Should Green Industrial Policy be Technology Neutral?

GIP & Technology Neutrality

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Abstract: Green industrial policy (GIP) first emerged following the Global Financial Crisis and is a central pillar of the responses of many governments to the twin challenges of climate change and COVID19-induced recession. Our survey of the small but growing literature on the concept highlights its roots in neoclassical welfare economics, with an emphasis on addressing market failures; while its branches intertwine with concepts such as sustainability transitions and strategic niche management. The principle of technology neutrality is often referenced explicitly in GIP. The centrality of technology-specific market failures, a need for policy learning, and the importance of reducing uncertainty for market participants all speak strongly against applying this principle in GIP.

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Abstract: The central question of this paper is whether technology neutrality is, on balance, a helpful principle for Green industrial policy (GIP). To answer this question, we first conduct a systematic literature review to understand what GIP is. We find the term is most often used by authors in a neoclassical economic tradition and propose a definition that encapsulates the dominant elements of various definitions in this literature. Using a transdisciplinary approach we turn to the question of technology neutrality in GIP. Considering a range of disciplinary perspectives and arguments, we conclude the weight of argument and evidence lies strongly against de juro technology neutrality in GIP. Furthermore, the literature provides a range of alternative principles and approaches that can better address potential government failures in GIP and related policies. Finally, combining theoretical approaches and case study evidence from the U.S. Inflation Reduction Act and E.U. Carbon Border Adjustment Mechanism, we provide potential explanations for why technology neutrality nonetheless remains a popular principle in GIP.

Keywords: *green industrial policy, technology neutrality, Inflation Reduction Act, Carbon Border Adjustment Mechanism*

1 The Paradox of Technology Neutrality in Green Industrial Policy

Green industrial policy (GIP) emerged in many countries as a central pillar of many governments' attempts to simultaneously green and stimulate their economies. The European Union and South Korea are among those who have announced a New Green Deal in 2020 with the U.S. implementing its Inflation Reduction Act in 2022 ((“The European Green Deal,” n.d.; Bistline et al. 2023; Han and Lee 2023). GIP for specific industries is even more widespread; no less than 20 countries have developed hydrogen strategies or have entered the substantive stage of development. Another 17 hydrogen strategies are at the initial stage of policy discussion (Albrecht et al. 2020).

Since the early 2000s, technology neutrality has been a popular regulatory and policy principle for environmental and energy policies, including GIP. In his speech on climate change in 2008, the then US president G.W. Bush stated, ‘incentives should be technology-neutral because the government should not be picking winners and losers in this emerging market’ (Roberts 2008). Similarly, the principle of technology neutrality is an important justification for an EU-wide energy roadmap – ‘the Roadmap does not replace national, regional and local efforts to modernize energy supply, but seeks to develop a long-term European technology-neutral framework in which these policies will be more effective' (European Commission 2011, 4).

The current paper considers two key questions: is technology neutrality a sound principle for GIP-making? And if not, why is it so prevalent? Arguments for and against technology neutrality have been the topic of previous literature across several disciplines. While the principle has its share of supporters in the literature (Roberts 2008), the bulk of the literature that we identified was critical – particularly in contexts that fit the definition of GIP (Metcalf 2009). Previous literature notwithstanding, major recent policy developments have motivated our efforts to collate and expand upon these arguments, and to understand the persistence of technology neutrality principles in policy.

The remainder of this paper is organized as follows. Section 2 elaborates our transdisciplinary method. Section 3 summarizes the results of our structured review of the literature on GIP and uses it to provide careful definition of the concept - necessary for discussion of the relevance of technology neutrality in the context of GIP. Section 4 draws on a combination of targeted literature review and original analysis to discuss arguments for and against technology neutrality as a general policy principle. Section 5 extends this analysis of technology neutrality to the context of GIP. In light of these findings, Section 6 draws on political economy and regulatory studies literatures to propose possible explanations for the ongoing popularity of technology neutrality with GIP drafters. Support for this explanation is provided by empirical evidence about the impact of technology neutrality in GIP based on case studies of the United States (U.S.) Inflation Reduction Act, and the European Union's (E.U.) Fit for 55 Package. Section 7 Concludes.

2 Method and Conceptual Framework

One of the novel elements of the current paper is its consciously transdisciplinary approach. The authors have expertise in legal scholarship, economics, political economy and engineering. All these disciplines are drawn upon in our analysis. Sections 3-5 draw heavily on neoclassical economic theory. Section 6 draws on engineering expertise to provide novel insights into the implications of the rules in the U.S. Inflation Reduction Act and the E.U.'s Carbon Border Adjustment Mechanism and uses political economy and legal analysis. While different disciplines were drawn upon more heavily in different sections of the paper, every section reflects an integrated understanding of the topics being discussed. Far from being superficial, the result is a richer discussion of the appropriateness of technology neutrality for GIP than would be possible from the perspective of any of these disciplines alone.

2.1 Structured Literature Review of Green Industrial Policy

GIP is a rapidly evolving field in which many key publications are in the so-called grey literature. To ensure we had the most up to date literature and captured important policy publications, we used Google Scholar for our search. We searched research outputs containing 'Green Industrial Policy(ies)' in their title. In total 49 unique papers were found. We filtered further and deleted 15 country-specific case studies that only explain the practice without further theoretical implications for GIP, as well as 12 publications on the intersection of GIP and WTO (World Trade Organization), climate finance, or economic geography. One paper has the citation detail, but the full text is not available, and another is not available in English. Therefore, a total of 20 research outputs were reviewed. Our central purpose was to examine what the literature thinks GIP is, and to understand how it can contribute to greening economies.

The organizing framework for the structured review is neoclassical economics, especially welfare economics. We acknowledge that there are alternative theoretical framings and associated terminology for green industrial policy, including socio-technical sustainability transitions (Geels 2018; Löfgren and Rootzén 2021), evolutionary economics (Bergh et al. 2007), and mission oriented innovation policies (Mazzucato 2018). These alternative frameworks have much to recommend them and our focus here on the neoclassical framework and its associated "Green Industrial Policy" terminology by no means indicates the alternative frameworks are inferior.

