Three dimensions of Green Industrial Policy in the context of climate change and sustainable development

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Abstract

Climate change has taken an increasingly important space in the development agenda. However, whether most countries can meet the challenge of mitigating climate change while simultaneously ensuring growth and poverty reduction remains debatable. This research contributes to the growing literature at the intersection of environment sustainability and economic/industrial development by identifying three dimensions of Green Industrial Policy (GIP), which rely on different approaches to mitigate climate change. Those three dimensions are: (i) the consumption-centred dimension; (ii) the firm-level sustainability dimension, (iii) the productionist innovation-driven dimension. This paper then applies this green industrial policy framework and examines the implications of pursuing different levels of GIP by drawing on a country case study (Ecuador). Two main findings arise from this study. Firstly, a greener consumption is necessary but can hardly be achieved without industrial policies to stimulate green manufacturing and low carbon innovation. Green industrial policy therefore has a central role to play in the structural transformation towards a low carbon future. Secondly, a holistic and complementary approach is needed across the three dimensions of green industrial policy to ensure a coherent and developmental transition towards a low carbon economy.

Acknowledgements

The authors would like to thank Ha-Joon Chang, Kathy Hochstetler, Roger Fouquet, James Putzel, Florian Schaeffler, Ben Radley, David Leal, Carlos López-Gómez, Michele Palladino, Andres Mejía-Acosta, Teddy Brett, Jostein Hauge, and Jennifer Castaneda-Navarrete for their helpful comments on earlier drafts of this paper. We also thank the participants of the EAEPE annual conference and the UNCTAD 2019 workshop on the global green new deal, for insightful discussions and comments. Special thanks also go to David Delgado for his valuable support during fieldwork in Ecuador, and to David Forgacs from Saule Technologies. We are also grateful to all public officials, business executives, civil society members and scholars for sharing their insights and time during fieldwork interviews. Any remaining errors are our sole responsibility.

Both authors contributed to the conceptual part of the paper. AL was granted the funding and was responsible for the Ecuador case study. GA was responsible for the Saule Technology case study.

This research has been partly supported by a research award from the Mohammed Bin Rashid Initiative for Global Prosperity and the Institute for Manufacturing (University of Cambridge).

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1. INTRODUCTION

Climate change and environmental sustainability have taken an increasingly important space in academic and policy debates. However, whether most countries can reduce their CO_2 emissions while simultaneously ensuring growth and poverty reduction remains a challenging question.[1] In particular, the extent to which developing countries will benefit from energy transition has been seriously overlooked. This research aims to answer some of these pressing concerns by investigating the interplay between green consumption and green production, and addressing the role of industrial policy in maximizing the developmental spillovers from energy transitions, thereby bringing a productionist developmental approach (see Chang and Andreoni, 2017; Haraguchi et al., 2017) into the climate change and sustainable development agenda.

While the general discourse has focused on the urgency to shift consumption towards "greener" products and cleaner energy sources, we observe that a surprisingly scant attention has been given to what shifting to greener consumption would entail in terms of the transformation of productive structures. The challenge of climate change mitigation goes beyond "consuming less", as it also involves producing *differently* to sustain low carbon consumption patterns. Green industrial policy is of central importance in that perspective. In an attempt to build on the scholarly work that recognizes the importance of green industrial policy in the context of climate change (e.g. Aiginger 2015; Dietsche, 2018; Hallegatte et al. 2013; Lütkenhorst et al. 2014; Naudé, 2011; Rodrik 2014), and that investigates the synergies between environmental sustainability and economic development (e.g. Porter and van der Lynde, 1995; Pollin 2015, Garret-Peltier 2017; Cantore and Cheng, 2018; Fouquet, 2019), this paper identifies three main approaches to address climate change: (i) the consumption-centred approach; (ii) the firm-level sustainability approach; (iii) productionist innovation-driven agenda. We argue that these three dimensions are essential and highly interconnected in the process towards a more sustainable social and economic model. In building our framework, we critically categorize and review the main policy tools that have been put forward to date, such as regulations and market-based mechanisms, as well as assess their strengths and limitations.

