Green Industrial Policy and Technology Neutrality: Odd Couple or Unholy Marriage?

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[redacted] Introduction

In response to the twin crises of climate change and the COVID-19 pandemic, green industrial policy (GIP) has moved from a fringe interest to a central pillar of government policy in many countries around the world. The European Union and South Korea are among those who have announced a New Green Deal in 2020, and Democratic US President-Elect Joe Biden also has one as part of his platform (https://joebiden.com/climate-plan/#). GIP for specific industries is even more wide-spread; to date nine countries in the world have comprehensive national hydrogen strategies and a further eleven are in the process of developing one (Uwe Albrecht et al., 2020). Rapid technological development is a central pillar of many of these same programs.

Technology neutrality has long been a favored principle for the design of policy and regulation in areas characterized by rapid technological change. It is argued that technology neutrality enhances competition and supports the longevity of law and policy. The European Green Deal, the Australian National Hydrogen Strategy, and Australian Low Emissions Technology Investment Roadmap make explicit reference to the principle of technology neutrality. Yet technology neutrality is not without its critics (Reed, 2007; Azar and Sandén, 2011; Giannopoulou, 2011; Haar, 2007; Selvadurai, 2018), especially when applied to energy transition policy (Azar and Sandén, 2011; Metcalf, 2009). Given that GIP entails governments promoting certain industries (and hence their associated technologies), it is also questionable whether technology neutrality is logically consistent with GIP.

The current paper asks three questions: Does it ever make sense to use technology neutrality as a design principle for green industrial policy? If so, what are the pitfalls to avoid? And how can they be avoided? To facilitate concrete examples of our points and approach, we use the Australian National Hydrogen Strategy (ANHS) as a case study.

Our work contributes to the relatively small literature on the application of technology neutrality in industry policy. Authors writing favorably on its application in industry policy often do so in passing, assuming its benefits are largely self-evident (Styczynski and Hughes, 2019; Australian Department od Industry, 2017; Schwarzer, 2013; Trubnikov, 2017; Warwick, 2013). Both Styczynski and Hughes (2019) and Gentzoglanis and Henten (2010) are among those who argue the relationship between industry policy and technology neutrality is complicated. Interestingly, examples of literature critical of the application of technology neutrality as a principle for industry policy are most easily found in the literature on green industrial policy (e.g. Elkerbout, 2017; Hallegatte et al., 2013; Luetkenhorst and Pegels, 2014)The conclusion of our analysis is nuanced. We argue that while technology neutrality, blindly applied, can be contradictory to the goals of GIP, the concept should not be thrown out wholesale. We define a refined principle of Conditional Technology Neutrality (CTN) which we believe can be a useful principle applied to the design and implementation of GIP. In our definition, ***CTN means that a policy does not favor any particular means of achieving the desired objective. Specifically, a policy must equally support all methods capable of achieving the***

objective. However, the objective itself may entail implicit technology bias, and it may help further more than one societal goal. We further identify a set of recommendations for the application of CNT in GIP and explain their use and significance for the example of the ANHS.

Primary among the potential pitfalls of applying technology neutrality to GIP are vagueness and ambiguity, leaving room for strategic and political gaming by powerful actors; and short-term, economically focused objectives which are counter to the environmental goals of the GIP. Key recommendations include the importance of linking CTN to a specific policy objective that is clear and is consistent with the medium-to-long-term, multi-dimensional goals of the GIP.

The rest of this paper is organized as follows. Section 2 draws on both legal and economic scholarship to discuss the definition of, and motivation for, the principle of technology neutrality. Section 3 similarly defines and motivates the concept of GIP and discusses some current examples. It also introduces the ANHS as our case study of GIP. Section 4 summarizes the major critiques of technology neutrality in the literature. Section 5 begins with a conceptual analysis of the logic of applying technology neutrality to GIP, motivating the need for the principle of "conditional technology neutrality". Section 5 then provides a set of recommendations for how to apply CTN to GIP so that it is supportive of the underlying goals of the policy. Section 6 concludes.

[redacted]Technology Neutrality

2.1. What is technology neutrality?

2.1.1. The definition and formulation of technology neutrality

Despite the wide adoption of technology neutrality, most policies merely mention it as an over-arching regulatory principle without clarifying what it means, where it applies and how it is applied. Meanwhile in the academic literature, definitions of technology neutrality have proliferated across disciplines including law, public policy, economics.

In the context of GIP, key contributions to the definition of the concept include Ohm (2010) 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". An important application is in the stage of drafting laws – "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" (Selvadurai, 2018). Wylly (2015) broadens Ohm's definition to "policy [which] does not favor any particular means of achieving the desired goal. Specifically, a policy must equally support all methods capable of achieving this outcome". Thompson (2011)'s definition reflects the non-interventionist approach, defining it as "the idea that law should not pick technological winners and losers, that law should neither help nor hinder particular types of technological artefacts." Thompson proposes the criterion of "functional equivalence" 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. Definitions of technology neutrality specific to policy for "green"/ "clean" technologies include, Azar & Sandén (2011) "policies that promote technologies with no or low carbon emissions but do not specify which such technologies should be supported".

2.1.2. Emergence as a policy principle

Technology neutrality has been widely used around the world. It originated in the US in the 1980s in the information and communication technologies.[1] It was later adopted as a general guiding regulatory principle in the US in computing technology and online services. The US *Framework of Electronic Commerce* further promoted technology neutrality from a domestic regulatory principle in the US to an internationally recognized regulatory principle. In this Framework, the US government states that United Nations Commission on International Trade Law (UNCITRAL) and other international actors should follow four principles in drafting rules governing global electronic commerce – "rules should be technology-neutral (i.e., the rules should neither require nor assume a particular technology) and forward-looking (i.e., the rules should not hinder the use or development of technologies in the future)" (the White House, 1997). The EU also began to incorporate the principle of technology neutrality in the late 1990s, in its regulations on electronic signatures, personal data protection, the protection of minors and human dignity in audio-visual and information services (Reed, 2007). The early development of the principle was mainly confined to the ICT sector and the major policy objective was to promote on-line and off-line equivalence. (European Union, 1998).

Since the early 2000s, technology neutrality has also been a popular regulatory and policy principle for environmental and energy policies. In his speech on climate change in 2008, the then US president G.W. Bush stated, "incentive should be technology-neutral because the government should not be picking winners and losers in this emerging market" (Roberts, 2008). 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).

2.2. Why technology neutrality?

2.2.1. The legal view of technology neutrality

Technology neutrality has been celebrated by legal scholars for various reasons. For some, technology neutrality is an intrinsic pursuit of law. As pointed by Giannopoulou (2010, p1), 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. Technology neutrality has also been seen as promoting free competition among different technologies – "the concept of technology neutrality involves a series of principles that seek to describe a free and competitive scenario among all technically feasible solutions" (Rios, 2013).