Neoclassical welfare economics was chosen as the organising framework for our review for three reasons. Firstly, our review found it to be the dominant framework employed in the literature which uses the term "Green Industrial Policy". Secondly, of the possible framings for GIP and related concepts, neoclassical economics was considered to be the most favourable to technology neutrality as neoclassical economics traditionally focuses "leveling the playing field" and avoiding governments "picking winners" (Mazzucato 2018). Since we find that technology neutrality is not a helpful principle for GIP, our chosen framing is therefore a conservative choice – making it harder to make our argument. Had we chosen one of the alternative framings that are less favourable to technology neutrality, we may have opened ourselves to criticisms of knocking down a straw man. Thirdly, the welfare economic approach to policy is widely espoused by organizations such as the OECD (Organisation for Economic Co-operation and Development) Best Practice Principles for the Governance of Regulators (OECD 2014, 10).

The First Welfare Theorem of neoclassical economics says that, in the absence of market failures, the most efficient outcome (including all forms of social and environmental costs and benefits) is achieved when the government does not intervene. A "market failure" is therefore implicitly defined as anything which causes one of the assumptions underpinning the First Welfare Theorem to fail. In other words the presence of one or more market failures means that the free market alone will not achieve the optimal (i.e. most efficient) outcome. In the framework of Neoclassical Welfare Economics, therefore, market failures provide a potential efficiency justification for government policy or regulatory intervention.

Another cornerstone of neoclassical welfare economics is the principle of targeting – which says that the most efficient government intervention will be one that is directly targeted at fixing a given market failure. For example, if the market failure is an externality associated with carbon emissions, the 'first-best', targeted policy will be to make market participants internalize the social cost of their actions, by putting a price on carbon. If the market failure is credit constraint for developers of projects that rely on new, high-risk technologies, a first-best response is the provision of credit via, for example, a government green bank.

Economists are aware that it is not always possible to implement the first-best policy intervention to address a given market failure. In this case, a 'second-best' policy may (or may not) be worthwhile[1]. For example, if it is politically infeasible to put a sufficient price on carbon emissions, a subsidy for supply of renewable energy is a second-best approach.

An important distinction in the literature on GIP is the extent to which it is seen as primarily aimed at addressing environmental market failures (primarily greenhouse gas externalities) or industry-related market failures (such as knowledge spillovers, credit constraints and coordination failures). A related distinction is whether GIP instruments are considered first- or second-best responses to the market failures in question. We note both of these dimensions for each of the papers reviewed.

2.2 Critical review of Technology Neutrality and its application in GIP

To understand the definitions, motivations and critiques of technology neutrality, a targeted review of the legal and economic literature and key policy grey literature was undertaken. Priority was given to sources discussing technology neutrality in the context of industry policy in general, or GIP in particular. Notably, much of the literature on technology neutrality is in the context of the regulation of information and communication technologies. This literature was included where relevant to our context.

Perhaps, surprisingly, we found that technology neutrality is rarely mentioned in economic literature. Where it is mentioned, it is not motivated theoretically. The current paper therefore provides a novel contribution by considering the case for technology neutrality from the perspective of welfare economic theory. In doing so, it aligns the theoretical framework for technology neutrality with that of the dominant literature on GIP.

Some of the strongest arguments in favour of technology neutrality are political-economic. It was important, therefore, to consider these arguments from the perspective of this frame. A combination of political-economic and legal analysis was also used to provide potential explanations for the ongoing popularity of technology neutrality among the architects of GIP.

3 What is Green Industrial Policy?

Table A1 in the Appendix provides the results of our structured review of the literature on GIP. In the current section, we discuss the implications of our findings for the role of GIP in greening the economy and conclude with a "largest common denominator" definition of GIP.

3.1 An inclusive definition of Green Industrial Policy

In the current paper, we opted to identify a definition of GIP based on a 'largest common denominator' of definitions in the literature surveyed. That is, we sought to create a definition that was consistent with the majority of papers surveyed. Taking this approach, **we define green industrial policy to comprise sector-targeted policies that support the growth and development of certain industries and technologies with the aim of furthering both economic and environmental goals.**

This definition includes first-best policies aimed at addressing industry- or technology-specific market failures (such as knowledge spillovers, external economies of scale, and information asymmetry) for industries which are believed to have potential to bring environmental benefits relative to current industries in the economy. In other words, it encompasses traditional industry and innovation policy for green industries. The broad consensus of GIP in the literature reviewed also includes second-best policies targeting economy-wide environment-related market failures such as emissions externalities by encouraging supply from specific industries. In other words, it encompasses supply-side environmental policy carrots such as feed-in tariffs for renewable energy.

In our view, demand-side policies fall clearly into the definition of GIP only when there is a clear pathway to local economic benefit such as jobs, technological advancement or improved global competitiveness for local producers. Hence Chinese, South Korean, Japanese, U.S. and German demand-side electric vehicle policy may uncontroversially be considered industry policy. In places such as Australia, it is better understood as green transport policy or climate policy.

Another grey area on the boundary of GIP and climate/energy policies is programmes which incentivize (e.g. through subsidies) household and commercial infrastructure investments such as rooftop solar, batteries and building efficiency improvements. As per the above discussion, in many cases these will not classify as GIP for the industries producing the infrastructure being installed, however, they may classify as GIP insofar as they support the development of service industries installing and maintaining the (potentially imported) hardware.

It is also worth noting some policies that may help green the economy but do not fall within our definition of GIP because they were either not mentioned by a substantial portion of papers, or were explicitly excluded by one or more. Importantly, “first-best” economy-wide, environmental policy such as carbon pricing does not fall within our definition. Neither do ‘sunset’ policies aimed at speeding the decline of particularly harmful industries such as coal-fired power. These sunset policies may help speed the decline of industries through either punitive measures or through measures which provide safety-nets and hence reduce political opposition to the necessary structural change. Industry-specific policies aimed at achieving technique (c.f. composition) improvements are also excluded from our largest common denominator definition of GIP. Examples of this type of policy include vehicle-emission, energy-efficiency and fuel standards.

3.2 How to think about GIP

3.2.1 Environmental or Industry Policy?

Green Industrial Policy can be viewed variously as environmental policy aimed at industry, or industry policy aimed at supporting green industries. The surveyed literature included examples of both views, as well as many papers for which neither view was dominant. Taking a neoclassical economic lens, we define environmental policies as those targeting environmental market failures (mainly externalities) and industry policies as those targeting market failures impacting industry development, including credit constraints, knowledge spillovers, and external economies of scale. According to this definition, all surveyed papers indicated GIP should encompass some form of industry policy, and 16 of the 20 indicated it should encompass environmental policy.

3.2.2 First- or second-best policy?

The literature portrays a range of views on whether GIP comprises a first- or second-best policy response. Generally, authors who think the key role of GIP is to address environmental externalities will see it as a first-best policy response only where their definition of GIP includes policies directly targeting externalities (such as carbon pricing). Most authors, however, do not include pricing of externalities and similar policy "sticks" within the scope of GIP. Overall 15 papers portray GIP as having at least some element of second-best policy response. This figure highlights the importance of political economy concerns in shaping GIP.

