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The political economy of growth and skills in the green transition

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Executive summary

- Despite growing pressures to move away from fossil fuels, there is variation in the extent to which advanced economies commit to a green transition. Key industrial and macroeconomic determinants of a green transition are often unclear, as well as who can be identified as a green 'leader' or green 'laggard' on a global landscape.
- This working paper inspects the hypothesis of diverse green-industrial 'mixes' mirroring distinct capitalist types, and their complementarity with skill regimes across countries. Drawing from the three-tiered typology of 'innovation', 'manufacturing' and 'deployment' in the renewable sector, it also verifies how political-economic features dovetail with labour market demands for 'green skills' – for instance green-doctorate jobs, green high-skill technical professions, or mid-level vocational training in the green sector.
- Findings support the idea of a green 'division of labour' while also identifying green leadership with a handful of countries: Denmark, Finland, Germany and Switzerland present fairly balanced and robust green growth regimes, leading across all three tiers of innovation, manufacturing and deployment. Other countries tend to specialize in some of these three dimensions, or lag behind.
- In terms of *skills*, the analysis explores and to some extent validates the association between deployment (installment of green energy devices) and green mid-level technical skillsets; between manufacturing and green high-skill technical work; and between innovation and green high-level academic and professional skill distributions.
- Against this backdrop, it is crucial for governments to account for country-specific political-economic features when promoting a green transition. Synergies between existing macroeconomic and industrial structures, labour market skillsets, and green growth strategies might help steer the transition in the most effective way, and overcome trade-offs between economic prosperity and climate change mitigation.

Abstract

How do countries position themselves in the global green value chain? What are the implications for green skills? This paper attempts to answer these questions by developing a number of theoretical expectations based on recent comparative political economy (CPE) literature and by testing them empirically through a newly compiled dataset. We focus in particular on countries' performance in three key segments of the green transition (innovation, manufacturing and deployment) and on the associated demand for green skills. Challenging the emergent CPE consensus of a division of labour between countries in the global green value chain, we find that the global green economy is by and large dominated by a handful of Nordic and Continental European CMEs that do not specialize in one segment of the green transition but rather perform strongly across innovation, manufacturing and deployment. At the same time, we find that different green skills bundle coherently around different segments of the green transition: green innovation triggers demand for green professional jobs underpinned by high-level skills; green manufacturing produces strong demand for high and medium-high technical skills; and deployment positively correlates with intermediate vocational skills. Our findings suggest that existing CPE heuristics may be ill-suited to make sense of how the green transition has been unfolding across affluent countries.

1. Introduction

The transition towards low-carbon economies entails deep transformations – ranging from investments in renewable energy technologies and innovation to the large-scale diffusion of green equipment, such as solar panels and wind turbines. A new global value chain is in the making, with countries occupying different segments in a way that potentially changes their prior institutional, industrial and macro-economic characteristics (Nahm, 2021). While the idea of a global green 'race' had some traction in early literature, studies now tend to agree that a global 'division of labour' is more realistic (Aklin & Urpelainen, 2018; Lachapelle et al., 2017). Countries can decide to specialize in different paths to decarbonization, such as *innovation* (advancing research for green inventions), *manufacturing* (low-fossil production of machineries and components), or *deployment*.

In recent years a relevant stream of research has emerged on the nexus between Comparative Political Economy (CPE) and climate and green-industrial policy agendas. Scholars have interrogated the structural pressure for a green transition through the lenses of capitalist 'varieties' and models/regimes, as well as the related skillsets needed to nurture environmentally sustainable economies and societies (Ćetković & Buzogány, 2016; Driscoll, 2024; May & Schedelik, 2021; Mikler & Harrison, 2012; Nahm, 2022). This literature has developed the broad expectation that demand-driven economies in the Liberal world (such as the US, UK, and Australia) and Nordic Europe may thrive on a mix of green innovation and high-level academic skills; that manufacturing champions such as Germany and Austria dominate green exports, not least thanks to the significant supply of a highly-skilled technical workforce; and that mixed-market economies (such as in Southern and Central-Eastern Europe), which occupy downstream segments in the green value chain, invest in large-scale deployment and mid-level technical skills (Guarascio et al., 2024). Overall, this portrait suggests a division of labour between green market 'makers' (innovators and manufacturers) and 'takers' (deployers).

In this paper we delve into the relationship between structural factors, skill regimes and decarbonization strategies, and assess the existence of a division of labour between 'green makers' and 'green takers' in the global economy, addressing the following research question: To what extent do countries' industrial, growth and skill 'mixes' reflect distinct decarbonization strategies? Conceptually, we build upon Bruegel's (2024b) tripartite typology of innovation, manufacturing and deployment to identify different segments of the green global value chain. Empirically, we compile a unique dataset, including information on crucial indicators of a green transition as well as novel data on green skills and occupations from Bruegel's Twin Transition (2024a) platform.

Our findings partly reject the idea of a green global division of labour motivated by the functional interconnection between structural and skillset features. The main message of this paper is that, while some distinctions emerge across capitalist types and skill regimes, the global green economy is by and large dominated by a handful of Nordic and Continental European CMEs (Guarascio et al., 2024) – notably Denmark and Germany, and to some extent Sweden, Finland, Switzerland and Austria – who achieve quite balanced and generous green capitalist 'mixes' across all three functions. At the same time, more relevant differences stand out when it comes to the demand for skills across the emergent green markets. While demand for green skills in Nordic CMEs is dominated by high-level, academically-oriented skills, in line with the requirements of green innovation, Continental CMEs feature stronger demand for highly-level technical skills, complementary to green manufacturing exports. Finally, some Southern and Central-Eastern economies display larger shares of mid-level technical skills, which dovetail greater concentration toward deployment within national green transition strategies.

The paper makes three contributions. For one, we elaborate what is to our knowledge the first empirical investigation of green skills on the backdrop of established CPE typologies. Second, we reassess prior theoretical expectations on the nexus between structural factors and decarbonization coming from the literature, both conceptually and in the light of new evidence. Third, we marry these new reflections with a detailed assessment of how skill regimes themselves transform and adapt in the global green transition. To this end, the next section of the paper surveys the literature on CPE, skills and the green transition. The following section describes the data used and presents some hypotheses, which will be verified in the subsequent section. The final section summarizes the main findings and draws broader conclusions on the nexus between capitalist types, skill regimes and the policy and politics of decarbonization.

2. Comparative capitalism, skills and the green transition

In this section, we take stock of the CPE literature in the context of the green transition, and elaborate expectations regarding the relationship between political-economic regimes and decarbonization trajectories. Based on the three-tiered typology of 'innovation', 'manufacturing' and 'deployment', we first revisit conventional CPE regime expectations and then conceptualize potential links between varieties of green capitalism and skill formation systems across advanced democracies. We delve into each of these topics in turn.

Comparative capitalism in the green transition

Early CPE contributions have placed great emphasis in *innovation* and the different 'shapes' it takes across capitalist economies. Hall and Soskice's (2001) introduction to Varieties of Capitalism prominently argued that Liberal Market Economies (LMEs) and Coordinated Market Economies (CMEs) are characterized by different forms of innovation. In LMEs, business success is primarily associated with path-breaking, *radical* innovation, which entails 'substantial shifts in product lines, the development of entirely new goods, or major changes to the production' (p. 38-39). On the other hand, firms in CMEs foster *incremental* innovation, 'marked by continuous but small-scale improvements to existing product lines and production processes'. Radical innovation is crucial in 'fast-moving technology' sectors such as ICTs, semiconductors or biotechnology. Incremental innovation, instead, plays a vital role in the manufacturing sector, whose aim is to keep high quality standards in existing production lines and maximize cost-efficiency. Institutions such as works councils, inter-firm networks, and corporate governance are particularly suitable for the CME model of incremental innovation, while loose labour regulations, equity markets and the diffusion of venture capital encourage radical innovation in LMEs.

In recent years, scholars have discussed the extent to which different innovation regimes also condition countries' path to a green transition. Nahm (2021) argues that, rather than fiercely competing, countries tend to position themselves along different segments of the green global supply chain (what he labels as 'collaborative advantage'), for instance specializing in either radical innovation or the more gradual decarbonization of manufacturing processes. In a similar manner, Lachapelle et al. (2017) present distinct 'accumulation strategies':

> 'Patent innovation entails an accumulation strategy which is rent-seeking – to invest in the production of essentially monopolistic sources of income. This entails research laboratories (public and private), venture capitalists, state funding for R&D, etc., all of which combine to generate IP for new products to be licensed and sold. Manufacturing entails a classic Fordist accumulation strategy based on investment in productive activities for sale in the market, deploying labour and machinery in particular. Installation involves an accumulation strategy centred on the sale of electricity from units installed, which in many cases is a combination of both established large-scale utility companies and smaller community-owned or new entrants to electricity markets.' (p. 320).

