in sectors considered strategically vital (Molthof et al., 2021; Crespi et al., 2021). Compared to 2020-2021, for example, Europe's dependencies on China, and the critical material supply chains it controls, are now much more openly discussed; yet, there are substantial regional differences in terms of how well these dependencies are recognised (Kivimaa and Sivonen, 2023). These developments have further fuelled debates on technological sovereignty and strategic autonomy.

There are various apprehensions, including the resurgence of more interventionist and protectionist policies (Molthof et al., 2021) accompanied by increasing isolationism. There are fears that such policies could disrupt free trade flows and undermine global production interdependencies that have benefited Europe and other parts of the world. Additionally, there are worries about potential declines in science, technology, and innovation collaborations, a reduction in the global mobility of talent, and the escalation of subsidy races (OECD, 2023a, see also Box 1). For example, pertaining to the latter, the impacts on regional innovation systems, need to be assessed. Above all of this looms the concern that tackling the sustainability crisis could suffer because this requires open science, open innovation and global cooperation (OECD, 2023a; Soete and Burgelman, 2023).

The notions of strategic autonomy and technological sovereignty remain fuzzy concepts. They appeared in 2013 in the context of defence and security policies and are now spilling over to other policy areas, including trade, industrial and innovation policy (Molthof et al., 2021; OECD, 2023a). There is no commonly agreed understanding of those terms[5]. Clear conceptualisations are missing (Crespi et al. 2021).

Edler et al. (2023, p. 1) point out that technology sovereignty should be understood "as sovereignty of governmental action, rather than (territorial) sovereignty *over* something". Consequently, the authors define it as "the ability of a state or a federation of states to provide the technologies it deems critical for its welfare, competitiveness, and ability to act, and to be able to develop these or source them from other economic areas

[5] In this regard, Crespi et al. (2021, p. 349) note that "recently, the notion of technological sovereignty has been put in the context of a series of related concepts, such as strategic autonomy/sovereignty, economic sovereignty, innovation sovereignty, regulatory sovereignty and digital sovereignty. These terms are often used interchangeably (Kelly et al., 2020), a factor that contributes to confusion in the debate, avoiding a clear definition of the perimeter of objectives to be achieved and therefore the identification of appropriate policy strategies".

without one-sided structural dependency" (Edler et al., 2023, p. 2; see also Crespi et al., 2021). It is added that technology sovereignty should not be seen "as an end in itself" or a standalone goal, but as a tool to attain the primary objectives of innovation policy, that is, fostering competitiveness and establishing capacities for transformative policies (Edler et al., 2023). Crespi et al. (2021, p. 348) "argue that technological sovereignty can represent an emerging framework in which the renewed interest in European industrial policy can be incorporated […] the choice of objectives (missions), strategies and instruments of industrial policy should take the actual context, constraints and ambitions (in terms of a European technological sovereignty) into account". These interpretations of the concept and its connections to industrial policy raise questions about its practical implications, its impact on regional development, and its interaction with place-based transformative innovation and industrial policies like the Partnerships for Regional Innovation (PRI) framework.

Policy interventions to enhance technological sovereignty and strategic autonomy typically consist of (a combination of) protection, promotion and projection measures (OECD, 2023a). Box 1 summarises their potential effects.

Box 1: Policy interventions for open strategic autonomy and technological sovereignty

Protection measures: The OECD (2023a) highlights that protective measures, including export controls, foreign direct investment (FDI) screening, negative lists, and research security measures, are expected to trigger a decoupling from technology (and potentially science) ecosystems in China. This could lead to a decline in science and technology connections. Additionally, trade and investment restrictions will adversely affect technology-intensive companies. Lastly, both the public science sector and the corporate sector could confront skill shortages if the movement of international talent becomes restricted.

Promotion measures: Such measures include industrial policies aimed at bolstering industrial capacity and reducing reliance on foreign suppliers. They could benefit science and innovation activities. These measures have the potential to augment the availability of resources and funding for research and innovation. It is emphasised that a comprehensive perspective encompassing the entire innovation chain is crucial, along with a prioritisation of activities oriented towards sustainability transitions. Investing in domestic skill development is seen to hold significance, particularly if international mobility declines as a result of OSA policies. Recent EU and US industrial policies highlight fostering international ties with like-minded nations, which could spark new collaboration opportunities. Promotion measures, however, can also have negative effects. One such concern is the risk of a subsidy race, potentially overshadowing cooperative technological advancements. The danger is that domestic STI ecosystems might suffer irreversible damage if high-tech firms relocate due to generous subsidies elsewhere.

Projection measures: Measures such as STI alliances and technical standards are said to have the potential to promote a diversification of international STI relations. These measures are frequently integrated into broader recoupling strategies that prioritise aspects like supply chains, collaborative STI efforts, and the enhancement of STI capabilities. These projection measures are also viewed as a means to facilitate the worldwide spread of sustainability values and to stimulate investments in research and the development of innovative capabilities in middle- and low-income economies.

Source: OECD (2023a)

While the potential impacts of OSA agendas are discussed in more detail in section 4, it can already be noted at this point that there are likely to be uneven regional effects resulting from the policy interventions described in Box 1. In fact, while the measures have first and foremost a national or, as in the case of the EU, supranational purpose such as "de-risking" particular strategic external dependencies, the impacts of OSA interventions will often be most acutely experienced at the regional level, with outcomes likely to vary spatially, affecting some regions more strongly than others. Overall, the regional effects of policy interventions seeking to promote technological sovereignty and strategic autonomy have received very little attention so far. Furthermore, we see potential links between such policy interventions and cohesion policy (see section 4), which also hitherto remain unexplored.

Protection measures: Regions heavily dependent on international technology flows and trade, especially those with strong ties to the technology ecosystems of countries targeted by protective measures, could experience significant disruptions. Urban areas, science hubs, and regions with a high concentration of technology-intensive industries might be more affected due to their reliance on global technological networks and the inflow of foreign talent. The consequences may be graver for territories that are particularly exposed to the outcomes of the failure to take collective global action, notably the impacts of accelerating climate change such as desertification, rising sea levels, habitat loss and associated losses in resource endowments.

Some of the less developed regions of Europe may benefit from the substitution of European imports in critical value chains with domestic supplies. However, with the possible exception of a few cases (e.g. recycling of critical raw materials), these benefits will crucially hinge on pre-existing conditions (e.g. availability of raw materials, suitability for renewable energy investments, and a sizeable stock of related physical and human capital investments) that are not equally distributed across Europe. The re-shoring of manufacturing and of scientific and technological collaborations may also benefit some less developed regions. Shorter distances between the places of production and consumption provide new opportunities to also use demand-side policies to spur and steer industrial development in less developed territories. These opportunities will, however, not be realised automatically. Strategic policy interventions will be required to ensure that the time-bound opportunities systematically favour less developed regions.

Promotion measures: Some regions, particularly industrial heartlands and other places with a strong manufacturing base, could benefit from promotion measures aimed at bolstering industrial capacity and reducing reliance on foreign suppliers. These measures could lead to a revitalisation of mature industries, generating job opportunities and boosting economic development within these regions. Furthermore, less-developed regions, those in focus of the Just Transition Mechanism, might benefit from promotion measures through opportunities to diversify into new industrial activities. Support for sustainability transitions in particular stands to multiply the opportunities for the economic diversification of less-developed regions, which beyond their agri-food and tourism sectors, tend to lack other areas of obvious strengths to diversify from and are particularly susceptible to the tendency to pursue whatever sector happens to be fashionable. The two-decade-long timeframe of the European Green Deal enables more ambitious diversification strategies, by providing some reassurance that both policy support and household and business investments will be heading in the same broad direction. Subsidy races could also affect regions negatively, compelling them to compete with other regions for public subsidies and private funding.

Projection measures: Finally, regions with established research and innovation capabilities might be better positioned to benefit from projection measures, as these could facilitate collaborations with international partners. Science hubs and urban areas with strong universities may diversify their STI relations and attract global partnerships and investments, spurring research and development efforts. Less favoured regions might also benefit if projection measures lead to a greater dispersion of innovative capabilities or if projection measures lead to cross-border partnerships that strengthen their innovation capabilities and economic diversification opportunities.

Overall, the implications for regions can be expected to vary depending on their economic structure, technological capabilities, skill base, institutional capacities, and historically grown international connections and embeddedness in global innovation and production networks (Isaksen and Trippl, 2016; Binz and Truffer, 2017). While some measures might create opportunities for economic development and innovation, others could introduce challenges related to technology access, talent mobility, and competition for resources. In certain regions, the pursuit of strategic autonomy may also hinder the advancement of sustainability transitions. This is particularly seen with respect to the energy transition, and the stalling of phase-out plans of fossil fuels from 2022 onwards. The extent of these implications will also largely depend on how effectively regions adapt to the changing context and navigate the evolving supranational and national policy environments. However, it is clear that many policy interventions to enhance technological sovereignty and strategic autonomy such as de-risking, increasing resilience or “economic security” follow national and supranational goals. Adapting such policies to regional settings could significantly enhance their overall impact and effectiveness. We come back to this in section 4.

3 Priority areas for OSA industrial policy

Without attempting to be exhaustive, we address in this section four areas/sectors which have been at the centre of the OSA debate: (1) the defence/military sector; (2) the energy transition part of the European Green Deal; (3) microchips manufacture with the recent implementation of the Chips Act; and, (4) critical raw materials, exemplifying efforts to “de-risk” future economic dependencies.