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. Constantly changing technologies and established legal frameworks are in continuous conflict with each other (Selvadurai, 2018). 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. Therefore, technology neutrality

[1] According to (Reed, 2007), the first use of the term was in the description of the US Electronic Communications Privacy Act 1986.

will “limit negative externalities associated with having multiple laws for similar conduct in different technological environments” (Lipinski, 2003).

2.2.2. The economic view of technology neutrality

The underlying rationales for technology neutrality as a regulatory and policy principle differ between economists and lawyers. From the perspective of neoclassical welfare economics, technology neutrality is an emergent property of an efficient policy approach – not a defining characteristic. Economists use technology neutrality as a way of communicating their concept of good policy to non-economist audiences.

The welfare economic approach to policy – widely espoused by organizations such as the OECD Best Practice Principles for the Governance of Regulators (OECD, 2014, p. 10) – follows from the first welfare theorem. Namely, in the absence of market failures, the most efficient outcome (including all forms of social and environmental costs and benefits in the definition of efficiency) is achieved when the government does not intervene. The presence of one or more market failures, however, means that the market alone will not achieve the optimal outcome. Market failures, therefore, provide a potential efficiency justification for government policy or regulatory intervention.

Another cornerstone of neoclassical welfare economics is the principle of targeting – the most efficient government intervention will be one that is directly targeted at fixing a market failure. For example, if the market failure is that there is an externality associated with carbon emissions, the targeted policy will be to make market participants internalize the social cost of their actions, by putting a price on carbon. A carbon price is a classic example of a technology-neutral policy toward climate mitigation. However, technology neutrality is a consequence of the underlying neoclassical welfare economic theory – not a fundamental principle of it.

Technology neutrality is not the only popular principle of good policy-making that can be understood to have its roots in neoclassical welfare economics. The idea that “for each policy problem you need one policy lever” can also be seen to follow directly from the principle of targeting. The neoclassical view is that efficient policy will always have a single, clearly stated objective. Efficient policy will involve a technologically neutral intervention to fix a particular market failure.

A final economic motivation for technology neutrality is the maximization of competition in the market. Imperfect competition (such as monopoly and monopsony) is a pervasive market failure which, in and of itself, leads to higher prices for consumers and lower-than-optimal provision of goods and services in the market. Technology-biased policies and laws which reduce market competition can therefore be costly.

It is important to clarify, that a desire to increase competition in the market is not a justification for the use of technology-biased policies. Where a single technology dominates simply because it is better able to meet the objective at a lower cost, it should be allowed to dominate.[2] Technology-

[2] Note the link to an objective of the policy to which the principle of technology neutrality is being applied is crucial here, and that the objective may include environmental goals. Alternatively, environmental and other externalities may be addressed through complementary policies. We are not recommending that the cheapest technology be allowed to dominate if social and environmental costs are external to the market.

biased policies, such as subsidizing inferior technologies in order to reduce the market power of companies using the dominant technology are inefficient. Furthermore, artificially restricting the dominant technology from expanding to its natural size can maintain costs, and hence price for consumers, higher than they would otherwise be. We have seen repeatedly that when dominant technologies are allowed to expand, they move rapidly down the cost curve and prices fall for consumers. The mechanism for this cost reduction is economies of scale, including dynamic economies of scale (i.e. learning by doing). In renewable energy, wind turbines and silicon-based photovoltaic cells are key examples. Finally, technology-competition does not necessarily lead to a more competitive market. It may be that the dominant technology is characterized by relatively low economies of scale, inducing a large number of competitive firms in the market. In the case of low-emissions electricity, for example, the wide-spread adoption of residential rooftop solar is evidence that generation using solar panels exhibits relatively low economies of scale compared to generating electricity by firing natural gas and capturing and storing the resulting emissions. Attempts to subsidize the latter to maintain technology competition are likely, therefore, lead to fewer producers and a less competitive clean electricity market. Overall, a proper understanding of economic theory emphasizes that the role of government should be to ensure a level playing field and address market failures, then let the market decide the optimal number of competing technologies.

[redacted] Green Industrial Policy

3.1. What is green industrial policy?

Although a relatively new concept, green industrial policy already has a number of definitions. Two influential definitions from the literature are Altenburg and Rodrik (2017) and Hallegatte et al. (2013). Altenburg and Rodrik (2017, p.2) define GIP as "policy options for managing structural change that accounts for both the productivity and the environmental challenges in a harmonized way." (Hallegatte et al., 2013, p. 3) define GIP as "industrial policies with an environmental goal—or more precisely, as sector-targeted policies that affect the economic production structure with the aim of generating environmental benefits."

For the purposes of this paper we will take a narrower definition of GIP, which combines aspects of both Altenburg and Rodrik (2017) and Hallegatte et al. (2013) definitions. ***We define green industrial policy as sector-targeted policies that affect the economic production structure with the aim of furthering both productivity and environmental goals in a harmonized way.*** Hence we are interested in government policy towards sectors which they believe have the potential to win not one, but two races.

3.2. Why green industrial policy?

In recent years more and more states are taking measures to respond to profound environmental crises, in particular climate change.[3] Many of these measures are GIP in the sense that they are employed to influence a country's economic structure in order to pursue a desired objective

[3] We are aware that there are other existential threats such as the loss of biodiversity, ozone depletion, ocean acidification, water shortage, soil degradation, accumulation of nitrogen in aquatic ecosystems and the accumulation of chemical waste and plastics. *See* Rockström et al. (2009). We use the case of CO_2 emissions in this paper as one case to demonstrate the relationship between technology neutrality and GIP.

beyond enhancing productivity and competitiveness. GIP allows governments to target policies and industries which simultaneously address both environmental and economic problems.

Injecting environmental and sustainable development goals (United Nations, 2015) into industry policies requires productivity-enhancing economic development to be aligned with environmental objectives and national interests to be compatible with the protection of global commons (Altenburg and Assmann, 2017). Research shows that implementing GIP may bring about broader social and economic co-benefits, including improved conditions for human health, preservation of resources for sustainable growth, create employment and avoidance of high switching costs in the future to immediate cost reductions through resource-efficient production (Esposito et al., 2017).