Since the early 2000s the US has specialized in the creation of green technologies, while countries such as Germany and China have focused on equipment modernization and large-scale production. In line with the idea of radical innovation, in the US 'renewable energy industries were predominately populated by startup firms with capabilities in inventing new technologies, but with minimal in-house production facilities and expertise' (Nahm, 2022). LMEs enable firms to quickly develop new technologies - in a 'revolutionary' rather than 'evolutionary' fashion (Ćetković & Buzogány, 2016; May & Schedelik, 2021; Mikler & Harrison, 2012). While making strides in terms of innovation, the US has failed to specialize in the manufacturing or deployment of clean energy devices to the same extent (Lachapelle et al., 2017). By contrast, typical CMEs such as Germany, as well as East Asian countries, have invested in the incremental innovation of 'research-intensive medium-tech products in traditional industrial sectors' such as automotives, mechanical and electric components (Ćetković & Buzogány, 2016).

Some scholars have also problematized the relationship between varieties of capitalism and green innovation. While the expectation of CMEs fostering incremental advances is borne by solid empirical evidence, the same cannot be said of LMEs and radical innovation. Over the last two decades breakthrough inventions in the green sector have lagged behind in the US, the UK, Australia and Ireland compared to other countries. For Mikler and Harrison (2012), the reason lies in the lack of state effort in promoting environmentally related innovation in these countries. Large public funding is needed to create a market for green products and energies in the first place; simple profit-driven incentives are unlikely to encourage disruptive, 'Schumpeterian-type' innovation (Mazzucato, 2024). Under this different light, the 'US's lack of leadership on climate change is as much a consequence of its variety of capitalism as an absence of political will' (Mikler and Harrison, 2012). These studies suggest that the ability to pursue radical innovations might be associated not only with different capitalist regimes, but also with different policy choices and their underlying politics (Wood et al., 2020). Powerful opposition from fossil fuel industries and/or the weakness of renewable energy producers might have hampered state support for green innovation in LMEs such as those of the UK and US (Aklin & Urpelainen, 2018; Kupzok & Nahm, 2024; Lockwood, 2022).

More recent developments in CPE and environmental policy literatures explore the relationship between different macroeconomic setups and green-industrial strategies. Nahm (2022) proposes a fascinating argument to explain why world leaders in manufacturing, such as China and Germany, have been more effective in their decarbonization strategies than, for instance, the Anglo-Saxon countries. In the former group manufacturers have found it profitable to move into the green energy and product markets, thereby promoting industrial decarbonization early on. In the latter group, instead, a relatively small export sector and the presence of powerful opponents have paradoxically led to a stalemate in the fields of climate and green industrial policy. As a result, in the UK and the US 'emissions reductions also came about simply due to deindustrialization and an increasing reliance on imports of industrial goods in consumption-led economies dominated by services' (ibidem, p. 457). In a subsequent study, Kupzok and Nahm (2024) show that a large and influential 'decarbonizable sector' in the economy can muster crucial support for a green transition, for instance by assembling a coalition with service industries and other climate-sensitive actors. Decarbonizable industries, which include chemicals, metal, electricity, battery, beverage and food producers, rely on fossil fuels but spot economic opportunities in decarbonization, which is why they shift in favour of green industrial strategies. These findings dovetail with recent discussions on growth models (GM) and growth regimes (GR) (Baccaro et al., 2022; Baccaro & Pontusson, 2016; Hassel & Palier, 2021). Authors in these streams have shown that countries foster growth via different 'drivers'. Economies in the Anglo-Saxon group tend to display a negative balance of payments and rely on private consumption or finance-led growth to promote prosperity. Continental and Nordic European economies, by contrast, largely depend on export, either in the form of manufacturing products (Continental) or 'dynamic' high-end services - such as finance, ICT and insurance sectors (Nordic). Instinctively, there are reasons to believe that countries' reaction to climate change may also reflect their structural characteristics and institutional legacies, with each country specializing in something in a way that accommodates their (relatively long-standing) 'accumulation strategy' (Lachapelle et al., 2017). Continental economies that focus on manufacturing exports should bank on clean green-tech production to a larger extent than 'consumption-led' Anglo-Saxon countries. In the German case, during the recent energy crisis policymakers have shown a distinct interest in 'decarbonizing business as usual' and readapting their role as the export champion in the new green economy (McDaniel & Bailey, 2024). Similarly, 'dynamic-service'-led economies in Nordic Europe (also defined as 'balanced growth models') may find it profitable to foster innovation in green services: as persuasively shown by Driscoll (2024), these countries invest to a larger extent in environmentally related R&D, in line with the structural requirements of their economy, which pays 'less attention towards fossil fuels and carbon-intensive manufacturing' (p. 285).

Finally, GM-GS scholarship might also enable us to elaborate expectations on *deployment*, that is, countries' capacity to install and adopt clean energy devices (e.g. solar panels, wind turbines, geothermal energies, electric cars, etc.). While export-led countries find a competitive edge in 'making' these markets (that is, specializing in the invention or production of these technologies), large domestic demand-led economies could be seen as market 'takers', to the extent that they lack the capacity to produce these technologies in-house while pursuing decarbonization goals. At the same time, deployment is likely to create economies of scale and further feed into clean energy markets, thereby aligning with consumption-led growth models and strategies.

Skills and institutional complementarities in the green transition

The second goal of this paper is to articulate the nexus between the types of green capitalism and skill regimes. Our broad expectation is that the skill content and complexity decreases as we move from innovation towards deployment. This happens as countries specialize in different segments of the green value chain in a manner that conforms to their peculiar skill profile. For the innovation segment, high-level academic skills are likely to be key; for the manufacturing segment, high-quality vocational training skills are at the core of the policy mix; and for the deployment segment, mid-level vocational skills are expected to feature most prominently. We elaborate on these points below. Original contributions in CPE have emphasized how CMEs and LME foster distinct educational-training regimes and, in turn, skill distributions (Estevez-Abe et al., 2001; Iversen & Stephens, 2008). CMEs tend to focus on high-quality intermediate skills, which form 'the backbone of thriving manufacturing sectors' (Di Carlo & Durazzi, 2023). Continental European countries such as Germany, Austria and Switzerland feature a qualified technical workforce whose 'specific' skills are useful for sectors such as the automobile, chemical or machine tool. CMEs have historically provided for the creation of such intermediate skills via well-embedded vocational education and training systems (Busemeyer, 2009; Estevez-Abe et al., 2001; Hall & Soskice, 2001). Workforce pools in LMEs are instead skewed towards 'general' skills, which fit the purpose of fast-expanding service sectors both at the 'bottom' (low-end services such as retail and hospitality) and 'top' (insurance, finance, ICT) ends of skill distribution (Iversen & Wren, 1998; Wren, 2020). These skills are 'created' primarily via general academic education, both at secondary and tertiary levels.

In recent years broad distinctions between general and specific skills have been called into question, also in the light of the large-scale expansion of higher education and countries' transition into the so-called 'knowledge economy' (Diessner et al., 2022; Durazzi, 2023; Hope & Martelli, 2019; Iversen & Soskice, 2020). Processes of tertiarization and de-industrialization have been conducive to the expansion of service-sector jobs with academic requirements (Wren, 2020). Scholars have observed a general 'up-skill shift', with distinct consequences across politico-economic regimes (Di Carlo & Durazzi, 2023). In this context, LMEs have invested more significantly in growth strategies oriented towards high-end services. Conversely, CMEs and East-Asian economies have upwardly transformed their industrial structures via the integration of high-quality technologies and technical innovation (Durazzi, 2023; Emmenegger et al., 2023; Thelen, 2019). In these skill systems, higher education has served the purpose of supplying an increasing number of Science, Technology, Engineering and Mathematics (STEM) graduates, whose skills are complementary to mid-skilled workers employed in the same manufacturing companies and trained via vocational education (see also Thelen, 2019).

Moreover, scholars have also invited more caution when distinguishing 'weak' and 'strong' VET systems, calling for a more granular analysis in the latter group (Busemeyer, 2009; Busemeyer & Trampusch, 2011). Within the CMEs themselves, it is possible to distinguish between countries that feature a solid connection between upper secondary school and vocational training (such as Sweden and the Netherlands), and 'dual' systems that foster an institutional separation between academic and vocational paths (Germany, Austria, Switzerland). This distinction is likely to feature more strongly in the knowledge-economy transition. In Northern Europe, a strong bond of academic and vocational education complements high-end, dynamic-services markets (Hassel & Palier, 2021). In the Continental European core, collective skill formation systems (based on a collaboration of associations, firms and the state) support the technological upgrading of manufacturing sectors. The literature also suggests that countries take advantage of their existing skillsets when fostering decarbonization strategies (Ćetković & Buzogány, 2016; May & Schedelik, 2021). At a glance, we may foresee two groups of countries investing in high academic skills in the green sector: LMEs, in line with the ambition of promoting disruptive innovation and firm-based R&D; and dynamic-services CMEs, to maximize their service export-led growth strategies (Hassel & Palier, 2021). Endowed with a smaller manufacturing base than Continental European CMEs, both groups are likely to rely on high academic skills in order to invest in either their innovation capacity (LMEs) and/or in high-end, environmentally related services (dynamic-services CMEs) such as environmental protocols, certifications, and initiatives for climate change mitigation in post-industrial economies. As anticipated, Manufacturing export CMEs should instead capitalize on both company-specific and high-level technical skills 'to invest in incrementally improving existing product lines' (May & Schedelik, 2021, p. 461).

