Assessing the Reshoring of Supply Chains in Low Carbon Technologies: The State of Affairs and Implications

Andreas Goldthau[a], Llewelyn Hughes[b], Jonas Nahm[c]

Abstract

China's ability to use process innovation in manufacturing made the country a key player in the clean tech sector. Specifically, China's dominance in solar and battery manufacturing has triggered political discussions in Western capitals about re-offshoring from China to alternative locations, and possible reshoring to geographies closer to home. The paper catalogues and assesses policies put in place in China, Europe, Japan, and the United States to incentivize reshoring and re-offshoring. It then explores whether and to what extent these measures are likely to impact the geography of select low carbon technologies. The paper finds that most policy measures in place aim at diversifying supply chains and improving domestic competitiveness rather than outright reshoring. Nonetheless, some policies explicitly aim at reshoring, including EU and US tariffs on Chinese solar PV modules. We argue that the effects of potential reshoring measures are a function of technology complexity and their geographical concentration. In light of this, the paper discusses the possible implications of reshoring measures for climate change and economic development. It draws conclusions for policy based on a public interest approach, focusing on national competitiveness and industrial policy; climate change; and upgrading as part of the development imperative.

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1. Introduction

A core feature of the global economy over the last three decades has been the rise of offshoring and an increased use of outsourcing (Baldwin and Clark 2000). Offshoring—through which companies relocate stages of the supply chain to third-party countries—has been enabled by the rise of contract manufacturing, which itself is made possible by the digitalization of key stages of the production process. The same underlying processes have also enabled the increased use of outsourcing. Outsourcing generally describes the process in which stages of the supply chain that were previously incorporated within a single company structure are contracted outside the firm to third-party suppliers. Together, offshoring and outsourcing have come to be known as core features of globalization, and have led to the emergence of a complex web of global supply chains for many different products.

There is an extensive literature on the motivation for companies to engage in offshoring and outsourcing of productive activities, centering on the impact of specialization on productivity and ultimately on product prices (Schmeisser 2013). This reflects the fact that the value of trade in intermediate products—defined as products which are used as inputs into further productive processes—has grown enormously as a share of world trade. To date, intermediate products make up around half of global exchange in goods (UNCTAD 2021). As a result, global supply chains have come to define the governance of the production of a large share of products traded in the world economy across many different sectors.

A recent debate has emerged amongst governments in leading economies about supply chain resilience, prompted by the COVID-19 virus, and geopolitical tensions. The degree of concentration within a particular segment of the supply chain, for example, is identified as a factor that can amplify or weaken the effect of international shocks such as supply disruptions. There is also an important geospatial component. Countries that incorporate a relatively higher share of foreign imports face higher exposure to supply shocks (Organisation for Economic Co-operation and Development, 2020). The final risk of is a combination of exposure to a given shock and the vulnerability of a firm

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to that shock (Lund et al. 2020). Many factors contribute to overall vulnerability to supply shocks, including the complexity of a product, the complexity of the supply network transportation and logistics, organizational effectiveness, and the degree of demand planning (Lund *et al.*, 2020). Such concerns about supply chain resilience have amplified existing unease about import dependence in markets for low carbon technologies—wind, solar, storage. These sectors are crucial for climate change mitigation, and remain policy-driven markets that depend on government support to compete with incumbent products that are lower cost in the absence of a mechanism to account for the social cost of greenhouse gas emissions. Given the need to spend taxpayer money, few governments have been content with being mere importers of clean energy technologies (Nahm 2021).

In the United States, there is bipartisan pushback against the economic reliance on China in a number of key industrial sectors. Already before the onset of the COVID-19 pandemic, voices across Washington began promoting economic decoupling from China. Although opinions differed on what exactly such measures should entail, agreement emerged that China was unwilling to accept the global rules of engagement, requiring the United States to shift strategy. Such views originated in the realization that the core assumptions underlying U.S.-China relations in recent decades had been unsound: economic integration had not in fact led China to align with Western political norms and economic practices. These views are shared across the aisle. The Center for American Progress called for the need to "limit, leverage, and compete" with China, essentially advocating a strategy of putting U.S. interests first and using economic interdependence for political gain (Hart and Magsamen 2019). The Trump administration also imposed import tariffs in steel, aluminum, and other industries.

Perhaps less forcefully than in the United States, European officials have also begun to question the economic dependence on China, particularly in sectors, such as batteries, which are deemed of strategic importance for both energy security and the continued viability of the European automotive industries. A case in point is the EU Commissioner for the Internal Market, Thierry Breton, calling for more "strategic autonomy" in key sectors such as green technologies to limit economic and geopolitical "unwanted dependencies" (Simon 2020). The COVID-19 pandemic further accelerated such tendencies. It highlighted not only the vulnerability of the world's economic supply chains to external shocks, but also strengthened mercantilist calls for national self-sufficiency in China, the United States, and elsewhere (Farrell and Newman 2020).

Although reshoring has become an important part of the policy debate, the empirical evidence of its existence is less certain. Fundamental questions remain about how to define reshoring, the extent to which reshoring is occurring, and whether the rhetoric about reshoring is underpinned by policies that actually advance reshoring goals. A first important challenge here is measuring change in the organization of global supply chains. One way is using a macro approach, utilizing global input output tables. A micro approach, in contrast, utilizes data at the level of the firm in order to understand how these firms are organizing their production networks. As Johnson (2017) notes, "researchers have struggled to create a coherent empirical portrait of global value chains" (1), and an important reason is that national statistical data is not collected in order to measure GSCs. Moreover, GSC measurement is limited by the degree of granularity that is available in national statistical data related to trade. This is also the case for low carbon energy technologies, and remains a barrier to a proper assessment of the degree of offshoring, reshoring, and near-shoring. Systematic and comprehensive data on the prevalence of outsourcing and offshoring in low carbon technologies is not available. Yet, as we document below, case study evidence shows both offshoring and outsourcing are prevalent in the low carbon technologies domain, leading to the creation of global supply chains for solar photovoltaic modules, wind power facilities, electric vehicles, and the core components entailed in their production.

A second important challenge is conceptual. In the area of low carbon technologies, for example, debates about the merits of reshoring are occurring at the same time as many governments are investing billions of dollars in packages designed to revitalize domestic economies by supporting investment in industries and technologies relevant to decarbonization. Because these industries are considered important sectors for future economic competitiveness, there exists a more general trend towards a strategic positioning of countries in the low carbon tech domain. Such efforts include the use of trade measures but for most part entail classic industrial policy (Hughes and Meckling 2017). Although these measures are geared towards fostering domestic industries, including in manufacturing, they are not primarily meant to relocate production capacity from elsewhere. It is therefore important to distinguish between (1) investments in manufacturing capacity which are occurring in a given location because of the benefits of specialization, economies of scale, or other factors, and (2) those activities which are occurring because targeted incentives have been put in place by governments to support the reshoring of economic activities.

An important question arising in this context is what the implications of reshoring might be for the relative competitiveness of low carbon technology solutions to climate change and industrial upgrading. Although in some markets key technologies such as solar photovoltaics are competing on a non-subsidized basis with traditional fossil fuels, many markets remain policy driven. Data from REN21 (2020), for example, shows that subsidies such as feeding tariffs continue to be used in a large number of jurisdictions to support the deployment of renewable energy technologies. If locational choices—and choices about whether to return productive activities inside the firm, or to continue outsourcing to third-party providers—are determined by cost, then reshoring may lead to an increase in costs that could slow the deployment of low carbon technologies. The extent to which reshoring is occurring in low carbon sectors, therefore, is of immediate relevance to the global low carbon energy transition. It also affects whether supply chains in low carbon tech may continue to deliver economies of scale, high innovation rates, and steep cost declines for globally beneficial outcomes.

In this paper we focus on public policies aimed at altering clean technology supply chains and the extent to which these policies may impact the low carbon transition and upgrading . The first part of the paper provides the conceptual underpinning of the study. The second part of the paper examines the frequency with which reshoring initiatives are being implemented by governments in countries that are central to the global energy transition—China, the European Union, Japan, and the United States. We then examine key low carbon technologies and consider the extent to which they are vulnerable to reshoring activities. Whilst global supply chains govern the production of many key technologies of importance to climate change, the structure and complexity of these supply chains differ by technology. By extension, the vulnerability of global supply chains to efforts by national governments to encourage reshoring are different, depending on technology and associated supply chain characteristics. We examine the global organization of production for solar photovoltaic modules, wind turbines, and batteries to assess the relative vulnerability to reshoring activities. A final section concludes that any policies facilitating cost reduction in low carbon technologies is desirable from a climate perspective, even if bordering at reshoring. Such measures ideally yield both cost reduction in LTCs *and* domestic economic benefits. However, they can easily tilt towards less collectively beneficial outcomes. Given China's central role in some clean tech supply chains, it is most exposed to such a scenario. We conclude with policy recommendations.