This paper is structured as follows. Section 2 presents some of the key trends in existing academic and policy debates around climate change and highlights the dynamics of employment creation, innovation and technological developments that underpin the transition towards a low-carbon economic model. Section 3 presents our main contribution to this debate: a matrix representing the three dimensions of Green Industrial Policy. Section 4 presents the country-case study of Ecuador, in which we apply our green industrial policy framework in order to explain why and how the country's energy transition has not been accompanied by an industrial transformation. Section 5 puts forward the key findings and policy implications of our study.

[1] In order to achieve the international target of avoiding a more than 2C increase in global temperature, the world must achieve zero net emissions (IPCC 2015).

2. THEORETICAL AND POLICY CONTEXT FOR GREEN GROWTH

2.1 Debates on climate change and the development agenda

This section reviews some of the popular arguments that arise from the policy and academic debates surrounding climate change.

Climate change is a global problem, and its mitigation consequently faces several issues, such as a collective action problem. Individuals and nations may find it attractive to free ride and benefit from the action of others, because the protection of the environment also provides globally available benefits unconstrained by national boundaries (Stiglitz, 2015; Grasso, 2004).[2] As a result, a fundamental and unresolved issue relates to the imbalances across countries and sectors in terms of responsibilities for climate change. Some populations suffer more from the consequences of climate change than others, while the adjustments that have to be made to avoid climate change are greater for some than others (Stiglitz, 2015). There is consequently a problem of distribution of cost, benefits, and responsibilities for the climate emergency. Who should pay the price to lower greenhouse gas (GHG) emissions? The developed countries that have polluted throughout the past? The developing countries that are likely to pollute more as they are going through early stages of industrialization and development? Despite the fact that late industrialisers have been increasingly responsible for a large share of global CO_2 emissions, Naude (2011) shows that even large emerging economies like China and India emit relatively little in per capita terms and that "most of the current industrially-generated stock of carbon in the atmosphere has been caused by advanced economies, where most of the technological capability, know-how, human skills and financial resources reside to mitigate climate change and adapt to its impacts" (Naude, 2011).

As a result, some scholars have argued that it is advanced countries that should pay for the costs associated with the mitigation of climate change. Others have further argued that developing countries should be able to keep growing, and that advanced economies should start to de-grow to ensure environmental sustainability (Hickel, 2020; Steinberger and Hofferberth, 2019). The underlying assumption behind the degrowth argument is that carbon emissions are the intrinsic outcome of economic growth, and that the only solution to reduce emissions is for some countries to halt their growth. This trend of argument has often been used to support the increasingly popular de-growth narrative, which portrays economic growth and environmental sustainability as incompatible (Alexander, 2012; Latouche, 2010).

Hickel and Kallis (2019) further argue that decoupling of GDP growth and carbon emission has not been possible. In a similar perspective, according to the Kaya Identity, GHG emissions arise from human activity through increases in income, energy intensity and population growth. Within this framework, industrialization contributes towards GHG emissions through (i) contributing to general GDP growth; (ii) having a dramatic overall impact on energy demand and use; and (iii) using carbon-intense

[2] In other words, "global warming is the quintessential global pure public good because each country's release of GHGs augments the world's atmospheric stock in an additive fashion and each country's cutback results in a greater cost than benefit for that country unless assurances can be given that a sufficient number of action will act" (Sandler, 1998:225).

production methods. [3]

$$GHG\ emissions = population \times \left\{\left(\frac{GDP}{population}\right) \times \left(\frac{Energy\ Use}{GDP}\right) \times \left(\frac{GHG\ emissions}{Energy\ Use}\right)\right\}$$