Finally, domestic demand-led countries may want to profit from mid-level technical skills to streamline the deployment of renewable energy capacity. For instance, Ćetković and Buzogány (2016) point out that typical characteristics of LMEs such as 'the lack of vocational training and the associated lack of a qualified workforce in the renewable energy sector (Renewable UK, 2013), together with the limited coordination mechanisms among the state, industry and the financial sector [...] prevent the UK from fully replicating the renewable energy development path of CME states'. Similarly, Di Carlo and Durazzi (2023) maintain that, in Mixed-Market Economies (MMEs) such as Italy and Spain, 'firms perform simple and low value-added assembly and processing operations, employing a large pool of unskilled employees at relatively low labour costs' (p. 332). Due to their basic skill and technology requirements, these countries are more likely to invest in downstream segments of the green global value chain (namely deployment) than countries with already well-developed manufacturing and innovation sectors; hence they require mid-level technical skillsets. Having assessed the literature on CPE, skills and decarbonization, the next section presents the data used for this study, and formulates some hypotheses to be tested in the empirical section.

3. Data, methods and hypotheses

For the empirical section of this paper we gather data on 30 OECD countries from 2000 to 2023. We rely on a novel dataset, assembling information from a variety of sources, such as the International Renewable Energy Agency (IRENA), the Organization for Economic Co-operation and Development (OECD), Bruegel and Eurostat. Our mapping across the three dimensions of innovation, manufacturing and deployment is based on the following variables:

- *Innovation:* we measure green innovation with two sets of variables. The first, well-established in the literature, is the number of environmentally related technologies (patents) per one thousand inhabitants, from the OECD (2024). This is an indicator of green invention weighted by population. We triangulate this data with more granular patent information from IRENA (2024), which offers a breakdown of the cumulative share of green patents in specific sectors: industry, energy, renewables.
- *Manufacturing:* the main variable we use is the gross value added (GVA) of industries identified as 'green' (such as electric car or solar panel manufacturers), as a share of GDP. This data is extracted from Eurostat (2024). While not providing a perfectly 'clean' and detailed indicator of green manufacturing, we triangulate this data with information from the Bruegel Clean Tech Tracker (Bruegel, 2024b) on the raw number of clean-tech manufacturers across European countries, weighted by population size.
- *Deployment:* we adopt a fairly established proxy in the literature, namely the installed solar and wind capacity per capita from IRENA (2024). The index is measured in Megawatt per capita and accounts for two different sources of clean energy (solar and wind). Later in the section, focusing on a smaller subset of countries allows us to account for a third dimension of interest when it comes to deployment – the diffusion of electric vehicles (EVs) – also extracted from the Bruegel Clean Tech Tracker (2024b).

After exploring cross-country variation in terms of innovation, manufacturing and deployment, we delve into the distribution of green skills to examine the association between structural factors and countries' demand for green skills. In this case we use the Bruegel 'Twin Transition Skills Dashboard' (Bruegel, 2024a). The dataset draws from a meticulous analysis of green job vacancies across the web. Bruegel experts classify them according to the skills required for the job and the type of occupation (following standard ISO-08 typology), allowing us to gauge 'quantity' and 'quality' of green jobs and associated skills across the Continent.

In line with the discussion in the previous section, we aim to probe four sets of hypotheses.

- *H1a: LMEs invest in green innovation (patents per capita) to a larger extent than other countries.*
- *H1b: Nordic CMEs (dynamic-services export-led) invest in green innovation (patents per capita) to a larger extent than other countries.*

Hypotheses 1a and 1b address green innovation and test two different (yet non-mutually exclusive) frameworks. From the varieties of capitalism literature, we draw the expectation that LMEs are more consequential in disruptive, clean energy innovation than the rest of the OECD group. Likewise, the GM-GR literature might suggest that dynamic-services export-led economies have incentives to invest in green innovation – not least thanks to a larger supply of highly educated workers in knowledge-intensive sectors.

- *H2a: Continental CMEs (manufacturing export-led) invest in clean-tech manufacturing more than other countries.*
- *H2b: LMEs and MMEs (internal demand-led) invest in clean-tech manufacturing less than other countries.*

The second set of hypotheses regards manufacturing. CMEs in Continental Europe should have incentives to upgrade their industrial systems and adapt them to the green economy, thereby fostering 'incremental' innovation. Conversely, we might expect less efforts for expanding the clean-manufacturing base in typically demand-led economies such as the Anglo-Saxon and some Southern European countries. 'Balanced' or dynamic-services export-led economies in Northern Europe probably lie in the middle between these two groups.

- *H3: Demand-led economies (both finance- and domestic consumption-led) invest in deployment (clean energy capacity) more than other countries.*

As regards deployment, we conjecture that countries in the Anglo-Saxon and Southern European regions are by and large 'takers' of these markets. Lacking either the manufacturing base to produce green technologies or the adequate institutions and skill pools to invent them, they may want to expand the clean energy market as a driver of internal aggregate demand. Incidentally, balanced economies may also invest in deployment, at least to a larger extent than manufacturing CMEs.

- *H4a: green innovators are associated with demand for high-level academic skills;*
- *H4b: green manufacturers are associated with demand for high-level vocational skills;*
- *H4c: green deployers are associated with demand for mid-level vocational skills.*

Finally, we formulate skill-related hypotheses 4a, 4b and 4c as a logical consequence of the above. In a logic of functional complementarity among structural requirements, industrial regimes and skill profiles, we may expect that green innovators are associated with larger shares of high-level academic skills to cater to dynamic services and foster path-breaking technological advances in the green sector; green manufacturers rely on high-level technical skills to pursue incremental innovation in their core industries; and green deployers resort to mid-level vocational skills for expansion of clean energy capacity, notably the installation of solar panels, wind turbines, and the like.

4. Findings

This section presents the empirical evidence. We first assess the extent to which a tripartite green global division of labour exists. Then we examine whether green skills bundle across countries in line with the characteristics of national green economic activities.

CMEs lead in all three dimensions of the green transition – albeit with some intra-group differences

Figure 1 charts the levels of green innovation from 2000 to 2019 in a small group of advanced economies that represent distinct 'types' of capitalism. The first plot on the left-hand side accounts for cumulative patents on wind and solar technologies, which, as suggested by Nahm (2022), should capture a sector especially at the 'frontier' of green innovation. The central plot is taken from the same dataset, but it accounts for *all* environmentally related patents, while the right-hand one is an established indicator of green innovation: green patents per one thousand inhabitants from the OECD. The three images show a relatively similar distribution. CMEs such as Denmark, Japan and Germany are world leaders in green innovation. Australia and the US rank third and fifth in the IRENA variables, respectively. The OECD indicator, instead, emphasizes even more the distance between CMEs and LMEs, with Sweden positioning at fourth place after Denmark, Japan and Germany. Given our interest in understanding how countries occupy different segments of the green global value chain, it is relevant to compare countries' level of innovation and deployment simultaneously across time. Figure 2 shows countries' trajectories between 2000 (beginning of the arrow line) and 2019 (end of the arrow line) across innovation and deployment. Innovation variables are the same as in figure 1. For deployment, we use an index of installed wind and solar energy capacity per capita from IRENA. Denmark again tops all other countries when it comes to both deployment and innovation, starting from relatively higher positions on both axes (especially deployment) in 2000. Germany and Japan also record high levels in both dimensions, as well as Australia (albeit only in the IRENA variables). Over time, some countries have found a much better niche in innovation than deployment, as is the case with LMEs (New Zealand, US, Canada). The opposite is true for the Netherlands, Belgium, Ireland, Italy, Portugal and Greece, who tend to do 'more' deployment than innovation. The OECD indicator confirms the trend of some LMEs specializing in innovation (the US, Canada) and Southern European countries investing in deployment more than in innovation (Italy, Spain, Portugal, Greece).