2. Conceptualizing Re-Shoring, Off-shoring, and Near-shoring

2.1. What is Reshoring?

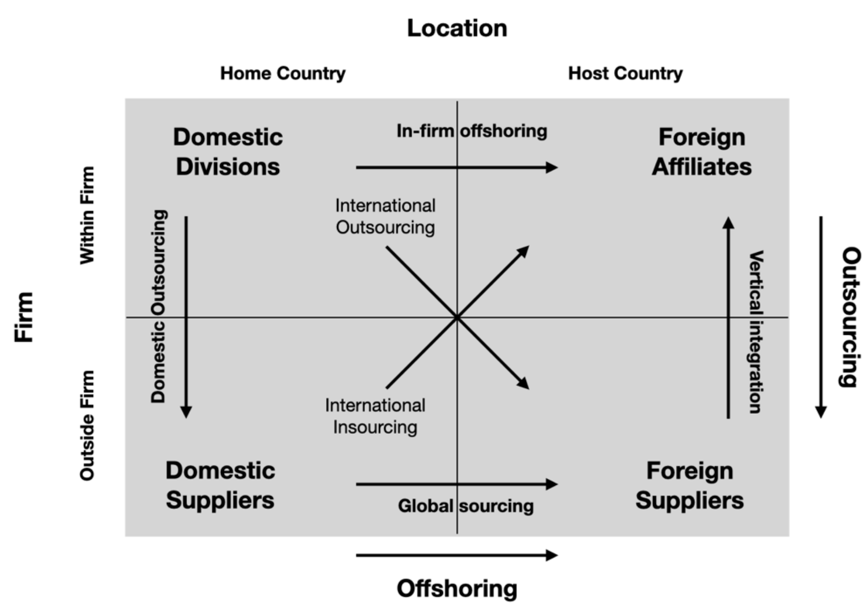
A core problem in assessing the degree to which reshoring is occurring is conceptual. There is an important distinction that needs to be drawn between government support for investments in productive facilities that are new, and targeted support for the relocation of productive facilities to the home country. An additional distinction can be drawn between reshoring, in which a set of economic activities are returned to a country in which a company is headquartered, and diversification, in which companies shift manufacturing or add additional capacity in a new and additional location, without forcing the relocation within national boundaries.

These distinctions also have an important implication for measurement. In examining policies to support the low carbon energy transition, we distinguish between policies that are specifically designed to reshore, those that focus on diversification, and those policies which are designed to increase productive capacity and national competitiveness within a given country more generally.

We follow definitions for reshoring, offshoring, and outsourcing from De Backer et al. (2016). Accordingly, we define reshoring as the "reverse decision with respect to a previous offshore in the process resulting in the transfer of activities to the home country" (8). Reshoring can be distinguished from "industry policy", defined as "selective, targeted government intervention that attempts to alter the sectoral structure of production toward sectors that are expected to offer better growth than would occur in the (non-interventionist) market equilibrium" (Naughton 2021). It can also be distinguished from "diversification", which we use to refer to the shift of previously offshored activities to a third country.

From a climate standpoint, but also from a consumer perspective, the reason to be potentially concerned about reshoring is because of the potential implications for the cost of final products. In the case of the low carbon energy transition, many technologies continue to compete against incumbent, emissions-intensive products that are lower in price. This includes extant coal generating capacity and vehicle fleets using internal combustion engines. Governments have responded to this challenge through use of industry policies to support the deployment of low carbon technologies. The most well-known example of this is the feed-in tariff that was introduced by the German government in 1990, and has since played a substantial role in financing the deployment of renewable energy technologies (Laird and Stefes 2009). The feed in tariff and similar subsidy measures have been adopted by numerous governments following their success in Germany, and have been a key driver of renewable energy deployments globally. Companies have taken advantage of the benefits of both outsourcing and offshoring in order to specialize, create economies of scale, and increase productivity in response to these growing markets. In the case of solar photovoltaics, the presence of global supply chains has been an important reason for the rapid falls in price of that technology, enabling it to begin to compete with incumbent fossil fuel power generation on a non-subsidized basis in a number of jurisdictions (Nahm 2021).

Figure 1: Firm's strategies of outsourcing and offshoring



Source: De Backer et al. (2016, 8).

There are a number of reasons why a company may decide to reshore productive activities that are unrelated to government policies. Governments may nevertheless choose to support reshoring in low carbon technologies due to concerns about supply chain resilience. The emergence of COVID-19 for example, has highlighted the importance of resilience in supply chains (Farrell and Newman 2020). Although not necessarily targeting low carbon technologies specifically, policies may provide an incentive for companies to re-shore or diversify productive activities in order to increase supply chain resilience. The pandemic could also accelerate a trend towards 'de-globalization', including in the energy domain (Kuzemko et al. 2020). A second reason governments may wish to re-shore productive activities is because of geopolitical tensions. This is of particular relevance to China, which has played an important role in the lowering of costs of a number of low carbon technologies.

There is an increasingly substantial set of literature on the implications of COVID-19 for progress on climate change. Hepburn et al. (2020), for example, survey more than 200 central bank and finance ministry officials as well as other experts from G-20 countries to understand the implications of fiscal stimulus packages on climate change. They find that survey respondents saw substantial benefit for targeting fiscal stimulus measures towards climate related economic goals, such as investment in clean physical infrastructure, building efficiency retrofit, investment in ecosystem resilience, and clean research and development investment. Thus far, however, there is little evidence that G20 economies have used fiscal stimulus spending to invest in emissions reductions. Estimates show that, over the course of 2020, only 6 percent of recovery spending was targeting activities that would reduce greenhouse gas emissions (Nahm et al. 2021). There is less accumulated evidence about the effects of this supply shock through the more indirect route of politically-induced supply chain reorganization, and what this means for the competitiveness of renewable energy technologies relative to incumbent fossil fuels. There also remains the question whether companies are making significant changes to their organization of production as a result of geopolitical tensions driven by concerns about China, or conversely, companies headquarters in China reorienting supply chains domestically because of geopolitical concerns.

2.2. Assessing the Prevalence of Reshoring Policies

In terms of measurement strategy for identifying and categorizing policies according to their goals, there are two possible approaches to take. The first of these provides an assessment of the intent of a particular policy. Financial support measures to encourage the domestic manufacturing capacity of low carbon technology may indeed be targeted at "bringing production back home". They may, however, also be about fostering domestic process innovation and entail supporting the deployment of low carbon solutions. They way to tell the difference is using language drawn from implemented laws or policies—to identify whether reshoring was the intention of the policy, or other policy goals.

The second approach is behavioral. Rather than examining the stated intent of a policy, it is possible to examine the content of the policy itself. In this case a key question is whether there is a stated condition associated with the policy that targets a particular country and/or sector, and imposes some kind of sanction, or provides some kind of positive incentive, to induce re-shoring by companies. A central consideration is whether the incentive targets existing productive activities, or whether it is targeting the development of new productive activities. In the latter case, for example, the policy can be indistinguishable from green industry policy designed to support the deployment of low carbon technologies. Green industrial policies may include a local content requirement (LCR) as a condition for public investment, but may not be targeting the relocation of existing productive capacity that was previously outsourced or offshored.

In this study we adopt the second approach, examining the content of low carbon technology policies to see whether incentives are designed to shift existing productive capacity from a designated country and to re-shore it. We collected data on recent policies implemented by governments in the United States, the European Union, China, and Japan, related to low carbon technologies. It is beyond the scope of this paper to provide a comprehensive list of governmental efforts in low carbon technology support. The data presented here therefore provide a sample of key policies in industrial policy, diversification and reshoring. Country-level policies within the European Union focus on the UK and France, the two cases with pertinent initiatives.

We then examined the content of these policies to see if they included specific clauses designed to shift existing productive capacity from a designated country. In doing so, we focus on the *expected* outcome of a given policy. Tariffs, for example, increase the price of imports relative to domestic production for a given product. The implementation of a tariff, in and of itself, does not necessarily imply reshoring. For example, the implementation of a discriminatory tariff may lead to an increase in new productive capacity within the jurisdiction of the government implementing the tariff. But it may not lead to the shift back of economic activities which were previously offshored. When the policy specifically targets companies which previously manufactured domestically, on the other hand, then it can be considered reshoring.

Conversely, we do not focus on the *de facto* outcome of policies. Doing so would require micro data at the level of the firm, such as survey data, that would allow an assessment of whether companies are reshoring productive activities when they make a given investment, or whether the investment is additional to existing activities. Instead, we are interested in where the policies are *designed* to encourage reshoring. We distinguish between policies that seek to diversify critical supply chains and reduce the dependence on individual economies that could exploit such dependence strategically. In the space of low carbon energy technologies, the global dependence on China for rare earths and minerals has often been considered from this perspective (Smith Stegen 2015), though this is not the primary focus of the present paper. More generally, this set of policies is aimed at enhancing supply chain resilience. Second, we mark traditional industrial policies that have the stated goal of national competitiveness. Such policies offer support, for instance, to fill important gaps in domestic supply chains in order to take advantage of new opportunities in emerging clean energy sectors. Third, we include policies that explicitly aim at reshoring and target specific economies from which firms are expected to relocate productive activities. Though rare, such policies have generally targeted China, given its dominance in the production of low carbon technologies. The stated goal of many of the economic recovery policies currently debated by the U.S. government is to forge economic decoupling and reshoring from China, which is increasingly seen as a hostile partner.

In sum, we differentiate between policies aimed at diversifying supply chains for fostering resilience, industry policies aimed at supporting additive investments in production in sectors that are expected to offer better growth opportunities, and policies with the explicit purpose of reshoring economic activity. Policies can be aimed at several or all of these goals, albeit with different time horizons. Because the lines between these categories are blurry, the coding strategy relies on the stated goal of the pertinent policy.

Our findings suggest that the low carbon technology sectors are dominated by with policies seeking to bolster national competitiveness through support for research, commercialization, and production. We find little evidence of reshoring. Despite political rhetoric to suggest otherwise, the vast majority of policies and financial support for low carbon technologies has taken the form of more conventional industrial policies.

3. Reshoring Policies by Jurisdiction

3.1. China

For decades, China's economic development strategy explicitly encouraged foreign direct investment and joint ventures between domestic firms and global partners to promote technology transfers and industrial upgrading. After technology imports had given way in the 1990s to encouraging technology transfers to Chinese firms, the central government in 2006 declared the pursuit of 'indigenous innovation' the primary goal of the 11th Five-Year Plan (2006-2010). In the energy sector, the indigenous innovation guidelines resulted in the aggressive expansion of renewable energy markets and increased support for domestic R&D activities.

Between 2010 and 2012 alone, wind and solar firms received credit lines of USD 47 billion by Chinese banks. The China Development Bank, one of three state-owned policy banks, reportedly extended USD 29 billion in credit to the 15 largest wind and solar firms (Bakewell 2011). Other reports suggest that state-owned banks provided USD 18 billion in loans to large wind and solar firms for the expansion of manufacturing facilities. These loans were backed by municipal and provincial governments, allowing firms to expand manufacturing capacity even after the global financial crisis in 2009, when the collapse of European markets led to global overcapacity and few lenders were willing to fund further expansion of manufacturing plants (Bradsher 2012).