Kaya Identity

In line with this narrative, it has been argued that progress in industrial energy efficiency and CO_2 intensity have been more than offset by growing industrial production (IEA, 2009). [4] [5] Nevertheless, the Kaya identity overlooks the opportunity cost of producing green technology. While emphasizing the conflict between economic growth and environmental sustainability, the de-growth argument ignores the potential that new technologies have in drastically reducing the material and energy content of consumption patterns and production methods (Perez, 2016). For example, while the production process of solar cells emits CO_2, the emissions from coal energy production that would be substituted by solar energy production should also be subtracted in order to assess the net impact of solar cells production in terms of long-term CO_2 emissions. Similarly, the production of electric car batteries should not be equated with the production of petrol engines as the two industrial activities may have very different long-term impact on the environment.[6] The Kaya identity therefore fails to consider that not all types of industrialisation are equal in terms of effect on global CO_2 emissions. Beyond the narrow focus on manufacturing processes, we should therefore consider the entire lifecycle of GHG emissions of different technologies, from production, distribution, as well as the consumption of the finished good.

Economic development and climate change mitigation have often been viewed as separate end goals in global development policy circles, including in the sustainable development goals (SDGs). For instance, while SDG7 and SDG13 are mostly concerned with climate change adaptation and access to clean energy, they make no mention of clean energy production and green technology-upgrading. Meanwhile, SDG9 focuses on industry, innovation and infrastructure but makes no mention of the need for transition towards a low carbon economy. As a result, the SDGs fail to put forward the potential synergies and trade-offs between these two developmental goals. Nevertheless, the transition to a low carbon economy requires infrastructure, innovation, and investment (Okereke et al. 2019), and needs to be supported by a manufacturing transition. This vacuum can be filled by the notion of green growth, which we turn towards in the next subsection.

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[3] The Kaya identity bears the name of the Japanese energy economist Yoichi Kaya that introduced it in 1990. The identity states that GHG emissions can be expressed as the products of population, GDP per capita, energy use per GDP and carbon intensity (measured through emissions per unity of energy consumed).

[4] According to the US Department of Energy (2015:1), the term *industrial energy efficiency* stands for "the energy efficiency derived from commercial technologies and measures to improve energy efficiency or to generate or transmit electric power and heat, including electric motor efficiency improvements, demand response, direct or indirect combined heat and power, and waste heat recovery".

[5] CO_2 intensity can be defined as the average emission rate of a given pollutant from a given source relative to the intensity of a specific activity (World Bank Glossary definition)

[6] The production of electric batteries may be carbon intensive, but their diffusion and use enables to reduce CO2 emissions on the long-term, as it provides an alternative to conventional vehicles (as long as clean energies constitute the main source of electricity generation for charging electric batteries). The reverse is also true. So called green technologies may involve low carbon consumption, but their production processes may be so carbon intensive that it offsets the low carbon benefits of their usage

2.2 What is green growth?

The climate agreement reached at the Paris COP21 called for an acceleration of the transition towards a more sustainable and greener growth model (OECD 2015; United Nations 2015). However, how to achieve a green growth model?

Green growth can be defined as "economic growth that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental impacts and resilient […]" (World Bank, 2012:2). The notion of green growth is based on the underlying view that growth and environmental sustainability do not need to be dissociated from one another and can be compatible, and that conventional growth is unlikely to be sustainable in the long run (Fouquet and Hippe, 2019).

The notion of green growth is rooted in a broader and growing literature that attempts to bridge the environmental urgency with economic and industrial development (see Porter and van der Lynde, 1995; Aiginger 2015; Pollin 2015, Garret-Peltier 2017; Cantore and Cheng, 2018; Fraccaschia et al., 2018; and Fouquet, 2019; for instance). Porter and van der Lynde (1995) argued that properly crafted environmental standards can trigger innovation offsets, allowing companies to improve their resource productivity. More recently, other authors found a positive effect of national energy efficiency program or pollution standards on productivity (see Filippini et al. 2020, for a study on Chinese iron and steel firms, and Naso Huang, and Swanson, 2019 for a study of the ammonia, paper and cement industries also in China).[7] Cantore and Cheng (2018) also argue that environmental policies and industrial policies may not be rival but provide suggestive evidence that environmental market policies may trigger the development of local industrial capabilities.