3.1 The military sector

One important starting point for pushing both research and industrial policy in the direction of strategic autonomy and technological sovereignty is to strengthen military capabilities. Such objectives have been largely absent in the European integration project as it took form and became institutionalised following the Second World War. European integration became first and foremost a peace project even though it saw its birth in the midst of the cold war. Hence the peaceful exploitation of nuclear power, as with the setting up of Euratom, a forerunner of the European Community of Coal and Steel, which became fully part of the European project. The same goes for the development of civil aviation with the development of the Concorde and the creation of Airbus. Dual-use military applications of civilian technologies remained, however, explicitly outside of the European scope of action; they were even explicitly eliminated from any of the research support programmes of the EC when they were first developed in the 1980s and subsequently renewed and enlarged to the current Horizon Europe EUR 80 billion R&D support programme. The Treaty on the European Union actually restricted the use of the EU budget for defence (European Court of Auditors, 2023). EU action in the field of defence is limited to the common security and defence policy as an external crisis management tool and not intended to be a collective European defence policy, encompassing for example a common definition of the threats. This constraint complicates the EU long-term planning for EU spending in the defence area. Thus, in the case of Horizon Europe, legislation explicitly prohibits the use of research money for military applications (see e.g. European Commission, 2021).

Similarly, at the industrial level, the individual Member States’ defence industries did not benefit from any of the Single Market reforms introduced in 1992. Military production and procurement remained entirely subject to national decision making. Those European Member States, which had been part of the NATO alliance, did coordinate their procurement policies but more with the US than with European partners. This became even more pronounced following the end of the cold war with many of the new Member States looking for their military security to NATO and to the US rather than to European partners. As a result, the industrial sector with possibly the greatest "single market“ opportunities, never developed in Europe: the advantages of European scale were not realised[6]. European defence markets did not contribute to the overall competitiveness of Europe's defence and security industries. By contrast most dual-use, technological breakthroughs of existing, often highly specialised defence firms in individual Member States, particularly the small ones, were transferred to, and became exploited in the US. Only large Member States (the UK before Brexit, Germany and France) succeeded in developing a dynamic defence sector/industry. In short, there is little doubt that the fragmented European defence market has not contributed to the overall competitiveness of Europe's defence and security industries, on the contrary. And while the recent EUR 7.9 billion European Defence Fund (EDF) set up in 2021 can be considered as a significant milestone for collaborative military R&D programmes across Members States, the EU still lacks a longer-term strategy for the EDF[7].

[6] As highlighted in the official Consilium document: “To ensure the long-term competitiveness of the European defence industry and secure the modern capabilities needed, it is essential to retain defence Research & Technology (R&T) expertise, especially in critical defence technologies. The European Council invites the Member States to increase investment in cooperative research programmes, in particular collaborative investments, and to maximise synergies between national and EU research. Civilian and defence research reinforce each other, including in key enabling technologies and on energy efficiency technology.” https://data.consilium.europa.eu/doc/document/ST-217-2013-INIT/en/pdf

[7] As the European Court of Auditors (2023, p.5) notices ”the Commission has not yet sufficiently addressed strategic issues in order for projects under the EDF to have their intended impact. PADR defence research projects do not, from

A political side effect of the Russian invasion of Ukraine is undoubtedly the realisation in both European and national Member States policy circles that Europe's integration project, which was based primarily on "soft power", is not fully sustainable in the current multipolar world of geopolitical tensions. The aim though is not so much achieving military technological sovereignty, with many EU Member States being now also full members of NATO, but rather to exploit in a more proactive way the technological and industrial advantages of dual-use opportunities associated with military and relevant civilian research carried out in Europe[8].

Military research, just like space research, because it has been shielded from immediate commercial application pressures, often offers opportunities for more radical disruptive innovations as illustrated in the case of the US DARPA (Defense Advanced Research Projects Agency). Cutting off or preventing military-civilian fusion as is the case today in European research programmes, or was until recently the case in US space programmes, appears today to have been a too restrictive approach to industrial-led research and innovation-led procurement. As Schwaag Serger et al. (2023) note: "DARPA has allowed the US to drive disruptive innovation and technology development that meet both national defense needs and benefit US economic growth (through commercial applications). China has pursued civil-military fusion for many years. For historical reasons, Europe has sought to keep civilian and military research and innovation systems apart. Yet as illustrated in many new areas, such as space, public-private cooperation has accelerated technological advances[9]. In a time of increasing geopolitical tensions where our freedom and democracy are increasingly threatened, innovation, security and sustainability need to cross-fertilize and reinforce each other. This need is now also captured in NATO's new strategic concept that combines the three areas in its recent strategy "Technology innovation for a greener defence" (European Leadership Network, 2022). Europe can and should assume a leading position in linking defense, innovation and sustainability – *triple use* – for the benefit of national security and competitiveness." (Schwaag Serger, S. et al., 2023).

There are also major regional implications of the recognition that the defence sector plays a significant role in Europe's efforts to bolster strategic autonomy and technological sovereignty. The geographical concentration within the EU of particular defence production sectors and more broadly military facilities grew out of a historical process of the allocation by individual Member States of defence budgets to places often in border regions and in the periphery of the country. They were formally part of individual European countries' industrialisation process in the 19th and 20th centuries and following the Second World War, a cold war period with the establishment of NATO, and subsequently a disarmament period with the enlargement of the EU to the Eastern European countries and the realisation of a so-called peace dividend.

We discuss in section 4, how such earlier defence-oriented industrial policies could be considered as national "cohesion" policy tools *avant la lettre*. It opens today the way for a new role of European cohesion policies: contributing now directly to Europe's security.

3.2 Energy transition

The European energy transition is not a single transition. Several transitions are taking place in EU Member States, in different forms and speeds. What connects these transitions is a predominant pursuit of non-fossil fuels expansion and increased electrification based on the European Green Deal and the EU Energy Union

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the outset, include a plan specifying how research results will be dealt with at later stages, in terms of additional research, development, manufacturing, procurement, and other aspects."

[8] In defence research, the figures are actually striking: in 2019 the US spent some $69 billion on defence R&D, compared to $4.1 billion for the whole of the EU; $3.7 billion for Korea, $2 billion for the UK and $1.4 billion for Turkey. Within the EU, Germany spent $2 billion, France $1.1 followed by Poland with $0.27 billion.

[9] This holds not just for the US but also for e.g. the so-called Quadrilateral Security Dialogue of Australia, India, Japan and the US. The latter "Quad" is now developing into a platform for mutual security (see https://isic-japan.org/event/commanding-heights/).

principles. As noted by Mata Peréz et al. (2019), the countries and regions differ regarding the speed of hydrocarbon phase-out and its employment and economic impacts. In addition, there is diversity in terms of approaches taken towards nuclear power – and prior to 2022, in stances regarding the Nord Stream gas pipelines flowing from Russia to Germany.

Particularly with respect to the European Green Deal, one of the flagships of the present European Commission, the new industrial policy inspired by strategic autonomy now serves a very different purpose and aim. It is no longer about strengthening Europe's industrial competitiveness or enabling particular European industries to further expand. It is now about "competitive sustainability". Over the last 75 years or so, Europe became internationally specialised, particularly in energy-intensive industrial production processes, ranging from the production of iron and steel to the manufacture of combustion engine-driven motor cars and machine equipment.

The enlargement of the EU in the 1990s further "widened" these European industrial value chains across the EU towards both the Southern and Eastern parts of Europe. They were also broadened to include other sectors of the economy including the agro-industrial, chemicals, aerospace, mechanical and electrical engineering sectors. As a result, today Europe probably faces more than other countries in the world, a radical structural transformation of most of those energy intensive-industrial sectors towards green energy-based sectors (OECD, 2023b). As argued by Soete and Stierna (2023), this involves not just the systemic transformation of industrial production and supply chains with heavy investments in new, green energy production sites and new, renewable energy grids but also a possible relocation of industries near more easily accessible renewable green energy sources – or green hydrogen facilities increasingly planned. At the same time, the (re-)use of existing materials might also lead to more revolutionary rather than incremental applications of circular economy principles. These, in turn, could result in radical shifts towards reliance on local suppliers as opposed to the well-established global value chains, again with significant internal industrial relocation implications[10].

So far, the EC as responsible authority for the European Green Deal has been trying to orchestrate this industrial transformation from a European perspective, but each individual European Member State or particular regions within Member States are trying to implement this transformation from the perspective of their own industrial policy interests. And these interests do not necessarily align. A core reason for this is that the cost of producing renewable energy differs substantially across places. Another reason is the differing degree of far-right political party representation in regions which has been noted to correlate with opposition to renewable energy (Vihma et al., 2021; Żuk and Szulecki, 2020).

Hydropower, one of the oldest sources of renewable energy, deriving power from the flowing of water covers today some 17 per cent of the EU's electricity needs (and one third of the EU's total renewable electricity production). It is subject to steeply decreasing returns in location and hence limited to the few places located primarily in mountainous countries with low population densities such as Norway and Sweden or the European regions surrounding the Alpes and the Balkan Peninsula. The Netherlands or large parts of Belgium provide very limited opportunities for hydropower production.