China's leadership in Beijing has continued to emphasize technological and economic independence from the West, most recently in its 14th Five-Year Plan, but it has also continued to frame such plans primarily in terms of national competitiveness and the need to fill gaps in domestic supply chains. Since we define reshoring in this paper primarily as the attempt to "bring back" productive activities that were once lost from the domestic economy, China is in principle an unlikely location for reshoring. As it rose through the tanks to become the workbench of the world starting with the 1980s economic reforms, it was primarily a location for offshoring and outsourcing. It has now become a primary target for reshoring by other economies.

Calls for technological and economic dependence have nonetheless pervaded Chinese industrial policymaking, perhaps most prominently in the "Made in China 2025" initiative. Initially published in 2015, "Made in China 2025" emphasized that foreign firms controlled products in high-tech manufacturing and pointed to the importance of filling domestic gaps in energy supply chains. The policy stated the goal of achieving, by 2025, an "independent, controllable, and complete" domestic clean energy supply chain, including annual sales of 3 million electric vehicles and an 80 percent market share for Chinese auto manufacturers. It criticized China's dependence on imported materials required to produce clean energy technologies—including electric vehicles, wind, solar, and smart grids. It also established goals to become the largest global market for industrial robots—both an attempt to prevent losing productive activities to cheaper South Asian competitors and an attempt to move into higher value-added activities in existing domestic industries (Wübbeke et al. 2016). In line with these goals, the Strategic New Industry Development Plan issued as part of the 13th Five-Year Plan (2016-2020) discussed the need to remove domestic bottlenecks in the production of crystalline silicon cells and critical manufacturing equipment, much of which were imported from abroad (State Council 2016). Despite such goals, the 13th Five-Year Plan did not mention the notion of autonomous domestic supply chains. The 13th Five-Year Plan for the development of the solar industry even emphasized the need to build strategic alliances with other economies to strengthen clean energy supply chains (National energy Administration 2016).

The 14th Five-Year Plan, issued in late 2020, first introduced the need to diversify energy sources and the sources of energy imports (National Development and Reform Commission 2021). It emphasized the need to improve energy security and announced goals to build an independent domestic manufacturing industry, including in the energy sector. The 14th Five-Year Plan also affirmed the need to improve the competitiveness of complete domestic supply chains for high-speed rail, clean energy technologies, and electric vehicles. The main target was to build independent energy supply chains and minimize reliance on foreign economies in the energy sector. Such goals were also included in sector-specific policy guidance. For instance, the development plan for the electric vehicle industry announced the need to develop the entire domestic supply chain for batteries to include lithium, nickel, cobalt, and platinum and core manufacturing equipment (State Council 2020).

In two central-level meetings in fall 2020, Xi Jinping himself highlighted the need to construct independent, controllable, secure, and stable supply chains, including those related to renewables (Xi 2020). In December 2020, the head of the Ministry of Information Technology and Industry also published an opinion piece in the *People's Daily*, echoing Xi's message that import substitution is critical to developing independent and secure renewable energy supply and industry chains (Xiao 2021). While these goals re-emphasize the notion of technological independence for specific industrial sectors and the need to diversify supply chains to reduce risk exposure to economic sanctions from other economies, the 14th Five-Year Plan does not mention specific economies directly. Moreover, recent policy documents have generally framed the need to fill gaps in domestic supply chains as a security issue and as an industrial policy exercise that would allow China to move into higher value-added segments of energy supply chains.

Thus far, the central government plans to increase the technological independence of China's energy sectors lack concrete implementation plans and do not detail how the center and subnational governments plan to achieve breakthroughs in bottleneck technologies. They do not explicitly mention potential sanctions or trade barriers for imported technologies, nor do they identify countries to which China feels particularly exposed. Despite the lack of detail, these plans suggest that China will continue to favor home-grown technologies in the context of ongoing trade conflicts and ambitious economic development plans. They also indicate that China will accelerate its clean energy transition in industries such as transportation, which is highly import-dependent in fuel and core technologies. The push for economic and technological autonomy will favor transportation electrification, where China has a lot of domestic IP. It will also likely mean that China will not share with the rest of the world its vast amount of data on the integration of new energy technologies, where it also has an advantage.

Table 1: Chinese Government Representative Policy Measures

Actor	**Year**	**Initiative/Policy**	**Types of initiative/policy**	**Targeted countries**
Central government	2016	13th 5-Year Plan's Solar energy development plan	Diversification/ industrial policy	Not specified
Central government	2016	13th 5-Year Plan's Strategic new industry development plan	Industrial policy	Not specified
Central government	2016	Made in China 2025	Industrial policy	Not specified

Central government	2019	National Manufacturing Transformation and Upgrading Fund	Industrial policy	Not specified
Central government	2020	14th 5-Year Plan	Diversification/ industrial policy	Not specified
Central government	2020	State Council's NEV industry development plan (2021-35)	Diversification/ industrial policy	Not specified
Central government	2020	Guiding opinions on expanding investment in strategic emerging industries and cultivating new growth drivers	Industrial policy	Not specified
Central government	2021	Basic Electronic Components Industry Development Action Plan (2021-2023)	Industrial policy	Not specified
Central government	2020	CCP Central Economic Work Conference 2021	Industrial policy	Not specified
Shanghai municipal government	2021	Shanghai NEV development plan (2021-25)	Industrial policy	Not specified
Jiangsu provincial government	2021	Jiangsu provincial 14th 5-Year Plan	Industrial policy	Not specified
Guangdong provincial government	2021	Guangdong provincial plan for offshore wind development	Industrial policy	Not specified
Zhejiang provincial government	2020	Zhejiang action plan for the restructuring of the manufacturing industry's base and the upgrading of industrial chains (2020-2025)	Diversification/ industrial policy	Not specified

Zhejiang provincial government	2021	Zhejiang 14th 5-Year Plan for NEV development	Diversification/ industrial policy	Not specified
Shandong provincial government	2021	Shandong 14th 5-Year Plan for manufacturing	Industrial policy	Not specified

3.2. European Union

The European Union has traditionally been concerned with its strategic positioning in the energy domain. Given a long-standing debate on lopsided import structures in fossil fuels, notably from Russia, supply diversification and energy sector resilience has been high on the EU's policy agenda for decades. Much of the EU's regulatory and policy focus throughout the past three decades therefore centered on deepening the energy market, enhancing pertinent infrastructures such as interconnectors, and increasing the share of non-fossil fuels in the energy mix. Three major energy packages in 1996/8, 2003 and 2009, coupled with the 2018 Regulation on the Governance of the Energy Union integrated the EU's gas and electricity markets, while the 2017 Clean Energy for All Europeans package was established to foster the decarbonization of the EU energy system.

Low carbon energy technologies play an important role when it comes to EU energy sector resilience and industrial competitiveness. Already in its 2010 Communication titled "*Energy 2020. A strategy for competitive, sustainable and secure energy*", the European Commission warns of "fierce competition in international technology markets", with countries such as "China, Japan, South Korea and the USA ... pursuing an ambitious industrial strategy in solar, wind and nuclear markets" (European Commission 2010), 15). The EU's 2014 guidelines on state aid for environmental protection and energy make specific reference to the importance of the low-carbon economy for creating "new opportunities for economic growth and greater innovation and boost the Union's competitiveness" (European Commission 2014), 2). The decline of Europe's solar industry, and the almost complete loss of manufacturing capacity to China in the second decade of the 2000s, made renewables subject to growing concerns around EU technology leadership in a strategically important sector.

Such concerns received new impetus during the COVID-19 pandemic. For European policymakers, the pandemic demonstrated the fragility of global supply chains in medical equipment such as ventilators or face masks, as well as in other goods and services more generally. More importantly, the global race for Covid19 vaccines, massive state aid programs aimed at ramping up national R&D and production capacities coupled with nation-first approaches and preferential contracts giving the UK and the US a headstart in vaccination programs drove the point home that Europe needs to rethink their approach to an open market approach in strategic industries. For example, the

European Parliament's Committee on International Trade (INTA) commissioned a study on "*Post Covid-19 value chains: options for reshoring production back to Europe in a globalised economy*", among other discussing ways to "capture leading shares in emerging technologies" such as pharmaceuticals and renewables, "including through reshoring" (European Parliament 2021, xi, 28). Moreover, in a joint letter to the EU Commission, eight European energy ministers in early 2020 demanded wind, solar and energy storage technologies be given the status of "strategic value chains" in a post-Covid recovery, also with a view to making them eligible for public financial support (Agence Europe 2020).

While the EU's approach to energy sector governance has traditionally been primarily market-centered—a function of the EU's institutional set-up and its normative "DNA" (Goldthau and Sitter 2015)—it always entailed a strategic element. For example, the Projects of Common Interest singled out specific pieces of infrastructure as being of Europe-wide importance. Moreover, the Commission applied regulation in a strategic way, for example to favor certain energy import pipelines over others (Goldthau and Sitter 2020). The EU also did not shy away from using trade measures to protect the European solar industry, with the 2013 import duties on Chinese-manufactured solar panels representing a prime example. In other words, the EU indeed disposes of and has experimented with regulatory and trade-related instruments to foster its economic interests in the energy domain.

However, the empirical evidence on cleantech related policies suggests that the EU has neither been overly strategic about keeping or influencing pertinent supply chains, nor has it moved to openly manipulate the geography of low carbon tech production. The systematic assessment of EU policies reveals that few of the pertinent initiatives in the European Union and its member states are indeed aimed at bringing production capacity in cleantech "back home" (see table 1). Explicit reshoring or nearshoring remains the exception rather than the rule. There also exist few incidents of an openly strategic use of EU regulation for the purpose of making companies rethink their siting decisions in renewables production. With this, it can be stated that there exists a significant gap between public debates and policies as implemented.

