Latecomer development in a "greening" world: Introduction to the Special Issue

Article *in* World Development · November 2020

DOI: 10.1016/j.worlddev.2020.105084

CITATION
1

READS
33

2 authors:

Anna Pegels
Deutsches Institut für Entwicklungspolitik
23 PUBLICATIONS **530** CITATIONS
SEE PROFILE

Tilman Altenburg
Deutsches Institut für Entwicklungspolitik
80 PUBLICATIONS **1,947** CITATIONS
SEE PROFILE

World Development 135 (2020) 105084

Contents lists available at ScienceDirect

World Development

journal homepage: www.elsevier.com/locate/worlddev

Latecomer development in a "greening" world: Introduction to the Special Issue

Anna Pegels *, Tilman Altenburg

Deutsches Institut für Entwicklungspolitik/German Development Institute, Germany

ARTICLE INFO

Article history:

Keywords:
Latecomer development
Developing countries
Green economy
Ecological boundaries
Green transformation
Co-benefits

ABSTRACT

The current transgression of ecological boundaries requires a transformation to a 'Green Economy', with rigorous and fast reductions of pollution and resource consumption. Transformative policy reforms towards this aim can lead to economic co-benefits, but they can also be costly, at least for certain economic actors. Furthermore, they can involve trade-offs between current and future wellbeing.

Timing and sequencing of reforms is thus far from trivial. More research is needed to inform policymakers in search of the right coping strategies, in particular in economic latecomer countries with persisting poverty and a high need for short-term growth. The main research question of this article is thus: *Which economic opportunities arise from orienting economic latecomer strategies towards green technologies and institutions now, versus growing first and cleaning up later?*

Literature already provides a fair basis of evidence on this question. However, it is biased towards industrialised countries, and towards a subset of green incentives and technologies, such as carbon pricing and renewable energy support. The aim of this article, therefore, is threefold. First and foremost, we review and structure existing evidence and the new evidence provided by this Special Issue along the economic arguments for "greening now" vs. "cleaning up later". We thus aim to provide an analytical reference point for the growing body of evidence on economic co-benefits of green transformations, helping to structure the debate, to widen its perspective and encourage further research on emerging aspects. Second, we put this structure in the context of latecomer countries, making the identified issues relevant for their framework conditions and showing where and how the articles assembled in the Special Issue fit in the overall debate. Third, we broaden our assessment to include particularly under-researched areas of green transformations in latecomer countries, such as electric mobility, agriculture, steel, and waste management.

In reviewing the evidence, we find that early greening is likely to bring economic co-benefits, for example in terms of efficiency-induced competitiveness and in gaining a foothold in the markets of the future. Delaying action, in contrast, risks permanent environmental damage, lock-in of polluting socio-technical pathways, and losses from asset stranding. Yet, the decision between "greening now" and "cleaning up later" is not dichotomous. Careful timing and sequencing of green policy reforms are key, and political decision makers can select and design their national policies in ways that turn changing framework conditions into economic opportunities.

1. Introduction

Starting with the industrial revolution, human economic activities have changed the world's natural environment much more profoundly than in any earlier period (Steffen, Crutzen, & McNeill, 2007; UNEP, 2019). We see this impact accelerating from decade to decade (McNeill, 2014), to the point where global warming and the transgression of other ecological boundaries are raising concerns about catastrophic and irreversible changes in global ecosystems, undermining their ability to sustain human civilization.

The need to rigorously reduce environmental pollution and resource consumption is scientifically undisputed. This calls for a shift to a 'Green Economy' (UNEP, 2011) that recognizes the value of natural resources and environmental services and sets incentives to decouple economic growth from resource consumption, phase out pollutants, such as greenhouse gases or plastic products, and replace resource-intensive and polluting industries and tech-

* Corresponding author at: Tulpenfeld 6, 53113 Bonn, Germany.
E-mail addresses: anna.pegels@die-gdi.de (A. Pegels), tilman.altenburg@die-gdi.de (T. Altenburg).

https://doi.org/10.1016/j.worlddev.2020.105084
0305-750X/

nologies with sustainable ones. The transition to a Green Economy requires fundamental policy reforms, such as the introduction of a carbon price and taxation of various other environmental 'bads', as well as regulatory frameworks that discourage or even ban unsustainable production and consumption (Altenburg & Rodrik, 2017; IPCC, 2014; Pegels, 2014).

Such reforms, aiming to internalize environmental externalities, also enhance macro-economic efficiency. But they can obviously come at a cost for certain economic actors, for example, when pollutants are priced or fossil fuel assets have to be written off. These costs can result in competitiveness and job losses when countries take action unilaterally, and their competitors do not follow suit. In the face of opportunity costs, policymakers may find it more appropriate to channel scarce private and public funds towards growth-enhancing assets (such as education or infrastructure) and use increasing revenues to clean the environment up at a later stage – unless the environmental damage is irreversible ("growing first and cleaning up later", O'Connor, 1996). By the same logic, countries may wait until environmental solutions have been developed elsewhere and incremental improvements, learning by doing, and economies of scale have brought costs down, rather than incurring development costs themselves (Arrow, 1971; Guo & Fan, 2017). Delaying environmental action may also be preferred to avoid political resistance.

Yet, *not* embarking on a green transformation, or doing so late, also implies costs. These are undoubtedly higher in the mid to longer run. They include the costs related to environmental damage as well as the extra costs of having to pursue more radical restructuring measures if they are delayed to the future (Acemoglu, Aghion, Bursztyn, & Hemous, 2012; Stern, 2007). For climate change mitigation, a major report to the US government found that "net mitigation costs increase, on average, by approximately 40 percent for each decade of delay" in achieving a specified climate target (Council of Economic Advisors, 2014).

In addition to avoiding environmental costs, early adopters of the green transformation may reap direct economic benefits. The so-called 'Porter hypothesis', for example, suggests that early adoption of stringent "environmental regulations can trigger innovation that may partially or more than fully offset the costs of complying with them" (Porter & van der Linde, 1995). It puts early adopters in an advantageous position once other countries start requiring greener products and processes.

The above considerations illustrate that timing and sequencing of reforms in a way that optimizes the potential trade-off between aligning the economy with the earth's carrying capacity while maintaining incentives for short-term wealth creation is far from trivial. More research is needed to inform policymakers in search of the right coping strategies. This applies all the more to economic latecomer countries with persisting poverty. In comparison to highly industrialised countries, these countries typically have a higher need for short-term growth and a comparatively smaller per capita ecological footprint.

The main research question of this Special Issue is thus: *Which economic opportunities arise from orienting economic latecomer strategies towards green technologies and institutions now, versus growing first and cleaning up later?*

This question is motivated by two particularly important research gaps. First, most of the research on the relationship between environmental policies and economic opportunities has focused on advanced industrialised countries. For example, Ambec et al.'s meta-analysis of 17 empirical studies on the Porter hypothesis exclusively covers OECD countries (Ambec, Cohen, Elgie, & Lanoie, 2013). Very little evidence exists for developing countries. These countries are economic latecomers that integrated in global markets with a time lag. Therefore, they combine disadvantages in terms of lack of experiences, economies of scale and network economies with the advantages of being able to build on technological solutions developed by economically advanced countries (Gerschenkron, 1962; Lin, 2016; Mathews, 2006). These peculiarities of latecomers are of fundamental importance when it comes to strategic choices whether to "grow first and clean up later" (when the countries are richer and environmental technologies can be purchased at lower cost) or to "green now" in order to reap early mover advantages.

This Special Issue aims to close this gap by focusing on evidence from latecomer countries in the global economy, covering small low-income countries as well as large emerging economies. This collection of evidence is timely, because many latecomers have now adopted green growth strategies for the first time and/or are struggling to operationalise their so-called Nationally Determined Contributions to the Paris Agreement on climate change. Yet, it is also challenging, because implementation of potentially transformative environmental policies is lagging behind and economic effects are only starting to materialise. This is why the Special Issue includes various papers that *model* the likely effects of environmental incentives (Ansari & Holz, Daniels et al., de Melo & Solleder, Nechifor et al., Siddiqi et al.). Other papers focus on those few emerging markets that already have enacted major green technology programmes, particularly China (Altenburg et al., Lema et al., Zeng et al., Nechifor et al.). The papers focusing on low- and lower-middle income countries mostly explore changes in agriculture (Barbier) and renewable energy (Probst et al.), where the green transformation is already underway.

Second, most of the literature is highly specialized, considering only a small subset of green incentives and neglecting others. For example, the effects of the Clean Development Mechanism are fairly well-studied (Dechezleprêtre, Glachant, & Ménière, 2008; Popp, 2011); likewise, there is an impressive amount of empirical literature on economic effects of subsidies for the wind and solar industries (Lewis, 2014; Solangi, 2011, UNIDO/GGGI, 2015). In contrast, there is very little research on economic opportunities and threats stemming from other green incentives. As a result, decision-makers can only assess the effects of a small subset of green transformation policies.