Similarly, there are huge locational differences across Europe in wind velocity and sun hours, the two other major sources of renewable energy production in Europe.[11] Wind velocity is highest in offshore windfarms on

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[10] The subsequent text is based on Soete and Stierna (2023).

[11] The use of deep geothermal energy for electricity generation and industrial production in Europe has a similar place-based characteristics. Natural settings are found in very few places (e.g. Iceland, Italy, Canary Islands). Advanced

the North and Baltic Sea and onshore windfarms along coastal areas (EEA, 2009). Investment costs for building offshore windfarms are much higher than for onshore windfarms. However, once the higher wind velocity on open seas is taken into account, the generation cost for wind energy, particularly in the low depth (less than 50 meters) areas of both the North Sea and the Baltic Sea is more or less equal to coastal area onshore windfarms.

Finally, in the case of solar renewable energy, place matters again, with much more radiation and number of hours of sun in southern Europe than in the middle and northern parts of Europe. In the most southern parts of Europe with an average of 4,000 hours of sun a year, there are opportunities for "concentrated solar power" production allowing for thermal and hydrogen storage, providing cheap power up to 24 hours a day. Technological development in wind and solar power, however, makes it also increasingly a more accessible energy source to different European locations.

Up to recently, sun, wind, water and geothermal energy were no match for dominant fossil-based energy system. However, thanks to renewable energy technology development and innovation, today, all major renewable energy sources benefit from lower marginal lifetime costs than fossil-based energy (IRENA, 2022). In short, Europe's future green energy system will be much more place-based one with substantial differences in the costs of renewable energy production. Places along the North and Baltic Seas near offshore windfarms with possibilities for close-by hydrogen energy production[12], or alternatively Southern European places in Spain, Italy or the Balkan with up to four times more hours of sun, will become more interesting locations for energy-intensive industries.

Ricardo Hausmann (2021) claimed that the difference in locational costs in the production of renewable energy is likely to remain one of the fundamental characteristics of renewable energy as opposed to energy based on fossil fuels. In his words, coal and oil have: "*a unique feature… they are amazingly energetic per unit of volume and weight. This fact, combined with advances in transportation technologies in the twentieth century, meant that the world became "flat" from an energy point of view… absence of local energy sources was not an obstacle… Yet, as the world weans itself off coal and oil, energy flatness will become a thing of the past. With the exception of nuclear power, all green sources of energy – sun, wind, hydro, and geothermal – are unevenly distributed and costly to transport. Even if firms insist on using fossil fuels together with carbon capture and storage, they will benefit from proximity to geological formations that can store carbon dioxide – and these are not ubiquitous. In a decarbonizing world, therefore, energy-intensive activities will again have to take place near specific locations, just as in the days of waterwheels."* (Hausmann, 2021).

As a result, Europe's new renewable energy system is likely to become more decentralised. In the previous "flat energy" system, the place-based nature of coal mining or oil and gas winning was accompanied both by heavy local and infrastructural grid investments, providing more or less equal access to cheap fossil-fuel based energy. In the new, green energy system, there will be more place-based opportunities emerging related to relatively easily accessible renewable energy, benefitting local creative entrepreneurs and overall more competitive and differentiated markets.

Nevertheless, there are some limitations to the expansion of these energy sources in certain parts of Europe. For instance, wind power construction has been limited in the Eastern parts of EU countries sharing a border with Russia, because wind turbines have been noted to disturb the reliable operation of the defence sector's air surveillance radars (Kivimaa and Sivonen, 2023). Solar power, in turn, can also lead to trade-offs, brought about by detrimental effects on natural habitats and land degradation in certain regions (Lambert et al., 2021).

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technological investments are being made in Germany, France and the Netherlands. See Bruhn et al. (2022) and case studies of the GEO ENERGY EUROPE project: https://www.geoenergyeurope.com/case-studies

[12] Such as such as Rotterdam or Delfzijl in The Netherlands or Antwerp and Zeebrugge in Belgium

In short, with respect to the European energy transformation challenge, the new industrial policy will now also have to pay particular attention to the relocation implications of the renewable energy transformation. The green transformation relocation patterns across Europe do not fit current industrial locations for example in landlocked areas with limited wind velocity and sun hours. Over the earlier part of the 19th century, many of those regions[13] became areas of industrial concentration because of their cheap local accessibility of coal, replaced later on by the easiness of pipeline energy transportation along the lines of Hausmann's "flat energy world". The same pattern could be observed with respect to hydropower often located in mountainous areas which required both huge local investments and infrastructural grid investments.

Viewed through the glasses of the old, centralised energy systems, there will be a national policy tendency to prioritise infrastructural grid investments, linking the new locations of green energy production to the old industrial concentration areas. In short, trying to get back to the old "flat energy world" with European countries investing each in primarily the domestic, new renewable energy grid infrastructure to enable the smooth energy transformation of their own landlocked industrial zones. However, from an overall European perspective, such national investments aimed at transforming existing industry's competitiveness into a sustainable one will be particularly costly. It will as Hausmann suggests, undermine Europe's overall "competitive sustainability" in some of the heavy, energy-intensive industrial sectors, while at the same time forgoing new, place-based opportunities associated with the relocation of energy-intensive industries. However, it is also important to consider the economic and social costs that would arise in those regions that would suffer from the relocation of their industries.

The energy transition is, however, likely to benefit Europe's pursuits in OSA. For many regions, previously dependent on fossil fuel energy imports, wind and solar power (and to some degree nuclear power) will create new opportunities as net energy exporters. These regions will also become more attractive to new industrial facilities when cheap energy is abundant, and a locus of industrial eco-systems that can create solutions also for the intermittency of renewable energy sources, for instance, via battery or green hydrogen production. Some of the concerns that this development needs to address, however, include the justice aspects of this transition and critical materials supply (which is addressed below). The energy transition deals with justice aspects both locally – via the decline of fossil industries and the social and environmental aspects of emerging green energy industries – as well as globally by reducing the injustice effects of fossil energy supply chains but with potential new injustices via critical material and component supply and end-of-life processes (e.g. Sovacool et al. 2019; Kivimaa et al. 2023).

3.3 The manufacture of microchips

With sales exceeding USD 550 billion in 2021, the global semiconductor market holds significant value (Yeung, 2022). Projections indicate that it will surpass one trillion US dollars by 2030. Currently, European production contributes roughly only 10 per cent to this overall figure. Over the past three decades, the European semiconductor industry has experienced a relative decline due to the rapid expansion of the industry in North America and Asia (Dornbusch, 2018), which has raised concerns about the sector's competitiveness.

The semiconductor industry stands out among the sectors that are receiving significant attention in ongoing discussions about open strategic autonomy and technological sovereignty. The sector's strategic importance stems from the fact that chips serve as vital components not only in the military and aerospace sectors, and in consumer electronics (such as smartphones, laptops, tablets, and television sets), but also play a critical role in facilitating energy and mobility transitions. Semiconductors are utilised in diverse renewable energy technologies, including solar panels and wind turbines. They also find applications in other areas that support

[13] Examples include among others the German Ruhr industrial region or the Dutch Southern Limburg area.

green transitions, such as energy-efficient lighting, smart homes, and buildings. Moreover, semiconductors play a key role in mobility transitions, as they are indispensable for the production of electric vehicles and charging stations. At the same time, it is important to bear in mind that the industry has a substantial negative environmental impact (Villard et al., 2015; Sharma, 2023). The fabrication of chips entails substantial water and energy consumption, contributes to air pollution and creates hazardous waste[14]. A paradoxical relationship between semiconductors and sustainability transitions becomes apparent. This can, if at all, only be resolved by integrating a temporal perspective, meaning that the environmental costs of production are offset in the long term by the contribution of the products to the transition towards sustainability. Regarding environmental (and social) costs, upstream industries would also need to be taken into account. Semiconductor production requires critical raw minerals/materials and rare earth elements, the extraction of which produces negative social consequences and environmental damages, particularly in less-developed regions in the Global South. We will come back to that in section 4.3.

Recognising the strategic importance of the semiconductor industry, the EU is committed to enhancing its technological leadership in that field while also fortifying itself against supply shortages and production bottlenecks caused by disrupted supply chains. In this context, the EU Chips Act (European Commission, 2022; see also Box 2) plays a pivotal role. One of its primary goals is to drive large-scale technological capacity building and innovation. Additionally, it aims to enhance the security of supply within the EU by attracting investments and boosting production capacities (OECD, 2023a).

The European Chips Act is also seen as a response to the US Chips and Science Act, which mobilises USD 52.7 billion for research, development, manufacturing and talent development in the field of semiconductors. Importantly, a regional dimension appears to be considered in policy considerations. The act has allocated USD 10 billion to foster regional economic development by facilitating the establishment of regional partnerships between businesses, universities, and local communities, with a focus on nurturing the technology development, innovation, and manufacturing (OECD, 2023a, referring to The White House, 2022[57]). Furthermore, there are plans to establish a Chip 4 Alliance. This initiative aims to form a substantial consortium of chip manufacturers spanning the United States, Japan, South Korea, and Taiwan, with the purpose of collectively countering China's influence (Johnston and Huggins, 2023). Thus, it recognises that strategic autonomy requires trusted international partners. The US Chips and Science Act mobilises USD 500 million over five years for an International Technology Security and Innovation Fund (U.S. Department of State, 2023), aiming to enhance international coordination of activities related to security and supply-chains (OECD 2023a).