Renewable energies have gained particular attention in the green growth discussion due to their positive impact on the environment (see Fouquet and Hippe, 2019; Stern and Rydge, 2012) but also due their economic impact, especially in terms of the potential for technological innovation in those sectors and their contribution to jobs creation:
First, the potential for innovation in green industries (intended as their opportunity to become economically feasible considering the rate at which decrease in production costs could accelerate their production) has been seriously underestimated, even by some of the most authoritative and competent international institutions, as shown by Zenghelis (2018). Several studies confirm that regions with a green specialisation have already achieved a critical mass of high-value, knowledge intensive activities in green industries (Grillitsch and Hansen, 2019; OECD, 2019).

Second, considerable job opportunities arise from the transition towards clean energy. The International Renewable Energy Agency (IRENA, 2019) shows that 11 million people were employed across the renewables sector in 2018, with solar photovoltaics ranking as the largest employer amongst renewable energies. However, it is worth highlighting the heterogeneous geographical distribution of such jobs. IRENA (2016) has raised awareness on the uneven consequences of renewable energy deployment globally by showing that doubling the share of renewable energy by 2030 would mostly

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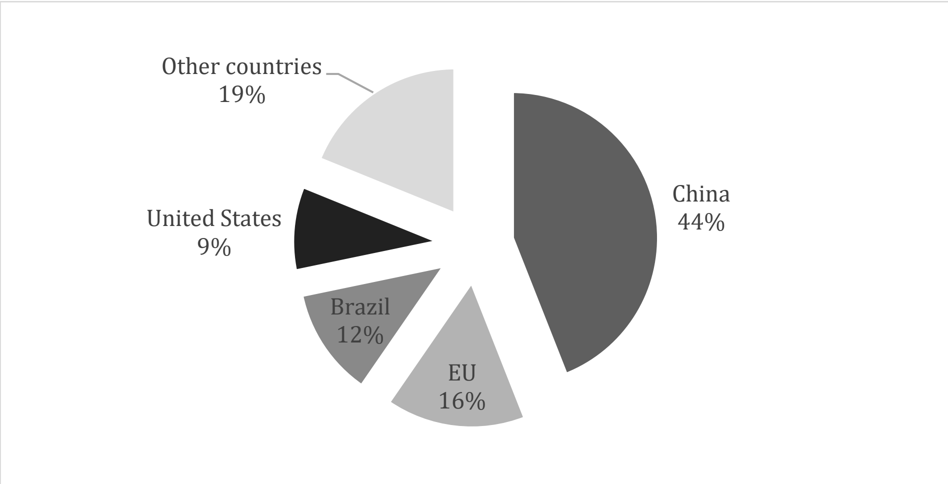
[7] Naso, Huang, and Swanson (2019) find that pollution standards led to an increase in industry productivity in developing cities compared to other cities, which suggests that environmental regulations might also influence spatial development by reducing geographical disparities.