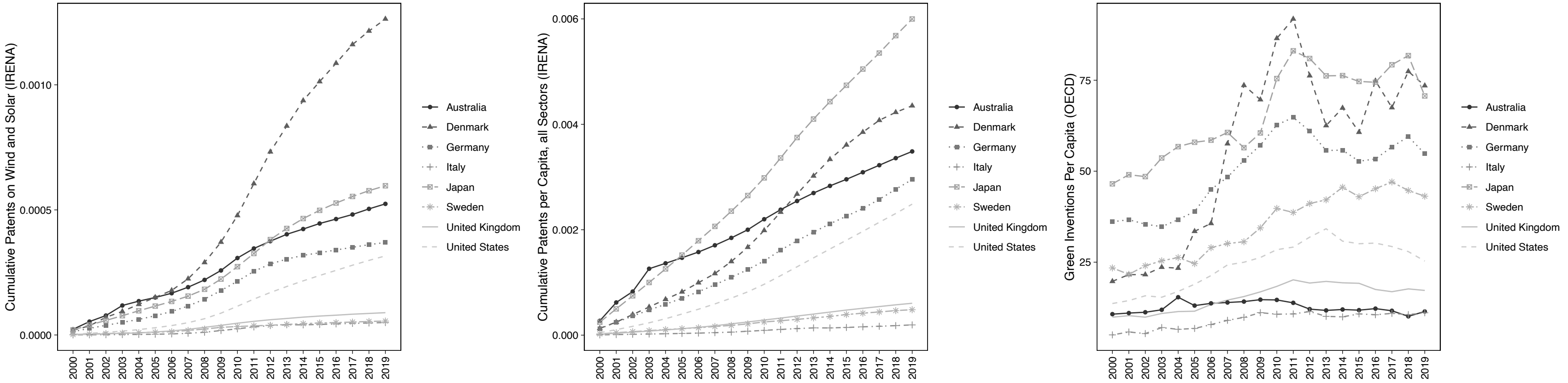

Figure 1. Green innovation from 2000 to 2019 in 8 OECD countries (Australia, Denmark, Germany, Italy, Japan, Sweden, the UK, the US). Left-hand figure: cumulative patents on wind and solar technology (IRENA). Central figure: cumulative number of all environmentally related patents (IRENA). Right-hand figure: green patents per capita (OECD).

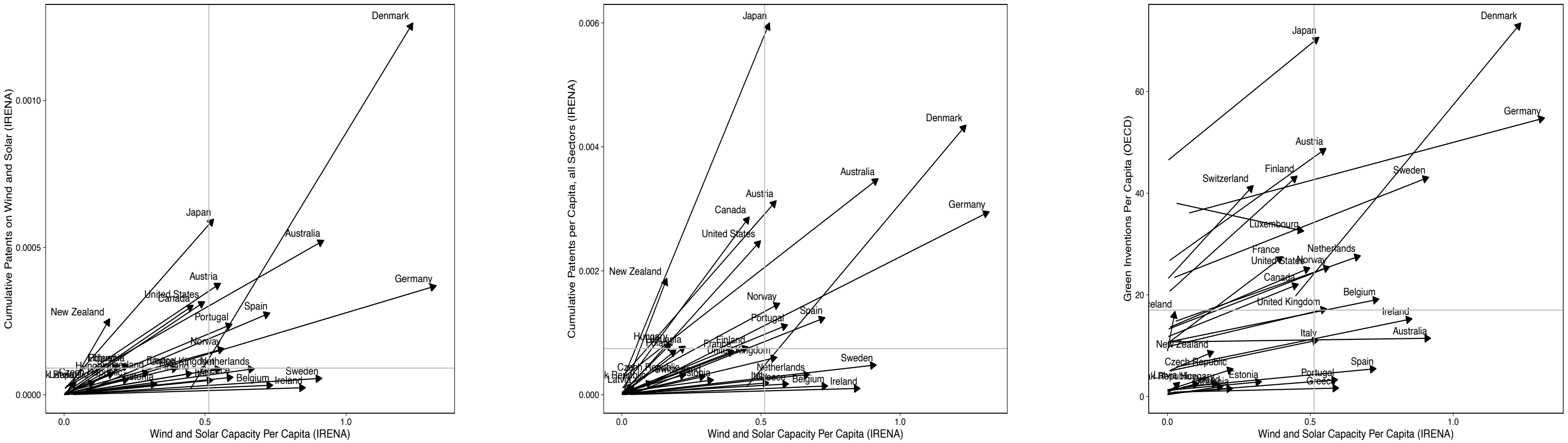

Figure 2. Levels of innovation vs deployment per capita over time in 33 countries. The beginning of the arrow represents countries' position in 2000; the end of the arrow represents countries' position in 2019. Grey lines represent median values for the end of the period. Variables on the y axis: the same as above. Variable on the x axis: installed wind and solar capacity per capita, in GW, per one thousand inhabitants (IRENA).

When it comes to the 'size' of the green manufacturing sector (figure 3), both typical industrial-export CMEs and service-oriented Nordic CMEs rank at the top of the distribution. In this case, we are forced to look at a smaller group of countries (EU members) since no high-quality comparable data is available at the international level. We cross-check two variables: the gross value added of green industry (from Eurostat) as a share of GDP, and the number of clean tech manufacturing companies (Bruegel), which we weight by population size. Austria, Finland and Denmark show very high levels of GVA in the green industry, followed by Portugal, Czechia and Germany. Central and East European countries perform relatively well on this dimension, while France, Greece, Ireland, Belgium, the Netherlands, Sweden and Spain fall towards the lower tail of the distribution. The Bruegel variable on clean tech firms shows a relatively similar variation, with the notable exception of Austria and Portugal (which record lower levels on this scale), and Estonia, Sweden, Spain, Netherlands and Norway (which record higher levels on this scale).

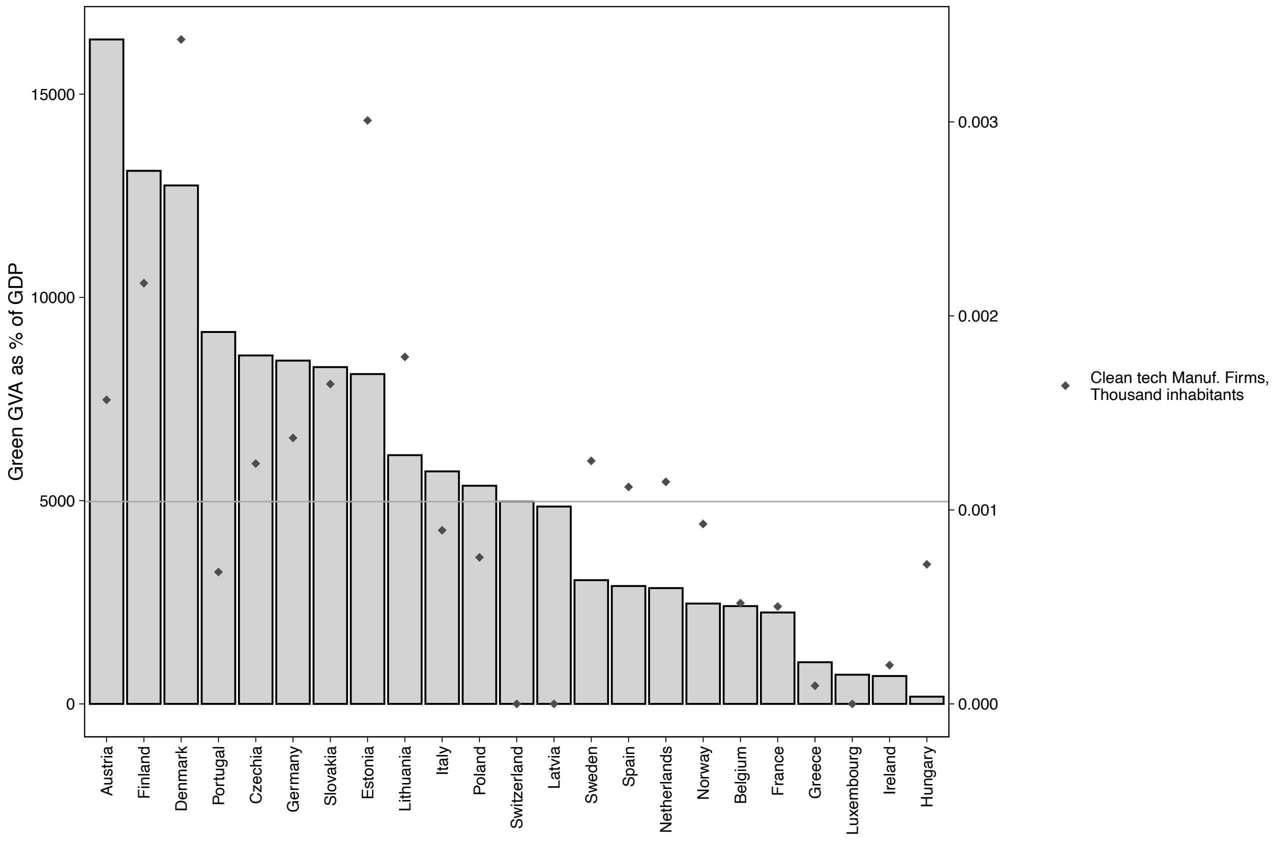

Figure 3. Size of the green manufacturing sector across European countries. Bars: gross value added (GVA) of green industry as a share of GDP (Eurostat). Dots: number of clean tech manufacturing firms, weighted by population size (Bruegel).