Box 2: European Chips Act

With its Chips Act, the EU seeks to boost Europe's semiconductor ecosystem, develop more resilient supply chains, enhance strategic independence, and increase the EU's global market share in semiconductors from the current 10 per cent to 20 per cent by 2030 (European Commission, 2022; OECD, 2023a). The European Chips Act makes significant funding available. In total, around 43 billion EUR[15] (to be matched by private investment) should be earmarked.

The Chips Act aims to (1) strengthen Europe's leadership in research and technology of the next generation of chips; (2) enhance the innovation capacity in the design, manufacturing and packaging of advanced chips; (3)

[14] This is not to deny that in recent years, semiconductor companies have made efforts to alleviate the environmental impact of chip manufacturing. However, as the industry is poised for significant growth in the coming years, ecological problems will remain a pertinent concern in their host regions.

[15] The majority of it (approx. EUR 28 billion) is expected to come from existing programs (such as Horizon Europe and Digital Europe), which will be supplemented by an additional EUR 15 billion of public and private investments (European Commission, 2022).

increase production capacity from the current 10 per cent to 20 per cent of the global market by 2030; (4) deal with skills shortages; and, (5) develop an in-depth understanding of the global semiconductor supply chains (European Commission, 2022).

The Chips Act proposes:

- Investments in next-generation technologies
- Providing access across Europe to design tools and pilot lines for the prototyping, testing and experimentation of cutting-edge chips
- Certification procedures for energy-efficient and trusted chips to guarantee quality and security for critical applications
- A more investor-friendly framework for establishing manufacturing facilities in Europe
- Support for innovative start-ups, scale-ups and SMEs in accessing equity finance
- Fostering skills, talent and innovation in microelectronics
- Tools for anticipating and responding to semiconductors shortages and crises to ensure security of supply
- Building semiconductor international partnerships with like-minded countries"

Source: European Commission (2022)[16]

The EU Chip Act is also linked to IPCEIs (Important Project of Common European Interest) in microelectronics (European Commission, 2023)[17].

The European Chip Act has faced criticism for several reasons (Huggins et al., 2023; Johnston and Huggins, 2023). Digital sovereignty is seen as an unviable and undesirable approach for Europe (Gropp, 2023). Given the extensive global interdependency of the semiconductor industry, maintaining international connectivity remains crucial (Huggins et al., 2023, p. 531). Furthermore, questions arise regarding the sufficiency of the EUR 43 billion investment[18].

Finally, Johnston and Huggins (2023) argue that the EU Chips Act is rather spatially blind in its efforts to enhance the innovation and production capacity of the European semiconductor industry. They suggest that a more effective strategy would involve embracing a place-based approach that harnesses the strengths of different regions. This approach is believed to amplify the Act's impact, considering that Europe hosts several well-established clusters that encompass a comprehensive ecosystem of semiconductor design and manufacturing, including companies and research organisations. This would entail moving away from a one-size-fits-all approach and implementing targeted interventions that capitalise on the strengths of individual clusters and their home regions while mitigating their specific weaknesses.

3.4 Critical raw materials

Europe has always relied heavily on raw material imports. In a certain way, this has been part of a historically-grown specialisation pattern whereby many of the (Western) European countries built their industrialisation in the 19th and 20th centuries on the basis of the extraction of natural resources from old colonial territories. The process of decolonisation did not change these international dependencies, on the contrary. Many of the large mineral extraction firms became global multinational companies, diversifying their supply sources across the developing country world in Africa, Asia and Latin America. Whereas in many areas, Europe had domestic access to raw materials including rare earth materials, the international dependencies

[16] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en

[17] https://ec.europa.eu/commission/presscorner/detail/en/IP_23_3087

[18] To provide context, establishing a new manufacturing facility requires an investment ranging from USD 13 billion to USD20 billion (Huggins et al., 2023).

behind the dominant global value chains meant that the extraction of such raw materials in low-income countries incurred a much lower economic, but at the same time often a much higher social and ecological cost.

The discussion on critical raw materials, and in particular rare earth minerals, has increased as a result of advancing energy and digital transitions. In both sectors, the new technologies based on innovative developments need a multitude of materials, while the material requirements differ based on the technology in question. “Lithium, nickel, cobalt, manganese and graphite are crucial to battery performance. Rare earth elements are essential for permanent magnets that are used in wind turbines and EV motors. Electricity networks need a huge amount of copper and aluminium, with copper being a cornerstone for all electricity-related technologies” (IEA, 2023). In its report from 2023, the European Commission differentiates between strategic and non-strategic critical materials (European Commission, Grohol and Veeh, 2023). China controls the production and extraction of many of the materials, with extraction of Chinese ownership placed also outside China.

Many EU Member States (or more specific regions within Member States) also hold facilities for the extraction and/or production of critical raw materials, but typically amounting to less than 3 per cent of global supply – with the exception of Finland producing 11 per cent and Belgium 5 per cent of global supply of cobalt; France producing 49 per cent of hafnium and Spain 34 per cent of sprontium (European Commission, Grohol and Veeh, 2023). While in theory, these materials improve the EU’s OSA, many mining and production companies are internationally owned large players. Moreover, with the growing pressure to increase the mining of critical materials located in the EU’s Arctic member states and above the Arctic Circle, there are concerns with respect to the culture, livelihoods and natural environment of the Indigenous Sami people in Finland and Sweden (Koivurova et al. 2015; Ramasar et al. 2022). Yet, international mining companies can be very persuasive actors in particular regions, for instance, providing funding for new services such as sports halls in more deprived areas - increasing the attractiveness of mining despite their social or environmental costs.

With the introduction of principles of sustainability in international trade[19] and in particular the European Green Deal and the Carbon Border Adjustment Mechanism (CBAM), such international processes of extraction of raw materials including rare earth materials, can no longer be based on such exploitative and neo-colonial premises but will require paradigm shift with a central focus on the implementation of economic extraction models enhancing regeneration and circularity. Achieving this in the current context of geopolitical tensions and an emerging multipolar world, represents a fundamental challenge for the EU.

The European Critical Raw Materials (CRM) Act, proposed by the EC in March 2023 and adopted by the Council in June 2023, is in other words part of a much broader discussion, not just of Europe’s external dependencies on a number of so-called critical materials but also of Europe’s role as global standard and norm setting agent and as core proponent of the attainment of the UN Sustainable Development Goals.

In a narrow sense, the CRM Act seeks to address the risk of disruption of the supply of particular critical raw materials “due to their concentration of sources and lack of good, affordable substitutes”, striving amongst others to: “increase and diversify the EU’s critical raw materials supply; strengthen circularity, including recycling; and support research and innovation on resource efficiency and the development of substitutes”[20]. In this sense, the debate about the need for the CRM Act and the “discovery” of the EU’s raw material dependency runs very much in parallel with the debate on technology sovereignty. Technology sovereignty

[19] In particular the so-called Singapore opinion of the European Court of Justice (May 16th, 2017), concluding that sustainability is now an integral part of trade policy and that the EU has the monopoly of negotiation opening effectively the road to the implementation of the European Green Deal in trade negotiations including now the introduction of the Carbon Border Adjustment Mechanism (CBAM) which will be introduced in October 2023.

[20] Infographic - An EU critical raw materials act for the future of EU supply chains, https://www.consilium.europa.eu/en/infographics/critical-raw-materials/

looks at the dependency regarding key competences for important technologies. The CRM Act highlights the fact that while the EU might have strong endogenous technological competences in particular technologies, including those linked to renewables, from a value upstream position, it could be in a very technology dependent situation, precisely because the technology requires CRM, pointing to a supply risk.

In a broader sense, the CRM Act calls for a new perspective on the value of material needs, the optimisation of production, substitution and waste reduction, and thus on future-proofing European value chains. While the debate about Europe's raw material dependency appears to run closely in parallel to the debate on technology sovereignty reinforcing the case for independence from foreign countries (in particular China), it also raises more fundamental questions about global planetary boundaries and the need to fundamentally change Europe's cooperation patterns. As the ESIR (2023) expert group put it recently: "Simply trying to compete with other superpowers on access to key natural resources, often with no respect for the well-being of countries that possess them, may only result in a "race to the bottom", with the added risk that we exchange old dependencies for new ones. Rather, the EU could embed in its future industrial plans a gradual reduction in the use of critical raw materials, moving towards a purely regenerative, circular-economic model.[21] However, some studies have found that pure reliance on circular economy based recycling of materials would not suffice with the projected need for materials based on the expansion of renewable energy, electrification of transport, and digitalisation (Michaux, 2021). Nevertheless, we need a broadening of the Circular Economy Plan towards new forms of material efficiency such as sharing and life-time extension, as well as a debate about the role of material consumption for wealth creation. But we must also debate the prerequisites to open-up old or new mines in Europe, and the important environmental and social ramifications in doing so[22]. Europe cannot be credible in its aspiration for a Green economy if at the same time it pushes an extractive economy outside of its borders. Our methodologies for assessing future raw materials demand must be further developed and should play a central role in Europe's industrial decisions."