[Figure 1 here]

3.2.3 Innovation or Scale-up of Green Technologies and Industries?

The surveyed literature suggests GIP supports both innovation and the emergence of new technologies,[2] and scale-up of existing green technologies and associated industries. Innovation and emergence of new technologies was clearly identified in 18 of the 20 papers, and scale-up of green industries in 12. This suggests that much of the literature on GIP does not distinguish green innovation policies from green industrial policies.

3.2.4 Composition or technique effects?

Grossman and Krueger's (1991) scale, composition, and technique effects of trade policy provide an additional conceptual frame through which to understand the literature on GIP. Of particular relevance are the composition and technique effects. The composition effect of a policy on the environment is that which occurs through changing the composition of activities in the economy – that is – *what* goods and services are being produced. Positive composition effects lead to the growth of clean industries relative to dirty ones. GIP could have a composition effect, for example, through speeding the decline of the coal industry and the rise of the wind energy industry. The technique effect of a policy on the environment is that which occurs through changing how much environmental damage is incurred by a given activity – that is – *how* given goods and services are produced. Positive technique effects make dirty industries cleaner. For example, GIP could have a technique effect by supporting installation of carbon capture and storage technology to reduce the emissions associated with coal fired power stations.

We classified all the surveyed papers as having compositional changes at the heart of GIP. Of those, four papers were also classified as having a role for technique effects in GIP.

3.2.5 Supply or demand effects?

Green industrial transformation can be achieved through influencing the behavior of both producers and consumers. All the surveyed papers included supply-side policies (i.e. those affecting producers) within the scope of GIP. Several papers also included demand-side policies in the definition of GIP. Demand-side policies include potentially discriminatory government procurement policies, local content requirements and import barriers. Non-discriminatory demand-side policies include tax-breaks and subsidies for the purchase of goods and services with environmental benefits – electric vehicles, rooftop solar and household batteries for example.

3.3 Principles for GIP

Industry policy fell out of favour among mainstream Western economists from around the 1980s-2010s. Traditional industry policy approaches such as discriminatory trade and investment policies under the guise of infant industry protection led to the general conviction that although market failures are bad, government failure is worse. It was argued that governments either had insufficient information to 'pick winners' or they were too prone to capture by vested interests (Rodrik 2014). Industry policy was considered a waste of public money at best, and dangerously inefficient and distorting at worst.

Over the last couple of decades, the work of authors like Dani Rodrik, Ha-Joon Chang, Antonio Andreoni, Robert Wade, and Justin Lin has reformed industry policy in the eyes of many (Chang and Andreoni 2020; Wade 2012). Careful study of industry policy successes and failures allowed these authors to distill recommendations for approaches to industry policy that tip the balance in favour of the benefits of correcting market failures outweighing the costs of rent-seeking and government failure.

Rodrik (2014) identifies three key principles for successful GIP: embeddedness, accountability, and discipline. Embeddedness involves a significant amount of interaction and communication between the public and private sectors, as such, it helps governments overcome informational asymmetries than can plague GIP. Accountability towards the public also helps to ensure agency-business relationships are not overly self-serving and helps legitimize GIP. Discipline requires support policies to be reduced or removed if they are not (or no longer) achieving goals. Discipline is supported by 'clear objectives, measurable targets, close monitoring, proper evaluation, well-designed rules, and professionalism' (Rodrik, 2014, p.487). Rodrik's approach emphasizes industry policy as a process of discovery for the government, and highlights the importance of updating, revising, or removing policies as new information is gained.

Other leading authors place even more emphasis on the "responsive regulation" principle embodied in Rodrik's concept of discipline for GIP. (Hallegatte et al. 2013) recommend iterative policy design and (Pegels et al. 2018) identify systematic policy learning as one of three central requirements for successful GIP.

4 Technology neutrality as a policy design principle

4.1 What is technology neutrality?

While rarely defined in the policies in which it is invoked, definitions of technology neutrality have proliferated in academic literature, particularly in law and public policy. In the legal literature, key contributions include (Ohm 2010a, 1685), who defines technology neutrality as the principle that 'laws should refer to the effects, functions or general characteristics of technology, but never to a particular type of class of technology'. Similarly, according to (Selvadurai 2018) 'a technology-neutral approach to legal drafting involves a description of the result to be achieved without specifying the technology to be employed or regulated'. (Thompson 2011) reflects non-interventionist approach to policy design, arguing that 'law should not pick technological winners and losers, ... law should neither help nor hinder particular types of technological artefacts.'

Other particularly relevant definitions of technology neutrality in the context of GIP are (Wylly 2015), according to whom technology neutral 'policy does not favour any particular means of achieving the desired goal. Specifically, a policy must equally support all methods capable of achieving this outcome'. Azar and Sandén (2011, p.135) provide a definition specific to policy for 'green'/ 'clean' technologies as: 'policies that promote technologies with no or low carbon emissions but do not specify which such technologies should be supported'.

An important distinction in the above definitions is between those which imply de jure and those which imply de facto technology neutrality. For example, the definitions of (Azar and Sandén 2011; Selvadurai 2018; Ohm 2010b) imply a de jure understanding of technology neutrality because they require that technologies are not explicitly specified in the law or policy. On the other hand, Wylly (2015) and Thompson (2011) refer to technology neutrality in the de facto implications of the law or policy. Given the difficulty of determining whether policy is de facto technology neutrality, or of designing one which is known in advance to be technology neutrality, we side with the former authors. For this paper's purposes, technology neutral policy does not distinguish *de jure* between functionally equivalent technologies. A feed-in tariff which is equal for all renewable energy sources is, according to our definition, a technology-neutral policy instrument.

Finally, although not identified in the literature or clarified in policies we identified, we note that technology neutrality is a relative principle. Specifically, for GIP, whether an instrument is technology neutral or not must be determined in the context of the policy in which it is invoked. For example, in an economy-wide policy on reducing greenhouse gas emissions, a carbon price would be a technology neutral policy but a renewable energy feed-in tariff would not. However, in the context of a policy on renewable energy, an equal feed-in tariff for any form of renewable electricity would be a technology neutral approach, but differential tariffs for solar and wind would not.