Among the few national-level European reshoring initiatives that exist, France's post-COVID "France Relance" recovery plan merits attention. As part of a comprehensive policy package aimed at "upgrading" domestic manufacturing and increasing support for R&D, the French government pledged EUR 34 billion to a set of measures, including measures supporting reshoring. The plan singles out five strategic sectors, but although relocation is hoped to reduce the carbon intensity of production in France, the cleantech sector is not explicitly mentioned (Ministère de l'Europe et des Affaires Etrangères 2020). Previous French initiatives, notably the 2013 Colbert 2.0. program, essentially centered in encouraging reshoring through information and did not go beyond an online tool backed up by insignificant financial incentives. Another national-level example is the United Kingdom's 2014 "Reshoring UK" initiative, explicitly meant to "encourage manufacturing production back to the UK" (UK Trade & Investment (UKTI) 2014). The centerpiece of the program consists of expert services and advice, coupled with (limited) financial support for small and medium sized companies interested in relocating. Large companies do not profit from financial support.

That said, the EU does indeed focus on enhancing what serves the leitmotiv of 'technological sovereignty', that is tech leadership in strategic sectors and autonomy in select technology supply chains. European efforts here arguably qualify as industrial policy, and are primarily aimed at creating and supporting production capacity along the entire supply chain whilst increasing the competitiveness of the European economy. Stated policy goals also comprise diversifying international supply chains where sensitive to monopoly control. Prominent initiatives in this regard include the European Commission's 2020 "New Industrial Strategy", which was announced as central to maintaining "Europe's competitiveness and its strategic autonomy at a time of moving geopolitical plates" (European Commission 2020c). The strategy includes major cleantech industry-focused initiatives in the shape of the Clean Hydrogen Alliance or the Alliances on Low-Carbon Industries (European Commission 2020a). Acknowledging potential bottlenecks in critical minerals needed for wind or solar technologies, the Commission also set up an Action Plan on Critical Raw Materials.

The Commission's New Industrial Strategy ties into previous sectoral initiatives such as the 2017 European Battery Alliance, a stakeholder-based effort to strengthen Europe's knowledge base and manufacturing capacity in batteries, and by extension to support the bloc's automotive sector in the transition to EV based mobility. Besides private companies and the EU Commission, the Battery Alliance involves public finance institutions, notably in the shape of the European Investment Bank (EIB). According to its own statements, the EIB backed battery projects in Europe by up to EUR 1 billion since 2010 (European Investment Bank 2020). Yet rather than providing grants, which would amount to a direct financial incentive, public finance remains focused on funding demonstration projects or loans supporting bigger investment lines. A case in point is Northvolt's gigafactory in Sweden, which first profited from the InnovFin Energy Demonstration Programme, and subsequently from the EIB-administered European Fund for Strategic Investments (EFSI).

The volumes and direction of financial instruments available to the European Union may change against the backdrop of the Next Generation EU recovery fund. Out of the EUR 750 billion of grants made available, some EUR 150 billion are earmarked for the Strategic Investment Facility managed by InvestEU – the successor program to EFSI. The money is meant to be "boosting the resilience of strategic sectors, notably those linked to the green and digital transition" (European Commission 2020b). Individual countries go further than that. For example, France stressed the European economic recovery as an opportunity for "repatriating manufacturing chains" so as to put the country "at the forefront of cutting-edge technologies" (Gouvernement de France 2020). Finally, it is worth mentioning that the EU is experimenting with a combination of regulatory innovation and a targeted use of state aid policies in the shape of the Important Projects of Common European Interest (IPCEI). This instrument aims at facilitating European large-scale projects in strategic value chains, which as per the Commission's definition includes green infrastructure (European Commission 2021). Both of these, however, will be fully developed and unfold within the next few years only.

Table 2: European Representative Policy Measures

Actor	Year	Initiative/Policy	Types of initiative/policy	Targeted countries
France, Ministry for Industrial Renewal	2013	Initiative: Colbert 2.0	Reshoring	Not specified
France	2020	Initiative: France Recovery Plan	Reshoring	Not specified
UK Trade & Investment / Manufacturing Advisory Service	2014	Initiative: Reshore UK	Reshoring	Not specified
UK	2012-2020	Initiative: Advanced Manufacturing Supply Chain Initiative	Diversification /industrial policy	Not specified
EU	2013-2018	Initiative: Trade defense measures on solar panels	Diversification	China
EU	2021	Initiative: New Trade Strategy	Diversification	Not specified
EU Internal Market	2011-2020	Initiative: Sustainable Industry Low Carbon (SILC) programs 2011-2020	Diversification / industrial policy	Not specified
EU	2020	Initiative: New Industrial Strategy	Diversification/ industrial policy	Not specified
EU	2020/21	Initiative: Strategic Investment Facility (part of NextGeneration EU / EU Invest)	Diversification	Not specified
EU	2017	Initiative: European Clean Hydrogen Alliance	Diversification/ industrial policy	Not specified

EU Commission	2019	Initiative: European Battery Alliance	Diversification/ industrial policy	Not specified
EU Commission	2020	Initiative: Action Plan on Critical Raw Materials / European Raw Materials Alliance	Diversification/ industrial policy	China
EU Commission	2014/2021	Initiative: Important Project of Common European Interest	Industrial policy	Not specified

3.3. Japan

The Japanese government is required under the Basic Energy Act of 2001 to review mid-term policy settings for the energy sector every three years. In the most recent statement on energy policy released in 2018, the government restated the fundamental goals of Japan's energy policy as focusing on energy security, the environment, energy efficiency, and nuclear safety. In terms of supply, a core concern outlined in the basic energy strategy, and a motivation that has been a long-standing focus of Japan's energy policy, is the high level of importance of energy-related resources.

The government has introduced a range of different policy measures designed to support public policy goals in the energy sector. These focus on securing adequate access to upstream resources, improving the efficiency of energy use, diversifying fuel sources through the use of nuclear energy and renewable energy, and more recently the promotion of hydrogen and associated vectors such as ammonia.

The basic energy strategy also identifies the area of supply change as an important focus. For example, at notes that in the area public policy goals in the energy sector, the Japanese government plays a range of programs using funds acquisition through the national budget of solar PV panels battery technologies and other areas, China has become increasingly important. In the area of solar PV panels in particular, the strategy notes that supply has become dependent on China, as Japan's domestic production has stagnated. In response, the strategy states that Japan should aim to become a quarter technology provider within global supply chains for energy products (Japanese Government 2018), 9). In addition, in relation to supply chains, the strategy notes that supply chains for different energy types have distinct strengths and weaknesses, and that an appropriate response is to support the diversification of supply, in order to promote energy security (Japanese Government 2018), 14).

The government has a number of central and technology focused strategies which are developed under the umbrella of the basic energy strategy. In 2020, for example, the Japanese government approved the *Strategy for Transformative Environmental Innovation*, which identifies five key technology areas for concentrated public investments" non-fossil fuel energy sources, the energy network, hydrogen, carbon capture utilization and storage, and zero emissions agricultural services. The strategy also identifies 39 specific technology development themes for public support.

In order to support public policy goals in the energy sector, the Japanese government plays a range of programs using funds requisitioned through the national budget. Japan utilizes a annualized budgeting process, which means that funding for the energy sector is announced on an annual basis, including for multi-year programs focused on research and development, and similar such measures. Analysis of budgetary allocations focused on the energy sector show a broad range of different programs targeting research and development and energy related technologies, support for demonstration programs, support for international collaborative activities in low carbon technologies, as well as consumer subsidies designed to help accelerate the uptake of key decarbonization options such as electric vehicles.

For example, and requested 2021 budget items from Japan's Ministry of Economy, Trade, and Industry (METI), includes ¥1.52 billion in support for collaborative international research and development in technology is identified in the *Strategy for Transformative Environmental Innovation* statement. In the area of hydrogen research and development, ¥1.5 billion is allocated to the development of new manufacturing technologies, and ¥2.5 billion is allocated to research and development and new battery technology is required for the decarbonization of the transport sector. In addition, substantial funds are allocated to supporting the deployment of proven technologies through consumer subsidies. For example, ¥20 billion is allocated to subsidizing consumer purchases of lower carbon vehicles, as well as the deployment of charging infrastructure and developing a system supporting the reuse and recycling of batteries used an electric vehicles.

Budgetary allocations also focus on key initiatives in the management of supply chains for low carbon technologies. In the area of hydrogen, national budgetary funds are allocated to building global supply chains for hydrogen, which is identified as a key technology and Japan's research and development portfolio, as is recorded and the *Basic Energy Strategy*, and *the Strategy for Transformative Environmental Innovation*. In the budget requests for 2021, ¥7.48 billion is allocated to the demonstration of global hydrogen supply chains at scale, and the use of hydrogen for electricity generation.

The Japanese government in 2020 introduced to subsidy programs of particular relevance to the reassuring debate. A ¥15 billion yen fund was created in 2020 designed to support the transfer of productive facilities domestically, with the stated purpose of diversified supply chain risk. The fund specifically identifies supply chain risk that became clear through the COVID-19 crisis, and target products that are important to the well-being of the population, or which are identified as having a high level of concentration in production facilities. The funds can be used for the purchase of buildings and infrastructure, as well as software systems, with up to ¾ of costs covered by the subsidy. While the fund does not specifically target low carbon technologies, they are not excluded from applying for the subsidy. Recipients of the first round of subsidies included lithium-ion battery manufacturers, companies involved in the fabrication of materials utilizing rare earth elements, and companies involved in wind turbine component manufacturing (Mizuho Bank 2021).