One important role of GIPs is to phase out environmentally harmful industries and phase in environmentally sound substitutes. Theoretically this could be achieved by mechanisms which cause producers and consumers to fully internalize the social and environmental costs of their decisions. A relevant example is Pigouvian taxation of greenhouse gases – where emitters pay the marginal social/environmental cost of their emissions. In many cases, however, there are political or practical limitations to this theoretically optimal approach. As a result, harmful industries enjoy implicit subsidies through their unpaid use of common natural capital and ecosystem services. To counter this implicit subsidy to harmful industries, governments must differentiate, and in certain cases favor, certain technologies/sectors to achieve a more efficient (socially optimal) economic structure.

This leads to a central question that we ask in this paper: how can technology neutrality be implemented as part of the green industrial policy?

3.3. Green industrial policy examples

The clean energy transition has undoubtedly been the primary environmental driver for the growing interest in GIP in recent years. Altenburg and Assmann's (2017) volume contains almost exclusively examples from the energy sector, including countries as diverse as Brazil, China, and Morocco (Altenburg and Assmann, 2017). In response to the COVID-19 crisis several jurisdictions, notably the European Union and South Korea have announced "New Green Deals" which place heavy emphasis on the energy transition (European Commission, 2019; Greenpeace International, 2020).

Within the energy transition, there has been particular interest recently in GIP to support hydrogen as a replacement for fossil fuels. 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 (Uwe Albrecht et al., 2020). The current paper will use the ANHS as a case study to illustrate concepts and ideas.

3.4. The Australian National Hydrogen Strategy case study

The ANHS was developed by the Hydrogen Strategy Task Force, led by the Australian Chief Scientist. As stated by The Hon Angus Taylor MP Minister for Energy and Emissions Reduction, "This Strategy sets a path to build Australia's hydrogen industry", to "accelerate the commercialization of hydrogen, reduce technical uncertainties and build up our domestic supply chains and production capabilities"(COAG, 2019). The ANHS defined 15 measures of success and delivered overarching recommendations and a list of 57 actions, which were unanimously accepted by Commonwealth and State Energy Ministers in November 2019. The overarching objective of the ANHS appears to be summarized by the statement that success is a "clean, innovative, safe and competitive industry".

In understanding the ANHS as a piece of GIP, the reference to "clean" is important. The Strategy also states "unless otherwise indicated, references to hydrogen in this report refer to clean hydrogen. Clean hydrogen is produced using renewable energy or using fossil fuels with substantial carbon capture and storage (CCS)" (COAG, 2019, p. xiv).

To place this definition in context, consider that the currently dominant technologies for global hydrogen production are reforming (using natural gas and other hydrocarbons) and gasification (using coal). Together these technologies represent a well-established industry producing 70 million tons of hydrogen a year (IEA, 2019). However, these processes are emission intensive and produce roughly 10 kg CO_2 /kg H_2 when using natural gas as a feed stock, and 20 kg CO_2 /kg H_2 when using coal. Employing CCS to make fossil-fuel based hydrogen 'clean' is relatively new, and currently there are only two commercial hydrogen plants world-wide with integrated CCS (IEA, 2019). The range of carbon capture and retention rates can vary widely, resulting in specific emissions ranging from 1-4 CO_2 /kg H_2 depending on the technology used (Muradov, 2017) and whether the CO_2 is subsequently used. Hydrogen can be produced without fossil fuels by electrolysis of water, powered by renewable or nuclear energy. Electrolysis is currently not competitive with existing methods of hydrogen production (CSIRO, 2018; IEA, 2019). However, when renewably powered it is a truly zero-carbon pathway and will likely have additional benefits to the energy sector, such as helping to stabilize the grid and supporting the continued development of a renewable energy industry (IRENA, 2019). There are also a range of other low and zero-emissions hydrogen generation technologies under development, including the Hazer process and direct solar hydrogen production (ARENA, 2019; Rothschild and Dotan, 2017).

[redacted] Technology Neutrality and GIP: an unholy marriage?

Despite its wide application in many areas, the principle of technology neutrality has been criticized broadly as discussed above. This section will analyze these criticisms in the context of the GIP.

4.1. Reduced clarity in policy and legislation implementation

There are two ways in which attempts to apply the principle of technology neutrality in law and policy can cause problematic loss of clarity. The first is through reference to technology neutrality without defining the principle. As discussed in Section 2.1, the concept of technology neutrality can be ambiguous and numerous definitions abound in scholarship and practice. Where the exact definition of technology neutrality in use is not specified, the resulting vagueness enables policymakers and legislators to adhere to different meanings of technology neutrality (Haar, 2007). A technology-neutral policy that commands government not to pick the winners from the market and a technology-neutral policy that requires performance standards instead of design standards will have different policy ramifications.

Thompson (2011) highlights the second reason application of the principle of technology neutrality can cause a loss of clarity - namely that drafting law and policy in technology neutral language requires a higher level of abstraction. Similarly, Moses (2003) notes that words have their limits and it is impossible to keep sufficient precision and clarity as well as catering for longevity of legislation with rapidly changing technologies. As high-level abstraction needs to be interpreted and clarified to be implemented, and there can be more than one interpretation.

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. Ambiguity can also be exploited by powerful groups to achieve certain political purposes (Byers, 2020; Son and Lee, 2018). Furthermore, there is ample empirical evidence that policy ambiguity and uncertainty suppress investment in a range of settings.[4]

4.2. Lock-in and dynamic inefficiency

Technology lock-in leading to dynamic inefficiency is probably the most common criticism of technology neutrality in the context of the clean energy sector (see for example Thompson 2011; Azar and Sandén, 2011; Jacobsson et al., 2017). Jacobsson et al. (2017) argue that the EU's energy policy emphasizes static efficiency and technology neutrality, which leads to neglect of dynamic efficiency. They argue that in the early stage of market formation, policies should focus on stimulating the generation of positive externalities such as R&D investment and fostering innovative capital goods industries. To achieve this, technology-specific R&D agendas are needed to supplement technology-neutral instruments. They further argue that dynamic efficiency is essential to balance tech-specific and tech-neutral policies which "involves identifying when a given technology has gone far enough down its learning curve to be effectively fostered by technology-neutral instruments." They also argue that the scope of the tech-specific policy needs to be broader to support "promising but immature technologies", otherwise these technologies will end up with lost industrialization opportunities. As enumerated by Azar and Sandén (2011), these technologies may include transmitting solar electricity from desert areas and infrastructure for hydrogen and electric vehicles. Therefore, by restraining government action, the market will implicitly pick the winners – low-cost technologies closest to the market. Following the principle, technologies with long-term research needs will be disadvantaged because the principle will guide firms to choose a low-cost, short-term strategy.