4.2 Arguments in favour of technology neutrality

4.2.1 The political-economic argument for technology neutrality

The leading argument in favour of technology neutrality in the context of GIP, or indeed industry policy more generally, is a political economy one. Government capture by industry is the biggest source of "government failure" in industry policy. Technology neutrality policy, so the argument goes, ties the government's hands and reduces the scope for lobbying and rent-seeking to pervert the policy process (Australian Department of Industry 2017; Schwarzer 2013; Trubnikov 2017; Warwick 2013). Some of these authors refer to technology neutrality as if it synonymous with non-discrimination and free and fair competition – and hence self-evidently a good principle.

4.2.2 Legal arguments for technology neutrality

Legal scholarship has also tended to take the wisdom of technology neutrality as self-evident, an intrinsic pursuit of law Giannopoulou (2010, p1), and a means of promoting free competition among different technologies (Rios 2013), and an approach to non-discrimination (Thompson, 2011). Thompson proposes the criterion of 'functional equivalence' (Thompson 2011, 311–12) be established as a threshold to decide which technologies should be taken into consideration under the principle; and the neutrality is demonstrated by the practice of non-discrimination among functionally equivalent technologies.

An emerging and more specific justification for the principle of technology neutrality in the legal scholarship has been its effects to maintain the longevity of laws. As pointed by (Giannopoulou 2010), a steady feature of the law has always been the aim to remain neutral and above technological progress, in order to remain applicable to all issues stemming from technological progress. Constantly changing technologies and established legal frameworks are in continuous conflict with each other, therefore, law reform initiatives must formulate technology neutral, flexible laws that will be able to adapt and evolve with technological change (Selvadurai 2018). Adopting technology neutrality will also maintain the coherence of the legal framework without creating voluminous and potentially overlapping and inconsistent legislative instruments (Selvadurai 2018; Lipinski 2003).

4.2.3 Economic arguments for technology neutrality

While legal scholars often take a principles-based approach to argument, economists lean towards theory-based. As we shall see, from the perspective of neoclassical welfare economics, technology neutrality can sometimes be an emergent property of an efficient policy approach – but is not a defining characteristic of it.

As discussed in Section 2, an efficient (first-best) policy instrument will be targeted directly at an identified market failure. The vast majority of market failures are not specific to a particular technology, and hence the first-best policy will not be either. Carbon prices are a classic example of a technology-neutral policy toward climate mitigation, favoured by economists. Notably, technology neutrality arises in this case as a consequence of the underlying neoclassical welfare economic theory – not a fundamental principle of it.

4.3 Arguments against technology neutrality

4.3.1 Economic arguments against technology neutrality

Importantly, there are also situations in which the first-best policy is not technology neutral. Namely, when the market failure being addressed by policy (or extent thereof) is specific to the technology. Such technology-specificity is, indeed, the norm for the industry- or innovation- related market failures discussed in the literature on GIP. For example, different technologies will exhibit varying degrees of external economies of scale (i.e. agglomeration economies). Similarly, technologies at distinct stages of development diffusion will suffer distinct levels of knowledge or discovery spillovers. Consequently, the first-best policies will be technology specific. Economic theory provides an argument against technology neutrality policy in these examples.

What about the case where the target market failure is not technology specific, but GIP policies being implemented as a second-best approach because the first best is politically infeasible? A case in point is when subsidies for renewable energy supply are used as a second-best alternative to carbon pricing. As pointed out by (Metcalf 2009), different renewable energy sources have characteristics which mean they displace diverse types of traditional energy sources. As a result, the abated carbon per supplied kilowatt-hour varies by technology, and consequently any subsidy intended as a second-best approach to the externality from carbon emissions should also vary by technology.[3] Hence the second-best policy response may be technology specific, even when the first best is not. Here again economic theory provides an argument against technology neutrality.

4.3.2 Economic critique of the legal arguments for technology neutrality

The legal argument for technology neutrality comprises three main elements: supporting competition, non-discrimination, and longevity and parsimony of laws. The former two of these are economic arguments, so it is appropriate to consider them from the perspective of economic theory. The latter point can also be understood from the perspective of economics as an argument about minimizing the transaction costs (alternatively implementation costs) of policy.

Economists are well-known for favouring competition. Imperfect competition, and the resulting market power, is a market failure which leads to less-than-optimal outcomes. However, this is not a sufficient argument for technology neutrality in policy. For one, a technology neutrality policy will not always increase the competition between technologies. If there is a dominant technology, a technology neutrality policy will allow that dominance where a technology biased policy may reduce it. Importantly, the dominant technology is likely to be the incumbent technology. Technology neutrality in such cases works against structural change. Secondly, a first-best policy aimed at a particular market failure – even a technology specific one - will never induce imperfect competition where it was not already present. A first-best response (technology neutral or not) may, however, exacerbate existing imperfect competition. In other words, the policy-makers face multiple market failures. In this situation, the theorem of the second best tells us that it is an empirical question whether a technology neutral instrument is the welfare-maximizing approach in any given situation. Overall, economic theory does not support ‘technology competition’ as a justification for applying technology neutral policy when the first-best policy is technology specific.

Non-discrimination is a legal and policy principle that is cherished by lawyers and economists alike. From the perspective of welfare economy theory, discrimination occurs when policy creates artificial advantages for certain actors or technologies. Importantly, the first best policy will never be discriminatory – even if it is *de jure* technology specific. The flip side of this is that deviations from the first-best policy made in the name of technology neutrality, may *de facto* discriminatory. This is essentially the argument made by (Metcalf 2009) as well as by several authors discussed in Section 5.

Finally, some legal scholars motivate technology neutrality as a means of increasing the longevity and parsimony of law and policy. In economic language, this argument would say that technology neutrality decreases the implementation costs of interventions aimed at addressing market failures. Welfare economic theory says that the presence of a market failure only justifies a policy intervention if the cost of implementing the intervention is less than the benefit obtained from addressing the market failure. Furthermore, lower implementation costs is a leading reason for the adoption of second best rather than first best policy options. Unfortunately, there is no general theoretical argument which allows us to say that parsimony and longevity will always be the dominant consideration. Economic theory tells us that the choice between a technology-specific first-best policy and a technology neutral second-best one should be made based on a case-by-case assessment of net costs and benefits.

Overall, through the lens of welfare-economic theory, technology neutrality is an emergent principle for efficient policy when the first-best policy can be applied and the market failure in question is not technology-specific. Technology neutrality may also be justifiable on a case-by-case basis when the first-best (technology specific) policy would cause either substantial costs in terms of exacerbating distortions due to imperfect competition or substantial implementation costs. In all other cases, economic theory supports technology-specific policy.