In this Special issue we therefore seek to provide a more complete perspective for scholars and policymakers by going beyond the well-studied green incentives and addressing under-researched facets of the green transformation. This includes explorations of green sectors other than renewable energies, such as waste (Daniels et al., Siddiqi et al.), steel (Nechifor et al.) agriculture (Barbier) and electric mobility (Altenburg et al.). Likewise, innovative approaches are taken with regard to incentives for the green transformation. The selection of papers covers the effects of environmental provisions in trade agreements (Brandi et al.; de Melo & Solleder), important indirect effects on country competitiveness such as technological lock-in risks (Ansari & Holz), as well as higher capital cost and financial exclusion of firms as a consequence of risk premiums on sovereign debt of climate-vulnerable countries (Kling et al.). The Special Issue thus covers a wide range of transmission mechanisms between incentives for a green economy and economic opportunities for latecomer economies.

Before we proceed, two clarifications are in order. First, what is to be regarded "green" is not always clearly defined. We consider an economic activity "green" if it creates products or services and/or employs business practices that lessen the environmental footprint. We recognize, however, that technologies can be designed and employed to pollute more or less extensively, and hence there are different shades of green. The boundaries of green production are furthermore blurred by the existence of trade-offs between environmental objectives, such as reducing carbon emissions and protecting biodiversity when biofuels are produced. Where such "nexus trade-offs" (ICA, IUCN, & IWA, 2015) exist,

Table 1
Economic arguments for "greening now" vs. "cleaning up later" strategies for latecomer economies.

"Greening now" may...	**"Cleaning up later"** may ...
1. Avoid irreversible environmental damage and the accumulation of costs to restore environmental equilibria, 2. Lower the costs of switching socio-technical pathways, 3. Reduce the risk of asset stranding, 4. Lower environmental risk premiums in capital markets, 5. Induce efficiency investments which immediately pay off, 6. Trigger early mover advantages, 7. Open up new employment opportunities, 8. Provide preferential access to international green funds and trade opportunities, 9. Reduce dependence on resource imports and economic volatility, and 10. Increase fiscal space through environmental fiscal reforms.	1. In the short run retain employment and competitiveness in polluting industries, or even attract investments from countries with more stringent regulations, 2. Avoid opportunity costs of expensive green investments and leave space for other welfare-enhancing investments, 3. Happen automatically as countries experience structural transformation towards services and away from industry.

greening strategies would aim for the best environmental net effects – which, admittedly, not only requires a very good understanding of ecosystem dynamics, but also involves ethical considerations.

Second, economic opportunities may be defined in a broad or a narrow way. Broadly defined, any measure to curb unsustainable resource use pays off in the long term. As the International Trade Union Confederation bluntly stated, "there are no jobs on a dead planet" (ITUC, 2015). Environmental degradation has many indirect negative effects on economic development, such as the health care costs and productivity losses related to urban air pollution (Watts, Amann, Ayeb-Karlsson et al. 2018; OECD, 2016) or the costs of managing the challenge of over 140 million expected climate migrants by 2050 (Rigaud, 2018). Unfortunately, but true to generally observable human behaviour, investors as well as policymakers tend to take their decisions with a fairly short term time horizon of less than 10 years and seek to directly benefit from their decisions, economically or politically. In this special issue, we therefore focus on economic opportunities more narrowly. This only includes those that impact directly and immediately on the performance and employment effects of firms, groups of firms and/or public revenue generation. To understand these immediate effects is particularly important when it comes to building societal consensus on, and implementing steps toward, green transformations. Furthermore, we do not, in this article, put a specific focus on the politics which are invariably a product of re-distributive processes initiated by such encompassing and mostly policy-driven transformation processes as the green transformation. The co-benefit, rent management, and coalition approaches taken inter alia by Dubash et al. (2013), Schmitz (2017), and Pegels, Vidican-Auktor, Lütkenhorst, and Altenburg (2017) provide the basis for a more political analysis and complement the economic analysis put forward in this article.

Given the patchwork of evidence, and the complexity of the trade-offs between greening national pathways and the development perspectives of latecomer economies, we use the following straightforward scheme to organize our review of available literature and the articles in this Special Issue aiming to fill the gaps (Table 1).

The remainder of this paper is organised in three sections. Sections 2 and 3 will discuss the economic arguments for immediately adopting green policies ("Greening now") versus delaying them ("Cleaning up later"). In both Sections we will explore the main arguments with all their ramifications, embedding them in existing empirical literature. While this literature is clearly biased towards OECD countries, our focus is on latecomer economies. We thus explore conceptually why and how latecomers face different challenges when embarking on a green transformation and we review the still scarce empirical research on the related economic opportunities and threats, including the new evidence presented in this Special Issue. Section 4 summarizes and identifies gaps for future research.

2. Economic arguments for immediately adopting green policies ("Greening now)

Our literature review reveals ten main economic arguments in favour of adopting green policies earlier than one's competitors in the global economy.

[1] Avoiding irreversible environmental damage. The counterfactual scenario to orienting economic development strategies towards green technologies and markets is not a continuation of the current status quo. The aggregated impacts of countries' current "grow first, clean up later" strategies are already now leading to environmental changes on the local and global scales, so that the counterfactual scenario to early greening is a future of environmental catastrophes. The damages are numerous and range from pollution of soil, water, and air, to irreversible loss of biodiversity and depletion of natural resources, and such impacts of climate change as rising likelihood of weather extremes and sea level rise. These changes, if not abated, will severely impact on future development achievements and opportunities. Some of the damages may be abrupt and re-inforce other damage (such as "climate tipping points"), and some are irreversible, at least on the time scale of human civilizations. A collapse of the West Antarctic Ice sheet or an ocean thermohaline circulation collapse, the dieback of the Amazon rainforest, sea level rise, and a shift of the West African monsoon are some examples for such abrupt and/or irreversible changes. Cai, Judd, and Lontzek (2013) and Cai, Judd, Lenton, Lontzek, and Narita (2015) show that significant reductions of future CO2 emissions may be the utility-maximizing policy choice in the context of irreversible environmental damages and tipping points, and Keller, Bolker, and Bradford (2004) show that this may even be the case when irreversible damages are small and uncertain. Even if damage is not irreversible, the costs of restoring environmental equilibria increase over time (Council of Economic Advisors, 2014). Early greening can avert the risks of current polluting pathways (Masson-Delmotte et al., 2019; Matthews & Solomon, 2013).

[2] Lowering the costs of switching socio-technical pathways. Socio-technical development is path-dependent in the sense that early investment decisions limit the options at later stages. As Safarzyńska et al. (2012) argue, once a path is stable, or "locked-in", it becomes costlier and politically more challenging to abandon. Switching costs in terms of capital refurbishing, and institutional and behavioural change increase (Unruh & Carrillo-Hermosilla, 2006; Unruh, 2002). Evolutionary models in sustainability transitions literature suggest that policies designed to "un-lock" a system are likely to be most effective in the early take-off and acceleration phases of systems development (Safarzyńska et al., 2012).

Switching costs increase further with shorter time windows and the necessity for abrupt change. Literature on sustainability transi-

tions stresses the need for 'socio-technical experiments' in overcoming incumbent and relatively stable socio-technical regimes, such as electricity or transport systems (Berkhout, Angel, & Wieczorek, 2009). Urgency to act to prevent environmental catastrophes, however, leaves less time for experimenting with various options, and for starting small and incrementally scaling up successful solutions. Under time pressure, risky large investments into not yet mature solutions may be needed. To avoid higher costs in the future, Acemoglu et al. (2012), for example, emphasize the importance of taxing carbon early on and complementing this with targeted research policies.

For latecomer countries, switching costs may still be comparatively low, since their socio-technical systems are still in earlier stages than those of industrialised countries. Low levels of development correspond with low levels of fixed assets, such as power plants, transport infrastructure, and urban buildings. New technologies and knowledge increase the potential energy and material-efficiency of this type of assets year by year. This is not to be understood as an argument for delaying greening, on the contrary. Infrastructure investments as such are necessary and continuously take place, and it makes sense to invest in state of the art efficiency. Existing infrastructure locks in energy use and corresponding greenhouse gas emissions for many decades, since the life span of assets such as energy, housing, and transport infrastructure is typically 30–100 years. Ürge-Vorsatz (2012) show how global energy use for heating and cooling of urban buildings would increase or decrease in different scenarios, depending on whether state-of-the-art efficiency levels are mandated or not. As latecomer countries are still at an early stage of their infrastructure development, they can apply state-of-the-art technologies. This can give them a cost advantage vis-à-vis early industrialised countries that need to continuously refurbish their infrastructure at high cost. At the same time, as Ramos-Mejía, Franco-Garcia, and Jauregui-Becker (2018) argue, sustainability transitions studies applied to the contexts of latecomer countries can be an opportunity to connect environmental sustainability with the agendas of poverty reduction, local community development and capacity building.