4.3. Other forms of indirect discrimination

Applying technology neutrality and leaving the market to pick the winner based on the lowest current cost (with the consequence of lock-in and dynamic inefficiency) is just one form of indirect discrimination. Greenberg (2016) argues that technology neutrality suffers from inherent flaws that undermine its ability to achieve the goals that it is originally set to achieve, based on a case study of applying technology neutrality in copyright law. Neutrality, he argues, is suboptimal, often self-defeating and not neutral at all. Azar and Sandén (2011) come to a similar conclusion for the clean energy sector, saying: technology neutrality is often an elusive objective that neither can nor should be prioritized as the main guiding principle. Popp (2019) also argues that in the clean energy sector, it is often found that broad-based technology-neutral goals may implicitly favor some technologies over others.

[4] See for example (Barradale, 2010; Handley and Limão, 2015; Wang et al., 2014)

[redacted] The Odd Couple: making technology neutrality and GIP work together

The criticisms in the previous section make clear that the case for applying the principle of technology neutrality in the context of GIP is far from clear. Indeed, at a certain level, technology neutrality in green industrial policy sounds like an oxymoron. At its heart technology neutrality is about removing the temptation for governments to try to "pick winners", while industry policy in general, and GIP in particular are about the government doing just that. While a technology-neutral, market-failure approach to policy focusses on fixing one problem across the whole of the economy, GIP focusses policy on one industry (for example, energy production), set of technologies (e.g. renewable energy technologies) or technology (e.g. solar panels) because it is capable of fixing multiple problems.

We take seriously the criticisms and concerns about the application of technology neutrality, particularly in the context of green industrial policy. None-the-less, we argue that the combination can work if technology neutrality is defined carefully and applied wisely. In the remainder of the paper we outline a view of what careful definition and wise application entail. We use the case study of the ANHS to illustrate our approach.

5.1. Defining conditional technology neutrality

Section 4.1 highlighted some of the issues that can arise from vague formation of policy and legislation. This problem also applies directly to many references to technology neutrality in GIP. As pointed out in Section 2.1, there is no widely agreed definition of technology neutrality. This means that when – as is often the case – technology neutrality is used without definition in policy or legislation, it is unclear what is meant.

In the context of GIP, there is the additional complication that the definition of technology neutrality may cause it to clash directly with the definition of GIP. We examine the nature of the conflict between the two concepts and derive a definition of Conditional Technology Neutrality which we believe can be usefully applied in GIP.

At a conceptual level, the first potential clash between technology neutrality and GIP is that any policy which applies to only one sector will be implicitly technology biased. Inherent technology bias (when viewed from a whole of economy perspective) is unavoidable in our definition of GIP in section 3.1, or in Hallegatte et al. (2013, p.3) definition of GIP as involving "sector-targeted policies." Whenever GIP is defined as policy applying to only certain sectors or industries, it can only be at best *conditionally* technology neutral, because some technologies are found predominantly or exclusively in certain industries and sectors. GIP for the renewable energy industry will not be technology neutral between wind turbines and coal-fired power plants. However, it can be neutral between wind turbines and solar panels. In the case of a clean hydrogen strategy, the policy ignores other technologies (e.g. soil carbon sequestration) which could plausibly support the same goals of reducing net greenhouse emissions and expanding employment.

Taking a broader view of industry policy (and hence GIP) diminishes, but does not entirely remove, the logical imperative to shift to *conditional* technology neutrality. According to Altenburg & Rodrik (2017, p.2) GIP "goes much beyond industry itself" and concerns "entire economies and not just manufacturing". None-the-less, Altenburg & Rodrik's definition still entails "policy options for managing structural change…" Whenever policy is managing structural change, it can at best be technology neutral conditional on the approach taken to the sector or industry within the overall structure of the economy.

"Conditionality" is, however, not the only potential clash between GIP and technology neutrality. Multiplicity of goals of GIP is also an issue. Both our definition of GIP and that of Altenburg & Rodrik (2017, p.2) make reference to addressing "both productivity and environmental challenges in a harmonized way." Definitions of technology neutrality, however, imply a one-dimensional objective. For example, Wylly (2015, p. 300) refers to policy that does not favor any particular means of achieving *a desired goal,* and that equally supports all methods capable of achieving *this outcome*. Clearly to be a meaningful starting point for analysis in the context of GIP, we need an amended concept of technology neutrality. We call this concept *conditional technology neutrality*.

We base our definition of conditional technology neutrality (CTN) on Wylly's (2015) definition of technology neutrality. ***In our definition, CTN means that a policy does not favor any particular means of achieving the desired objective. Specifically, a policy must equally support all methods capable of achieving the objective. However, the objective itself may entail implicit technology bias, and it may help further more than one societal goal.*** For example, a conditional technology neutral policy in the context of a green industrial policy is to set a feed-in tariff for renewable energy, regardless of whether it is from solar, wind, hydro or other. The objective of the GIP in this case is to expand renewable energy generating capacity. The (multiple) goals furthered by the objective could be reducing greenhouse gas emissions and increasing electricity supply for other industries. Clearly this objective entails some technology bias – it excludes alternative approaches to greenhouse gas mitigation such as carbon capture and use. Hence the traditional principle of technology neutrality will not be applicable. This CTN approach can be contrasted with a fully technology neutral approach. An example of the latter is to put a price on greenhouse gas emissions from all sources. The objective of a "carbon" price is to make economic actors to internalize the social and environmental cost of their greenhouse emission. A carbon price is not consistent with GIP as its (singular) goal is reduction of greenhouse gas emissions – it has no economic goal and makes no explicit attempt at altering the structure of the economy.

5.2. Clear objective

A clear definition of CTN, discussed above, is the first step towards avoiding the pitfall of vagueness and ambiguity discussed in Section 3.2. The second step is a clear objective for the policy to which the principle of CTN is to be applied. Our definition of CTN, like Wylly's (2015) definition of technology neutrality in general, makes clear that the existence of a single, defined objective is essential. A piece of GIP referring to the principle of technology neutrality without specifying clearly the associated objective, will lend itself to the sorts of criticisms discussed in Section 4. The ANHS is a case in point.

The ANHS (ANHS) document only mentions technology neutrality in one place, namely in the definition of clean hydrogen: "Unless otherwise indicated, references to hydrogen in this report refer to clean hydrogen. Clean hydrogen is produced using renewable energy or using fossil fuels with substantial carbon capture and storage (CCS). This definition reflects a technology-neutral stance."(COAG, 2019, p. xiv) Thus the Strategy appears to have applied the principle of technology neutrality to justify a relatively broad scope of the GIP. It is a somewhat counter-intuitive use of the principle of technology neutrality since industry policy inherently entails technology bias in its scope.