The strategy to import critical materials from abroad, in other words, also highlights the large impact of EU decision making on other countries. As argued here, many potential supply countries are low-income countries, which find themselves in the new emerging geopolitical world order in a position in which they are confronted with radical choices. Natural resource-based inclusive growth strategies could be interesting options for them, but have characteristically failed in the past. To make matters worse, they have been the basis of corruption, social exclusion and enduring poverty often carried out by European firms. Building new raw material partnerships with these countries requires a fundamental paradigm shift in which the EU will have to position itself as a new attractive partner for those countries' own social and ecological aims.

In a certain way this is very reminiscent of Europe's internal experience with raw materials extraction in low-income regions within the EU, the implications of which are discussed in section 4.

[21] Currently, this seems to be hardly the case: for example, PV, wind energy technologies and electric vehicles generally require more minerals to build than their fossil fuel-based counterparts. We have to augment the deployment of these technologies with a circular economy perspective early on.

[22] ESIR (2023)

4 Implications for regional development

In this section, we delve into the implications of the Open Strategic Autonomy agendas for regional development in Europe in a more systematic manner. We first start with a more conceptual discussion, drawing on insights obtained from economic geography research on path development and from studies on regional innovation systems (RIS). These will be particularly helpful in discussing some of the regional implications of the different industrial policy areas outlined in section 3. These implications have been more or less absent from the policy discussion on OSA and technological sovereignty, including the Green Industrial Plan. In what follows, our focus is on the opportunities for but also challenges and potential trade-offs associated with industrial development these ambitious policy agendas create in different types of regions.

4.1 Academic insights from economic geography and (regional) innovation studies

As highlighted in the previous sections, OSA agendas focus on specific industries and technologies, but are interlinked through the use of critical raw materials, energy and semiconductors in a wide range of sectors. To comprehend their uneven evolution across space, the diverse trajectories that can be observed and how they unfold in regions, economic geography insights into "new regional industrial path development" are crucial. This notion covers both the formation of new industrial activities in regions and the (radical) transformation of mature sectors.

The literature shows that new industrial paths[23] can emerge in various ways and based on different mechanisms in regions (Isaksen and Trippl, 2016, 2017). These include (1) the emergence of *new-to-the-world industries*, often rooted in radical innovations and technological breakthroughs (path creation) as well as (2) the rise of *new-to-the region sectors* based on the influx of non-local firms, labour, and other assets (path importation). Moreover, new sectors can also emerge through the recombination of existing knowledge, technologies, skills, and other assets present in the region (Boschma, 2017), thereby branching out from established industries (path diversification).

New regional industrial path development also encompasses radical "on path" changes, that is, major renewal and transformation processes in existing industries based on disruptive innovations (path transformation) (Baumgartinger-Seiringer et al., 2021). This clearly differs from path extension, that is, the continuation of existing industrial paths based on incremental innovation along well-established technological trajectories. However, this could eventually result in stagnation, decline, and path exhaustion in the longer run. Regions might find themselves locked-into old trajectories, suffering from limited opportunities for experimentation and constrained capacities to foster radical innovation.

A central question revolves around the possibilities for regions to engage in new regional industrial path development activities in strategic sectors that are the focus of efforts toward strategic autonomy and technological sovereignty. What types of industrial development are feasible in different types of regions? Another important question is what potentials for path transformation exist in places that already host strategic industries. What factors influence these potentials? Lastly, does achieving greater strategic autonomy also necessitate path extension, despite the risks of negative lock-in inherent in this form of path development?

Work at the intersection of economic geography and innovation studies shows that regions exhibit very different preconditions for path formation and transformation activities. Grasping the manifold regional impacts of OSA agendas thus requires recognition of different conditions found in Europe's regions.

[23] A regional industrial path is defined as "a set of functionally related firms and supportive actors and institutions that are established and legitimised beyond emergence and facing early stages of growth, developing new processes and products" (Binz et al., 2016, p. 177).

Place-based structures, including historically-grown industrial structures, innovation support configurations, and institutional set-ups (Asheim et al., 2019), clearly matter. New path development (i.e., the rise and transformation of industries) requires a rich regional asset base. Next to natural assets (resources), a broad set of other assets, which are seen as the product of the wider regional environment (MacKinnon et al., 2019) and the regional innovation system (RIS) (Trippl et al., 2020), matter. These encompass infrastructural and material assets (buildings, machines, networks and infrastructure), industrial assets (technology and firm competencies), human assets (labour skills, costs and knowledge), financial assets, institutional endowments (rules, routines, norms, values and culture) (Maskell and Malmberg, 1999; MacKinnon et al., 2019). Furthermore, the external connectedness (in terms of global market linkages, production networks, science, technology, innovation and other relations) of regions, matter. Inflows and outflows of firms, knowledge and other assets through extra regional networks, labour mobility and activities by multinational companies have been found to essentially shape regional industrial development (Trippl et al., 2018). As argued in section 2, these non-local linkages could be subject to change as a result of OSA policy interventions.

Many empirical studies have shown that regions vary significantly in terms of their RIS structures, endowments of assets and external connections needed for new industrial development (Asheim et al., 2019). Firms and other actors thus find different preconditions in regions for mobilising, attracting and modifying assets for fashioning new paths and facilitating shifts of old ones (MacKinnon et al., 2019) and for engaging in entrepreneurial, market formation, legitimisation and other activities that are considered vital for building or transforming an industry (Binz et al., 2016).

Extant research (Isaksen and Trippl, 2016, 2017) suggests that regions with thick innovation system structures, a rich asset base and strong external connections (typically found in metropolitan and urban places) are well-positioned to develop new paths. This statement needs to be qualified in relation to the strategic sectors under consideration. Regions that are already home to strategic sectors and exhibit innovation system structures tailored to their needs are well-positioned for the next round of path development in those industries (path transformation). Similarly, regions characterised by historically grown structures that show relatedness to the strategic sectors may have favourable conditions for diversifying into them (path diversification). Hence, it is not only about the degree of thickness found in the region but also about the region possessing the "right" specialisation (Zukauskaite et al, 2017). Less-developed regions (typically peripheral and rural places, but also places that are overspecialised in declining sectors) with less robust RIS structures, a weak asset base, poor institutional capacities, and deficiencies in external connectedness (i.e. weak connections or linkages that reflect one-sided dependencies) are said to hold fewer potentials for new industrial path development. In those places, path formation relies to a greater extent on a reconfiguration of their non-local linkages to stimulate the influx and anchoring of foreign firms, knowledge, talent and other non-local assets (path importation). This is likely to need a mix of support from both innovation and cohesion policies to contribute to strategic autonomy.

These studies suggest that different types of regions have varying opportunities for the formation and transformation of paths in strategic sectors. Policy interventions for achieving more strategic autonomy, technological sovereignty and economic security could spark highly diverse forms and mechanisms of path development, depending on the region (reflecting place specific features) and the sector (reflecting industrial specificities) under consideration. In sections 4.2 and 4.3 we will look into those patterns and dynamics for each of the cases discussed in section 3.

Before doing so, we offer a brief discussion of the wider economic, social and environmental effects of regional industrial path development. Europe's OSA inspired new industrial policies will create opportunities for path formation and transformation in several of its regions, potentially leading to direct economic gains such as regional economic growth and job creation in those places. However, it is vital to consider that path development can have broader effects, some of which point to trade-offs, that have long been ignored in extant research in economic geography and innovation studies as well as by policy approaches such as smart specialisation.

However, the manifold consequences of path development within the region and beyond are now receiving more attention in economic geography analyses[24] (MacKinnon et al., 2019; Breul et al., 2021; Baumgartinger-Seiringer et al., 2023; Chlebna et al., 2023; Eadson and van Veelen, 2023)[25]. This work points to a range of broader economic effects as well as to potential social and ecological outcomes of regional industrial path development. Such a perspective aligns more with the fundamental principles of the PRI, which seeks to foster the creation of co-benefits for the economy, society, and the environment.

Regarding the economic impact dimension, it is important to recognise that the rise and dynamic evolution of paths can not only yield economic benefits such as growth and job creation (and can have positive effects on other regional industries through knowledge flows or input-output relations) but can also give rise to unintended and undesirable economic outcomes in their host regions. Paths can adversely affect the development of other paths within the region, thereby inducing changes in the region's industry mix. One significant reason for this is the presence of negative inter-path relations (Frangenheim et al., 2020; Breul et al., 2021), which may arise, for instance, when these paths compete for scarce assets such as skilled workers or policy support. Consequently, the vibrancy in one path might impede the development of others. Moreover, the region's innovation system and its asset base could become increasingly specialised, serving the strategic industry at the expense of others or impeding the built-up of more challenge-oriented RIS structures (Tödtling et al., 2022; Trippl et al., 2023) to tackle pressing territorial sustainability challenges.

Furthermore, the extent to which paths contribute to regional economic development also depends on their territorial embeddedness. Paths that rely heavily on non-local assets and linkages, or are formed and dominated by external actors, and therefore weakly embedded in the region, can face the risk of "path capture" by those external actors (Morales and Atienza, 2023). The region is then "just a platform where the main output of […] economic activity is produced and grows, but most of the value is captured by external agents" (Morales and Atienza, 2023, p. 2). More generally, questions around regional opportunities for value capture associated with path development are crucial. It is important to recognise that not all industrial paths promote longer-term regional economic development and benefit regional actors.