The second policy of relevance is designed to strengthen supply chains between Japan and ASEAN countries, and allows for subsidy support for the new construction, or the increase in capacity for manufacturing facilities within the ASEAN region. Subsidy support is between ¥100 million and ¥5 billion and provides up to 2/3 of the funds required to purchase manufacturing facilities that are either new or an increase in manufacturing capacity. The subsidy program commenced in 2020, and runs until 2025. It does not target particular locations from which production facilities are required to move in order to be eligible for the subsidy, and therefore can be considered a form of diversification (JETRO 2020a). Again, the subsidy scheme is not specifically targeting low carbon technologies, but they are also not excluded, making the subsidy scheme relevant. Amongst 30 successful applications under the first round of the subsidy scheme, announced in July 2020, are rare metal fabrication facilities targeting investment in Thailand, and rare earth magnets manufacturers, focused on investment in Vietnam (JETRO 2020b). Subsequent rounds have enabled investment in where earth application facilities focused on India, electric vehicle component manufacturers, with the subsidy supporting investments in Indonesia, Thailand, and Malaysia, and magnet manufacturers using rare earth elements, in support of investment in Thailand (JETRO 2020d, c).

Table 3: Japanese Government Representative Policy Measures

Actor	**Year**	**Initiative/Policy**	**Types of initiative/policy**	**Targeted countries**
Gov. of Japan (GoJ)	2012 ~	Promotion of Development of Transformative Energy Efficiency Technologies	Industry policy	None specified
GoJ	2014 ~	Demonstration Project for Building Next-Generation Electricity Network to Promote Deployment of Distributed Energy	Industry policy	None specified
GoJ	2014 ~	New Technology and Advanced Research Program for Solving Medium-Long Issues in the Energy and Environmental Sectors	Industry policy	None specified

GoJ	2014 ~	Advanced Hydrogen Energy Production, Storage and Use Technology R&D Program	Industry policy	None specified
GoJ	2015 ~	R&D Program for Improving Cost and Durability of Next-Generation Fuel Cells for Commercialisation	Diversification	None specified
GoJ	2015 ~	R&D Program for Improving Cost and Reliability of Solar PV	Diversification	None specified
GoJ	2015 ~	Advanced Energy Technology International Joint R&D Project	Diversification	None specified
GoJ	2018	Basic Energy Strategy	Diversification/ industrial policy	None specified
GoJ	2020	Overseas Supply Chain Diversification Project	Diversification	Diversification to ASEAN region. No specified target country.
GoJ	2020	Subsidy in Support of Promoting Domestic Investment in Supply Chains	Reshoring	None specified

3.4. United States

In the United States, a declining manufacturing sector has long prompted concerns about national competitiveness and the ability to sustain an innovation-based economy without capabilities in commercialization and production (Berger 2013). Such concerns date back to the 1980s, when the United States feared losing its competitive edge over Japan rapidly growing economy. The IT boom in the United States distracted from a declining manufacturing sector in the 1990s, but the structural problems underlying a declining share of high-wage manufacturing employment were never fully addressed.

Over the past two decades, as China began to dominate the global supply chains for low carbon technologies, such concerns have led to the implementation of a series of trade barriers against Chinese imports. Initially focused on the import of Chinese wind turbine towers, tariffs were introduced against Chinese solar panels under the Obama administration (Lewis 2014, Lewis, Palm, and Feng 2019). These tariffs were renewed in 2018 under the Trump administration, again targeting Chinese solar cells despite vocal opposition from the domestic solar industry which feared the impact of rising prices (Groom 2019). To increase the competitiveness of the domestic steel and aluminum sectors, a second set of tariffs targeted steel and aluminum imports except those coming from Canada and Mexico. Prices rose by more than 60 percent over the course of 2018, impacting the U.S. wind industry which uses large amounts of steel in construction of turbine towers (Congressional Research Service 2020). Tariffs did not lead to a reshoring of manufacturing activity in the solar or steel sectors. Despite the justification of trade barriers across both Democratic and Republican administrations, manufacturing did not "come back" to the United States. In the solar sector, production simply relocated across East and South Asia to circumvent the U.S. tariffs.

The Biden administration has recently renewed efforts to bring manufacturing back to the United States. Such plans build on the momentum of a growing domestic movement behind a "Green New Deal," which has increasingly justified climate policy in economic terms and promised good (manufacturing) jobs as a result of investments in low carbon technologies. Tariffs implemented under previous administrations have thus far remained in place, and the Biden administration has launched a broad investigation into gaps in domestic supply chains.

In this vein, a number of recovery bills are currently debated in the House and the Senate that focus on diversification of supply chains, emphasize the need to be technologically independent, and predominately target China. Such bills include the proposal to establish a new directorate for technology and innovation within the National Science Foundations to develop a national strategy for economic security, including in clean energy sectors. The Strategic Competition Act, currently debated in the senate, seeks authorization to assist U.S. companies with supply chain diversification away from China, proposes new investments in domestic infrastructure to compete with China, and emphasizes the need to build alliances to counteract China's growing international influence. The American Jobs Plan seeks to build domestic jobs specifically by investing in new energy technologies and by reshoring jobs from China—including through government procurement of domestically manufactured electric vehicles and renewable energy technology. The Department of Energy has invested USD 30 million in research on a potential domestic supply chain for critical elements and minerals.

Although these bills are not yet passed into law, they indicate that the federal government in the United States is increasingly willing to intervene directly in the economy to achieve its desired industrial policy outcomes, including in clean energy sectors. But they also suggest that competition with China is exploited as a political tool to sell these proposals to the public, as investments in domestic industrial policy is now directly justified with the need to decouple economically from China.

Table 4: United States Government Representative Policy Measures

Actor	Year	Initiative/Policy	Types of initiative/policy	Targeted countries
Federal governmen t	2018	2018 Trade tariffs on solar modules	Reshoring/ diversification	China
Congress	2021	Endless Frontier Act (introduced)	Reshoring/ industrial policy	China (not explicitly mentioned, "foreign competitors stealing IP and trade secrets of the US and aggressively investing in fundamental research and commercialization to dominate the key technology fields of the future")
Congress	2021	Strategic Competition Act of 2021 (introduced)	Reshoring/ industrial policy	China
Congress	2021	National Manufacturing Guard Act of 2021 (introduced)	Reshoring/ industrial policy	China
Federal governmen t	2021	The American Jobs Plan	Reshoring/ industrial policy	China
Departme nt of Energy - Federal governmen t	2021	Up to $30 mn investment in research related to domestic supply chains of clean energy tech	Reshoring/ industrial policy	China
U.S. Solar Energy Industries Associatio n	2021	Solar Supply Chain Traceability Protocol	Diversification	China (not explicitly mentioned)
Departme nt of State - Federal	2020	Global Economic Activity and Recovery (GEAR) strategy	Diversification	China

government				
Federal government	2021	Executive order on America's supply chains	Reshoring/ industrial policy/ diversification	Not specified
Federal government	2020	Economic Prosperity Network	Diversification	China
Department of Energy - Federal government	2021	Call for public comment (Request for Information (RFI) on Risks in the High-Capacity Batteries, Including Electric Vehicle Batteries Supply Chain)	Reshoring/ diversification	Not specified

3.5. Summary of findings

The main finding from the empirical investigation in the previous section is that governments have, to date, passed few policies that are explicitly aimed at the reshoring of clean technoology manufacturing capacity once lost to other economies. The vast majority of policies in low carbon sectors fall under the rubric of industrial policies that are aimed at increasing national competitiveness in an attempt to combine environmental and economic objectives.

The EU has not moved to reshore low carbon technology supply chains. A key focus of the more recent policy proposals in Brussels and national capitals is about technological sovereignty but not necessarily reshoring. Reshoring is not the aim of financial support or trade measures, though China has emerged a major target of what Europe regards as systemic competition in key sectors, including low carbon technologies.

In the United States, the stated purpose of policies focuses on similar concerns, including diversification of supply chains and technological independence, notably from China. It is worth noting that these plans are not just efforts to maintain energy security and technological sovereignty by reshoring once-lost manufacturing activity, they also signal a return of industrial policy to Washington, DC, where free-market ideas have long dominated economic policymaking.

The Japanese government is also overwhelmingly focused on industry policies designed to increase national competitiveness in key technologies. In addition, beginning in 2020 Japan introduced two subsidy programs explicitly designed to shape supply chains. The first offers financial support to companies diversifying supply chains into the ASEAN region. The second offers subsidies to companies to reshore production facilities to Japan. Both are justified by the need to strengthen supply chain security by increasing diversification, given the COVID-19 crisis. The reshoring policy also targets industries where production is overly concentrated. Neither program specifically targets the energy sector, but low carbon technology manufacturing is eligible, and a number of companies of this kind have participated in the scheme to date.

Taken as a whole, there is thus little evidence that specific reshoring measures are being implemented. Concern about the implications of industry concentration and supply chain resilience could nevertheless see an increase in specific reshoring measures. China may be an implicit target for reshoring, given its rise in global production and, in part, the dominance exerted by Chinese companies in some clean technology areas.
Future reshoring thus have the potential to disrupt existing global supply chains for low carbon technologies, with possible implications for our ability to reach the Paris climate goals that require the rapid deployment of technologies manufactured in existing global supply chains as well as a fast reduction of technology costs. This aspect is what we turn to in the next two sections.

4. Do Policy Measures Change Geography of Select LCTs?

The current pandemic has raised questions about supply chain resilience. There are also concerns about rising geopolitical tensions. How easily could potential future reshoring measures resulting from such tensions affect the geography of low carbon energy technologies? Two factors influence the responsiveness of global supply chains to policy interventions: first, the complexity of the core technologies and the supply chains required to produce them; and second, the geographical concentration of these supply chains in individual economies. The remainder of this section discusses these two dimensions, before examining the impact of potential reshoring measures on the ability to achieve global climate goals and industrial upgrading of developing nations.

4.1. Comparing Supply Chain and Technological Complexity

For some low carbon technologies, production processes are standardized, and entail only a small number of suppliers and production steps. The commercial availability of automated production equipment has lowered barriers to entry and permitted companies to digitally transmit production blueprints to distant manufacturing locations. Such technologies can approximate modular production networks, in which innovation and production no longer need to be co-located and manufacturing locations can, in principle, be moved around the world with relative ease (Baldwin and Clark 2000). For other technologies—particularly in the early stage and rapidly growing clean energy sector—tacit knowledge remains critical for scale-up and commercialization. In such cases, core components may continue to be manufactured manually. Because not all design features can be modelled electronically, they may continue to require experimentation in development and in scale-up to mass production. Such supply chains can entail hundreds or even thousands of highly specialized suppliers. The latter types of technologies are far less likely to shift location in response to policy interventions, because tacit knowledge and specialized skills are not easily replicated elsewhere.