5 Technology Neutrality as a principle for Green Industrial Policy?

Section 4 considered general arguments for and against technology neutrality. In the current section we consider technology neutrality in the particular context of GIP.

5.1 Empirical evidence

The empirical consequences of applying technology neutrality in GIP have been studied in the literature. The first conclusion of this literature is that even if true (*de facto*) technology neutrality were desirable, it is almost never achievable, especially if policy-makers apply *de jure* technology neutrality policies (Greenberg, 2016). Considering case-study evidence from the clean energy sector, (Azar and Sandén 2011) conclude that true technology neutrality is often an elusive objective that neither can nor should be prioritised as the main guiding principle. Similarly, Metcalf (2009) and (Popp 2019) argue that in the clean energy sector, broad-based technology-neutral goals often implicitly favour some technologies over others.

5.2 Political arguments

Political scientists may feel that the economic arguments made thus far have failed to properly address their main argument in favour of technology neutrality in the context of GIP: that it counteracts the (substantial) potential for rent-seeking, lobbying and policy capture by vested interests. Let us now consider this argument from the perspective of political science.

Several previous authors have argued that technology neutrality in fact exacerbates policy capture by causing ambiguity and loss of clarity in policy (Moses, 2003; van der Haar, 2007; Thompson, 2011). Ambiguity can be appealing to policy-makers working on sensitive issues because it provides a means to conceal or postpone conflict by leading others to understand something in two or more ways (Byers, 2020). Similarly, a political economy literature argues that environmental policy is sometimes preferred over more efficient means of supporting certain industries because the added complexity helps to conceal the support and associated costs (Fischer 2017; Konisky 2024). Ambiguity can also be exploited by powerful groups to achieve political purposes (Son and Lee 2018; Byers 2020). Finally, it also works directly against the public transparency and accountability that Rodrik (2014) and Hallegatte *et al.* (2013) note is a crucial element of preventing capture of GIP.

There are two ways in which attempts to apply the principle of technology neutrality in law and policy can cause ambiguity and loss of clarity. The first way – as highlighted by (Moses 2003) and (Thompson 2011) - is that drafting law and policy in technology neutral language requires a higher level of abstraction. The second pathway to ambiguity is through reference to technology neutrality without defining the principle.

The concept of technology neutrality can be ambiguous, and numerous definitions abound in scholarship and practice. Where the exact definition of technology neutrality is not specified, the resulting vagueness enables policy-makers and legislators to adhere to different meanings of technology neutrality (van der Haar 2007). In particular, a *de jure* definition may be implied, but a *de facto* definition applied.

5.3 Economic arguments

The discussion in Section 4.2 argued that the primary economic motivation for technology neutrality arises when a policy instrument seeks to address market failures that are not technology specific. In the context of GIP, the most pertinent such market failures are environmental externalities – especially those due to greenhouse gas emissions. However, most definitions of GIP reviewed in Section 3 explicitly excluded first-best policies aimed at environmental externalities from the definition of GIP, with Harrison et al. (2017) being the exception. In contrast, most of the literature reviewed saw GIP as primarily aimed at either first-best policies towards technology-specific market failures (such as knowledge-spillovers) or second-best policies towards environmental externalities. As pointed out by (Metcalf 2009) the second-best policy towards environmental externalities will also generally vary by technology. Hence, from an economic perspective, the primary theoretical motivation for technology neutrality does not apply to GIP. Instead, there is a theoretical case for technology specificity in GIP.

An additional economic argument against technology neutrality in GIP is that it causes ambiguity and related uncertainty (as discussed above); whereas reducing market uncertainty is one of the most universally agreed objectives of GIP in the surveyed literature (Barradale 2010; Handley and Limão 2015). In particular, ambiguity and uncertainty are well-known to suppress investment in a range of settings (Bloom 2009; Gulen and Ion 2016).

Finally, Section 4.3.2 also noted secondary theoretical arguments for technology neutrality which arise on a case-by-case basis. The very nature of a case-by-case motivation speaks against the wisdom of applying technology neutrality as a general principle.

5.4 Legal arguments

In Section 4.3.2 we considered arguments for technology neutrality only through the lens of economics. It would be fair for legal scholars to object to all of their arguments in favour of technology neutrality being converted into economic concepts and then dismissed through economic arguments. In the specific context of GIP, we now consider the key arguments from legal scholarship in their own terms.

Consider first the argument for technology neutrality which rests on its ability to improve the longevity of law and policy. Two things speak against longevity being a major advantage in the context of GIP. Firstly, policy, by definition, does not have to go through the same legislative processes as law, and is thus much less time-consuming and costly to write and update (Franklin 2010). Secondly, and more importantly, all the literature surveyed on GIP highlighted the importance of GIP being monitored, reviewed, and updated systematically. Longevity is an explicitly unhelpful feature of GIP (Pegels et al. 2018; Rodrik 2014).

Longevity arguments notwithstanding, many authors who support the principle of technology neutrality do so on the basis that it is a form of non-discrimination (Australian Department of Industry, 2017; Thompson, 2011). Non-discrimination is an intuitively appealing principle, widely believed to support governance objectives of both efficiency and fairness. It is one of the powerful ideas, which we discuss in more detail in section 6.1. Its application as a central pillar in trade and investment law is generally applauded by scholars across disciplines from law to economics, and political science (Diebold, 2011). As Greenberg (2016) argues, however, a hasty application of such legal idea of equal treatment to technology neutrality would be misguided.

We carefully argue that there are important politico-legal differences between non-discrimination in international economic law and technology neutrality in policy – particularly GIP - which should not be overlooked. In trade and investment law, the political forces distorting policy away from the efficient choice are understood to be domestic. Trade law, therefore, exists to counteract the policy distortions resulting from domestic political forces and help level the playing field for foreign producers. Drafters of trade law also seem to have understood that any broad principle is in danger of being exploited to favour the powerful. Hence, even though trade law provides a legal remedy only to foreign producers, non-discrimination clauses have been written in a way that further bolsters protection against exploitation by domestic players. The most ubiquitous realization of the principle of non-discrimination clause in international economic law is the “National Treatment” clause – which asymmetrically protects foreign but not domestic actors from discrimination. Across the hundreds of trade agreements and thousands of investment agreements in which National Treatment clauses appear – they always specify that foreign producers or investors must receive treatment *no less favourable* than their domestic counterparts. In this way, non-discrimination principles and rules in trade law provide a countervailing force to political distortions and direct policies towards more fair and efficient outcomes (see Figure 2).