As we shift our attention to deployment, no-clear cut divides between capitalist 'families' emerges from the data. Figure 3 plots a dozen of advanced economies per level of deployment, from 2000 to 2019. It shows again that Denmark and Germany are the world leaders in installed wind and solar capacity per capita. They are followed by Australia and Sweden, and after them Spain, Japan, the UK, Austria, Italy, the US, Finland and France. A first interim assessment suggests that some CMEs (both service- and manufacturing-exports oriented) outweigh all other countries along virtually all three axes of green capitalism – *in primis* Denmark and Germany – while other specialize in one or two 'sides' of this virtual triangle.

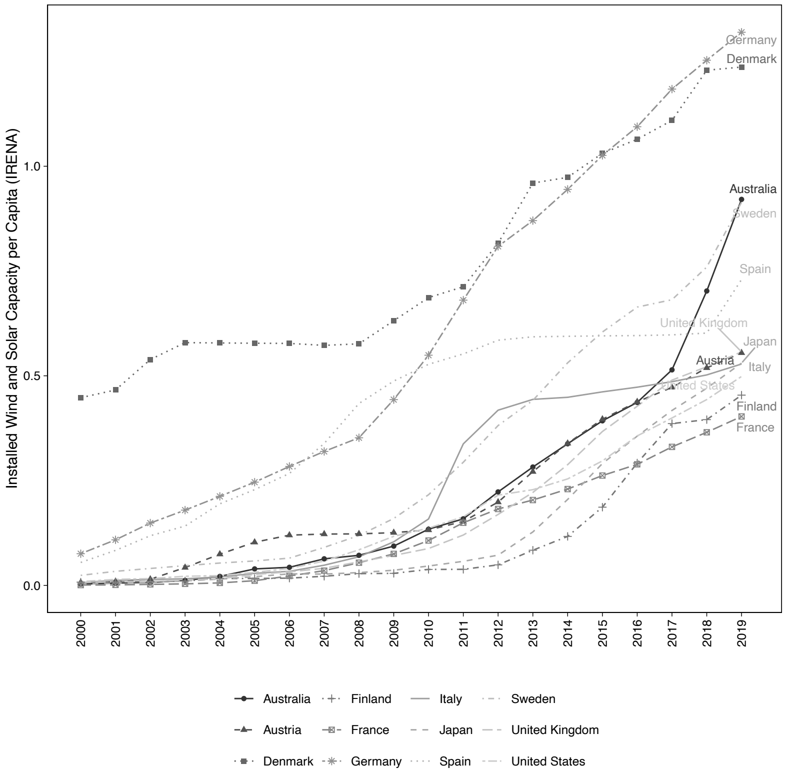

Figure 4. deployment shares from 2000 to 2019, in 12 countries (Australia, Finland, Italy, Sweden, Austria, France, Japan, the UK, Denmark, Germany, Spain, the US). The plot shows levels of installed wind and solar capacity per capita, in GW, per one thousand inhabitants (IRENA).

Given the *prima facie* correlation between the three dimensions of innovation-manufacturing-deployment, in the last part of this subsection it is worth observing how the variables position relative to each other, and if any significant country groups emerge. Figure 5 plots countries according to each of the three dimensions in pairs, with dot size representing the third excluded dimension. Here we show countries at a single point in time (2021), representing the end point of the period under observation. Furthermore, we extract green industry GVA from the Eurostat database, which unfortunately excludes all non-EU countries (such as most LMEs and Japan). On the other hand, restricting our analysis to a subset of EU countries allows us to account for a third and significant dimension of deployment: electric vehicle (EV) capacity (Bruegel, 2024b), which is henceforth included in the deployment index.

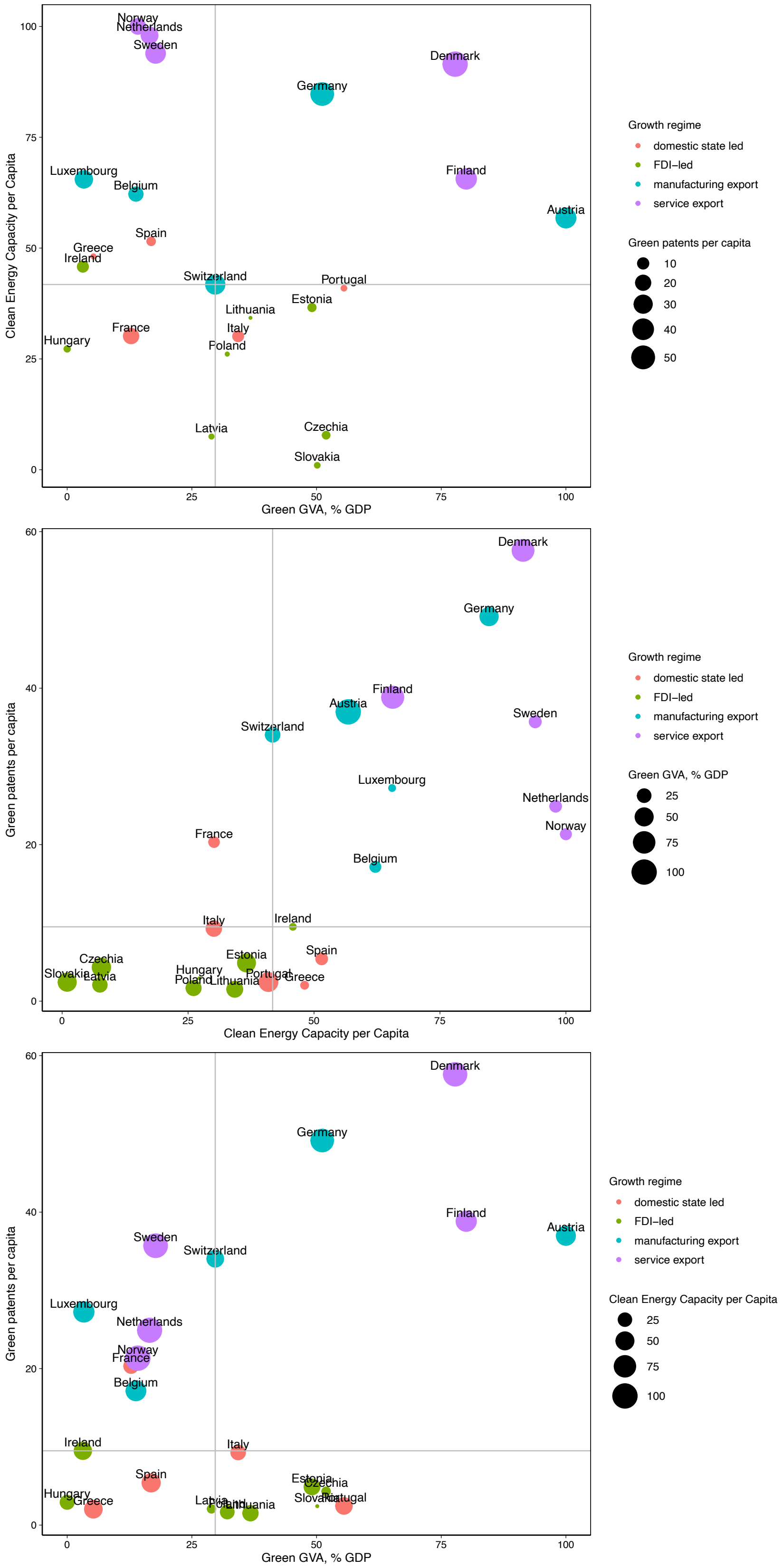

Figure 5. Combinations of innovation, manufacturing and deployment in EU countries, 2021 or closest available. In pairs, charts display two dimensions against each other, and the third dimension as dot size. Proxy for innovation: green patents per one thousand inhabitant (OECD). Manufacturing: share of the green GVA in industry as a share of GDP (Eurostat). Deployment: diffusion of installed wind, solar and electric vehicles (EVs) per capita (IRENA and Bruegel). Colours represent growth regime types (Hassel & Palier, 2021). Grey lines represent median values.

The distribution plotted in figure 5 broadly mirrors our theoretical expectations. Most FDI-led economies display higher shares of green industry GVA than clean energy deployment capacity per capita. Likewise, we see that service-oriented, ‘balanced’ economies such as Norway, Sweden and the Netherlands have above-median values for deployment and below-median for manufacturing. Denmark, Germany, Finland and Austria score highly in both dimensions. In the central plot of figure 5, we observe a positive association between innovation and deployment. FDI-led economies record low levels in both deployment and innovation; domestic state-led economies follow closely, but position themselves closer to the median; manufacturing export-led economies score middle-to-high levels in both variables; Finland, Germany and Denmark again take the lead in both dimensions. Finally, the bottom-end plot of figure 5 shows a rather neat division: domestic state- and FDI-led economies cluster in the bottom quadrants of the chart; service-oriented knowledge economies of Northern Europe invest more in innovation than in manufacturing, while Germany, Finland, Denmark and Austria are positioned in the top-right corner. Interestingly, a positive association between innovation and manufacturing seems to hold for CMEs, but disappears completely for non-CMEs.