The three low carbon technologies examined in this paper—solar PV, wind, and batteries—exhibit variation along both technological and supply chain complexity. The production of crystalline silicon solar PV modules, the standard technology in the contemporary solar industries, occurs in five major steps. It begins with the production of silicon, the main raw material, and continued with the cutting of wafter from silicon ingots to the production of cells, which are ultimately assembled into modules (Shah and Greenblatt 2010). The production of silicon is very energy-intensive and therefore often located in parts of the world where energy costs are low. The remaining steps in the solar supply chain involve few suppliers and are highly automated. Aside from cost advantages achieved by reaching scale-economies, there is in principle no cost advantage to manufacturing in any particular location, even if China has established considerable know-how in bringing new solar PV technologies to mass production rapidly (Nahm 2021, Goodrich et al. 2013). As individual components are easily shipped from one location to another as they progress toward the final product, it is also conceivable for different production steps to occur in different parts of the world. In the past, this has happened, for instance, in response to local content regulations that have made local solar subsidies conditional on the local assembly of modules (Lewis 2014).

The supply chain for wind turbines is more complex, with turbines assembled from more than 8,000 parts and produced by more than 1,000 suppliers (American Wind Energy Association 2015). The most important components are the tower, the gearbox, the turbine generator, the nacelle which houses the components, and the blades, which surpass the wingspan of the largest aircraft for the latest turbine generations. In the wind industry, tacit knowledge remains important for new product generations, because exponential forces of ever large turbines are often difficult to anticipate in advance. Because of the many moving parts and long lists of components—many of which are heavy and therefore difficult to ship—the wind industry is dominated by global clusters, in which component producers co-locate in proximity to the final installation location.

Matters are also complex in the battery industry, which both entails a larger number of steps and advanced manufacturing capabilities to maintain precise quality standards across large number of cells. The production of lithium-ion batteries—those used in electric vehicles as well as on-grid storage—entails three major steps. It begins with the mining and refining of raw materials—including lithium and cobalt—the location of which is dictated by natural resource endowments and difficult to move geographically. It continues with the production of a series of core components, including the cathode, the anode, the separator, and the electrolyte eventually used in the battery cell. Once the individual cells are manufactured, they are assembled into battery packs, which require all cells to be meeting the same performance standards to perform optimally. Battery chemistries for electric vehicle batteries are often developed in close collaboration with the automotive customer to ensure that the desired performance parameters are met. Co-location of battery production and automotive R&D can therefore be beneficial. Innovation in the development of lithium-ion batteries was long focused on the demands of the consumer electronics industry, primarily located in Asia. R&D and commercialization efforts for modern EV batteries often build on this expertise, putting North America and Europe at a disadvantage (Pisano and Shih 2009).

Figure 3 provides stylized supply chains in wind, solar and battery technologies. Given these different degrees of complexity, the most likely to respond to reshoring efforts are global supply chains for the production of standard, polysilicon solar PV modules. By contrast, wind turbine supply chains are perhaps most difficult reshore due to their complexity. They also are the least likely target of such efforts since much production continues to occur in the final home market.

Table 5: Wind, solar, and battery supply chain

Low carbon energy technology	**Raw materials**	**Core components**	**Assembly**
Wind turbine	Concrete Steel	Generator Gearbox Bearing Blades Tower	Nacelle assembly before onsite installation
Solar PV	Polysilicon	Cells manufactured from wafers	Module assembly from individual cells
Lithium-ion battery	Lithium Nickel Cobalt	Cells contain: Cathode Anode Separator Electrolyte	Battery pack assembly

4.2. Accounting for Geographic Concentration

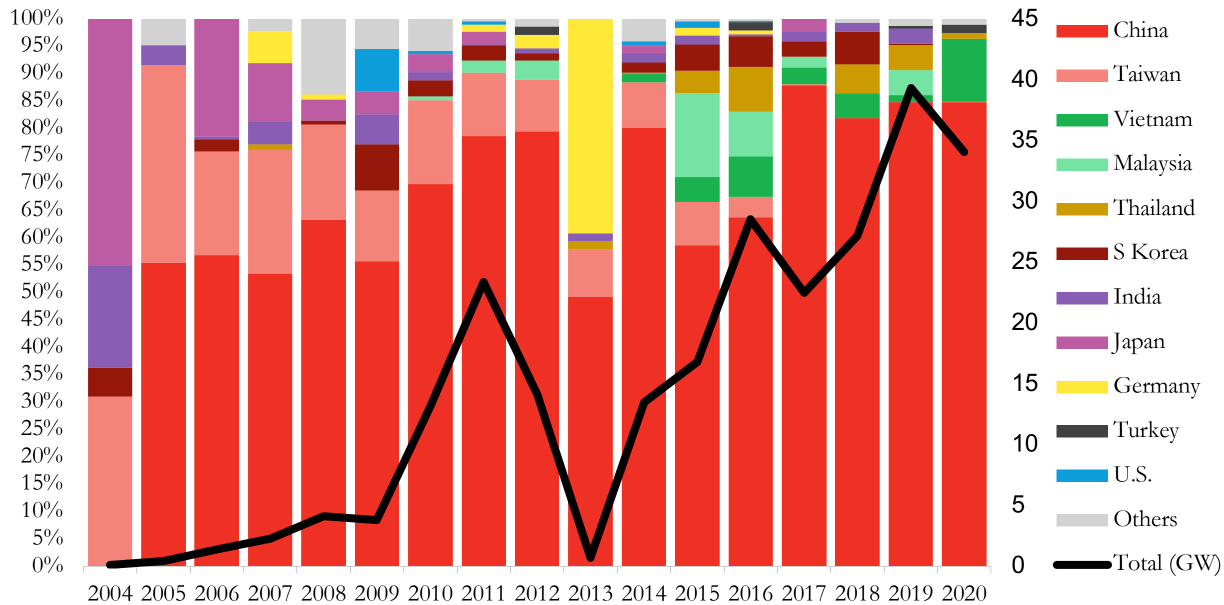
In addition to varying complexity of low carbon energy technologies and the supply chains required to produce them, low carbon energy industries exhibit differences in their geographic concentration. For the reshoring low carbon technologies this is important in two ways: first, the concentration of existing industries determines the availability of substitute skills and production capacity elsewhere in the world. Diversification of supply chains is more difficult if the entire industry is currently concentrated in a single country. Second, geographic concentration matters politically. If countries are overly dependent on a single economy that currently houses an entire industry, policies to attempt reshoring for reasons of energy security and to prevent supply chain disruptions may be more likely than in cases when production capacity is spread around the globe.

China currently accounts for more than 75 percent of production capacity for non-consumer batteries, including those used in electric vehicles. China outranked the United States for almost all individual steps in the supply chain, including in the mining and production of Nickel, Cobalt, and Lithium, in the manufacturing of cathodes and anodes, and lithium-ion cell manufacturing (LePan 2019, Rogers and Plumer 2021). Building on prior experience in the production of batteries for consumer electronics, Chinese firms then entered markets for electric busses and taxi fleets before upgrading to more demanding battery technologies for consumer vehicles. Both European and U.S. governments have long registered concerns about this reliance on China for the highest-value component of electric vehicles, but efforts to create U.S. and European battery industries have thus far not been successful (de Chant 2021). From this perspective, the most likely but also most challenging target of reshoring efforts is the lithium-ion industry.

With roughly two-thirds of production capacity currently in China, the global solar industry is a close second to the battery sector in its geographic concentration. For 15 of the past 17 years, China has added more production capacity for crystalline solar cells than any other country in the world (see Figure 2). Despite U.S. tariffs on Chinese solar cells and modules, China continues to account for roughly two-thirds of global production capacity. While these tariffs have, over time, led to a relocation of production capacity to other Asian economies—most notably Vietnam and Malaysia—they have not led to a wholesale reorganization of the global solar industry nor have they succeeded in reshoring manufacturing capacity to the United States. This suggests that even in highly concentrated sectors, reshoring efforts are time-consuming and may yield only limited impact.

Although China is also the largest producer of wind turbines in the world, its position in this industry is far less dominant than in solar and batteries and primarily driven by its large domestic market. In 2020, China accounted for 58 percent of production capacity for wind turbine nacelles, primarily for its large and growing domestic market. But Brazil, Denmark, Germany, and the United States also had sizable manufacturing capacity and large domestic clusters of suppliers for a range of components. Moreover, even though China is home to the world's largest wind turbine manufacturing industry, the majority of production capacity is used for domestic installations. The world's largest exporters of wind turbine components are Denmark and Germany, which jointly make up more than 60 percent of global exports in 2019 (BloombergNEF 2021). Reshoring might be less attractive in the wind industry because much production already occurs in the home market. However, the existence of many global wind industry clusters would make efforts to relocate global supply chains less cumbersome than in solar and batteries.

Figure 2: Crystal silicon cell capacity additions per year



Source: Bloomberg New Energy Finance

4.3. Assessing Potential Impact of Reshoring on Solar, Wind, and Battery Supply Chains

The potential impact of reshoring activities is challenging to quantify, as are reshoring activities themselves. Some evidence on the implications of reshoring measures can be gleaned from the solar PV industry, where the United States imposed a series of duties restraints on imports over the decade. The US International Trade Commission (ITC) ordered import duties to be imposed on solar PV cells manufactured in China in 2012, expanding to incorporate Taiwan manufacturing in 2014. In 2018 a uniform tariff was imposed on solar modules, with the tariff level tapering over time and a window of 2.5 GW exempt (Swanson and Plumer 2018).