The principle of technology neutrality is also mentioned in the Terms of Reference for the Strategy (COAG, 2019, p. 95), implying technology neutrality should apply to the overall objective. The objective of the ANHS may be understood to be "a clean, innovative, safe and competitive [hydrogen] industry"(COAG, 2019, p. 70). This objective is explained and clarified further in Table 6.1 of the ANHS (reproduced in Table 1, below). Even with the additional explanation in the table, the objective is not clear enough to avoid pitfalls such as political gaming and investment disincentive arising from vagueness (see Section 4.1).

Table 1: 2030 Measures of success for a clean, innovative, safe and competitive industry

Clean	Carbon intensity of Australian hydrogen production meets community, customer and consumer expectations and is decreasing over time Australia has a robust certification scheme in place that is internationally accepted
Innovative	Australia is regarded as having a highly innovative hydrogen industry and supportive research and development environment The sustainability of water use for Australian hydrogen production continues to improve
Safe	Australia has an excellent hydrogen-related safety track record Competitive
Competitive	Australian hydrogen is cost-competitive domestically and internationally Australia has a 'hydrogen-ready' workforce that is responsive to industry's needs

The Strategy was cognizant of the need to evolve and an adaptive approach is central to it. Moving forward, we recommend further clarification of its objective be a priority in this adaptive approach. Indeed, some progress in this regard has already been made on the "competitive" aspect of the objective. The Australian Technology Investment Roadmap has identified a stretch goal for costs of $AU2 per kilogram of hydrogen (Australian Government, 2020, p. 18). Thus the "competitive" aspect of the objective is now clear and quantified.

The "clean" aspect of the objective needs similar clarification. Currently "clean" is defined as "Carbon intensity of Australian hydrogen production meets community, customer and consumer expectations and is decreasing over time" and "Australia has a robust certification scheme in place that is internationally accepted". One approach to a clear and unambiguous definition of "clean" would quantify a maximum net embedded greenhouse emission content per kilogram, and the boundaries of the supply chain included in the emissions calculation (White et al., 2021). If it is desired to allow a transition pathway to increasingly clean hydrogen, a maximum emissions trajectory could be defined. Such a trajectory could be as simple as "zero-emissions by 2050". An alternative approach to defining "clean" would be to define it as having no greenhouse externality – that is – requiring all parts of the supply chain to pay the full social and environmental cost of any greenhouse emissions they cause. “Carbon” pricing is, of course, the ultimate technology neutral approach to addressing greenhouse gas emissions.

5.3. Objective compatible with productivity and environmental goals

Although applying CTN correctly requires identification of a single, clear objective, the objective itself may be designed to further multiple goals. Indeed, in the context of GIP, it is necessary that the objective furthers both productivity and environmental goals. In the absence of a clear objective which unambiguously supports both types of goals, there is a danger that application of the principle of technology neutrality could actually work against the achievement of some goals. As discussed in Section 4.3, true technology neutrality is an elusive goal. In many cases, application of the principle of technology neutrality itself leads to implicit technology bias. The ANHS is once again a case in point.

The vague, “technology neutral”, definition of “clean” in the objectives of the ANHS mean that it is possible that pursuit of the Strategy will be counter to the environmental goal of reducing greenhouse gas emissions. For example, the ANHS recommends “Providing targeted support for pilot, trial and demonstration projects”. If the Strategy required projects to have truly low emissions (e.g. less than 1-2 kg CO_2/kg H_2 throughout the project life), funding would likely favor the development of renewable technologies for hydrogen production. Currently, however, the “competitive” component of the objective is relatively clear at $2/kg (which renewable generation currently cannot meet) while the “clean” component is vague. The likely consequence is that government support will allow existing fossil fuel production technologies to ramp up quickly, initially without CCS. It is worth noting that there is already an existing Australian project following this route: HESC will demonstrate proof of concept hydrogen production via coal gasification but will not include CCS in the pilot stage (Hydrogen Engineering Australia, 2020). Preferencing such projects could mean the nascent demand for hydrogen is met with a cheap and dirty supply, delaying the growth of newer, cleaner technologies, and resulting in significant emissions.

The above example illustrates a key potential pitfall of poor application of the principle of technology neutrality. Technology neutrality requires that “policy does not favor any particular (must equally support all) means of achieving the desired objective” (Section 5.1). Yet the current Strategy not only provides an implicit subsidy to relatively polluting technologies in the form of unpriced carbon emissions, but it also has the potential to open the door for a disproportionate share of direct government support to go to these technologies because they are best placed to meet the “competitiveness” aspect of the objective in the short term. Defining “clean” hydrogen as that which pays the full social and environmental cost of its greenhouse emissions is a simple way of removing both forms of subsidy and restoring true technology neutrality to the policy.

5.4. Long-term objective

It is clear from the discussion in Section 4.2 that potential dynamic inefficiency (due to technology lock-in) is one of the most frequently-cited concerns in the literature on technology neutrality. Static and dynamic economies of scale (otherwise known as learning-by-doing) are commonplace in modern economies – particularly during techno-economic transitions. As a result, short-term objectives can be highly detrimental to achievement of long-term goals. The solution, therefore, is to set an objective which balances short-term and long-term social, environmental and economic goals in a manner consistent with the principle of inter-generational equity.

The heading of Table 6.1 of the ANHS implies the strategy's objectives are for 2030. In the context of climate mitigation and technological transition, a ten-year horizon is relatively short, and likely to direct industry growth on a suboptimal path from the perspective of underlying longer-term goals of the policy. Many green industrial policies around the world are targeted at supporting the goal of net zero emissions by 2050. This would seem an appropriate ambition and timeframe for the ANHS given hydrogen is of interest internationally primarily to support zero-emissions by 2050 goals.

5.5. Apply the principle of targeting

The welfare-economic view, discussed in Section 2.2.2, is that technology neutrality is an emergent property of good policy, rather than an underlying principle. Arguably, many of the criticisms of technology neutrality could be addressed by prioritizing the welfare-economic principles, over technology neutrality. Consider, for example, the concerns about implicit bias and lock-in discussed in Sections 4.2 and 4.3.

Sometimes implicit bias arising from the application of the principle of technology neutrality can be understood as a form of unintended consequence of a policy. Economists have long been aware of this problem. Bhagwati and Ramaswami (1963) showed that any policy which is not directly targeted at addressing a market failure will inevitably cause secondary distortions. Their solution - commonly referred to as the "principle of targeting" - says that in order to avoid creating secondary distortions, policy must be targeted directly at addressing the identified market failure.