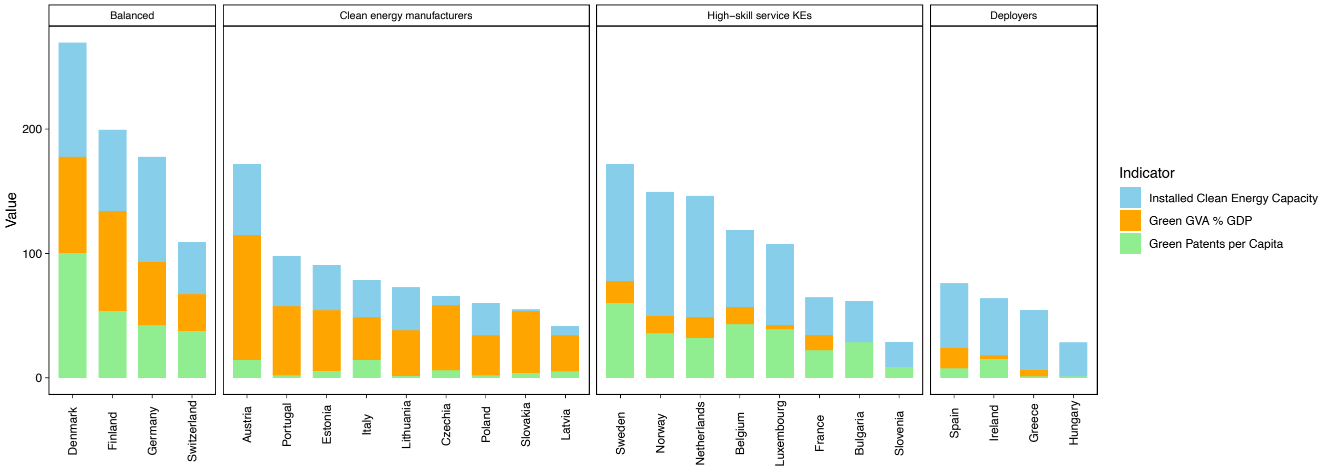

Figure 6. Stacked bar chart with relative and absolute levels of innovation, manufacturing and deployment. Variables are rescaled 0-100 and summed within each country to create a composite index. Groupings are our own elaboration.

Finally, figure 6 tries to clarify countries’ trajectories further by creating a composite index. We rescale all three variables from 0 to 100 and produce a stacked bar chart, useful to describe at once countries’ absolute effort and their green ‘mixes’ across the three dimensions. After having calculated the scores, we create country groupings according to the relative and absolute scores in each of the three categories. A first group of countries (Denmark, Finland, Germany, Switzerland) achieve both high absolute scores (above 100 cumulatively) and a relatively even distribution across the tree dimensions. We refer to this group as *balanced* *leaders*. A second group, which we label *clean energy manufacturers*, stands out for high relative levels of manufacturing, combined with medium to low levels of deployment and very limited innovation. This group includes mostly FDI-led and domestic state-led economies, as well as Austria due to its disproportional effort in manufacturing *vis à vis* the other two. The third group (most of Nordic Europe, together with Belgium, Luxembourg, France, Slovenia and Bulgaria) is labelled as *high-skill service KEs*. These countries feature relatively high levels of innovation and deployment, and limited manufacturing capacity. Finally, a group of *deployers*, covering Spain, Ireland, Greece and Hungary, is characterized by being overall laggards in the green transition and gearing their (modest) green efforts towards deployment. By way of concluding this sub-section, it is important to note that there are several countries that attain borderline scores and could be legitimately placed in a different group. At the same time, Figure 6 provides, in our view, two important insights that stand regardless of specific borderline choices that may be made with respect to country groupings. Firstly, there are stark quantitative differences in the extent to which countries have embarked upon the twin transition, with a small number of countries (chiefly Denmark, Germany and Finland) that outperform the others. These countries also post a strong performance across the three functions of the green transition, suggesting that in the presence of 'mature' green markets, innovation, manufacturing and deployment tend to reinforce each other. Secondly, when zooming in on countries at lower levels of the green transition, we note greater imbalances across the three functions. Smaller green markets, in other words, tend to specialize disproportionately in either innovation, manufacturing or deployment.

Different green skillsets in different green worlds

We now turn to the variation in green skillsets and discuss relevant associations with structural factors. We examine data from the Bruegel's twin transition dataset (Bruegel, 2024a), which pools information on green job postings across skills and occupations in the EU. Figure 7 describes the raw number of green jobs every 1000 postings from 2019 to 2023. It is possible to observe that between roughly 20 and 30 out of every 1000 jobs are categorized as 'green' in Continental European economies. These figures are slightly higher for Nordic Europeans, and lower for Southern and Central-Eastern Europe. Denmark and Sweden record the highest shares of green jobs in the whole group.

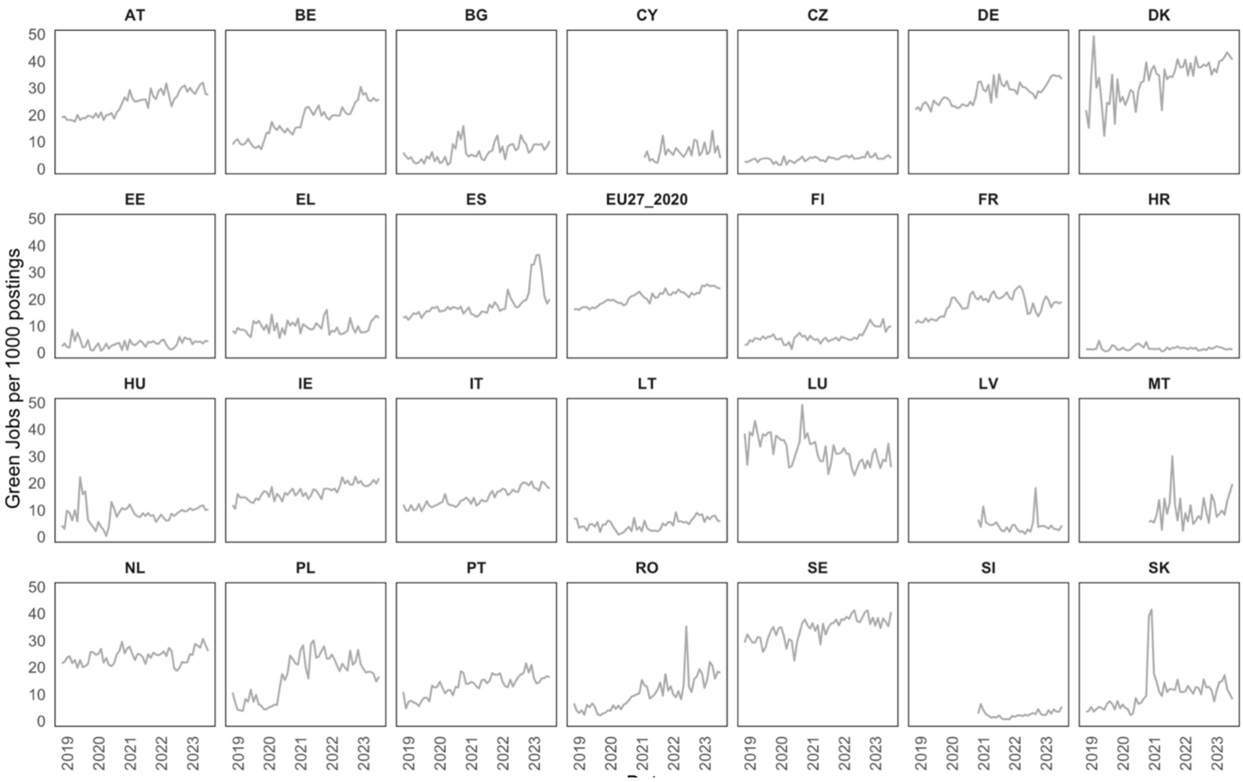

Figure 7. Number of green jobs per 1000 postings in EU countries, 2019-2023 (Bruegel).