[3] Reducing the risk of asset stranding. Given that global framework conditions are changing and related to the above risk of lock-in, we see the stranding of polluting assets as a main economic threat resulting from a so-called "grow first, clean up later" strategy. Driven by stringent environmental policies, the increasing competitiveness of green technologies, social movements such as the DivestInvest global investor movement (DivestInvest, 2019), as well as increasing environmental impacts, existing assets can experience a gradual or even complete devaluation (Bergman, 2018; Caldecott, 2017; Carbon Tracker Initiative, 2013; Piggot, 2018). This can concern natural resources such as fossil fuel reserves, capital assets such as power plants, but also human capital, for example expertise in the construction of internal combustion engines (Hubacek & Baiocchi, 2018; Kefford, Ballinger, Schmeda-Lopez, Greig, & Smart, 2018; Prinz & Pegels, 2018). Countries which have built their development strategies on the exploitation of fossil fuels are particularly prone to asset stranding. Bos and Gupta (2018) analyse five types of risk arising from investing in fossil fuel reserves. Ecological risks include, inter alia, climate change, water scarcity, and local pollution. Legal risks arise from potential environmental litigation against companies or nation states. Political risks include diplomatic pressure and potential sanctions on states that fail to adhere to environmental agreements. Social risks include, inter alia, health risks due to pollution or disasters and risks of stranding employment along with related assets. Economic risks include risks such as decommissioning costs, debt or a lack of investments in other areas, compensation requirements resulting from possible future environmental litigation, and losses due to destabilization resulting from political or social risks. To this list, Rentschler (2013) adds the volatility of oil price markets as a macroeconomic risk which can be hedged by investing in renewable energies. Mercure et al. (2018) estimate that the stranding of fossil fuel assets could amount to a discounted global wealth loss of 1 to 4 trillion USD, and that due to already ongoing changes in technological pathways, part of this asset stranding is independent from a stringent implementation of the Paris Agreement on climate change. Ansari and Holz (this Issue) show for the Middle East that adhering to fossil fuels as a basis for national wealth can indeed be an extremely risky strategy.

[4] Lowering environmental risk premiums in capital markets. Latecomer countries, many of which already suffer from difficult financing conditions, are most at risk of also suffering from global environmental change.[1] Since financial rating agencies factor any kind of country risk into their calculations, and lower ratings directly translate into higher interest rates, the expectation of increasing environmental impacts may affect developing countries' financing conditions disproportionately. The effects are twofold. First, the costs of sovereign lending and debt repayment increase, restricting the fiscal space for growth-enhancing public investment. Second, central banks pass the higher interest rates on to national banks, leading to credit rationing and higher capital costs for private enterprises, thus stifling the growth prospects further (Kling et al., this Issue).

It is in these countries' interest, therefore, to act on two fronts. First, they need to adopt whatever green polices they consider necessary to reduce their exposure to environmental risks. Second, considering that many environmental risks, especially those stemming from global warming, are beyond their national sphere of influence, it is in their interest to lobby for more stringent international regulations. This is what the Alliance of Small Island States (AOSIS), for example, has been practicing quite successfully in the international climate negotiations (Ourbak & Magnan, 2018).

[5] Inducing efficiency investments which immediately pay off. Public policies may encourage resource-saving investments which have a high return on investment. As Porter (1991) and Porter and van der Linde (1995) hypothesized, strict environmental regulations force companies to develop greener technologies, thereby inducing innovations that may offset or even exceed the costs of regulation compliance. The same logic applies if governments offer positive incentives instead of enforcing regulation. While critics argue that if such investments pay for themselves, firms and households would adopt them without governments applying 'carrots or sticks', evidence shows that this is often not the case. On the individual level, barriers rooted in human behaviour may be an issue, such as bounded rationality, a bias towards short-term gains or towards already owned assets (Fay et al., 2015; Figueroa, de Molière, Pegels, Never, & Kutzner, 2019; Gillingham, 2009). On the systems level, lock-in of inefficient infrastructure, as discussed above, may be a barrier.

When testing the Porter hypothesis, two levels of innovations can be distinguished (Lanoie et al., 2008; Ambec et al., 2013). The "weak" Porter hypothesis states that induced improvements at least recover the cost of compliance. The "strong" Porter hypothesis goes one step further. Here, it is argued that stringent regulations unleash technological learning which translates into substantive innovations that open up new patterns of competitive specialisation. It is assumed that if a country imposes regulations earlier than other countries, firms operating in this demanding environment will develop innovations that turn into an early

[1] The Germanwatch Global Climate Risk Index that ranks countries according to the socio-economic impacts of extreme weather events states that "less developed countries are generally more affected than industrialised countries" (Eckstein, Hutfils, & Winges, 2018: 1). Among the 10 countries most affected from 1998 to 2017, all but Puerto Rico were developing countries.

mover advantage when other countries impose similar environmental requirements at a later stage. The strong Porter hypothesis would then be reflected in growing market shares, export competitiveness, and increased patenting. We will explore the "weak" hypothesis first and then discuss the "strong" one under Section [6].

The "weak" Porter hypothesis has been widely confirmed for developed countries, using a variety of methodologies (Aghion, Dechezleprêtre, Hémous, Martin, & Van Reenen, 2016; Brunnermeier & Cohen, 2003; Calel & Dechezleprêtre, 2014; Jaffe & Palmer, 1997; Newell, Jaffe, & Stavins, 1999; Popp, 2002).[2] For latecomer economies, however, it is still largely unexplored. Amann et al. (this Issue), therefore, shed some light on the effects of environmental reforms on firm level efficiency by analyzing the impact of environmental tax reforms on competitiveness of Omani firms. Using a novel firm-level micro data set on manufacturing enterprises, the study shows that increases in fossil fuel energy factor prices lead to improvements in productivity as well as efficiency, and notable business upgrading.

More research is needed to test this hypothesis across latecomer countries and for a variety of environmental policies. We hypothesize that, compared to developed countries, such research is likely to find larger positive effects of environmental policy-induced innovations, because firms in latecomer countries tend to have large untapped productivity potentials.

[6] Triggering early mover advantages. The "strong" Porter hypothesis – environmental regulations inducing early mover advantages – has been contested. Recent meta-analyses of evidence seem to support it (Ambec et al., 2013; Cohen & Tubb, 2017). Controlling for GDP and economic complexity, Mealy and Teytelboym (2019) show that countries with more stringent environmental policies export a larger number and more sophisticated green products competitively. But there is also evidence of ambitious environmental policies having adverse effects on competitiveness of some pollution- and energy-intensive sectors, at least in the short run (Dechezleprêtre & Sato, 2017).

It should be noted that existing analyses are likely to underestimate the effects of more stringent environmental policies on competitiveness, firstly because of the time lag involved, and secondly because they may not be able to attribute dynamic spillover effects to the original policy intervention. Due to network and bandwagon effects, innovations tend to be cumulative and occur in path-dependent ways. Initial impulses for technological specialisation thus predetermine subsequent innovations while at the same time blocking alternative pathways (Nelson & Winter, 1982; Dosi, 1988). Initial decisions to promote renewable energy, for example, may not only encourage innovations in solar and wind energy technologies, but also induce subsequent innovations in energy storage, smart grids and a variety of specialised technical and financial services. Shifting the power sector towards renewable energies furthermore creates incentives to electrify the transport sector: for environmental reasons, since electricity based mobility only reduces emissions if the electricity comes from renewable sources, and for technical reasons, since fleets of electric cars may be used to smoothen supply peaks which are typical for renewables-based energy systems. Mealy and Teytelboym (2019, p. 4) confirm such spillovers, showing that "countries that currently export a significant number of green complex products are generally well placed to diversify into other green complex products in the future." Aghion et al. (2016) show that path dependence works both ways: Countries with early investments in "dirty" industries will tend to further innovate in dirty industries, whereas early movers in clean technologies will find more and more profitable new opportunities along the clean technological trajectory (see also Aghion, Hemous, & Veugelers, 2009).

This strategic bifurcation will become much more relevant if and when the necessity and costs of compliance with environmental regulations increase. In the past, these costs represented only a small fraction of total production costs; hence, the effects on competitiveness were quite limited (Roediger-Schluga, 2002). Considering that governments agreed to decarbonise the global economy over the next few decades, the need for carbon pricing is now widely accepted and increasingly applied around the world (World Bank, 2019). Other environmental policies, for example with respect to air pollution or plastics pollution, are becoming more and more stringent (Nielsen, Holmberg, & Stripple, 2019), so that the relative demand for greener goods and services can be expected to increase. Early mover advantages in these areas will then provide greater potential benefits.

It should further be noted that the literature on the Porter hypothesis so far mainly analyses OECD countries. Only a few recent publications address green innovation and competitiveness in emerging markets. Among those, China stands out with some extraordinary success cases.[3] Fu and Zhang (2011) as well as Altenburg (2016) both document a number of competitive new green industry developments in China and India. Fankhauser et al. (this Issue) perform a cross-country analysis to explore whether the economic activities with green innovation coincide with those where revealed comparative advantages exist. The analysis includes a range of emerging and non-OECD economies. It shows that China and Brazil, for example, tend to be particularly competitive in industries with green innovation, whereas Russia's and Turkey's advantages are concentrated in activities with little green innovation.