[Figure 2 here]

Technology neutrality principles in domestic policy do not counteract political power in the way non-discrimination rules in trade & investment law do. Firstly, technology neutrality statements are just that – neutral. Unlike trade & investment law they are not asymmetrically drafted to protect new industries from the political power of incumbents. Secondly, the principle of technology neutrality is ambiguous enough that it can be used to argue in favour of certain policy choices can be made by proponents of any technology. This is particularly problematic because the best-resourced proponents are likely to be in a position to capture regulators (G. Stigler 1971), form powerful coalitions to make the most persuasive arguments (Downie 2018), provide information and framing (Smink et al. 2015), and ‘buy’ favourable policy with contributions (Grossman and Helpman 1994). These well-resourced proponents are, in general, the incumbent industries (Smink et al. 2015). Both theory and empirical evidence tell us that incumbent industries are also the most politically powerful industries (Ford and Newell 2021). We discuss the empirical side of incumbents as powerful interest groups in more detail in section 6.2.

[Figure 3 here]

Overall – while non-discrimination in trade & investment law counteracts political power – technology neutrality in industry policy exacerbates it. Technology neutrality, therefore, can be expected to distort policy further in favour of incumbents (see Figure 3). As such, it can be expected to work directly against the structural change that GIP seeks to achieve.

6 Why is technology neutrality such an enduring principle in GIP?

Sections 4 and 5 suggest that while there are some authors favour of the principle of technology neutrality, the bulk of the literature and the weight of our argument speak against its application, especially in the context of GIP. It seems fair to ask, then, why technology neutrality remains such a commonly cited principle in GIP around the world? To answer this question, we draw on insights from political science, policy studies and regulation & governance literatures.

Across political science and policy studies literatures, two drivers of policy change stand out: powerful ideas and powerful interest groups.[4] Although the precise definition of these concepts varies, the general implication is the same: powerful ideas can away policy evolution (Campbell 1998; Schmidt 2008a). We argue that in the case of technology neutrality, the relevant idea is the principle of non-discrimination.

Arguably the most widely held belief in the literature is that interest groups have profound influence on policy evolution. The entire field of political economy is dedicated to studying how economic interests – particularly of industry groups – shape policy and regulation (Becker 1983; Grossman and Helpman 1994; G. Stigler 1971). But what interest group would benefit from such a broad feature as technology neutrality? As discussed in Section 5.2, the regulation & governance literature suggests that well-resourced incumbents will generally benefit from the obfuscation and ambiguity provided by technology neutrality.

6.1 Powerful ideas

Over the past four decades, a trio of powerful ideas has repeatedly oriented policy design: non-discrimination, greater competition, and government failure. Non-discrimination—canonised in international economic law via most-favoured-nation and national-treatment obligations—became a widely admired governance principle across law, economics and political science, shaping expectations about what “fair” policy looks like (Horn and Mavroidis, 2001; Sykes, 1999). Because ideas travel (Hall 1993; Schmidt 2008), this norm has often been imported into domestic economic regulation in the guise of technology-neutral drafting, with the implicit claim that equal treatment across technologies is both fair and efficiency-enhancing. The normative pull of the non-discrimination idea thus helps explain why it surfaces as a design touchstone even outside its original trade-law context.The second and third ideas—greater competition and government failure—have likewise exerted strong influence since the 1980s. A robust empirical literature links competitive pressure to higher productivity and innovation, reinforcing a pro-competition policy reflex (Nickell 1996; Aghion et al. 2005). In parallel, public-choice and capture theories cautioned that activist industrial policy risks being distorted by rent-seeking, anchoring a presumption in favour of arm's-length, general instruments (G. J. Stigler 1971; Laffont and Tirole 1991; Pack and Saggi 2006). Together, these ideas make broad, ostensibly neutral frameworks appear safer and more legitimate than targeted interventions. In the context of green industrial policy, however, their uncritical transposition can be misleading: while they provide important heuristics, they do not, on their own, determine welfare-maximising instrument choice in settings marked by technology-specific market failures and dynamic lock-in.

6.2 Powerful interest groups

There is evidence to suggest technology neutrality is a principle devised and espoused by politically powerful incumbent industries. Incumbent industries first argued for technology neutral legal and policy reform to ensure that emerging digital technologies did not have unfair advantage. According to (Reed 2007), the first use of the term "technology neutrality" was in the description of the US Electronic Communications Privacy Act 1986. Development of the principle remained mainly confined to the Information and Communication Technologies sector, with the major policy objective of promoting on-line and off-line equivalence to the end of the 20th century (European Union 1998).

Empirical evidence also supports the argument that technology neutrality favours incumbent industries in GIP. Azar and Sandén (2011) argued that technology neutrality policies are disadvantaging potentially important, early-stage technologies such as transmitting solar electricity from desert areas and infrastructure for hydrogen and electric vehicles. Similarly, according to Jacobsson et al. (2017), the technology neutrality mandate in the EU's energy policy is leading to neglect of policies which focus on stimulating the generation of positive externalities such as R&D investment and fostering innovative capital goods industries. These authors have also argued that the tendency to favour more established technologies has particularly negative consequences in the context of energy transition, where long-lived infrastructure leads to technology lock-in and dynamic inefficiency (Thompson 2011). Below we add to this body of empirical evidence with case studies from the two of the largest and most globally influential GIP packages to date: the United States (U.S.) Inflation Reduction Act; and the European Union's (E.U.) Fit for 55 Package.

6.2.1 Technology neutrality in the U.S. Inflation Reduction Act (IRA)

Consider first the U.S. Inflation Reduction Act (IRA) which provides separate support instruments for clean electricity, clean hydrogen, and carbon sequestration. Each of these instruments individually are designed to be technology neutral. For example, the Clean

Electricity Production Tax Credit and the Clean Electricity Investment Tax Credit are available to any form of electricity generation (and some storage) that have an anticipated greenhouse gas emissions rate of zero. These credits will replace current instruments that are similar except for the fact that the current instruments apply only to renewable energy generation (US EPA 2022). The new instruments, which are touted for being "not technology specific" treat nuclear generation (which currently provides 20% of U.S. electricity) the same as they do wind (10%), solar (3%) or any of the other more minor renewable energy sources. [5]

Even more interesting are the implications of the IRA for incentives in hydrogen production. The Act introduces a new Clean Hydrogen Production Tax Credit (45V). The credit provides a four-tier incentive which depends on the carbon intensity of the hydrogen production, but not on the technology used. So long as the associated emissions per kilogram of are the same, hydrogen from electrolysis using electricity (possibly grid-connected) would, therefore, be eligible for the same level of credit as hydrogen made from reforming of methane or coal (possibly in combination with carbon capture and storage, CCS). The latter, "blue hydrogen", processes also have an alternative potential tax credit.