As anticipated, Bruegel complements the raw number of green job postings with information on occupational groups through the ISCO-08 categorization. Using the ISCO categorization is particularly insightful to gauge levels and types of skills because it provides explicit information about the skills required for particular occupations, entailing an assessment of both the formal levels of education required for a certain occupation, as well as the complexity of skills. In particular, there are three levels/types of skills from the ISCO classification that we deem particularly relevant for our investigation. Skill level 4, which is the highest skill level, is assigned to the occupational category of ‘Professionals’, which is described as formed of workers who ‘increase the existing stock of knowledge [and] apply scientific […] concepts and theories […]’ (ILO, 2012, p. 109). These are typically university-educated workers. Skill level 3, which captures medium-high skills, is assigned to occupation category ‘Technicians and Associate Professionals’ who perform ‘technical and related tasks connected with research and the application of scientific […] concepts and operational methods’ (ILO, 2012, p. 169). These workers’ educational attainment typically straddles university education and high-end vocational training programmes. Finally, skill level 2 are the typical intermediate level skills, squarely formed within (upper-) secondary vocational training. This level encompasses a host of ISCO occupations, such as ‘Clerical Support Workers’, ‘Service and Sales Workers’, ‘Craft and Related Trades Workers’, ‘Plant and Machine

Operators, and Assemblers' as well as 'Elementary Occupations'. We are particularly interested in the *technical-oriented* level 2 occupations, namely, 'Craft and Related Trades Workers' and 'Plant and Machine Operators', and Assemblers', which we hypothesized to be the most relevant in the context of the twin transition, and in particular of its 'deployment' leg (recall *H4c*). Given our overarching hypothesis of an association between different types and levels of skills and different green specializations, we first assess whether there is meaningful cross-country variation in green skill distribution. Figure 8 shows the distribution of green occupations across Europe by ISCO groups, reporting the same figure ranked according to the three different occupational – and therefore skill – categories of theoretical interest, namely high, medium-high and intermediate skills, proxied respectively by the 'Professionals', 'Technicians and Associate Professionals' and the sum of Craft and Related Trades Workers' and 'Plant and Machine Operators', which we collectively label (Semi)skilled Technical Workers. As figure 8 shows substantial cross-country variation in the distribution of green skills, we proceed to assess whether there is a positive association between the type of green skills that are in demand across countries and their specialization in green innovation, manufacturing or deployment. In line with the 'decreasing' skill complexity hypothesis outlined in section 3, we are particularly interested in the association between high skills and innovation, high and medium-high skills and manufacturing and intermediate skills and deployment.

Figure 9 provides the results of this exercise. Overall, we find the expected positive associations between high and medium-high skills and green manufacturing and between intermediate skills and green deployment. While the slopes go in the expected direction, these relationships are nonetheless rather weak. This, at least in part, is potentially due to the selection of variables that are imperfect proxies trying to capture relatively recent socio-economic developments for which an agreed and systematic set of indicators does not yet exist. The relationship between innovation and high-level skills goes *prima facie* even in the opposite direction, as suggested by the negative slope when plotting green patents against green professionals. At the same time, a sizeable share of countries in the sample feature very low patents per capita, suggesting that their green innovation markets are rather limited. To assess whether the size of countries' green innovation markets biases the results, we split the sample between countries with above- and below- median levels of green innovation. The results of the split sample analysis are reported in figure 10 and show a strongly positive relationship between green professionals and green innovation in above-average innovators, suggesting that 'mature' green innovation markets produce the expected demand of high-level green skills.

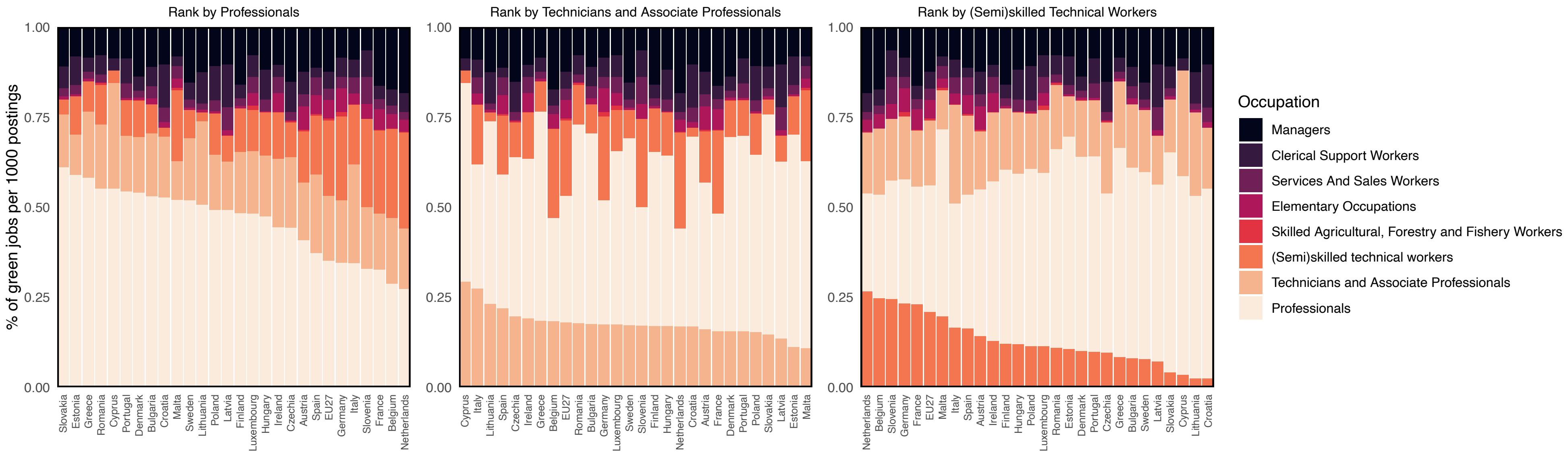

Figure 8. Distribution of green occupations across EU countries (2021), ranked by three different categories: 'Professionals' (left), 'Technicians and associate professionals' (center), and '(Semi)skilled technical workers' (right, which we calculate as the sum of the ISCO-08 groups 'Plant, machine operators and assemblers' and 'Craft and related trades workers').

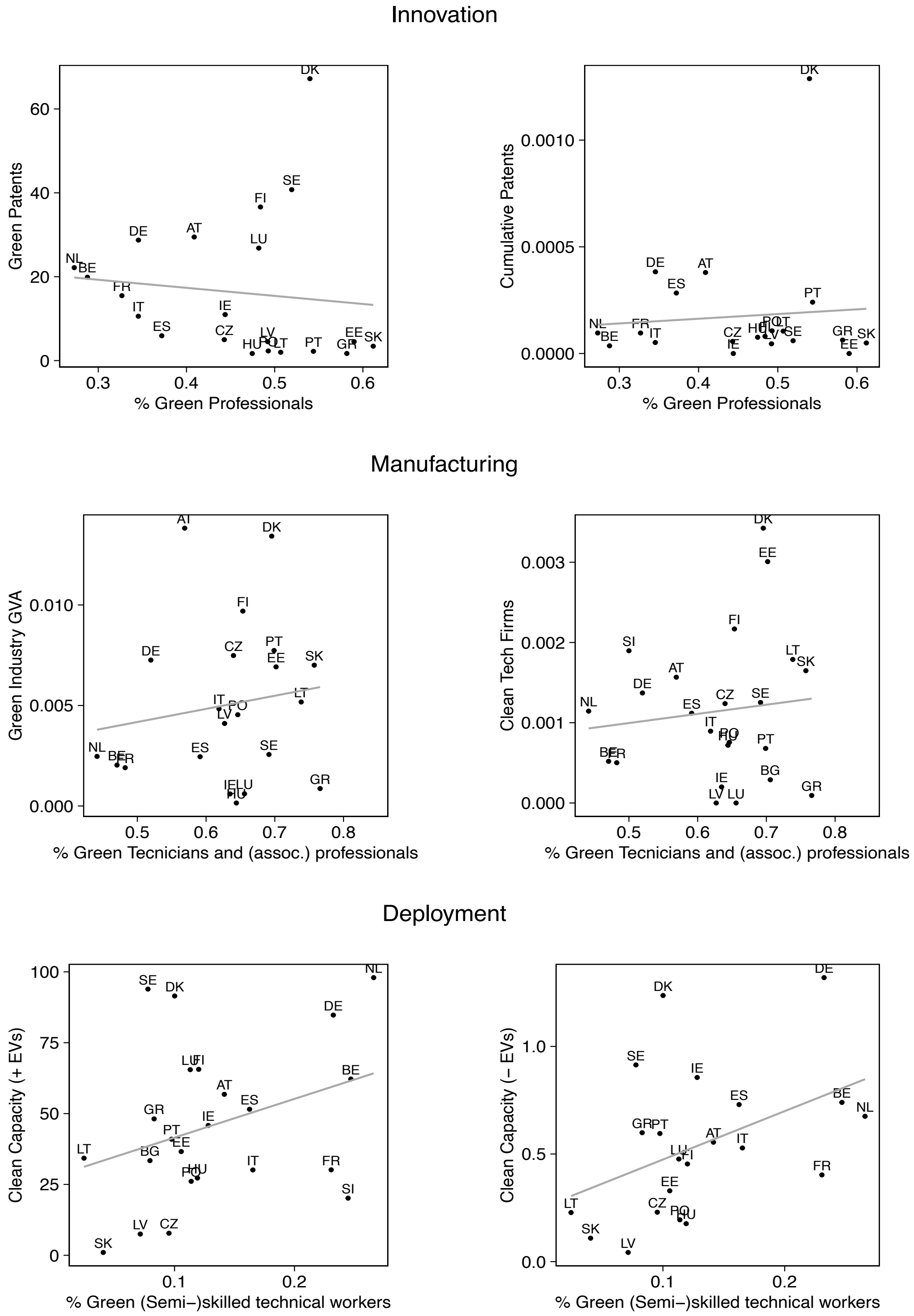

Figure 9. Associations between green occupations (Bruegel) and green structural variables. Top row: share of green 'professionals' vs. green patents per capita (left), and cumulative patents on renewable energy (right; OECD, IRENA). Middle row: shares of green 'technicians and (associate) professionals' (calculated as the sum of ISCO-08 groups 'Professionals' and 'Technicians and associate professionals') vs. green industry GVA as a share of GDP (left), and number of clean tech manufacturers per one thousand inhabitants (right; Eurostat, Bruegel). Bottom row: shares of '(Semi)skilled technical workers' (sum of ISCO-08 groups 'Plant, machine operators and assemblers' and 'Crafts and related trades workers') vs. diffusion of installed clean energy (wind, solar, EV) per capita (left), and same indicator but excluding electric vehicles (right; Bruegel, IRENA). Solid lines indicate the best fit. Year 2021 or latest available.