For latecomer countries in the range of low and lower middle income countries, we find very little evidence of environmental stringency inducing competitive advantages. At a first glance, this is unsurprising: These countries typically lack firms operating at the technological frontier as well as differentiated national innovation systems from which "new-to-the-world" innovations might emerge. Moreover, these countries may lag behind with regard to stringency, and especially enforcement of, environmental regulations. Yet, they may be able to develop early mover advantages relative to other countries with similar endowments. Countries and firms can supply "greener products as a vertical differentiation strategy" (Ambec et al., 2017: 39), that is, they can tap into markets which either require compliance with high standards or where consumers are willing to pay for superior environmental performance. Henson and Jaffee (2006) show that stricter environmental product standards imposed by importing countries can exclude many exporting firms and even entire countries from global food value chains. Those who are faster or more reliable in compliance may therefore increase their market shares.

[7] Opening up new employment opportunities. Estimating the employment effects of an early greening strategy is challenging. Firstly, we are interested in net effects, which means that gains in green jobs need to be compared to losses in "brown" industries. Both effects depend on a range of factors other than environmental policies. Secondly, most industries adopt greener practices incrementally, which makes it difficult to draw a clear boundary between "green" and "brown" jobs.

While this makes it impossible to make accurate statements at the aggregate level, some shifts towards greener practices have clearly discernible effects on employment. In the automobile

[2] These studies are mainly based on enterprise surveys from the US or Europe. Aghion et al. (2016) study patent filings of the global car industry with the US and European patent offices. These might cover a very small proportion of car manufacturers from other countries, mainly China.

[3] For example, Huang, Negro, Hekkert, and Bi (2016) for solar photovoltaics, Altenburg et al. (2019) for electric vehicles and lithium batteries and Nechifor et al. (2020) for scrap steel usage (the latter two in this Issue).

industry, for example, the shift from producing cars with an internal combustion engine to electric cars can reduce jobs (for example, around 75,000 in Germany's drive train industry), as electric cars require fewer parts and less assembly work (Fraunhofer IAO, 2019).

Yet there are at least four economic activities where "going green" can be expected to be more employment-intensive:

- Renewable energy systems. According to a thorough review of existing evidence for Europe, such systems create three times more employment per KWh than fossil fuels-based electricity (Blyth, 2014). Globally, 11 million people were employed in renewable energy generation in 2018, mostly in developing countries. Especially large direct employment effects were found in solar photovoltaics in China and India, and in biofuels production in Brazil and Colombia (IRENA, 2019).
- Energy efficiency, for example in buildings. As energy-efficient buildings require higher quality and additional insulation material, labour requirements are high compared to conventional buildings. In a meta-analysis of 13 studies on the net employment effects of energy-efficiency in buildings, Gouldson et al. find that across these studies "each investment of US$1 million generated an average of 14 job years of employment" (Gouldson, Sudmant, Khreis, & Papargyropoulou, 2018, p. 15).
- The switch to circular economy models. Reusing, repairing or recycling products from plastic, metal or paper, and composting organic waste can create considerable additional investments. GHK (2010) estimates the potential for additional jobs at 213,000 in Bangladesh, yet such estimates are obviously highly dependent on assumptions about underlying incentive systems. Some of these jobs are particularly suitable for low-skilled workers, such as material sorting and initial steps of processing (Daniels et al., this Issue).
- Organic agriculture is often more labour-intensive than conventional farming (see, for example, van der Vossen (2005) and Lygbaeck, Muschler, and Sinclair (2001) on organic coffee).

A word of caution is in order when interpreting this data. Positive employment gains in specific activities do not necessarily imply economy-wide employment gains. Furthermore, some of the employment is only short term, for example in renewable energy plant construction. As Blyth (2014: 3) put it, "long-term impacts will depend on how these investments ripple through the economy, and in particular the impact on disposable household incomes". Also, replacing existing business models with more labour-intensive ones is not per se desirable, as it tends to reduce labour-productivity. Nonetheless, the type of labour-intensive alternatives described above may be particularly attractive for latecomer economies where the marginal cost of labour tends to be low. Where tradable goods are concerned, like in organic food products, shifting to labour-intensive alternatives tends to strengthen latecomer economies' competitiveness relative to industrialised countries, as it reflects the former's factor cost endowment.

[8] Providing access to green funds and trade opportunities. International environmental agreements increasingly offer specific funds for latecomer countries. One such example is the Global Environment Facility, which was established in 1992 and provides finance to developing and transition countries to meet the objectives of international environmental agreements (GEF, 2019). Another example is the Green Climate Fund, which was established in 2010 as part of the financial mechanism of the United Nations Framework Convention on Climate Change (UNFCCC). It aims to mobilize USD 100 billion per year by 2020, with current pledges amounting to 10.4 billion (GCF, 2019). Developing countries can access these funds to realise early greening strategies.

Furthermore, bilateral and regional trade agreements increasingly include environmental provisions. This suggests that developing countries may be able to gain from early greening by being able to adapt to this trend. Brandi et al. (this Issue) find that current environmental provisions contribute to shifting the export profiles of developing countries from dirty to green, in particular for such countries that already have a relatively 'green' economy. Apart from this structural effect, however, they do not find considerable net effects on exports, neither for those provisions aiming to restrict trade in polluting goods or services, nor for those aiming to support green trade.

Furthermore, de Melo and Solleder (this Issue) show that it is important for developing countries to not just passively adapt to the trend of increasingly green trade, but also actively represent their interests in trade negotiations. Focusing on plurilateral negotiations on an Environmental Goods Agreement in the World Trade Organisation, they show that the list of environmental goods and services currently under negotiation mirrors the interests of industrialised rather than developing countries. Power asymmetries in the negotiations may force low income countries to open their markets for goods for which they have competitive disadvantages, and areas where they have competitive advantages may be left out, which would be detrimental for their producers. Having said that, the authors also point out that total welfare gains would be greatest for these countries. This seemingly counterintuitive finding results from the negative effects on producers being outweighed by positive effects on consumers, who would gain from a removal of currently relatively high trade barriers on environmental goods.

[9] Reducing dependence on resource imports and economic volatility. The opportunity of reducing volatility by greening the economy exists in all areas of resource imports, where investments in efficiency lead to decreased dependence. In addition to efficiency gains, countries that depend on fossil fuel imports can reduce dependence by diversifying their energy matrix towards locally available renewable energy sources. This enhances energy security, broadens the basis for economic growth through energy inputs, and reduces the exposure to volatile commodity markets and exchange rates (Rozenberg et al., 2010). Reducing the dependence on resource imports can be particularly beneficial for developing countries, since their trade matrices are, on average, less diversified, which makes them more vulnerable to international market fluctuations.

[10] Increasing fiscal space. It is part and parcel of an early greening strategy to correct environmental externalities, such as a missing price on emissions or overuse of resources, for example by Pigouvian taxation. This type of taxation increases macroeconomic efficiency since it includes formerly externalised costs to society into market prices. Carbon pricing, often implemented in the form of a tax on fossil fuels, would have to be part of such a strategy. Evidence suggests that fossil fuel energy taxation can have several advantages for developing countries, especially when compared to other taxes or carbon cap-and-trade schemes (Fay et al., 2015). Energy taxes provide a good tax base and raise revenues, typically with relatively easy monitoring of a few point sources, or at least an established network of measuring infrastructure, such as electricity or petrol meters. Energy taxes also reduce incentives for firms to remain in the informal sector, since formal and informal companies have to pay them alike when purchasing energy – in contrast to, for example, income or sales taxes, which only actors in the formal economy pay. The technical implementation of energy taxes is easier than that of cap-and-trade schemes, since most countries already have a tax system in place, whereas institutions for cap and trade would often need to be newly created. Having said that, energy prices tend to be a highly politicised issue, and increases can meet strong resistance from firms and consumers. To reduce opposition, the revenues from taxes on emis-

sions or on resource consumption can be channelled back to firms and consumers, thereby keeping the taxation revenue neutral. Revenues can also be used in favour of social expenditure or to lower wage costs, which further enhances competitive advantages.

Similar space can be created by reducing fossil fuel subsidies, which would be part of a comprehensive environmental fiscal reform. For latecomer countries, this approach is particularly promising. Coady, Parry, Sears, and Shang (2017: 7) estimate that post-tax fossil fuel subsidies in 2013 amounted to 13–18% of regional GDP in the Middle East, North Africa, and Pakistan region, the post-Soviet Commonwealth of Independent States, and Emerging and Developing Asia. These subsidies mostly benefit the richer segments of the population. Arze del Granado, Coady and Gillingham (2012) examine fossil fuel subsidies in 20 developing countries between 2005 and 2009 and find that the richest quintile of households benefits, on average, six times more than the poorest quintile. Removing those subsidies and investing the resources in pro-poor investments would, therefore, not just benefit the environment but also improve equality. As mentioned above, however, the removal of subsidies is often a highly politicised issue, and challenging to implement and maintain. As McCulloch, Moerenhout, and Yang (2020) show for Nigeria, fossil fuel subsidies can be deeply engrained in societal contracts, and reform attempts have led to mass protests in a number of developing countries (Hossain et al., 2018; Lockwood, 2015).