Unlike hydrogen produced from electrolysis, blue hydrogen can access the tax credit for carbon capture, utilization, and sequestration (45Q). The IRA raised the 45Q credit from $50 to $85/tonne CO_2 permanently sequestered in geological storage. Our calculations suggest that blue hydrogen with emissions intensities of over 4 $kgCO_2/kgH_2$ could get approximately 0.820 $/kg H_2 produced using the 45Q credit. This is more than hydrogen produced with as little as 1.5 $kgCO2/kgH_2$ could obtain using the 45V credit. This counter-intuitive result occurs because of the substantial proportion of greenhouse gas emissions from fossil hydrogen production that originate from fugitive emissions during the extraction of the fossil fuels, rather than from the production of the hydrogen from the fossil fuels (White et al. 2021). As a result, while each individual instrument in the IRA is designed to be technology neutral, the package overall provides higher subsidies to incumbent, higher polluting, fossil hydrogen production.

6.2.2 Technology neutrality in the E.U. Fit for 55 package

Despite similar broad commitment to technology neutrality/agnostic[1] approaches in the Fit for 55 package, the E.U.'s Carbon Border Adjustment Mechanism (CBAM) also implicitly favours fossil hydrogen over that produced via electrolysis. As was the case in the IRA, the

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[1] Technology agnostic policies are those that do not explicitly differentiate on the basis of technology. As such, they are de juro technology neutral without promising to be de facto neutral.

problem arises because of the importance of fugitive emissions in the overall supply chain emissions associated with fossil hydrogen. Despite the importance of emissions associated with the extraction of fossil inputs to hydrogen production, the CBAM Guidelines state that "Hydrogen is defined as a simple good as the raw materials and fuels used in its manufacture are considered to have zero embedded emissions". Further that "'Simple goods' means goods produced in a production process requiring exclusively input materials and fuels having zero embedded emissions." (European Commission 2024).[2] As a result of fugitive emissions being excluded from the CBAM, fossil hydrogen receives an implicit discount of the order of 30% compared to hydrogen produced from electrolysis. The result is another example of de jure technology neutrality but de facto discrimination in favour of incumbent industries. Specifically the combination of a broad technology neutrality principle and a technical detail (the designation as a simple good) provides an effective means of obscuring support for incumbent industries along the lines identified by Fischer (2017) and Konisky (2024).

7 Conclusion

Green industrial policy is an increasingly key component of government responses to twin environmental and economic crises in many countries. A structured review of the literature suggests a largest common denominator definition for green industrial policy comprises sector-targeted policies that support the growth and development of certain industries and technologies, with the aim of furthering both economic and environmental goals. In the language of neoclassical welfare economics, GIP comprises first-best policies towards innovation- and coordination-related market failures in green industries; and second-best policies towards environmental market failures.

Neoclassical economics is rightfully criticized for its inability to deal with complexity or systems interactions. The reward for this simplicity is analytical clarity. We apply this clarity to the concept of technology neutrality and its applicability to GIP. The neoclassical economic framework allows us to make definitive, first-principles arguments against *de jure* technology neutrality in GIP. The principle of targeting says that if the market failure in question varies by technology, so will optimal policy. In GIP, market failures which vary by technology and industry are ubiquitous. While our theoretical argument does not directly

[2] The rationale behind the concept of "simple goods" in the CBAM is to simplify embedded emissions accounting requirements for producers where the upstream emissions are considered sufficiently minor in comparison to direct process and energy-related (Scope 1 & 2) emissions. Like all aspects of CBAM design, the designation of hydrogen as a simple good was partly an outcome from consultation with industry.

address *de facto* technology neutrality, we concur with previous scholars that this aspirational principle is vague and almost impossible to achieve in practice.

The strongest argument in favour of technology neutrality in GIP comes from the political economy literature. The greatest threat to successful GIP is potential capture by vested interests: ‘government failure’ exceeding ‘market failure’. Technology neutrality is seen as a way to tie the government’s hands and reduce the option space for lobbying and rent seeking. We argue that more nuanced arguments from political economy provide a different perspective. They highlight that, rather than eliminating potential for bias, technology neutrality tends to make bias harder to identify, making public accountability more difficult and favouring incumbents with greater political resources. We provide pertinent examples of this phenomenon from recent major GIP from the U.S. and E.U.

Finally, we provide two potential explanations for the persistence of technology neutrality in GIP despite the many arguments against it. The first is that its prevalence and its tendency to favour politically powerful incumbents are no coincidence. The concept of technology neutrality originated from concerns of incumbent industries about “unfair” competition from new technologies. The second is that technology neutrality bears a superficial resemblance to the ever-popular principle of non-discrimination in trade law. In contrast to trade law, however, the principle of technology neutrality in policymaking provides a legal force that exacerbates rather than ameliorates the political forces applied by incumbent industries. As a result, technology neutrality in GIP can be expected to reinforce the status quo and work against achievement of the structural changes required to green our economies.

Like any policy offering government support for industry, GIP entails the danger of rent seeking and capture. While these are legitimate problems, application of technology neutrality is far from a panacea. In place of this problematic principle, policy-makers should be encouraged to follow the established best-practice of careful identification and targeting of market failures. Where the relevant market failures are technology independent, the correctly targeted policy will be technology neutral. Where relevant market failures are multiple, complex, and vary with technology - specific policies will generally be more efficient and transparent than agnostic ones. Rather than rely on technology neutrality, policy-makers should be encouraged to apply principles such as those of (Rodrik 2014) that were designed specifically to address the challenges of GIP.

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[1] “worthwhile” = “welfare improving” in the language of neoclassical economics.
[2] Outside of the GIP literature, early-stage technology policies are often referred to as “innovation policy”.
[3] Interestingly Metcalf (2009) is actually arguing that de Jure technology neutral policies of this type are not de facto
technology neutral.
[4] Across the various literatures, “ideas” may alternatively be referred to as “principles”, “norms”, “framing” or “narratives”. The adjective describing them may alternatively be “appealing” or “intuitive”.
[5] Percentage contribution to current energy mix sourced from U.S. Energy Information Administration FAQs: https://www.eia.gov/tools/faqs/faq.php?id=427&t=3, accessed 11 November 2023.

Figure 1: First- or second-best policy among 15 studies which portray GIP as having at least some element of second-best policy response.