The US initiative is valuable empirically because it allows for consideration of the different effects of policy measures designed to influence supply chain organization targeting a specific country or group of countries (i.e. discriminatory), versus a policy measure that is non-targeted (i.e. uniform). Modeling results suggest measures implemented by the US government had different effects on supply chain organization. The uniform tariff is estimated to be three to four times more effective at increasing domestic production in the United States, although the overall welfare benefit is more than offset by job losses due to decreased installation rates (Nguyen and Kinnucan 2019). This assessment is supported also for the case of European tariffs on Chinese solar PV imports (see Box 1). Separately, the non-discriminatory import tariff is estimated to have produced a small increase in economy-wide manufacturing employment, but this was offset by rising input costs, coupled with the effect of retaliatory measures of US trading partners (Flaaen and Pierce 2019). Amiti, Redding, and Weinstein (2019) find that "prices of US-made intermediate and final goods rose significantly in sectors affected by the tariffs relative to unaffected sectors, and the US economy experienced large changes to its supply-chain network, reductions in the availability of imported varieties, and complete pass-through of the tariffs into domestic prices of imported goods" (207-208). There is also evidence that exports were affected. Many companies import intermediate products, apply value adding activities, and then export. Import duties reduced their ability to do so, leading to a reduction in export growth (Handley, Kamal, and Monarch 2020). The environmental costs – through increased CO_2 emissions from reduced solar PV deployment rates – are also estimated to be substantial (Nguyen and Kinnucan 2019).

The efficacy of these policies in the solar PV industry in reshaping supply chains, although with negative welfare and environmental effects, can also be seen in the case of China. China imposed retaliatory measures in the form of duties against polysilicon imports from the United States, the European Union, and South Korea. Sandor et.al. (2018) find that a 10 percent increase in import duty on imports of polysilicon from the United States equated to a 40 percent fall in imports by volume, with the size of the fall in imports affected – amongst other factors – by the availability of alternative suppliers (Sandor et al. 2018).

There is thus some evidence that in the solar PV sector, the use of trade instruments can affect supply chain organization, although overall at the cost of welfare and the environment. Policy effects also vary by instrument design, as expected: uniform import tariffs appear to have been more effective at increasing domestic production in the targeted sector when compared to discriminatory tariffs. In the latter case, the presence of substitute suppliers can lead to diversification, in place of or in addition to increased manufacturing capability at home.

A key insight from the literature on the effect of technology characteristics on the potential for effective industrial policy is that productive activities that incorporate more complex technologies are more difficult to move (Sturgeon 2002, Baldwin and Clark 2000, Ernst and Naughton 2012, Gereffi 2018). Given the additional importance of the concentration of production on the effect of reshoring measures, in this section we consider the *potential* for reshoring policies to be effective in three key low-carbon technologies wind power, solar PV and lithium-ion batteries, given their different degrees of complexity and their different geographies of production. We are interested in two key aspects: the impact on the downward trajectory of clean technology costs; and the pace and scale of deployment. As we will detail further in section 5, both are central to climate change mitigation.

Box 1: A simple matrix of supply chain characteristics by technology

Geographical concentration of production

		High	Low
Technology complexity	High	Battery	Wind
	Low	Solar	

In the solar industry, by contrast, efforts to reshore the production of solar panels would likely lead to cost increases. In 2019, two thirds of the world's solar cells were produced in China. China is not only the largest producer of solar cells, but also dominates the production of wafers and polysilicon (Helveston and Nahm 2019) . Completely avoiding Chinese inputs would yield significant price increases in the short-term and inevitably entail to capacity shortages. As past experience with tariffs Chinese solar PV modules has shown, reshoring efforts may force Chinese producers to relocate production facilities in other markets to circumvent trade barriers but it will not necessarily lead to the relocation of manufacturing to advanced industrialized economies.

Following the implementation of solar tariffs against Chinese imports in the United States in 2012, Chinese manufacturers invested in capacity in Taiwan, and, after tariffs were extended to include Taiwanese solar panels in 2015, established manufacturing plants in Malaysia and Korea. Virtually no manufacturing relocated to the United States, however, where prices increased as a result of trade barriers to the consternation of the local installation and maintenance industry (Solar Energy Industries Association 2017). While such reorganization of supply chains was possible in response to the trade policies of one individual economy (the United States) against imports from another (China), the impact would likely be far more severe if other economies joined these efforts and sought to avoid Chinese inputs altogether. Replacing more than two thirds of global production capacity while ramping up global production to meet the scale of deployment required for short and medium-term climate targets will be extremely challenging at best.

Box 2: European trade measures on Chinese solar PVs

Against the backdrop of a rapidly shrink European solar manufacturing capacity and an antidumping investigation, the European Commission imposed import duties on solar wafers, panels and cells in 2013, complemented by the introduction of a minimum price floor and a volume cap, the latter of which being reported at 7 gigawatts (James 2013). The tariffs were meant to protect domestic European producers which claimed to lose thousands of jobs because of unfair competition from China. The measures were rolled over until they were lifted in 2018, reflecting a growing need of imports to achieve the EU's ambitious renewables targets. The measures failed to reshore manufacturing, however. Instead, they damaged firm values in the sector, including undermining the stock market value of European firms following the announcement (McCarthy 2016). When the import restrictions were lifted, European firms had seized to play a role among the world's top solar PV manufacturers.

In the wind industry, alternatives exist to Chinese turbines and components, thereby limiting the impact of reshoring. Since much production and assembly occurs close to the location of installation, the global wind industry has already established multiple clusters that could increase production if, for instance, reshoring policies attempted to bring wind turbine manufacturing back from China or forge the diversification of supply chains to other countries. Moreover, given the lower geographical concentration, components could simply be ordered and shipped from another location if any policymakers sought to avoid imports from a particular country. The impact on both cost declines and deployment would arguably be limited. Already, U.S. imports of wind power equipment manufactured in China have decreased from nearly USD 1 billion in 2017 to less than USD 500 million in 2019 (BloombergNEF 2021). Imports from China—the most likely target of U.S. reshoring policies—now make up less than 20 percent of overall imports although China remains the single largest source of imported turbines and components. Long-standing efforts to localize the production of wind turbines in the United States and elsewhere and the high cost of shipping for many wind turbine parts have led to globalized clusters that are less vulnerable to policy interference.

Reshoring efforts are likely to be even more detrimental in terms of cost and deployment trajectories in the lithium-ion battery sector, where China is home to an even greater share of global production capacity than in the solar PV industry. Global automakers have increasingly established partnerships with Chinese battery suppliers and are stocking their global EV manufacturing facilities with batteries produced in China. For instance, in 2020, Volkswagen bought a 26.5 percent stake in the Chinese battery manufacturer Guoxuan as part of its broader electrification strategy (Sun and Zhu 2020). Although both the United States and Europe have attempted to establish domestic battery industries to supply their auto firms, such efforts have done little to diversify global supply chains (de Chant 2021) and China continues produce nearly three quarters of global lithium-ion batteries.

The reason can be argued to lie in both a very high geographical concentration which is hard to break and a supply chain which is still relatively complex. At this point it is important to note that the development of highly concentrated manufacturing capabilities in low carbon energy technologies in China relied on unique institutional features of the country's domestic economy that supported investments in both innovation and manufacturing: central government incentives for R&D and local government support for manufacturing. To date, no other economy has been willing and able to devote a similar level of resources in the expansion of manufacturing capacity and manufacturing R&D in low carbon energy sectors. Provincial and municipal governments, dependent on tax revenue from the local manufacturing economy, augmented central government R&D support with incentives for mass production. China's provincial and municipal governments repurposed central government resources to broker bank loans and provide land, facilities, and tax incentives to manufacturers, including in clean energy technology sectors that were unable to attract large-scale financing in other parts of the world. Such loans for manufacturing facilities were provided even as central government policies encouraged industry consolidation.

Box 3: Impact of reshoring activities by technology

	Cost impact	**Deployment impact**
Solar	Significant impact on cost decline	Lead time to build up capacity elsewhere implies significant price increases and capacity shortages
Wind	Cost impact until replacement facilities are ramped up	Little impact
Battery	Substantial cost impact	Long lead time & required policy mix and resources imply impact on global production capacity

Yet, even with China's highly supportive domestic institutions and rapid developmental pace, it took nearly four decades for Chinese firms to establish the capabilities in commercialization and scale-up that the world now needs to bring new energy technologies to market. It is highly unlikely that any other economy will be able to replicate China's skills in scale-up and mass production in the timeframe required to avoid the worst consequences of climate change. Building supportive domestic institutions for the production of low carbon energy technologies, such as the ones that exist in China today, is both time and resource intensive. Reshoring efforts without such institutions, however, are unlikely to succeed, making a continued reliance on Chinese low carbon energy technologies the most promising path to solving the climate crisis. Box 3 summarizes the main findings.

5. Implications for Climate Change Policies and Upgrading

Reshoring is susceptible to having negative effects in terms of both costs and deployment rates of renewables, and the low carbon tech upgrading in developing countries. In what follows we draw implications for policy and provide a set of recommendations.

5.1. Reshoring and the global public interest

Meeting the goals of the Paris Agreement will require net-zero emissions by 2050 and substantial reductions before then. Already by 2030, emissions must have peaked and begun declining among major industrialized economies given the limited remaining carbon budget (IPCC 2018). In this context, attempts to shift the geography of existing supply chains for low carbon energy technologies will limit the ability to deploy low carbon technologies at scale.

To reach net-zero carbon emissions by 2050, scientists estimate that the United States alone would need to grow its wind and solar generating capacity from 150GW to roughly 600 GW by 2030. Some 50 million electric vehicles would need to be deployed domestically over the same period, up from less than 2 million today. Reaching net-zero carbon emissions by 2050 would require additional annual renewable energy installations of 100 GW until mid-century and complete electrification of the transportation sector (Larson et al. 2021, IEA 2021). Although demand for renewable energy technologies and batteries required for electric vehicles could, eventually, be met through domestic manufacturing, domestic production capacity is unlikely to be sufficient in time to meet 2030 goals. Given the limited remaining time to decarbonize power and transportation sectors, avoiding Chinese production capacity altogether would most likely put out of reach the necessary scale of deployment, as it is unrealistic to expect that any other economy will be replicate China's infrastructure for the mass production of low carbon technologies in the short run (Helveston and Nahm 2019).