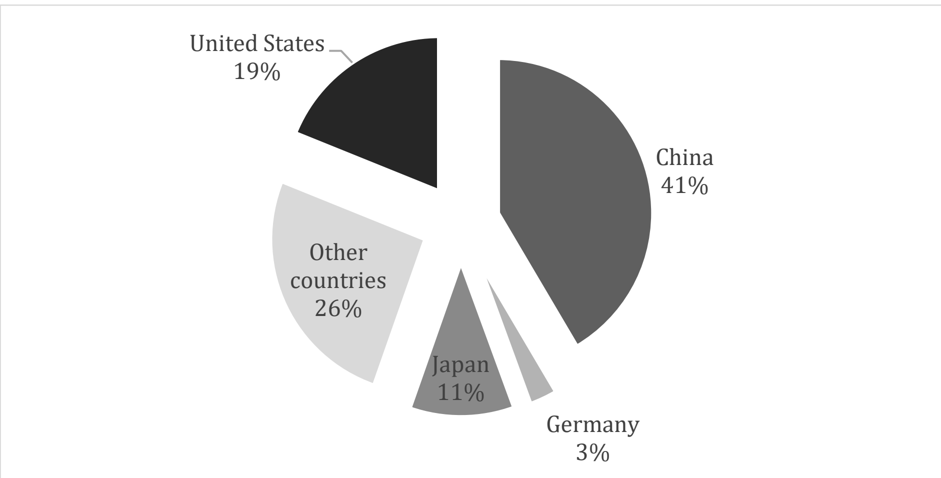
lead to increased employment in a handful of countries that already dominate the sector (see figure 1). A more optimistic view by Pollin (2015) suggests that building a clean energy economy will be a positive source of net job creation in all regions. With a series of studies using input-output statistical tables both in developed and developing economies, the author concludes that this is true even considering the job losses generated by polluting industry retrenchments. In other words, spending on clean energy delivers more jobs than spending on fossil fuels production, for two reasons: the higher labour intensity in clean energy (compared to machines, drilling operations and energy consumption of polluting industries); and the domestic content of spending which tends to increase when retrofitting existing building stocks (compared, for example, with imported oil) (Pollin, 2015). Similarly, Garrett-Peltier (2017) finds that 7.49 full time jobs are created in renewables from $1million spending, compared to only 2.65 jobs if investing the same amount in fossil fuels.

Figure 1: Distribution of renewable energy employment across countries in 2014 (in thousand jobs)



Source: Authors' based on data provided by IRENA (2016)

Figure 2: Share of Patents filed in renewable energy technologies by country in 2014.



Source: Authors' based on data provided by IRENA (2019)

A further interesting point is that three quarters of the patents (filed in the US) in renewable energy technologies originate from only four countries, which also appears to be amongst the countries with the largest employment generation in renewable energy sectors (see Figure 2). [8] Using data on 1 million patents and 3 million citations, Dechezlepretre et al. (2013) also finds that spillovers from low carbon innovation are over 40% greater than convention technologies in energy production and transportation sectors. The capacity to innovate thus appears to be important for making the most of energy transition as an industrial opportunity, as a source of value creation (and arguably of high quality job creation), which is why the role of green industrial policy is of particular relevance.

3. A NEW FRAMEWORK FOR GREEN INDUSTRIAL POLICY

Recent scholarly work has argued that *green* industrial policy is central to drive the structural transformation towards a more sustainable and greener economic system, especially in light of the important and long-term investments that green activities need (Aiginger 2015; Dietsche, 2018; Hallegatte et al. 2013; Lütkenhorst et al. 2014; Naudé, 2011; Rodrik 2014).

However, while the term 'green industrial policy' has gained popularity in recent years, it has been interpreted in various ways. In order to contribute to this rapidly growing body of literature, we have identified three dimensions of green industrial policies (GIPs), which are classified according to their policy objectives and challenges for climate change mitigation. These three dimensions are:

1) The consumption-centred dimension, which focuses on shifting consumer behaviour
2) The firm-level sustainability dimension, which focuses on incentivizing firms improve resource efficiency in their production processes
3) The productionist and innovation-centred dimension, which aims to shift the productive structure of an economy through low carbon innovation.

Table 1 summarizes these three different approaches, and puts forward their respective benefits, limitations and examples.

Table 1: Overview of the three dimensions of green industrial policy

Green Industrial Policy	**1st dimension**	**2nd dimension**	**3rd dimension**
Definition	Policies that seek to influence consumer behaviour	Incentives for firms to improve resource efficiency in their production processes and supply chains.	Policies promoting innovation and the development of low carbon industries.
Key actors	Consumers	Firms	States / Firms

[8] The Clean Energy Patent Growth Index (CEPGI) also shows that between 2002 and 2015, the top clean energy patenting companies (General Motors, Toyota, Honda, General Electric, Samsung, Ford, Hyundai and Nissan) have been concentrated in only a few industrialized economies. Indeed, referring to the US Clean Energy Patents (patents filed in the US), 46% of the patents filed in the US were granted to US applicants, 23% to Japanese, 8% to German, 7% to South Korean, and 3% to Taiwan.