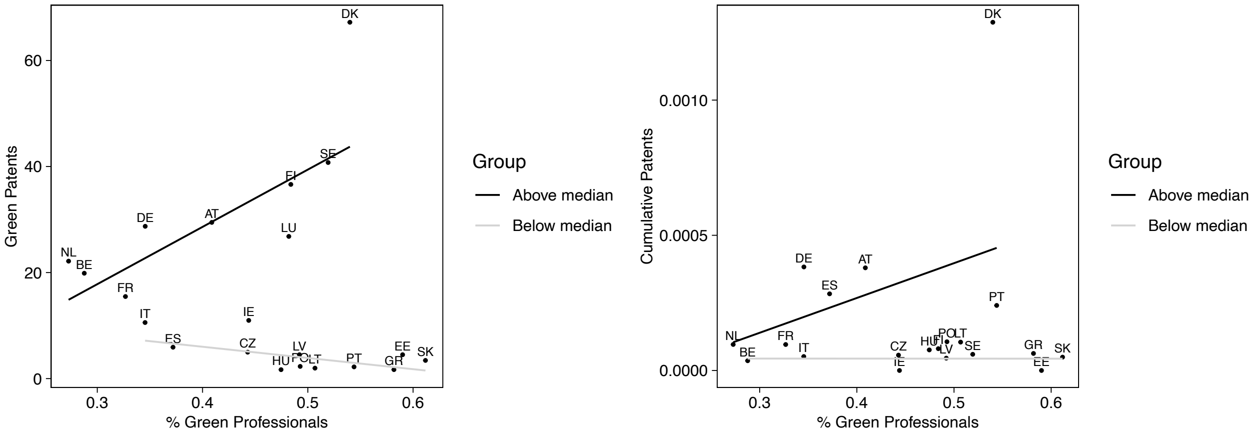

Figure 10. Split samples of associations between green professionals (Bruegel) and green innovation variables. On the left: share of green 'professionals' vs. green patents per capita (OECD). On the right: share of green professionals vs. cumulative patents on renewable energy (IRENA).

5. Discussion and conclusion: global 'division of labour' or winner-takes-all race?

When it comes to the green transition, recent studies have argued in favour of a global division of labour between countries, broadly overlapping with traditional CPE varieties and models (Driscoll, 2024; Lachapelle et al., 2017; Nahm, 2021, 2022). However, our evidence only partly conforms to these theoretical expectations. Our main finding is that, while countries tend to specialize between clusters across structural and skill dimensions, a handful of CMEs has outpaced the others in nearly every dimension under investigation. Denmark, Germany, Finland and – sometimes – Sweden, Switzerland and Austria stand out as global leaders in the green transition by all accounts. *Prima facie*, this calls into question whether countries' division into different segments of the global value chain has to do with structural 'requirements', as much as with endogenous political factors such as corporatism and the capacity to mobilize relevant coalitions in favour of decarbonization (Finnegan, 2022; Kupzok & Nahm, 2024; Lockwood, 2022; May & Schedelik, 2021; Meckling et al., 2015; Meckling & Nahm, 2022; Mikler & Harrison, 2012; Wood et al., 2020). While political initiative is likely to be key, there is some empirical ground to argue that industrial and growth features influence countries' decarbonization paths (Guarascio et al., 2024). Nordic CMEs such as Denmark and Sweden invest in green innovation to a larger extent than other countries (H1b), in line with the structural requirements of 'dynamic services' knowledge-based economies (Driscoll, 2024; Hassel et al., 2020). However, the evidence on the link between radical innovation and LMEs is less convincing. While Australia performs well on all innovation indicators, the US as well as smaller LMEs do not emerge as substantially more innovation-oriented than other countries.

The expectation of manufacturing export-led CMEs investing in 'incremental innovation' - namely, clean-tech manufacturing (H2a) - is to some extent borne by the data. Austria and Germany cultivate a larger green manufacturing sector than most Southern and Central-Eastern European countries. Likewise, service-oriented CMEs are – as expected – significantly less green industry-intensive than manufacturing CMEs, and well below median values. At the same time, we find surprisingly high manufacturing scores in Portugal, Estonia, Czech Republic and Slovakia (against our H2b), and relatively low scores in Switzerland and Belgium. More importantly, Finland and Denmark rank as EU-level leaders in incremental innovation (only after Austria), again raising the question if the green transition is a 'structural division of labour' story or a 'political institutions and will' story. Our findings reject with a fair degree of confidence the hypothesis that demand-led economies (both finance- and domestic consumption-led) invest in deployment more than other countries (H3). At the time of writing, the global race for clean energy deployment (via energy, wind or EVs) seems by and large dominated by CMEs. Germany and Denmark stay well ahead of the pack, consistently with their early-mover position in wind and solar energy and decades-long investments in these sectors (Aklin & Urpelainen, 2018; Nahm, 2021, 2022). Australia, Sweden and Spain take medium to high positions. When considering the deployment indicator that includes EVs, smaller CMEs such as Norway, Netherlands, Sweden and Finland rise up to the higher tail of the distribution. Regardless of the indicator used, there is weak evidence supporting the idea that demand-led economies invest in deployment more than others, as a potential 'engine' of aggregate demand, while export-led countries depress their domestic deployment to boost competition. If anything, the opposite seems to be the case: export-oriented economies are more invested in clean energy capacity than the rest of the OECD.

Using indicators on green job postings, the second empirical section of the paper has mapped countries' positions in terms of green skills distribution. The three skill-related hypotheses (H4a, H4b, H4c) find some support in the data. Innovation-oriented countries, such as the Nordic ones, have distinctly greater shares of green professional jobs underpinned by high-level skills, while green manufacturing produces strong demand for high and medium-high technical skills. Deployment, instead, positively correlates with intermediate vocational skills. The implications of these relationships are not trivial: as countries engage in different segments of the green transition, there are clear consequences also for the types of green jobs that the labour market will produce, which may in turn affect patterns of popular political support for the green transition.

The evidence discussed in this paper allows us to conclude that, while countries invest in the low-carbon economy consistently with their existing skill regimes, their position in the global value chain seems more dependent on political and institutional supply-side factors than mere growth drivers or structural requirements. For instance, while dynamic services CMEs such as Sweden, Norway and the Netherlands are more oriented towards invention and deployment than manufacturing, Finland and Denmark generally take the lead in all three sectors - supporting the idea of stronger synergies 'at home' (for instance between invention, creation and installment of solar panels) than across countries. The same applies to Germany: traditionally seen as the fossil fuel-dependent manufacturer *par excellence,* the largest economy in Europe has successfully promoted both 'incremental' and 'radical' innovation from the 2000s to our days. When looking at green capitalism 'mixes' across countries, Austria, Portugal and Italy come out as more skewed towards green manufacturing than, for instance, manufacturing export CMEs like Germany or Switzerland. At the same time, we do observe that some demand-driven economies (Spain, Portugal, Ireland and Greece) focus on green energy deployment and display mostly mid-level technical skill distributions. Along with adding to the literature on skill regimes and capitalist diversity, our findings speak to the recent scholarship on the political economy of decarbonization (Driscoll, 2024; Kupzok & Nahm, 2024; Meckling et al., 2015; Meckling & Nahm, 2018, 2022; Mildenberger, 2020; Nahm, 2021, 2022). Our analysis confirms that, while structural factors matter, dependence on carbon is not predestined. Political agency and entrepreneurship are likely to matter in how countries shift towards the green economy, as the Danish and German cases testify (Aklin & Urpelainen, 2018; Lachapelle et al., 2017). At the same time, countries seem, at least to some extent, attached to their political-economic 'starting position' when crafting new strategies for a transition, as proved by dynamic-services countries in Northern Europe opting for a mix of innovation and deployment; core CMEs such as Austria, Germany and Switzerland transitioning to clean tech manufacturing; and peripheral European countries moving to large-scale deployment. Even more importantly, countries' green-economy skillsets largely reflect their prior education and training regimes, which work as a functional complement to distinct decarbonization strategies.

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