3. Opportunities stemming from a 'Grow first, clean up later' strategy

While our literature review reveals the above opportunities arising from early greening strategies, there are also counter-arguments which support a delayed green transformation. These are discussed below.

[1] Retaining employment and competitiveness in polluting industries. The most prominent argument for delaying greening is the short-term oriented protection of jobs and competitiveness in incumbent, polluting industries. The competitiveness concern particularly applies to internalizing the environmental costs of pollution, when the stringency of environmental regulations differs between competing countries, and products are easily tradable. In such cases, internalizing the environmental costs of pollution may either lead to downsizing of economic activities in polluting industries, or to their re-location to less regulated "pollution havens" (Eskeland & Harrison, 2003). Evidence suggests that downsizing may occur – polluting industries which face an increase in climate related regulation can experience a subsequent increase in net imports (Hille, 2018; Levinson & Taylor, 2008). While evidence for the stronger form of the "pollution haven hypothesis", that is, firm re-location, exists in the case of subnational regulation (Fell & Maniloff, 2018; Grether, Mathys, & de Melo, 2012; Wu, Guo, Zhang, & Bu, 2017), there is only weak evidence for re-location of firm activities between countries (Cherniwchan, Copeland, & Taylor, 2017; Cole & Elliot, 2003; Hille, 2018; Levinson, 2009). Assessments of firm decisions highlight other, more important reasons for location choices, such as firms' ICT endowment and marketing and internationalization strategies (Antonietti, De Marchi, & Di Maria, 2017; Greaney, Li, & Tu, 2017).

The "pollution haven" argument may only hold as long as the costs caused by environmental damage are not factored in. These costs can outweigh the gains of attracting polluting industries even in the short run, and accumulate in the long run. Furthermore, once the economic structure is geared towards these industries, a pathway change can be hard to attain. Lastly, international coordination on environmental protection, such as carbon pricing, is increasing, thus decreasing competitiveness risks for participating countries (World Bank Group, 2019).

Nonetheless, even if beneficial on the national level, a transformation towards a green economy is likely to lead to structural changes and subsequent losses for individual industries, parts of the work force, and subnational regions in most countries. These shifts need to be carefully managed, and strategies found to allow for a transition without social disruptions.

[2] Avoiding opportunity costs of expensive green investments. Developing countries typically suffer from a shortage of public funds and high needs of investment in welfare-enhancing areas such as health, education, and public infrastructure. When environmentally friendly technologies are more expensive than their polluting counterparts, or when environmental costs are internalised, early greening may divert funds and lead to opportunity costs. This argument can apply at the national, firm, and individual levels (e.g. human capital investment). It does, however, not always hold, since investments in greening can have co-benefits with other areas of public welfare, firm competitiveness, or individual wellbeing. Cleaner air, for example, is an investment in public health, investments in a company's resource efficiency usually have short amortization periods, and a switch from motorised transport to cycling improves personal health.

It may, nonetheless, be an opportunity of late greening to wait for the increased certainty about future technological pathways, and already materialized economies of scale. Technologies tend to be costly at early stages of their life-cycles, and their costs may come down significantly as processes improve and economies of scale take effect. Many technologies, when scaled up, experience an exponential drop in costs – similar to Moore's law for the case of electronics (Farmer & Lafond, 2016; Moore, 1965). Many of the new green technologies have not yet realized their full cost degression potential, and as the case of solar photovoltaics shows, this potential can be large ('Swanson's law': Swanson, 2006, Fraunhofer ISE, 2015). Second (or third) movers can save on investments early movers had to undertake, and benefit from economies of scale (Pegels & Lütkenhorst, 2014, p. 531). Furthermore, many green technologies still have a higher risk of failure than the more mature technologies. Economic latecomer countries may legitimately claim that early industrializers go ahead and absorb most of the risk and cost of developing green solutions as a way of paying their historical debt for past pollution. This strategy, however, brings about the risk of locking in polluting technologies, and making it more difficult to catch up with increasingly green global technological pathways. Furthermore, in many cases green technologies are already now cheaper than their polluting counterparts. This applies in particular to resource efficiency investments, and increasingly to renewable energies. In these cases, early greening does not restrict, but increases funds for welfare-enhancing investments.

[3] Waiting for the 'Environmental Kuznets Curve effect'. Literature on the environmental Kuznets curve hypothesizes that environmental problems augment at early stages of economic growth, but at higher per capita incomes, growing economies have the financial means and technological capabilities to tackle them effectively. A transformation towards lower environmental impacts would then be a by-product of economic development. On the one hand, as discussed above, it is explained by increasing availability of technologies and related capabilities, which allow countries to tackle pollution more effectively (Grossman & Krueger, 1991). On the other hand, it is explained by structural change from a (polluting) secondary to the (cleaner) tertiary sector in the course of development, leading to an automatic reduction of pollution intensity of the economy. A growing body of literature, however, is showing flaws in these arguments. First, even if pollution intensities decrease with the availability of more efficient technologies,

the total effect is not necessarily decreased total pollution. When the economy and incomes grow, higher resulting levels of consumption and changing patterns of use and behaviour can compensate for the reduction in pollution intensity. This is often referred to as the 'rebound effect' (Binswanger, 2001; Freire-González, 2017; Khazzoom, 1980; Sorrell, Dimitropoulos, & Sommerville, 2009). Second, new technologies may also lead to new environmental issues, such as pollution from the mining of rare earths required for photovoltaics production, groundwater pollution from hydraulic fracturing, or the additional natural resources needed for bioenergy production (Fuso Nerini et al., 2018; Padilla, 2017). Third, structural change from industry to services does not necessarily reduce environmental pressures, since services are not automatically cleaner than industry (Padilla, 2017). Most services require inputs from upstream industrial activities, and some, such as luxury tourism, have a particularly high resource intensity. In sum, the mixed evidence on the existence of an Environmental Kuznets Curve suggests that a green economy is not an automatic by-product of growth, but requires clear and bold environmental policies (Ekins, 1997).

4. Summing up: should latecomer economies go green early? Evidence and research gaps

Our review of arguments for "greening now" versus "cleaning up later" and the empirical evidence supporting these arguments suggest that in many cases, the reasons to "green now" prevail. Governments that start earlier than others to steer their countries towards a green transformation are likely to see benefits in terms of efficiency-induced competitiveness and in gaining a foothold in the markets of the future. In contrast, most of the arguments for delaying action involve high risks of permanent environmental damage and lock-in of polluting socio-technical pathways which are costly to change and can lead to considerable losses from asset stranding. Yet, the decision between "greening now" and "cleaning up later" is not dichotomous. Some arguments call for a careful timing and sequencing of green policy reforms. Country specific aspects need to be considered such as the endowment with "green" and "brown" resources, the level of technological sophistication and innovativeness of its firms and supporting institutions as well as political support for, and opposition against, green policies. Furthermore, green investments can be sequenced according to their cost-benefit ratios. While some pay off immediately, others require higher ex ante investments and have longer amortization periods, but in turn contribute to shifting the socio-technical pathway rather than just incrementally improving the efficiency of inherently unsustainable systems.

The balance which governments strike thus also depends on their time horizon. Many of the opportunities of delaying green actions will only be short term effects. This applies, for example, to the opportunity of maintaining or even gaining competitiveness in polluting industries, which lock in a pollution intensive economic structure and bring the risk of disconnecting with an increasingly green global economy. The longer the time horizon considered, the more do the 'green now' strategies usually pay off.

For latecomer countries, the pro and counter arguments of early adoption of green policy reforms differ from those in advanced industrial economies. Latecomers can reap some extra-gains from greening early. These include, among others, particularly high returns on resource efficiency investments in firms; new employment opportunities for example in recycling, decentralised energy generation and organic farming which may be especially attractive for labour-abundant economies; preferential access to international green funds; and lower environmental risk premiums in capital markets. Yet some of the potential advantages attributed to early greening are more easily reaped by technologically advanced countries, for example early mover advantages in green high-tech solutions that create innovation rents and increase market shares.

The above assessment of latecomer development strategies, and of ensuing opportunities is, of course, not exogenously given. Governments have a lot of leeway to select and design their national policies in ways that turn changing framework conditions into economic opportunities. Across the board, the contributions to this Special Issue show that the degree to which countries reap economic co-benefits from greening is very much in their own hands. Probst and Dechezleprêtre, Probst et al., and Lema et al. show how African governments have turned renewable energy policies into local economic development motors. Daniels et al. show the potential for low-skilled employment of increased recycling activities, which is a policy priority for the South African government. Barbier discusses the policies which need to accompany a greening strategy to effectively tackle the key structural features of natural resource use and poverty in agriculture-based developing country economies. Zeng et al. show how China makes use of eco-industrial parks to green its economy and increase competitiveness, Altenburg et al. show how it uses green industrial policies to create competitive advantages in electric mobility, and Nechifor et al. show the competitiveness potential of Chinese steel recycling. In all the discussed country cases, governments were plainly committed to greening and deliberately combined environmental policies with measures aimed at reaping the economic co-benefits.