Problems like lock-in of inefficient technology can be minimized if the principle of targeting is applied. Consider the case of hydrogen production – where the dominant technology is currently reforming of fossil fuels. Hydrogen production by using renewable electricity to electrolyze water may ultimately be more efficient (especially if full environmental costs are considered). However, this cost-competitiveness will only arise after dynamic economies of scale have been realized. Uncertainty about the ultimate competitiveness, as well as credit constraints combine with these dynamic economies of scale to cause a market failure which will mean investment in renewable hydrogen will be sub-optimal. One solution to this market failure is for the government to provide a production subsidy (e.g. price guarantee above market price) to early investors in renewable hydrogen. Such an approach would be criticized as failing the principle of technology neutrality. A technology neutral alternative would be to provide such a subsidy for hydrogen production regardless of method. While this approach would be technology-neutral, it will have the unintended consequence of helping "lock-in" fossil fuel-based hydrogen production. Application of the principle of targeting would suggest a third alternative. Since credit constraint interacting with dynamic economies of scale is the source of the market failure, the targeted government policy would be to offer long-term loans to hydrogen producers at rates the market would offer for low-risk investments. This is a technology-neutral policy, targeted at the source of the inefficiency, which would not lead to lock-in of currently dominant technologies. The Australian Government's recent announcement that its Clean Energy Finance Corporation will receive extra funding to support low-emissions hydrogen is a good example of this targeted approach. (CEFC, 2020) .

5.6. Use one policy per market failure

In the context of green industrial policy, a second welfare economic principle is also important - Lipsey and Lancaster's (1956) "theory of the second best". This theory shows that in the presence of multiple market failures, attempts to rectify any one failure may exacerbate another and thereby actually make things "worse" (i.e. lead to an even less efficient situation and reduce overall welfare). A corollary of this theory is that a well-designed technology-neutral strategy toward a multi-dimensional set of goals will involve a set of policy instruments, each one targeted at an identified market failure.

The ANHS once again provides a useful illustration. We focus once again on the "competitive" and "clean" aspects of the Strategy's objective. The welfare economic view of the "competitive" component is that there are market failures such as credit constraints and imperfect information which are keeping investment in the nascent industry below the efficient level (Gourlay, White and Aisbett, 2020). Government subsidies are a means of addressing this market failure. Even in the ideal world where these subsidies are appropriately targeted (see section 5.5) we may still get inefficient outcomes if this "competitive" enhancing policy is not complemented with one targeted at the "clean" goal.

For example, carbon capture and storage arguably suffers as much as renewable hydrogen generation from lack of experience and being at the upper end of the learning curve. Carbon capture and storage is a complementary technology to fossil fuel-based hydrogen production. It reduces greenhouse emissions, but cannot to reduce them to a level comparable to renewable hydrogen production due to imperfect capture rates and fugitive emissions associated with the production of natural gas and coal feedstocks (White et al., 2021). Hence subsidies aimed only at the "competitive" component of green industrial policy objectives may have consequences contrary to the environmental objective. The theory of the second best tells us these consequences may actually leave society worse off – i.e. we would have been better off with no industry policy.

There are broadly two ways to avoid policies toward productivity goals working against policies toward environmental goals in GIP. The first-best approach is to ensure that the market failures related to the environmental goals are addressed with their own targeted policies. In the hydrogen example, the underlying market failure related to the "clean" component of the objective is unpriced greenhouse gas emissions. The targeted policy is to require all hydrogen producers to pay the full social and environmental cost of their greenhouse emissions. If this first-best approach is not politically feasible, a second-best alternative is to restrict access to government support for "competitive" goals to production that is "clean" in the sense that any unpriced carbon emissions are sufficiently small that they do not constitute an implicit subsidy. Unfortunately, the vague definition of "clean" hydrogen in the ANHS means it is unclear whether the second-best approach is being followed. Hydrogen produced "using fossil fuels with substantial carbon capture and storage (CCS)" can be associated with substantial greenhouse gas emissions (Jotzo et al., 2019), which if unpriced, represents an implicit subsidy for fossil fuel technologies compared to renewable-powered electrolysis.

5.7. Don't confuse equity and equality

Definitions of technology neutrality (including ours) often refer to "equality" or "non-discrimination". There is a sense in which the principle seems akin to giving all functionally equivalent technologies a "fair" chance at being successful, much like should be given children from different backgrounds. This sort of thinking is echoed by Australia's Chief Scientist, Alan Finkel in the ANHS when he says "There should be sufficient scope and support for any hydrogen technology to grow and develop" (COAG, 2019).

It is important to understand the differences between social policy and technology policy. For social policy, greater equality of outcomes (equity) is a legitimate goal. The pursuit of equity in the context of differing backgrounds requires un-equal policy treatment. For example, greater funding for schools in disadvantaged areas. For technology policy, on the other hand, economic efficiency is usually the goal. Equity and other distributional objectives of governments are usually best achieved through policy in other areas. Hence equal treatment – technology neutrality – is appropriate.

Technology neutral policy, therefore, will not provide "sufficient scope and support for any hydrogen technology to grow and develop", because some technologies are ultimately less well able to meet the objective of clean, low-cost supply. If treated in a technology neutral manner, these technologies will drop out of the race. The point being made here is subtle, so worthy of an example.

To clarify the argument being made here, we turn to the example of GIP for clean hydrogen production. An R&D grant scheme open to all hydrogen technologies on a competitive basis is an example of a technology neutral scheme – even though it will ultimately be more helpful to new technologies than mature ones. The objective of such a scheme is not to give new technologies a "fair go", but rather to address market failures around knowledge production. The focus is on efficiency, not equity. In contrast, providing a dedicated grant scheme for research on a particular clean hydrogen technology (e.g. carbon-capture and storage) in the interest of ensuring it has a "fair go" at competing with the dominant clean technology is not technology neutral, and not efficient.

5.8. Don't confuse maintaining technology competition with technology neutrality

Closely related to the distinction between equity and equal treatment, is the issue of technology neutrality's relationship with technology competition. As discussed in Section 2.2.1, legal scholars sometimes view technology neutrality as closely linked to "a free and competitive scenario among all technically feasible solutions" (Rios, 2013, p. 1). Competition and competitiveness are also important concepts in the ANHS. For example, the chief scientist Dr Alan Finkel says "the development of a vibrant hydrogen industry will rely on healthy competition"(Finkel, 2019). As discussed in Section 2.2.2, it is important to remember that technology-neutral policy will not necessarily increase the competition between technologies in the market, as a genuinely technology neutral approach may reveal a clear dominant technology. Similarly, policy which advantages some technologies in an attempt to maintain technological competition in the market is likely to be inefficient, unfair, and not technology neutral.[5]

[5] An illustrative analogy is a horse-race in which there is a champion competing. A "tech neutral" policy for the race is to ensure the track is even, the gates function well, and all horses are carrying the same weight. The race may not, however, end up being very competitive as the champion can win at a canter. In order to make the race more competitive, and to push the champion to put in maximum effort, one could handicap the race and make the champion carry more weight than its competitors. This would not be a "tech neutral" policy. Furthermore, it would lead to the race being finished in a slower time, and resources being wasted through investments in preparation of inferior horses. Finally, it is possible that the champion does not actually win – leading to an outcome that is both inefficient and unfair.