Aside from the wider economic outcomes, path development can also yield distinct social and environmental effects. Concerning the former, a crucial question concerns, for example, the kind of employment that is generated within paths and who benefits from it. Job opportunities and well-paid, safe work might not be equally attainable across various segments of the population (Lee, 2023). Moreover, there could also be broader, indirect social ramifications that draw attention to the positive and negative effects paths may have on income inequality, labour conditions, culture, social cohesion, and community well-being in their host regions.

Finally, the ecological impacts of path development require consideration. This is particularly pertinent in strategic sectors such as renewable energy, critical raw materials extraction and production, microchips and batteries, where path development generates both environmental benefits and costs. These sectors play a pivotal role in driving green transitions through their products, potentially bringing environmental benefits to

[24] The subsequent discussion is based on Baumgartinger-Seiringer et al. (2023)

[25] These contributions by economic geographers draw on and are enriched by research in fields such as sustainability transitions (e.g., Köhler et al., 2019), alternative economics (e.g., Raworth, 2017), new frames of innovative policy (e.g., Schot and Steinmueller, 2018), as well as inclusive innovation (e.g., Lee, 2023). They move beyond "innovative regional growth models often divorced from the broader economic, social and ecological context" (Donald and Gray, 2019) and seek to contribute to emerging debates on an alternative agenda for regional development, one that centres less on short-term growth and is more oriented towards environmental sustainability and inclusive development (e.g., Evenhuis 2017). To capture the manifold outcomes of regional industrial path development, these contributions stress that it is vital to shift attention "from first order outcomes about the extent industries embed and grow or decline in places, to examining critical factors of human and ecological well-being: livelihoods, participation in economic decision-making, recognition of differential rights and needs, and environmental impacts" (Eadson and van Veelen, 2023, p.228).

the user regions. At the same time, the manufacturing process in these sectors carries significant environmental burdens in their host regions, including greenhouse gas emissions, energy consumption, land degradation, habitat loss, and pollution. Further, environmental effects related with upstream stages of global value chains need to be acknowledged. Strategic industries like microchips and batteries that are reliant on critical materials are a good example of this. Places, where the extraction and processing of those materials take place, frequently grapple with substantial environmental and social costs (Sovacool et al., 2019). Regional industrial path development may thus be associated with a complex network of interlinked environmental effects spanning various regions.

In summary, industrial path development may come with various positive and negative economic, social, and environmental impacts within the host region and beyond. These impacts are place-specific, while they also depend on the industry under consideration. As the discussion above has illustrated, trade-offs can arise between the economic, social, and environmental dimensions of industrial path development, within the region or across regions and scales (see also Baumgartinger-Seiringer et al., 2023). Aligning path formation, extension and transformation activities in their territories to European OSA-driven industrial policies can position regions to contribute to ambitious supranational goals and generate economic value from these efforts. However, such alignment could also contradict other regional economic priorities and territorial social and environmental goals.

4.2 Potential regional development impacts of new industrial policy areas

In this subsection we discuss the potential regional impacts of the various, new industrial policy areas outlined in section 3, which are part of the new Green Industrial Plan and central in the current European debate on OSA and technological sovereignty.

As highlighted above, the regional effects of these policies have rarely been discussed. Yet it is clear that the energy transformation towards renewables, or each of the newly implemented "acts" of the Green Industrial Plan such as the Net-Zero Industry Act, the Chips Act, the Critical Materials Act all are likely to have significant regional impacts. How those regional impacts could become guiding elements in the design of OSA industrial policies, how regional development, research and innovation policies could contribute to European technological sovereignty are the central issues discussed here.

As already noted above in section 3, a key feature of each of these sectoral areas, is their strong spatial concentration. This holds for the defence sector whereby the current geographical concentration of defence production and military facilities within most European countries grew out of a historical process of the allocation of defence, both training and production, in regions and places in need of economic development and/or employment, in many ways a form of industrial defence policies with also as a side aim of representing a strong, national cohesion tool. It also holds for the energy transition towards renewables, bringing to an end from the perspective of energy costs, the "flat energy" industrial world of fossil fuels and reintroducing space as a crucial variable with respect to the industrial location of energy-intensive industries. It is particularly evident in the case of the Chips Act intervention which is having major uneven spatial economic and other outcomes given the strong spatial concentration of the European semiconductor industry in several clusters. Finally, it goes without saying that access to critical raw materials will be heavily spatially determined: access to such materials within Europe will have to take into account not just the geological dimensions, but also the local environmental aspects as well as proximity to refinement and other downstream sectors. Production of raw materials is less spatially pre-determined, offering opportunities for a larger number of regions.

In the subsequent discussion in section 4.3, emphasis will be placed on the development of regional industrial paths with a particular focus on the semiconductor industry. The regional industrial paths of the three other sectors can be analysed along similar lines.

In the case of the defence sector, the strong regional concentration of the manufacturing of military equipment, of ammunition, and of military infrastructure including military sea- and airports offers not only opportunities for closer collaboration along the lines of single market principles, but also for complementing the new European Defence Fund with European cohesion funds. In so far as European Member States often allocated their defence budgets in the past to regions and places in border regions, and often in the periphery of the country, they also focused on creating new economic development opportunities in such peripheral regions. These traditional national practices could now be extended to the European level, opening up the way for a new role of European cohesion policies, namely contributing directly to Europe's security. In short, fully exploiting now the existing "path dependent" industrial development process.

In contrast, from a spatial perspective in the case of the energy sector, the transformation challenge is likely to be much more disruptive as we argued in section 3 above. Here existing large industrial players will pressurise national policy makers to invest in a centralised energy infrastructure system, allowing them to carry out an energy transformation without any disruptive spatial implications. However, such outdated, centralised national industrial policies will not only be excessively expensive, they might also prevent new energy transformation opportunities to emerge at European level. As Soete and Stierna (2023) have argued, there is a need here for a new form of more disruptive, Schumpeterian industrial policy.

Finally, in the case of the critical raw materials, there are again obvious regional implications. So far it has been the cheap and easy access to such materials which has led to Europe's strong dependency on foreign and in particular Chinese supply of such materials. However, in some regions in Europe, such as the Per Geijer deposit in Kiruna, Sweden, large supplies of CRM have been discovered. One problem is that the time it will take to exploit such newly found reserves will be dependent on obtaining the necessary exploitation concessions, investigating further the deposit and the conditions for profitably and sustainably mining them. That involves permissions to use the surrounding land, environmental review applications, compensating measures, etc. In many other regions, such as in Spain's Galicia region (Monte Galineiro) and the Castilla y Leon region, the Matamulas site in Ciudad Real, rich in monazite -- an ore containing rare earth minerals including thorium, lanthanum and cerium, the potential exploitation of the sites raise major environmental issues. In short, in so far as practically no rare earth elements are currently mined in Europe, there is a need to reassess the role of mining in Europe and its local costs.

In each of those sectors, there will be a need to explore in more detail the potential economic effects and challenges in well-established centres, and the economic opportunities and potential dilemmas in regions with less robust structures.

In the context of the latter, we now turn to the specific case of the semiconductor industry which is analysed in more detail to underscore not only the economic but also the social and environmental dimensions, and potential trade-offs between them, of path development.

4.3 The semiconductor industry

We focus here on the semiconductor industry, the sector which has probably received most attention with the introduction earlier this year of the European Chips Act. We zoom in on two types of regions: places that are already home to the microchips industry (and thus well-equipped with RIS structures and assets relevant for semiconductor industrial activities) and those that (could) diversify into the sector. It is worth noting from the outset that the expansion of existing centres and the emergence of new semiconductor regions heavily rely on substantial government subsidies. Chip facilities receive state aid worldwide. Therefore, in Europe, the regions benefiting most from the Chips Act are likely to be those located in Member States with significant fiscal support power (see also Soete and Van Kerckhoven, 2023).

Established semiconductor hubs

A key feature of the European semiconductor industry is its strong spatial concentration in several clusters. These include amongst others Leuven (DSP Valley, Belgium), Dresden (Silicon Saxony, Germany), Eindhoven (Brainport Eindhoven, The Netherlands), and Grenoble (CEA-Leti Silicon Valley, France). Crucially, these clusters (i.e., industrial paths) are distinguished by substantial degrees of inter-firm collaboration and strong connections between companies and research facilities. Furthermore, these clusters do not exist in isolation, as cross-cluster collaboration has been identified spanning the semiconductor sector (Huggins et al., 2023; Johnson and Huggins, 2023).

There are strong reasons to assume that these clusters and their host regions will benefit the most from OSA policies in economic terms. The European Chips Act aims at attracting further investments in semiconductor production to a considerable extent. Established clusters are already profiting from this policy. In Saxony, which is home to Europe's largest semiconductor cluster (called Silicon Saxony), Infineon is currently building a highly-subsidised production facility. It is a EUR 5 billion investment that will create 1,000 new jobs. In August 2023, the Taiwanese company TSMC, the world's leading contract chip manufacturer, announced it would build a fabrication plant in Saxony's capital city Dresden to produce chips catering to the automotive industry and other industrial applications[26]. This endeavour constitutes a joint-venture involving the German companies Bosch and Infineon, and the Dutch firm NXP. It is notable that the German government will provide half of the total investment amount of EUR 10 billion from its Climate and Transformation Fund. The establishment of TSMC will lead to the creation of another 2,000 jobs in the cluster. This will however also further exacerbate the tense situation on the labour market, as the cluster is already struggling with a shortage of highly qualified chips specialists[27]. The scarcity of skilled labour is a concern the region (and other established hubs) shares with emerging semiconductor regions (see below). However, there are also other challenges.