In sum, there are strong indications that the green transformation of the global as well as national economies is accelerating. We are witnessing a self-reinforcing co-evolution of institutional and technological changes affecting the structure of industry, as described in Nelson's seminal paper (Nelson, 1994). Evidence of, and awareness about, environmental pressures are growing and permeating international and national policy frameworks. Technological change is increasingly being directed towards greener solutions, and policy incentives help to accelerate their diffusion and drive down their costs. New green technologies and business models gradually replace brown incumbents. This trend may still be too slow to avoid environmental catastrophes, especially when rebound effects are taken into account (Jackson, 2017), yet this will not stop the co-evolutionary trends towards what Perez (2016) has called a formidable green techno-economic paradigm change. As this happens, the pros and cons of greening early or sitting back need to be reassessed. Demand for research into the links between environmental incentives and economic development is therefore likely to increase. This Special issue is meant to become an analytical reference point for the growing body of empirical research on the economic co-benefits of the green transformation, helping to structure the debate, to widen its perspective and encourage further research on newly emerging aspects. Yet, it also shows that empirical evidence of the economic effects of green transformations is still scarce, especially for low- and lower middle income countries. More research is also needed to explore the wider societal effects of green transformations, including the distributional effects of the paradigm change, and solutions to manage the green transformation in a fair and equitable manner.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are grateful to the German Federal Ministry for Economic Cooperation and Development (BMZ) for funding this research,

and to two anonymous reviewers for providing very helpful comments. All remaining errors are entirely the authors'.

References

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The environment and directed technical change. *The American Economic Review, 102*, 131–166.

Aghion, P., Hemous, D., & Veugelers, R. (2009). No green growth without innovation. Bruegel Policy Brief 2009/07.

Aghion, P., Dechezleprêtre, A., Hémous, D., Martin, R., & Van Reenen, J. (2016). Carbon taxes, path dependency, and directed technical change: Evidence from the auto industry. *The Journal of Political Economy, 124*, 1–51. https://doi.org/10.1086/684581.

Altenburg, T. (Ed.). (2016). *Sustainability-oriented innovation systems in China and India*. Abingdon and New York: Routledge.

Altenburg, T., Corrocher, N., & Malerba, F. (2019). China's leapfrogging in electromobility. A story of green transformation driving competitive advantage. In T. Altenburg, A. Pegels, (Eds.), Latecomer development in a 'greening' world, 2020. World Development Special Issue.

Altenburg, T., & Rodrik, D. (2017). Green industrial policy: Accelerating structural change towards wealthy green economies. In T. Altenburg & C. Assmann (Eds.), *Green industrial policy: Concepts, policies, country experiences* (pp. 1–20). Geneva, Bonn: UN Environment, Deutsches Institut für Entwicklungspolitik.

Amann, J., Cantore, N., Cheng, C., Todorov, V., & Cali, M. (2019). Switching it up: The competitiveness effect of energy price reforms in Oman 2020. In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue.

Ambec, S., Cohen, M., Elgie, S., & Lanoie, P. (2013). The Porter hypothesis at 20: Can environmental regulation enhance innovation and competitiveness? *The Review of Environmental Economics and Policy, 7*, 2–22.

Ambec, S. (2017). Gaining competitive advantage with green industrial policy. In T. Altenburg & C. Assmann (Eds.), *Green industrial policy: Concepts, policies, country experiences* (pp. 38–49). Geneva, Bonn: UN Environment, Deutsches Institut für Entwicklungspolitik.

Ansari, D., & Holz, F. (2020). Between stranded assets and green transformation: Fossil-fuel-producing developing countries towards 2055. In T. Altenburg, A. Pegels, (Eds.), Latecomer development in a 'greening' world (First published in Vol. 130, pp. 104947). World Development Special Issue.

Antonietti, R., De Marchi, V., & Di Maria, E. (2017). Governing offshoring in a stringent environmental policy setting: Evidence from Italian manufacturing firms. *Journal of Cleaner Production, 155*, 103–113. https://doi.org/10.1016/j.jclepro.2016.11.106.

Arrow, K. J. (1971). The economic implications of learning by doing. In F. H. Hahn (Ed.), *Readings in the theory of growth*. London: Palgrave Macmillan.

Arze del Granado, J. F., Coady, D., & Gilligham, R. (2012). The unequal benefits of fuel subsidies: A review of evidence for developing countries. *World Development*, 2234–2248.

Barbier, E. (2020). Is Green Rural Transformation Possible in Developing Countries? In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue. First published in Volume 131, 104955.

Bergman, N. (2018). Impacts of the fossil fuel divestment movement: Effects on finance, policy and public discourse. *Sustainability*, 10.

Berkhout, F., Angel, D., & Wieczorek, A. J. (2009). Sustainability transitions in developing Asia: Are alternative development pathways likely? *Technological Forecasting and Social Change, 76*(2), 215.

Binswanger, M. (2001). Technological progress and sustainable development: What about the rebound effect? *Ecological Economics, 36*(1), 119–132.

Blyth, W. et al. (2014). *Low carbon jobs: The evidence for net job creation from policy support for energy efficiency and renewable energy*. London: UK Energy Research Centre.

Brandi, C., Schwab, J., Berger, A., & Morin, J. (2020). Do environmental provisions in trade agreements make exports from developing countries greener? In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue. First published in Volume 129, 104899.

Bos, K., & Gupta, J. (2018). Climate change: The risks of stranded fossil fuel assets and resources to the developing world. *Third World Quarterly, 39*(3), 436–453.

Brunnermeier, S. B., & Cohen, M. A. (2003). Determinants of environmental innovation in US manufacturing industries. *The Journal of Environmental Economics and Management, 45*, 278–293. https://doi.org/10.1016/S0095-0696(02)00058-X.

Cai, Y., Judd, K. L., Lenton, T. M., Lontzek, T. S., & Narita, D. (2015). Environmental tipping points significantly affect the cost – benefit assessment of climate policies. *Proceedings of the National Academy of Sciences, 112*(15), 4606–4611.

Cai, Y., Judd, K. L., & Lontzek, T. S. (2013). *The social cost of stochastic and irreversible climate change (No. w18704)*. National Bureau of Economic Research.

Caldecott, B. (2017). Introduction to special issue: Stranded assets and the environment. *Journal of Sustainable Finance & Investment, 7*(1), 1–13.

Calel, R., & Dechezleprêtre, A. (2014). Environmental policy and directed technological change: Evidence from the European carbon market. *Review of Economics and Statistics, 98*, 173–191. https://doi.org/10.1162/REST_a_00470.

Carbon Tracker Initiative (2013). *Unburnable carbon 2013: Wasted capital and stranded assets*. LSE, London: Carbon Tracker, The Grantham Research Institute.

Cherniwchan, J., Copeland, B., & Taylor, M. S. (2017). Trade and the environment: New methods, measurement and results. *Annual Review of Economics, 9*, 59–85.

Coady, D., Parry, I., Sears, L., & Shang, B. (2017). How Large Are Global Fossil Fuel Subsidies? *World Development, 91*, 11–27.

Cohen, M. A., & Tubb, A. (2017). The impact of environmental regulation on firm and country competitiveness: A meta-analysis of the porter hypothesis. *Journal of the Association of Environmental and Resource Economists, 5*, 371–399.

Cole, M., & Elliot, R. (2003). Determining the trade-environment composition effect: The role of capital, labor and environmental regulations. *The Journal of Environmental Economics and Management, 46*(3), 363–383.

Council of Economic Advisors (2014). The cost of delaying action to stem climate change. Available online: https://obamawhitehouse.archives.gov/sites/default/files/docs/the_cost_of_delaying_action_to_stem_climate_change.pdf.

Daniels, R., Hartley, F., & Caetano, T. (2019). Can waste management policies stimulate the economy? The South African case. In T. Altenburg, A. Pegels, (Eds.), 2020. Latecomer development in a 'greening' world. World Development Special Issue.

Dechezleprêtre, A., & Sato, M. (2017). The impacts of environmental regulations on competitiveness. *The Review of Environmental Economics and Policy, 11*, 183–206.

Dechezleprêtre, A., Glachant, M., & Ménière, Y. (2008). The Clean Development Mechanism and the international diffusion of technologies: An empirical study. *Energy Policy, 36*(4), 1273–1283.

de Melo, J., & Solleder, J. (2020). Barriers to trade in environmental goods: How important they are and what should developing countries expect from their removal. In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue. First published in Volume 130, 104910.

DivestInvest. (2019). Why DivestInvest? Available online: https://www.divestinvest.org/why-divestinvest/.

Dosi, G. (1982). Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. *Research Policy, 11*(3), 147–162.