[redacted] Conclusion

Technology neutrality is a popular policy principle, and green industrial policy is an increasingly popular policy response to environmental and economic crises. This paper has asked if and when technology neutrality is a principle which can support the achievement of the underlying goals of GIP.

A review of the legal and economic literature on technology neutrality revealed a range of definitions and motivations for the policy principle, and just as many criticisms of it. Among the most vocal critics are authors analyzing its application to renewable energy policies – a leading category of green industrial policy. Our conclusion from study of these literatures is that while technology neutrality has merit in theory, there are serious potential pitfalls in its application – particularly to GIP.

Our original conceptual analysis leads us to define conditional technology neutrality, which we argue is a relevant and potentially useful principle in the context of GIP. Conditional technology neutrality means that a policy does not favor any particular means of achieving the desired objective. Specifically, a policy must equally support all methods capable of achieving the objective. However, the objective itself may entail implicit technology bias, and it may help further more than one societal goal. We further provide recommendations for application of CTN that avoids common pitfalls identified in the literature.

Our recommendations for proper application of CTN follow from a combination of legal, economic, and policy analysis. For example, the need to specify a clear objective to which the CTN relates follows from legal discussions of the threats of vagueness and ambiguity. Meanwhile, the need to specify an appropriate time dimension to the objective follow from economic discussions of lock-in of inferior technologies. We have also argued that the principle of technology neutrality can be viewed as a principle which emerges from the application of standard welfare-economic policy theory. Some of our recommendations for successful application of CTN in GIP flow directly from application of related welfare-economic theory. Lastly, the recommendation that CTN not be confused with “policy to maintain technology competition in the market” arises from case-study analysis of documents from the ANHS. To our knowledge we are the first to draw the distinction between policies which maintain technology competition and technology neutral policies.

Bibliography

Altenburg, T., Assmann, C., 2017. Green Industrial Policy. Concept, Policies, Country Experiences. UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitk (DIE)., Geneva, Bonn.

Altenburg, T., Rodrik, D., 2017. GREEN INDUSTRIAL POLICY: ACCELERATING STRUCTURAL CHANGE TOWARDS WEALTHY GREEN ECONOMIES, in: Maschinen, B., Investition, A., Beschaffungen, G., Ersatzbeschaffungen, B., Mittelherkunft, S. (Eds.), GREEN INDUSTRIAL POLICY: CONCEPT, POLICIES, COUNTRY EXPERIENCES. UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE), Geneva, Bonn.

Annika Bose Styczynski, Hughes, L., 2019. Public policy strategies for next-generation vehicle technologies: An overview of leading markets. Environ. Innov. Soc. Transitions 31, 262–272. https://doi.org/10.1016/j.eist.2018.09.002

ARENA, 2019. The Hazer Process: Commercial Demonstration Plant [WWW Document]. URL https://arena.gov.au/projects/the-hazer-process-commercial-demonstration-plant/ (accessed 10.23.20).

Australian Department od Industry, 2017. Industry policy in a modern economy.

Australian Government, 2020. Technology Investment Roadmaps - First Low Emissions Technology Statement 2020.

Azar, C., Sandén, B.A., 2011. The elusive quest for technology-neutral policies. Environ. Innov. Soc. Transitions 1, 129–144. https://doi.org/10.4324/9781315525051-7

Barradale, M.J., 2010. Impact of public policy uncertainty on renewable energy investment: Wind power and the production tax credit. Energy Policy 38, 7698–7709. https://doi.org/10.1016/j.enpol.2010.08.021

Bhagwati, J., Ramaswami, V.K., 1963. Domestic Distortions, Tariffs and the Theory of Optimum Subsidy. J. Polit. Econ. 71, 44–50. https://doi.org/10.2307/1828374

Byers, M., 2020. Still agreeing to disagree: international security and constructive ambiguity. J. Use Force Int. Law. https://doi.org/10.1017/S0020589310000400

CEFC, 2020. CEFC statement on ARENA funding [WWW Document]. URL https://www.cefc.com.au/media/statement/cefc-statement-on-arena-funding/ (accessed 10.23.20).

COAG, 2019. Australia's National Hydrogen Strategy. Canberra.

CSIRO, 2018. National Hydrogen Roadmap.

Elkerbout, M., 2017. Transforming Energy-Intensive Industries Reflections on innovation, investment and finance challenges.

Esposito, M., Haider, A., Samaan, D., Semmler, W., 2017. Enhancing Job Creation through Green Transformation, in: Green Industrial Policy: Concept, Policies, Country Experiences. pp. 50–68.

European Commission, 2019. The European Green Deal, COM(2019) 640 final. https://doi.org/10.2307/j.ctvd1c6zh.7

European Commission, 2011. Energy Roadmap 2050.

European Union, 1998. European ministerial Conference : Global information networks: Realising the potential, Bonn, 6 to 8 July 1997: Declarations. [WWW Document]. URL https://publications.europa.eu/en/publication-detail/-/publication/0d76a85c-e66a-41af-91c2-28cd29a85094 (accessed 4.14.20).

Finkel, A.D., 2019. Australia’s hydrogen potential: A message from the Chief Scientist. Aust. Gov. Dep. Ind. Innov. Sci.

Gentzoglanis, A., Henten, A., 2010. Regulation and the evolution of the global telecommunications industry [WWW Document]. Regul. Evol. Glob. Telecommun. Ind. https://doi.org/10.1177/178359171001100406

Giannopoulou, A., 2011. Digital disposition of a work: from technical protection measures to creative commons. 4th Int. Conf. Inf. Law.

Giannopoulou, A., 2010. Digital disposition of a work : From technical protection measures to Creative commons. 4th Int. Conf. Inf. Law.

Greenberg, B.A., 2016. Rethinking technology neutrality. Minn. Law Rev. 100, 1495–1562.

Greenpeace International, 2020. South Korea’s ruling political party becomes East Asia’s first to announce Green New Deal manifesto [WWW Document]. Green Peace. URL https://www.greenpeace.org/international/press-release/29305/south-koreas-ruling-political-party-becomes-east-asias-first-to-announce-green-new-deal-manifesto/ (accessed 10.2.20).