The heavily subsidised establishments mentioned above strengthen existing clusters and solidify the role of their home regions as leading semiconductor hubs. The expansion of production within these regions is anticipated to help secure the supply of semiconductors in Europe, thus contributing to more strategic autonomy. An excessive focus on production may, however, result in the transformation of these clusters into industrial complexes characterised by large facilities and high-volume manufacturing (Huggins et al., 2023). Without a deliberate push for innovation, these regions could fall into a *path extension trap*. A focus on path transformation and inter-regional connectedness seems crucial for Europe's established semiconductor hubs.

Established semiconductor clusters in Europe find themselves at a pivotal juncture where they need to move beyond path extension and engage in path transformation activities. This entails engaging in more radical innovation activities by adopting emerging technologies. Given the systemic and open nature of innovation activities in the semiconductor industry, intra- and interregional networking will be crucial (Huggins et al., 2023, p. 532).

Enhancing interregional collaboration between European chip regions is vital. Although semiconductor clusters in Europe are already engaging in cooperative efforts to a certain extent, particularly in terms of information exchange, pan-European collaboration, which is necessary for them to effectively compete against the US and Asia, is underdeveloped (Huggins et al., 2023). Furthermore, are reconfiguration of relationships in terms of enhancing international connectedness should also encompass collaborative linkages with non-European partners (see also section 2).

[26] https://www.ft.com/content/ee01aae1-06ee-43f6-ad14-caacdffab93e
[27] https://www.ft.com/content/8cb93bc0-d560-45e8-8fd3-ffd9b95cbba0

In March 2023, an alliance of 13 chip regions[28] from nine EU member states was formed. The alliance aims to facilitate the exchange of knowledge, foster collaborations, encourage joint innovations, and support the development of a robust and integrated value chain (Eckstein, 2023). The focus of this new alliance spans across research and innovation, pioneering new technologies, promoting technology transfer, and ultimately reaching commercialisation. Furthermore, the alliance seeks to enhance qualification and talent development by promoting educational and training programs, thus enticing skilled professionals to contribute to the region's growth. In addition, the members aspire to stimulate regional clusters and cross-regional partnerships, culminating in the creation of a comprehensive European network of microelectronics regions. This alliance has just recently been established and it remains to be seen in which ways it will be able to contribute to the extent and depth of connectedness that is required. Yet, the formation of the alliance shows that established semiconductor regions have quickly responded to the Chips Act, positioning themselves and adopting EU's OSA objectives.

Emerging semiconductor regions

The Chips Act and other ambitious OSA policies could potentially create economic opportunities for regions with weaker structures that are not yet found on the chip map. In such areas, the rise of new economic activities related to semiconductors may occur through path importation, facilitated by the attraction of (foreign) direct investment (FDI). Two illustrative instances are Magdeburg (Saxony-Anhalt) and Saarland in Germany (see below). Importantly, the emerging paths are primarily driven by individual large companies enticed into the region through subsidies. This is a rather fragile form of path development. There is the risk that these companies stay only as long as subsidies continue to flow or they find more lucrative incentives elsewhere (Gropp, 2023). These places will face a significant challenge in enhancing the territorial embeddedness of the emerging path and transition from a single-plant path to a dynamic cluster by either developing endogenously or attracting suppliers, research organisations, and other key actors and assets.

Path formation in Saarland: from coal to semiconductors

A good example for path importation is the municipality of Ensdorf in Saarland, a place with a 200 year history in the extraction, processing and burning of coal which employed up to 4,000 people in the past. With an investment of over two billion euros, the US semiconductor manufacturer Wolfspeed and the German automotive supplier ZF Friedrichshafen plan to build a factory for silicon carbide chips at the site of the former coal power plant. These chips are particularly needed for electromobility, renewable energies and telecommunications. The project is part of the IPCEI on Microelectronics and Communication Technologies. The project is expected to contribute to a positive economic structural change in the region, creating an entirely new semiconductor path in the region with up to new 1,000 jobs and it is assumed to have substantial economic ripple effects (BMWK, 2023).

However, this perspective has limitations in assessing the potential effects of diversifying into the semiconductor industry. It is essential to consider broader regional development outcomes resulting from path formation activities in the field of chip manufacturing. These potential effects can be exemplified by Intel's investment near Magdeburg in Saxony-Anhalt.

Path formation from scratch in Saxony-Anhalt

In Magdeburg, Intel is constructing two wafer fabrication sites. It is a EUR 33 billion investment, supported by approximately EUR 10 billion in subsidies provided by the German federal government. While this could bring

[28] Members of the alliance are: Basque Country (ES), Bavaria (DE), Centro-Region (PT), Flanders (BE), Carinthia (AT), Catalonia (ES), North Brabant (NL), Overijssel (NL), Piedmont (IT), Provence-Alpes-Côte d'Azur (FR), Saxony (DE), Styria (AT), South Moravia (CZ).

economic impulses to the region and might, at least partially, contribute to ambitious OSA and technological sovereignty agendas, it also presents challenges.

One concern pertains to unresolved labour market issues. Intel's investment is expected to create 3,000 new jobs for specialists in chip production (Intel, 2023)[29], a talent pool that is presently lacking in the regional labour market. It is assumed that this gap in the job market can be filled by attracting foreign specialists and recruiting graduates from universities located in the region (Intel, 2023). Furthermore, there is a belief that path formation will provide job opportunities for skilled workers currently employed in other industries within the region. Path formation could lead to higher wages throughout the region. While this is not necessarily bad, it may carry the potential for adverse impacts on other industries. These negative effects worsen when skilled labour is poached from some of these industries. Inter-path competition over highly-qualified workers (and other assets) and rising wages can have crowding-out effects on other economic activities and paths located in the region, resulting in some existing companies and industries struggling to compete, possibly leading to their downsizing or even closure. Finally, the increasing alignment of innovation system configurations and other support structures with chip activities could have negative consequences for other industries in Saxony-Anhalt.

Furthermore, path formation requires wider changes in the region. The attraction of FDI does not suffice. In Magdeburg, there are concerns that the region's endowment of housing, schools, cultural offerings, streets, bicycle tracks, and so on is too poor to attract and accommodate a large number of specialists from around the world, who are supposed to flock in to complement the local labour force. Addressing this challenge would necessitate significant investment in both social and physical infrastructures[30].

Finally, there are environmental effects that should not be overlooked. The environmental impact of building and operating the factory in the region is predominantly negative. The construction of the factory will require the sealing off of 4.5 square kilometres of land, utilising 35,000 tons of steel, over 9 million meters of cable, and more than 600,000 cubic meters of concrete[31]. A vast area, which contains highly fertile loess soil, will be lost. Chip production is associated with high environmental costs (see also section 3.3). The operational phase of the factory will thus lead to undesirable ecological consequences, particularly due to its substantial water consumption for production. The sensitivity of the issue is heightened by the fact that Saxony-Anhalt has been suffering from droughts for years[32].

Box 3: Path formation and regional distribution of skills

Path formation and the regional development potential of new industrial policy areas, is closely related to the regional distribution of high digital skills to EU regions. For instance, advanced digital skills are essential in various aspects of semiconductor manufacturing and research, as these processes have become highly automated and data-driven. Regional development potential could be boosted by targeting regions with a high level of advanced digital skills, and a lower rate of a set of important indicators, including foreign direct investment, employment growth in ICT sectors and gross domestic product spending on R&D. Figure 1 panel A to D presents the above indices for the 27 EU Countries.

[29] https://download.intel.com/newsroom/2023/manufacturing/20230110_Factsheet_1_Magdeburg_EN.pdf
[30] https://www.deutschlandfunk.de/intel-chip-fabrik-magdeburg-sachsen-anhalt-100.html
[31] https://download.intel.com/newsroom/2023/manufacturing/20230110_Factsheet_1_Magdeburg_EN.pdf
[32] https://www.deutschlandfunk.de/intel-chip-fabrik-magdeburg-sachsen-anhalt-100.html

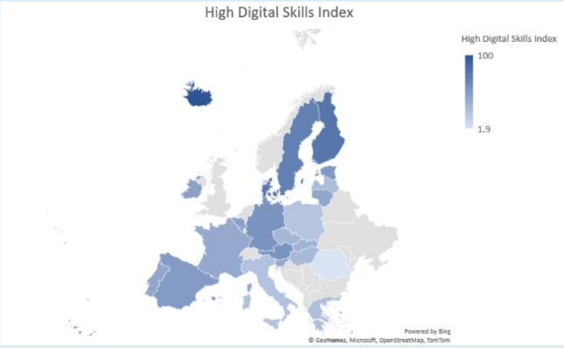

Figure 1-A: High Digital Skills Index

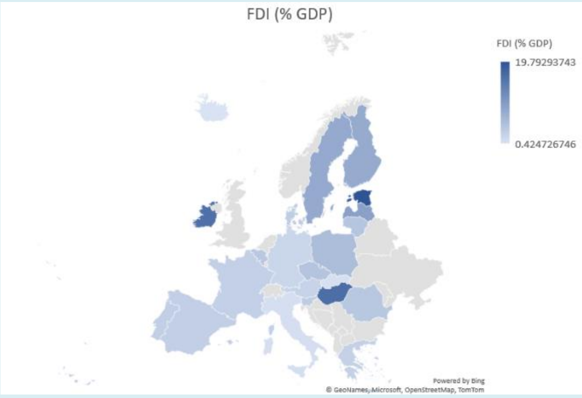

Figure 1-B: Foreign Direct Investment (%GDP)