Dubash, N., Raghunandan, D., Sant, G., & Sreenivas, A. (2013). Indian climate change policy: Exploring a co-benefits based approach. *Economic and Political Weekly, 48*(22), 47–61.

Eckstein, D., Hutfils, M., & Winges, M. (2018). Global climate risk index 2019: Who suffers most from extreme weather events? Weather-related loss events in 2017 and 1998 to 2017. Available online: https://www.germanwatch.org/sites/germanwatch.org/files/Global%20Climate%20Risk%20Index%202019_2.pdf.

Ekins, P. (1997). The Kuznets curve for the environment and economic growth: Examining the evidence. *Environment and Planning A: Economy and Space, 29*, 805–830. https://doi.org/10.1068/a290805.

Eskeland, G., & Harrison, A. E. (2003). Moving to greener pastures? Multinationals and the pollution haven hypothesis. *Journal of Development Economics, 70*(1), 1–23.

Fankhauser, S., Kotsch, R., & Srivastav, S. (2019). The prospects for low-carbon growth in emerging markets. In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue. 2020.

Farmer, J., & Lafond, F. (2016). How predictable is technological progress? *Research Policy, 45*(3), 647–665.

Fay, M., Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Narloch, U., & Kerr, T. (2015). *Decarbonizing development*. Washington, DC: World Bank.

Figueroa, A., de Molière, L., Pegels, A., Never, B., & Kutzner, F. (2019). Show me (more than) the money! Assessing the social and psychological dimensions to energy efficient lighting in Kenya. *Energy Research & Social Science, 47*, 224–232.

Fell, H., & Maniloff, P. (2018). Leakage in regional environmental policy: The case of the regional greenhouse gas initiative. *The Journal of Environmental Economics and Management, 87*, 1–23.

Fraunhofer IAO (2019). Wirkungen der Fahrzeugelektrifizierung auf die Beschäftigung am Standort Deutschland (ELAB). *Stuttgart* https://www.iao.fraunhofer.de/lang-en/press-and-media/latest-news/1388-mapping-out-the-future-for-the-automotive-industry.html.

Fraunhofer ISE, 2015. Current and future cost of photovoltaics. Long-term scenarios for market development, system prices and LCOE of utility-scale PV systems. Study on behalf of Agora Energiewende.

Freire-González, J. (2017). Evidence of direct and indirect rebound effect in households in EU-27 countries. *Energy Policy, 102*, 270–276.

Fu, X., & Zhang, J. (2011). Technology transfer, indigenous innovation and leapfrogging in green technology: The solar-PV industry in China and India. *Journal of Chinese Economic and Business Studies, 9*(4), 329–347.

Fuso Nerini, F., Tomei, J., To, L. S., Bisaga, I., Parikh, P., Black, M., et al. (2018). Mapping synergies and trade-offs between energy and the Sustainable Development Goals. *Nature Energy, 3*, 10–15.

Gerschenkron, A. (1962). Economic backwardness in historical perspective. In B. F. Hoselitz (Ed.), *The progress of underdeveloped areas*. University of Chicago Press.

GHK (2010). Estimating green jobs in Bangladesh. A report prepared by GHK for the International Labour Organisation, London.

Gillingham, K. et al. (2009). Energy efficiency economics and policy. *Annual Review of Resource Economics, 1*, 597–619.

.

Gouldson, A., Sudmant, A., Khreis, H., & Papargyropoulou, E. (2018). The economic and social benefits of low-carbon cities: A systematic review of the evidence. Coalition for urban transitions. London and Washington, DC.: http://newclimateeconomy.net/content/cities-working-papers.

Greaney, T. M., Li, Y., & Tu, D. (2017). Pollution control and foreign firms' exit behavior in China. *Trade, Growth and Economic Inequality in the Asia-Pacific Region, 48*, 148–159.

Green Climate Fund (GCF). (2019). Green Climate Fund. Who we are. Available online: https://www.greenclimate.fund/who-we-are/about-the-fund.

Grether, J. M., Mathys, N., & de Melo, J. (2012). Unravelling the world-wide pollution haven effect. *Journal of International Trade and Development, 21*(1), 131–162.

Grossman, G., & Krueger, A. (1991). *Environmental impacts of a North American free trade agreement* Working Paper: Vol. 3914. Cambridge, MA: National Bureau of Economic Research.

Guo, J.-X., & Fan, Y. (2017). Optimal abatement technology adoption based upon learning-by-doing with spillover effect. *Journal of Cleaner Production, 143*, 539–548.

Henson, S., & Jaffee, S. (2006). Food safety standards and trade: Enhancing competitiveness and avoiding exclusion of developing countries. *European Journal of Development Research, 18*(4).

Hille, E. (2018). Pollution havens: International empirical evidence using a shadow price measure of climate policy stringency. *Empir. Econ., 54*, 1137–1171.

Hossain, N., Aremu, F., Buschmann, A., Chaimite, E., Gukurume, S., Javed, U., et al. (2018). *Energy protests in fragile settings: The unruly politics of provisions in Egypt, Myanmar, Mozambique, Nigeria, Pakistan, and Zimbabwe, 2007–2017* IDS Working Paper 513. Brighton: IDS.

Huang, P., Negro, S. O., Hekkert, M. P., & Bi, K. (2016). How China became a leader in solar PV: An innovation system analysis. *Renewable and Sustainable Energy Reviews, 64*, 777–789.

Hubacek, K., & Baiocchi, G. (2018). Fossil fuel assets may turn toxic. *Joule, 2*, 1407–1409.

ICA, IUCN, & IWA. (2015). Nexus trade-offs and strategies for addressing the water, agriculture and energy security nexus in Africa. Geneva–December 2015.

ITUC (2015). Climate justice: There are no jobs on a dead planet. *Frontlines Briefing*. March. www.ituc-csi.org/ituc-frontlines-briefing-climate.

IPCC. (2014). Summary for policymakers. In Climate change 2014: mitigation of climate change. Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change, Cambridge, UK and New York, NY, USA.

IRENA (2019). *Renewable energy and jobs. Annual review 2019*. Masdar City: International Renewable Energy Agency (IRENA).

Jackson, T. (2017). *Prosperity without growth – Foundations for the economy of tomorrow*. London: Routledge.

Jaffe, A. B., & Palmer, K. (1997). Environmental regulation and innovation: A panel data study. *Review of Economics and Statistics, 79*, 610–619. https://doi.org/10.1162/003465397557196.

Keller, K., Bolker, B. M., & Bradford, D. F. (2004). Uncertain climate thresholds and optimal economic growth. *Journal of Environmental Economics and Management, 48*(1), 723–741.

Kefford, B. M., Ballinger, B., Schmeda-Lopez, D. R., Greig, C., & Smart, S. (2018). The early retirement challenge for fossil fuel power plants in deep decarbonisation scenarios. *Energy Policy, 119*, 294–306.

Khazzoom, J. (1980). Economic implications of mandated efficiency in standards for household appliances. *Energy Journal, 1*(4), 21–40.

Kling, G., Volz, U., Murinde, V., & Ayas, S. (2019). The impact of climate vulnerability on firms' cost of capital and access to finance. In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue. 2020.

Lanoie, T., Patry, M., & Lajeunesse, R. (2008). Environmental regulation and productivity: Testing the porter hypothesis. *Journal of Productivity Analysis, 30* (2), 121–128.

Lema, R., Bhamidipati, L., Gregersen, C., Hansen, U. E., & Kirchherr, J. (2019). Creating co-benefits or just cashing-in? China's investments in renewable energy in Africa. In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue. 2020.

Levinson, A. (2009). Technology, international trade, and pollution from U.S. manufacturing. *The American Economic Review, 99*(5), 2177–2192.

Levinson, A., & Taylor, M.S. (2008). Unmasking the pollution haven effect. International Economic Review, Department of Economics, University of Pennsylvania and Osaka University Institute of Social and Economic Research Association, 49(1), 223–254.

Lewis, J. I. (2014). Industrial policy, politics and competition in the wind power industry. *Business and Politics, 16*(4), 511–547.

Lin, J. Y. (2016). The latecomer advantages and disadvantages. A new structural economics perspective. In M. Andersson & T. Axelsson (Eds.), *Diverse development paths and structural transformation in the escape from poverty*. Oxford: Oxford University Press.

Lockwood, M. (2015). Fossil fuel subsidy reform, rent management and political fragmentation in developing countries. *New Political Economy, 20*(4), 475–494.

Lygbaeck, A., Muschler, R., & Sinclair, F. (2001). Productivity and profitability of multistrata organic versus conventional coffee farms in Costa Rica. *Agroforestry Systems, 53*, 205–213.

Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M., & Waterfield, T. (Eds.). (2019). *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. . Available online: https://www.ipcc.ch/sr15/.

Mathews, J. A. (2006). Catch-up strategies and the latecomer effect in industrial development. *New Political Economy, 11*(3), 313–335.

Matthews, H. D., & Solomon, S. (2013). Irreversible does not mean unavoidable. *Science, 340*(6131), 438–439.