Haar, I.M. van der, 2007. Technological Neutrality: What Does it Entail? SSRN Electron. J. https://doi.org/10.2139/ssrn.985260

Hallegatte, S., Fay, M., Vogt-Schilb, A., 2013. Green Industrial Policies - When and How. World Bank Policy Res. Work. Pap., Policy Research Working Papers 26. https://doi.org/10.1596/1813-9450-6677

Handley, K., Limão, N., 2015. Trade and investment under policy uncertainty: Theory and firm evidence. Am. Econ. J. Econ. Policy 7, 189–222. https://doi.org/10.1257/pol.20140068

Hydrogen Engineering Australia, 2020. HESC [WWW Document]. URL https://hydrogenenergysupplychain.com/ (accessed 6.2.20).

IEA, 2019. The future of hydrogen, International Energy Agency.

IRENA, 2019. HYDROGEN: A RENEWABLE ENERGY PERSPECTIVE.

Jacobsson, S., Bergek, A., Sandén, B., 2017. Improving the European Commission’s analytical base for designing instrument mixes in the energy sector: Market failures versus system weaknesses. Energy Res. Soc. Sci. 33, 11–20. https://doi.org/10.1016/j.erss.2017.09.009

Jotzo, F., Beck, F.J., Longden, T., 2019. For hydrogen to be truly ‘clean’ it must be made with renewables, not coal. Conversat.

Lipinski, T.A., 2003. The Myth of technological neutrality in copyright and the rights of institutional users: Recent legal challenges to the information organization as mediator and the impact of the DMCA, WIPO, and TEACH. J. Am. Soc. Inf. Sci. Technol. 54, 824–835.

https://doi.org/10.1002/asi.10269

Lipsey, R.G., Lancaster, K., 1956. The general theory of second best. Rev. Econ. Stud. 24, 11–32. https://doi.org/10.2307/2296233

Luetkenhorst, W., Pegels, A., 2014. Stable Policies Turbulent Markets. Germany's Green Industrial Policy: The Costs and Benefits of Promoting Solar PV and Wind Energy, International Institute for Sustainable Development publication. https://doi.org/10.2139/ssrn.2396803

Metcalf, G.E., 2009. Technology Neutrality in Energy Tax: Issues and Options. Testimony before Senat. Financ. 2009.

Moses, L., 2003. Adapting the Law to Technological Change: A Comparison of Common Law and Legislation. Univ. New South Wales Law Journal, 26, 394.

Muradov, N., 2017. Low to near-zero CO2 production of hydrogen from fossil fuels: Status and perspectives. Int. J. Hydrogen Energy. https://doi.org/10.1016/j.ijhydene.2017.04.101

OECD, 2014. The governance of regulators:, in: OECD Best Practice Principles for Regulatory Policy, OECD Best Practice Principles for Regulatory Policy. OECD. https://doi.org/10.1787/9789264255388-4-en

Ohm, P., 2010. The argument against technology-neutral surveillance laws. Tex. Law Rev. 88, 1685–1713.

Popp, D., 2019. Promoting Clean Energy Innovation. ifo DICE Rep. 17, 30–35.

Reed, C., 2007. Taking Sides on Technology Neutrality. SCRIPT-ed 4, 263–284. https://doi.org/10.2966/scrip.040307.263

Rios, M.D., 2013. Technological Neutrality and Conceptual Singularity. SSRN Electron. J. 2198887. https://doi.org/10.2139/ssrn.2198887

Roberts, D., 2008. President Bush's speech on climate change, 16 April 2008, as prepared for delivery [WWW Document]. Grist. URL https://grist.org/article/bush-on-climate/ (accessed 10.16.20).

Rockström, J., Persson, W.S.N., ChapinIII, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Wit, B.N.A. de, Hughes, T., Leeuw, S. van der, Rodhe, H., Sörlin, S., K., P., Snyder, Svedin, R.C., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Walker, J.H.B., Liverman, D., Richardson, K., Crutzen, P., Foley, J.A., 2009. A safe operating space for humanity Identifying. Nature 461, 472–475.

Rothschild, A., Dotan, H., 2017. Beating the Efficiency of Photovoltaics-Powered Electrolysis with Tandem Cell Photoelectrolysis. ACS Energy Lett. 2, 45–51. https://doi.org/10.1021/acsenergylett.6b00610

Schwarzer, J., 2013. Industrial Policy for a Green Economy.

Selvadurai, N., 2018. The Relevance of Technology Neutrality to the Design of Laws to Criminalise Cyberbullying. Int. J. Law Public Adm. 1, 14. https://doi.org/10.11114/ijlpa.v1i2.3769

Son, K.B., Lee, T.J., 2018. The trends and constructive ambiguity in international agreements on intellectual property and pharmaceutical affairs: Implications for domestic legislations in low-and middle-income countries. Glob. Public Health 13, 1169–1178. https://doi.org/10.1080/17441692.2017.1334807

the White House, 1997. Framework for global electronic commerce.

Thompson, M., 2011. The Neutralization of Harmony: The Problem of Technological Neutrality, East and West. Bost. Univ. J. Sci. Technol. Law 18.

Trubnikov, D., 2017. Analysing the Impact of Regulation on Disruptive Innovations: The Case of Wireless Technology. J. Ind. Compet. Trade 17, 399–420. https://doi.org/10.1007/s10842-016-0243-y

United Nations, 2015. Transforming Our World: The 2030 Agenda for Sustainable Development. https://doi.org/10.1891/9780826190123.ap02

Uwe Albrecht, Bünger, U., Michalski, J., Raksha, T., Wurster, R., Zerhusen, J., 2020. International hydrogen strategies:A study commissioned by and in cooperation with the World Energy Council Germany.

Wang, Y., Chen, C.R., Huang, Y.S., 2014. Economic policy uncertainty and corporate investment: Evidence from China. Pacific Basin Financ. J. 26, 227–243. https://doi.org/10.1016/j.pacfin.2013.12.008

Warwick, K., 2013. Beyond Industrial Policy: Emerging Issues and New Trends. OECD Sci. Technol. Ind. Policy Pap. 57. https://doi.org/http://dx.doi.org/10.1787/5k4869clw0xp-en OECD

White, L. V, Fazeli, R., Cheng, W., Aisbett, E., Beck, F.J., Baldwin, K.G.H., Howarth, P., O'Neill, L., 2021. Towards emissions certification systems for international trade in hydrogen: The policy challenge of defining boundaries for emissions accounting. Energy 215, 119139. https://doi.org/https://doi.org/10.1016/j.energy.2020.119139

Wylly, P., 2015. Evaluating the Costs of Technology Neutrality in Light of the Importance of Social Network Influences and Bandwagon Effects for Innovation Diffusion. New York Univ. Law J. 300–352.