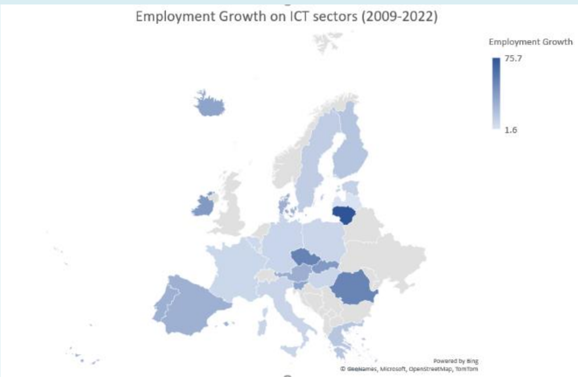

Figure 1-C: Employment Growth in ICT sectors (2009-2022)

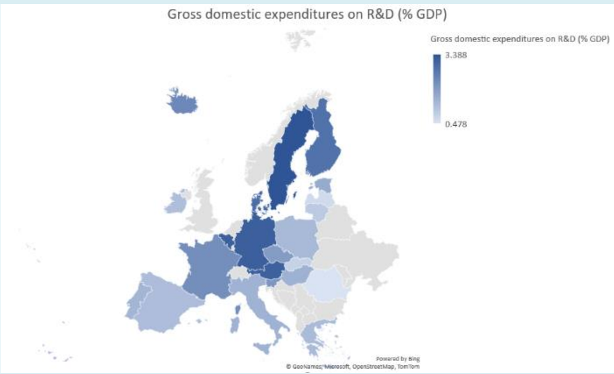

Figure 1-D: gross domestic product spending on R&D (%GDP)

Focusing only on the countries with a high Digital Skills Index above the median EU value, we calculate a simple index to track countries with a relatively low FDI, employment growth in ICT sectors and gross domestic product spending on R&D. For each country the Index is the sum of the cross sectional normalized (into [0,1][33]) variables.

Figure 2 can be used to identify countries with a small index value, where regional development could be boosted by path formation in the case of semiconductor manufacturing and research.

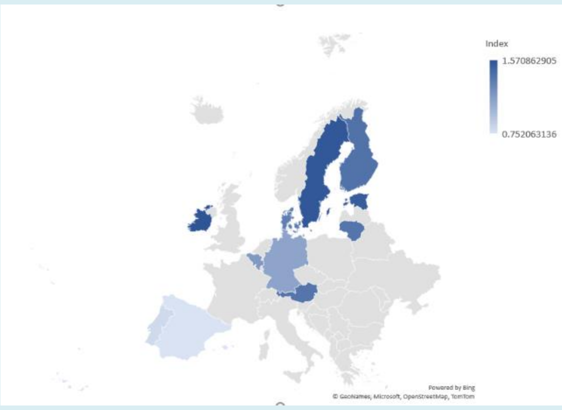

Figure 2: Countries with small index values

Source: CEDEFOP (2023), OECD (2023c)

Discussion

The EU's efforts to enhance its technological sovereignty in the field of microchips provides established semiconductor hubs with the possibility to gain economic benefits and jobs. It also comes with new hopes for less advantaged regions to undergo economic restructuring. For weaker regions there might be opportunities for diversifying into new paths as the cases of Saxony-Anhalt and Saarland in Germany exemplify.

However, the form of path development, as well as the economic benefits and challenges, differs significantly between established semiconductor hubs and phasing-in (emerging) regions. In established centres it takes place in the context of well-developed RIS and cluster structures and is shaped by the interplay of many firm actors, research bodies and intermediary organisations. These places face the challenge to move from path extension to path transformation and adapt their structures as well as internal and external connectivity accordingly. In phasing-in regions, path development would be based on a highly-subsidised investment by a single company. While this would create jobs in a strategically important industry, there is a concern that these firms become cathedrals in the desert, leading to the creation of innovation and production enclaves without proper embeddedness in the RIS and the wider region. Importantly, it is a fragile form of path development since foreign investors may leave the region if other locations entice them with lower costs or higher subsidies.

Potential social and environmental impacts must also be considered. As regards the latter, the further growth of established chip clusters and the rise of new regional centres will have environmental impacts in these regions, as chip production is highly energy- and water- intensive and is accompanied by air pollution and the release of hazardous waste (see section 3.3). Therefore, regions must find ways to address these territorial environmental challenges. This could be an opportunity for interregional collaboration between places suffering from similar problems or among regions along the value chain. It is worth considering the idea of providing subsidies contingent upon the companies showcasing tangible sustainability initiatives. By

[33] For each variable, cross sectional values are normalised using a max-min transformation.

implementing this criterion alongside the aforementioned interregional collaboration, OSA policies could pave the way for these regions to attain international leadership in sustainability efforts within the chip industry.

5 Conclusions

In this paper we have sought to shed a light on what emerging policy paradigms focussing on technology sovereignty and strategic autonomy mean from a regional perspective, and how national and EU efforts in this vein might affect and interact with regional industrial development. To our knowledge, very little attention has been paid to these dynamics. We showed that policies seeking to promote technology sovereignty and OSA have significant but highly varying effects on regions, depending on the latter's historically-grown economic structures, natural resources, science and technology capabilities, skill base, institutional capacities, and location. These place-specific factors condition the ways in which particular regions can benefit from OSA policies, and the degree to which they can pursue new or continue existing industrial activities in strategic sectors. There are strong grounds to argue that the policy dynamics that are currently unfolding will lead to uneven spatial outcomes and might not create opportunities for all regions in Europe. Regions with the "right conditions", assets, and the capacity to leverage them for OSA related industrial development, will be among the winning places, while others may experience adverse consequences.

These evolving geographies require close observation and may prompt a re-evaluation of established typologies or classification systems of territories. Traditional categories, like advanced versus lagging regions based solely on economic or conventional innovation indicators, may no longer suffice. Factors such as natural assets, energy costs, and a broader range of other determinants, including those related to social and environmental sustainability, will become increasingly important, influencing the distribution of development opportunities and welfare across territories. Hence, these factors should be incorporated into territorial typologies.

Furthermore, we showed that the effectiveness of such policies can interact with regional development and cohesion policies in certain contexts. To illustrate these points, we presented and discussed a number of concrete cases, namely the territorial dimensions of military security, energy transition, microchips and critical raw materials.

We arrived at the following conclusions. Technology sovereignty and open strategic autonomy have significant but varying regional dimensions which need to be taken into consideration in designing effective policy approaches. These approaches must consider not only regional economic impacts but also broader implications on the state of the local (and global) environment, the advancement of zero-carbon transitions and the effects on social justice locally and globally. In certain regions and sectors, pursuits of strategic autonomy may strengthen the fossil economy. The energy crisis of 2022 already shows signs of slowing down fossil fuel phase-out plans in regions with strong hydrocarbon economies in the past. For other places, such as more energy import dependent regions, the shift towards OSA creates a further push for the renewable energy expansion. These are also conditioned by political and cultural factors which affect attitudes towards the green transition.

Achieving OSA goals without undermining environmental and social sustainability, and without simply offshoring potential negative environmental and social consequences, requires a fundamental rethink and transformation of supply chains, material sourcing and use, radically different energy systems, and a new industrial policy and geography based upon the premises of renewable energy and sustainable material use. There are no easy solutions to these questions because, for instance, the mining of critical raw materials requires balancing between the EU's global justice (reducing the negative effects of mining in the Global South) and local justice (for instance, keeping mining efforts reasonable in areas populated by the Sami people and/or containing valuable natural environments).

From the perspective of regions that have the opportunity to reap economic gains from OSA agendas by expanding or diversifying into strategic sectors, the aforementioned social and environmental effects could present challenging dilemmas. Pursuing industrial development in OSA sectors could be in conflict with wider social and environmental sustainability goals in their territories. To facilitate regional choices, including considerations on how to strike a balance between economic, social, and environmental effects, it becomes imperative to measure these impacts. Thus, the provision of appropriate metrics to regional stakeholders is crucial.

Overall, we find that acknowledging and addressing the regional dimensions of technology sovereignty and open strategic autonomy is vital to achieving a secure, resilient and economically, socially and ecologically sustainable Europe.

A more general conclusion from this and previous analyses we have done (e.g. Schwaag Serger et al., 2023), is that not only OSA policies, but many other policies - EU and national ones - have been spatially blind and we are now beginning to understand the problems with this general spatial blindness, both for regional development and for the achievement of some of these policies. Examples of policy areas which need to pay more attention to their territorial articulation if they want to be effective concern sustainability, research, innovation and technology, defence, transformation, skills formation, etc. As a result, there is a need, firstly, for horizontal alignment of these policies, and secondly, for a vertical alignment of local/regional, national and EU policies.

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