In light of existing global interdependence in solar, wind, and lithium-ion battery supply chains, successful reshoring would likely increase the cost of new energy technologies. Since 2009, prices for wind turbines and solar panels have decreased by 69 percent and 88 percent, respectively, making these technologies competitive with conventional sources of energy in many parts of the world. This is particularly the case when they are deployed in conjunction with battery storage, where China's investments in new manufacturing capacity have also led to rapid cost declines (Lazard 2018).

Significant reshoring would also undermine the global division of labor in the development of new energy technologies, thereby slowing the global pace of innovation (Goldthau and Hughes 2020, Nahm 2021, Helveston and Nahm 2019). In low carbon energy sectors, collaboration with Chinese firms has historically enabled new technologies from the world to be commercialized in large quantities and at increasingly competitive prices. Such collaboration between American technology startups, European producers of manufacturing equipment, and Chinese firms specialized in mass production has been central to the development and commercialization of silicon inks for the solar PV industry and the commercialization of gearless wind turbine technologies (Nahm 2017) Similar patterns of collaboration are now emerging in the automotive sector, where manufacturers from around the world are working with Chinese manufacturers to develop lithium-ion batteries that meet their specifications (Nahm 2021). Successful collaborations with Chinese manufacturers have allowed Chinese producers to gain technological know-how from advanced foreign firms. In turn, foreign partners have incorporated the manufacturing and scale-up solutions of their Chinese partners into up-stream R&D activities.

Some have argued that China's manufacturing dominance has created lock-in effects and has prevented the commercialization of next generation clean energy technologies that cannot yet compete with existing products manufactured at scale in China (Sivaram, Dabiri, and Hart 2018). Yet reshoring of manufacturing to Europe and the United States could also threaten the existing division of labor in low carbon energy sectors, slowing down the pace of innovation while increasing the price for solar, wind, and battery technologies. In the short run, working with Chinese producers remains the most viable pathway to the rapid commercialization and deployment for new energy technologies at prices that allow them to compete with existing energy infrastructure.

As more countries embrace clean energy transitions—and as the world scales the production of low carbon energy technologies accordingly—emerging economies will find new opportunities to build up domestic production capacity for LCTs. For instance, according to IEA projections, annual additions in wind capacity are to grow from 68 GW in 2021 to up to 100 GW until 2025 depending on the scenario (IEA 2020). The geography of wind production is likely to change and move away from the OECD and China as new centers of demand are created in emerging economies. Capacity additions are expected to materialize, for example, in ASEAN countries such as Vietnam, but also Latin America (Hochstetler 2020). In the short to medium term, these countries will benefit from the economies of scale in production elsewhere—notably China—which supports the local deployment of onshore and offshore wind farms and ensures costs are coming close to grid parity. It is not inconceivable that as these markets grow, the economic case for near-market production becomes more compelling, as it does in the United States, Europe, and China at present. Yet it is important to note that this is likely to result in additional production capacity over time, not in reshoring. This trend would essentially reflect and result from a growing global demand of a very localized renewable energy technology.

Reshoring itself, however, is unlikely to have a positive impact on industrial upgrading and economic development in the global south. The parts of global low carbon technology supply chains that are most easily movable—and therefore most likely to respond to reshoring policies—are often the lowest value-added steps in the production of clean energy technologies. They generally offer limited development benefits for the economies that receive them. In many industrial sectors, global lead firms have long commanded the bulk of revenue, while outsourcing and offshoring simple production steps to subcontractors and subordinate suppliers (Nolan 2012, Gereffi, Humphrey, and Sturgeon 2005). While the invention and the commercialization of new technologies in such industries has often remained in advanced industrialized economies, blueprints for low value-added production steps could be transmitted electronically to low-cost manufacturing locations in developing economies. Such production activities could easily be separated from upstream research and development, yet often yielded few spillovers and possibilities for upgrading for the receiving economies. Developing countries therefore faced the risk of getting stuck in the lowest skill and lowest value-added parts of global supply chains (Steinfeld 2004).

In low carbon energy sectors, reshoring policies are therefore most likely to affect production steps such as the assembly of solar PV modules from pre-manufactured cells. Module assembly is highly automated, requires little tacit knowledge, but also offers few opportunities for upgrading. Much harder is the relocation of the production of polysilicon, the core material in traditional solar PV technologies. At its core, it entails a complex chemical process run by a highly trained workforce, which makes it difficult to move and especially difficult to move to emerging economies where such a workforce may not yet exist. In solar industry, where some production steps for cells and modules shifted to Vietnam and Malaysia in response to U.S. tariffs against Chinese solar panels, little evidence exists that knowledge-intensive research and development activities followed these production steps abroad. Similarly, the need for tacit knowledge and specialized labor in the development and production of gearboxes for the wind industry will make this high value-added activity difficult to move geographically, even if it potentially offers great opportunities for learning and upgrading.

Ultimately, the very premise of reshoring may also limit opportunities for emerging economies to benefit from such policies. Although very few reshoring policies exist in low carbon technology sectors, political rhetoric around reshoring emphasizes the notion of bringing manufacturing "back" to advanced industrial economies. If such policies were indeed successful, they would likely encourage producers to skip emerging economies altogether in an attempt to encourage domestic manufacturing in advanced industrial economies. New production capacity is more likely to move to emerging economies in response to the creation of local markets than as a result of reshoring.

5.2. Recommendations

As we have detailed in this paper, low carbon technology sectors are dominated by industry policies seeking to bolster national competitiveness through support for research, commercialization, and production. We find little evidence of reshoring—direct policy interventions with the goal of bringing productive activities back that were once offshored, despite political rhetoric. Nonetheless, if governments increasingly adopt a zero-sum approach to international trade, an increasing future use of reshoring policies is a distinct—and worrisome—possibility.

As a recent UNCTAG report argued, enhanced reshoring activities as a result of the COVID-19 pandemic could mean that "access to and upgrading along the GVC development ladder becomes more difficult for developing countries" (UNCTAD 2020), xiii). Ramping up clean technology solutions and having them replace fossil (energy) infrastructure is also a race against time given the rapidly filling carbon budget. Meeting the goals of the Paris agreement will require net-zero emissions by 2050, but transportation and power sectors need to be powered by renewable energy already in the mid-2030s (IPCC 2018). It therefore is imperative to create the conditions under which global supply chains in low carbon tech will continue delivering economies of scale, high innovation rates and steep cost declines, for globally mutually beneficial outcomes. To this end, three main policy recommendations follow from this paper.

First, in light of the urgency of decarbonizing the global economy, national **governments need to ensure that any policy support and public investment in production capacity for low carbon energy technologies is additive**. In order to combat climate change, any additional unit of renewable energy and every additional electric vehicle are needed to meet the goals of the Paris Agreement. Already the world is falling behind its target of limiting warming to 1.5C. Against this background, public support—and indeed industrial policy—for all segments of the clean energy supply chain is desirable, as it helps innovation and encourages the scaling up of production and the rapid deployment of solutions. Yet such measures for improved competitiveness of domestic clean energy industries are not incompatible with existing interdependencies in global supply chains. At least until domestic supply chains are fully capable of meeting domestic demand, investments in national competitiveness should coexist with the use of production capacity for low carbon energy technologies already in place today. Competition with China, national competitiveness, and enhancing resilience of clean energy supply chains can be useful political tools to shore up domestic support for green industrial policies. But such framing cannot change the fact that many economies will continue to be dependent on Chinese clean energy products, at least until domestic production has ramped up. It is also unlikely that entire supply chains for many low carbon energy technologies would ever exist entirely within national borders. As a consequence, competition and collaboration will need to coexist to ensure rapid progress toward decarbonization.

Second, **China should demonstrate a credible commitment to level the playing field, in low carbon technologies and beyond**. As we have discussed in this paper, the perceived imbalance in global clean energy supply chains fuel to calls for reshoring in Western economies, particularly in industries, such as solar PV and lithium-ion batteries, where China is especially dominant. Opening Chinese markets for clean energy technologies to global firms and muting calls for technological independence would help resolve such tensions. Abandoning the joint venture requirement for auto manufacturers and allowing international companies such as Tesla to build a wholly-owned production facility in Shanghai is a step in the right direction (McMorrow 2019). After decades of systematically pushing global wind turbine manufacturers out of the Chinese market, more such steps need to follow, also in the low carbon domain. A tit-for-tat approach centering on enhanced domestic market access for non-Chinese companies, neuralgic supply chains such as in rare earth materials, and public procurement, may be susceptible to reducing third countries' desire to alter the geography of global production.

Third, **Western governments should encourage the flow of capital towards fast-growing emerging economies to support decarbonization there**. A credible link between climate policies and economic opportunity is crucial to building the coalitions necessary for low carbon transitions. Neither reshoring nor green industrial policies—though the latter being in principle desirable—necessarily deliver green development opportunities for emerging economies. China's Belt and Road Initiative (BRI), which has funded infrastructure projects in more than 100 economies since its inception in 2013, to date lacks a climate commitment and has been frequently criticized for funding the export of dated fossil fuel infrastructure from China to the Global South. The G7 committing to raising their climate finance contribution and mobilizing private investment through the Build Back Better World Initiative (B3W) is an important step in the right direction. Creating a green alternative to the BRI could nudge China to step up its overseas green finance commitments. It could also create political support for climate policy through the creation of green industries in emerging economies with rapidly growing energy demand, neither of which could be achieved through reshoring measures. Given the trajectory of global energy demand growth, additional efforts are needed to support the derisking of clean energy investment in emerging economies, enhance the inflow of low carbon FDI, and facilitate the upgrading of those economies towards clean energy goals.

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