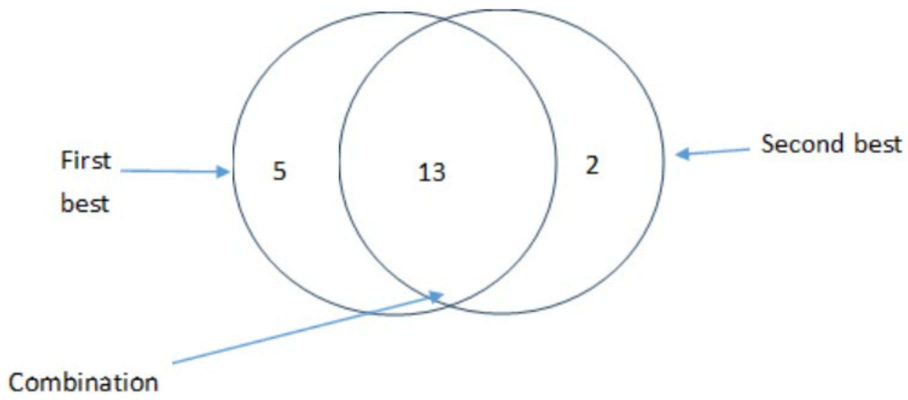


Figure 2: Legal rights to non-discrimination are available only to foreign producers in trade law, hence counteract political forces dominated by domestic constituents and help push policy towards efficient settings.

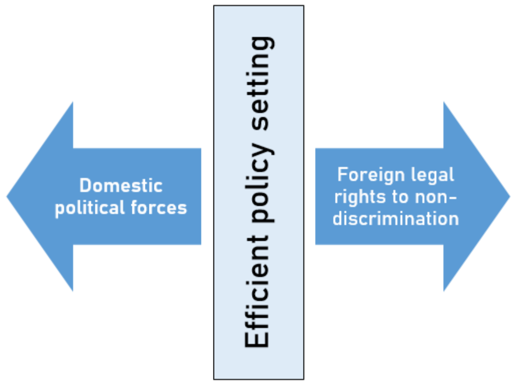
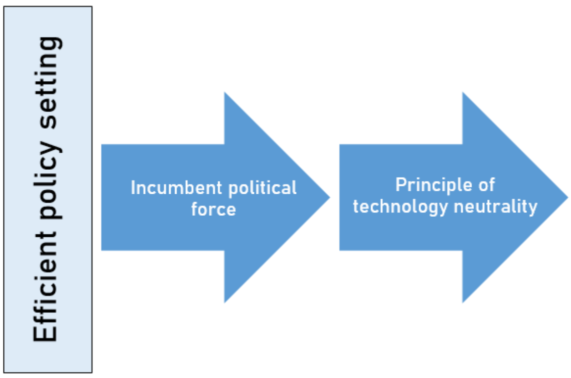


Figure 3: Principle of technology neutrality further empowers incumbent industries, pushing policy outcomes further from their efficient point.



Appendix A

Table A1: Summary of the GIP Literature

Author Date	1st or 2nd best?	Market Failures Targeted			Economy wide or sector-specific	Composition &/or technique	Composition goal			Motivation	Demandside (Y,N,FiT)	Examples (Policy, Instrument or Strategy)
		Environmental	Innovation	Industry			Shrink polluting	Grow less-polluting	Grow Green tech			
Harrison et al (2017)	first	Yes	Somewhat	Yes	both	Both	Yes	Yes	Somewhat	Sustainable development	Y P265, FiT	I
Rodrik (2014)	second	Somewhat	Yes	Somewhat	Tech sector	Composition	Somewhat	Somewhat	Yes	Green growth	N	I p473
Altenburg and Rodrik (2017)	first	Yes	Yes	Yes	Both	Composition	Yes	Yes	Yes	SDGs	N, FiT	I
Pegels (2017)	both	Yes	Yes	No	Sector	Composition	No	Yes	Yes	Green transition	FiT	P
Veiga and Rios (2017)	first	No	Yes	Yes	Sector	Composition	No	Yes	Yes	Energy security	Y	S
Altenburg & Rodrik (2017)	both	Yes	Yes	Yes	Sector	Composition	Yes	Yes	Yes	Sustainable development	Y p13	I p9
Pegels (2014)	Both	Yes	Yes	Yes	Sector	Composition	No	Yes	Yes	environmental sustainability	Y p21, Ch 3	I p5

Pegels & Lütkenhorst (2014)	both	Yes	Yes	No	Sector	Composition	No	Yes	Yes	Environmental sustainable economy	FiT p523	I p523
Hallegatte et al (2013)	both	Not directly	No	Yes	Sector	Composition	Yes	Yes	No	Greening growth	Y p7, FiT	P 7
Karp & Stevenson (2012)	First	No	Yes	Yes	Sector	Composition direct, technique indirect	No	Yes	Yes	Fossil fuel replacement	FiT	-
Schwarzer (2013)	both	No	Yes	Yes	Sector	Composition	No	Yes	Somewhat	Green growth	Y p37	I p44
Schmitz, Johnson & Altenburg (2015)	both	Yes	Yes	Yes	Sector	Composition	No	Yes	Yes	green transformation	N (focus on rents)	-
PAGE (2017)	both	Yes	Yes	Yes	Sector	both	Somewhat	Yes	Yes	transition to an inclusive green economy	N	I p7 Ch3, 4 others
Warwick (2012)	second	Yes	Yes	No	both	Composition	No	Yes	Yes	Green growth	N	I p43
Pegels, Vidican-Auktor, Lütkenhorst, and Altenburg (2018)	Both	Yes	Yes	No	Sector	Composition	No	Yes	Somewhat	Energy transition	Y p27, FiT	I p27
Shen, He & Yao (2021)	both	Yes	Yes	No	Sector	Composition	No	Yes	No	Energy transition	Y p2, FIT	I p2

Giordano (2015)	first	Yes	Yes	Yes	Sector	Compositi on	No	Yes	Yes	Green growth	Y (EVs)	I
Busch Foxon & Taylor (2018)	both	Yes	Yes	Yes	Sector	both	No	Yes	Yes	low carbon transformati on	Y (p119)	S
Lütkenhor st, Altenburg, Pegels & Vidican (2014)	both	Yes	Yes	Yes	Sector	Compositi on	No	Yes	Yes	green transformati on	Y p23	I
Fischer (2017)	both	Yes	Yes	Yes	Sector	Compositi on	No	Yes	Yes	develop clean energy alternatives	N	-