McCulloch, N., Moerenhout, T., & Yang, J. (2020). *Fuel subsidy reform and the social contract in Nigeria: A micro-economic analysis* ICTD Working Paper 104. Brighton: IDS.

McNeill, J. R. (2014). *The great acceleration: An environmental history of the anthropocene since 1945*. Cambridge: Harvard University Press.

Mealy, P., & Teytelboym, A. (2019). *Economic complexity and the green Economy*. Oxford: INET. Oxford Working Paper No. 2018-03.

Mercure, J. F., Pollitt, H., Viñuales, J. E., Edwards, N. R., Holden, P. B., Chewpreecha, U., et al. (2018). Macroeconomic impact of stranded fossil fuel assets. *Nature Climate Change, 8*(7), 588–593.

Moore, G. (1965). Cramming more components onto integrated circuits. *Electronics, 38*(8), 114–117.

Nechifor, V., Calzadilla, A., Bleischwitz, R., Winning, M., Tian, X., & Usubiaga, A. (2020). Steel in a circular economy: Global implications of a green shift in China. In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue. First published in Volume 127, 104775.

Nelson, R. R., & Winter, S. G. (1982). *An Evolutionary Theory of Economic Change*. Cambridge: Belknap Press/Harvard University Press.

Nelson, R. R. (1994). The co-evolution of technology, industrial structure, and supporting institutions. *Industrial and Corporate Change, 3*(1), 47–63.

Newell, R., Jaffe, A., & Stavins, R. (1999). The induced innovation hypothesis and energy-saving technological change. *The Quarterly Journal of Economics, 114*, 941–975.

Nielsen, T., Holmberg, K., & Stripple, J. (2019). Need a bag? A review of public policies on plastic carrier bags – Where, how and to what effect? *Waste Management, 87*, 428–440.

O'Connor, D. (1996). *Grow now/clean later, or pursuit of sustainable development?* OECD Technical Paper N° 111. Paris: OECD.

OECD (2016). *The economic consequences of outdoor air pollution*. Paris: OECD. Available online: https://www.oecd.org/environment/the-economic-consequences-of-outdoor-air-pollution-9789264257474-en.htm.

Ourbak, T., & Magnan, A. K. (2018). The Paris Agreement and climate change negotiations: Small Islands, big players. *Regional Environmental Change, 18*(8), 2201–2207.

Padilla, E. (2017). What can developing countries gain from a green transformation? In T. Altenburg & C. Assmann (Eds.), *Green industrial policy: Concepts, policies, country experiences* (pp. 22–37). Geneva, Bonn: UN Environment, Deutsches Institut für Entwicklungspolitik.

Pegels, A. (Ed.). (2014). *Green industrial policy in emerging countries, Routledge studies in ecological economics*. London: Routledge.

Pegels, A., & Lütkenhorst, W. (2014). Is Germany's energy transition a case of successful green industrial policy? Contrasting wind and solar PV. *Energy Policy, 74*, 522–534. https://doi.org/10.1016/j.enpol.2014.06.031.

Pegels, A., Vidican-Auktor, G., Lütkenhorst, W., & Altenburg, T. (2017). Politics of green energy policy. *Journal of Environment & Development, 27*(1), 26–45.

Perez, C. (2016). Capitalism, technology and a green global golden age: The role of history in helping to shape the future. *The Political Quarterly, 86*, 191–217.

Piggot, G. (2018). The influence of social movements on policies that constrain fossil fuel supply. *Climate Policy, 18*, 942–954. https://doi.org/10.1080/14693062.2017.1394255.

Popp, D. (2002). Induced innovation and energy prices. *The American Economic Review, 92*, 160–180.

Popp, D. (2011). International technology transfer, climate change, and the clean development mechanism. *Review of Environmental Economics and Policy, 5*(1), 131–152.

Porter, M. E. (1991). America's green strategy. *Scientific American*, 264.

Porter, M. E., & van der Linde, C. (1995). Green and competitive: Ending the stalemate. *Harvard Business Review, 73*, 120–134.

Prinz, L., & Pegels, A. (2018). The role of labour power in sustainability transitions: Insights from comparative political economy on Germany's electricity transition. *Energy Infrastructure and the Fate of the Nation, 41*, 210–219. https://doi.org/10.1016/j.erss.2018.04.010.

Probst, B., & Dechezleprêtre, A. (2019). Renewable energy policy, local content requirements and technology transfer: Evidence from South Africa. In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue. 2020.

Probst, B., Westermann, L., Anadon, L., & Kontoleon, A. (2019). Leveraging private investment to expand renewable power generation: Evidence on financial additionality and productivity gains from Uganda. In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue. 2020.

Ramos-Mejía, M., Franco-Garcia, M. L., & Jauregui-Becker, J. M. (2018). Sustainability transitions in the developing world: Challenges of socio-technical transformations unfolding in contexts of poverty. *Environmental Science & Policy, 84*, 217–223.

Rentschler, J. E. (2013). Oil price volatility, economic growth and the hedging role of renewable energy. *The World Bank Online*.

Rigaud, K. K. et al. (2018). *Groundswell: Preparing for internal climate migration*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/29461.

Roediger-Schluga, T. (2002). The stringency of environmental regulation and the 'Porter Hypothesis'. In L. Marsiliani, M. Rauscher, & C. Withagen (Eds.), *Environmental economics and the international economy. Economy & environment*. Dordrecht: Springer.

Rozenberg, J., Hallegatte, S., Vogt-Schilb, A., Sassi, O., Guivarch, C., Waisman, H., et al. (2010). Climate policies as a hedge against the uncertainty on future oil supply. *Climate Change Letters, 101*(3), 663–669.
Safarzyńska, K., Frenken, K., & Van Den Bergh, J. C. (2012). Evolutionary theorizing and modeling of sustainability transitions. *Research Policy, 41*(6), 1011–1024.
Schmitz, H. (2017). Who drives climate-relevant policies in the rising powers? *New Political Economy, 22*(5), 521–540.
Siddiqi, A., Haraguchi, M., & Narayanamurti, V. (2019). Urban waste to energy recovery assessment using stochastic simulations for new systems in developing countries. In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue. 2020.
Solangi, K. H. et al. (2011). A review on global solar energy policy. *Renewable and Sustainable Energy Reviews, 15*(4), 2140–2163.
Sorrell, S., Dimitropoulos, J., & Sommerville, M. (2009). Empirical estimates of the direct rebound effect: A review. *Energy Policy, 37*(4), 1356–1371.
Steffen, W., Crutzen, P. J., & McNeill, J. R. (2007). The anthropocene: Are humans now overwhelming the great forces of nature. *AMBIO A Journal of the Human Environment, 36*, 614–621. https://doi.org/10.1579/0044-7447(2007)36[614:TAAHNO]2.0.CO;2.
Stern, N. (2007). *The economics of climate change: The Stern review*. Cambridge: Cambridge University Press.
Swanson, R. (2006). A vision for crystalline silicon photovoltaics. *Progress in Photovoltaics, 14*(5), 443–453.
UNEP (2011). *Towards a green economy: Pathways to sustainable development and poverty eradication. Sustainable development*. UNEP/GRID-Arendal.
UNEP. (2019). Global environment outlook 6, Geneva.
UNIDO, & GGGI. (2015). Global green growth: Clean energy industry investments and expanding job opportunities. Volume I: Overall Findings. Vienna and Seoul.
Unruh, G. C. (2002). Escaping carbon lock-in. *Energy Policy, 30*, 317–325. https://doi.org/10.1016/S0301-4215(01)00098-2.
Unruh, G. C., & Carrillo-Hermosilla, J. (2006). Globalizing carbon lock-in. *Energy Policy, 34*, 1185–1197. https://doi.org/10.1016/j.enpol.2004.10.013.
Ürge-Vorsatz, D. et al. (2012). Chapter 10 – Energy end-use: Building global energy assessment – Toward a sustainable future. Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria: Cambridge University Press, 649–760.
van der Vossen, H. (2005). A critical analysis of the agronomic and economic sustainability of organic coffee production. *Experimental Agriculture, 41*, 449–473.
Watts, N., Amann, M., Ayeb-Karlsson, S., et al. (2018). The Lancet Countdown on health and climate change: From 25 years of inaction to a global transformation for public health. *Lancet, 391*, 581–630.
World Bank Group (2019). *State and trends of carbon pricing 2019*. Washington, DC: World Bank. Available online: https://openknowledge.worldbank.org/handle/10986/31755. License: CC BY 3.0 IGO.
Wu, H., Guo, H., Zhang, B., & Bu, M. (2017). Westward movement of new polluting firms in China: Pollution reduction mandates and location choice. *Institute for Social and Economic Change, 45*, 119–138. https://doi.org/10.1016/j.jce.2016.01.001.
Zeng, D. Z., Shi, L., & Lütkenhorst, W. (2019). China's green transformation through eco-industrial parks. In T. Altenburg & A. Pegels (Eds.), *Latecomer development in a 'greening' world*. World Development Special Issue. 2020.