Objectives	Shift consumers' behaviour mainly through demand-side policies	Firms improvement of their production efficiency and their resource use through circular economy processes	Shift of the economy towards low carbon sector
Time horizon	Short term	Medium to long term	Long term
Examples	Incentives for car sharing; subsidies for electric and efficient vehicles (EEV); the ban of incandescent bulks in the EU; green mortgages that involve lower interest rates for energy efficient housing.	Targets for greenhouse gases emission; incentives for adopting circular economy models; incentives for automotive producers to adopt more efficient exhaust pipes; carbon taxes; limiting the transportation of materials in production processes.	Demand and supply side policies. R&D support, subsidized credits for EEV producers and/or solar panel producers; Feed in Tariffs.
Benefits	Changing consumer behaviour can have an impact on production through the power of consumers on the governance of buyer-driven value chains.	Can help deliver the same final goods with less CO_2 emissions/waste and better production efficiency, thereby entailing some changes in production systems without having to change consumer preference.	Takes into account the production-side of climate change mitigation, thereby making the production structure more compatible with sustainability.
Limitations	Consumer behaviour is unlikely to change if: Consumers have imperfect information; the cost of changing consumption towards a "greener" one is too high when alternatives are lacking.	Such policies have a clear limit without complementary investments in R&D for technology to improve resource efficiency	Difficult to achieve in many developing countries that lack the technological and institutional capacity to coordinate innovation in new green technology sectors.

Before further delving into the different components of our green industrial policy matrix, it is worth explaining the relevance of our matrix for categorising existing policy instruments. Against the backdrop of a cacophony of one-size-fits-all climate change mitigation measures, our matrix can help disentangle and go beyond the emphasis of single instruments that have dominated the debate.

Broadly speaking, climate mitigation measures can take the form of government regulations or market-based mechanisms. Market-based mechanisms (such as carbon taxes, carbon permits and tradable rights, feed-in-tariffs) are the standard neoclassical economics response to climate change, which explains why it has gained increasing popularity amongst economists in recent decades. According to the Nobel laureate William Nordhaus (2007:29), "raising the price of carbon is a necessary and sufficient step for tackling global warming. The rest is largely fluff". Market-based mechanisms aim to increase the cost of products that rely on carbon-intensive production processes by manipulating prices and, according their advocates, these mechanisms should create the space for entrepreneurs to develop lower carbon alternatives (see Weitzman, 2007).[9] For instance, carbon credits provide an incentive to cut emissions, because firms can sell the remaining permits that they do not use.
It is very difficult to assess the impact of instruments such as carbon taxes and GHG trading systems both due to lack of data and to the fact that emissions are affected by other multiple exogenous factors; nonetheless there is a general agreement that they were at least able to affect business as usual emissions (Haites, 2018). There are two important market-based measures that have become popular as environmental demand-pull policies (Noailly and Smeets, 2012): feed in tariffs (FIT) and renewable energy certificates (RECs). The former are subsidies that allow renewable energy producers to sell at a guaranteed price per KWh generated over a given time period (Couture and Gagnon, 2010). The latter are legal instruments proving that electricity comes from a green energy source (Critchfield, 2015).[10] Their impact depends on different factors, including the type and maturity level of the technologies they use. For instance, Johnstone et al. (2010) argue that only FITs induced innovation in solar technologies while REC favour innovation in more mature technologies such as wind power. These measures proved to be effective in a number of countries. For instance, in Germany, through the Renewable Energy Source Act (2000), the government set up FITs and RECs that incentivized the consumption and production of solar energy, which expanded the market scale of solar energy and consequently increased the profitability of the technology.

However, such solutions have also received a lot of criticisms over the years (see Barker, 1993; Haites, 2018). Lewney (2020) explains that carbon pricing is necessary but not sufficient because prices can be an ineffective signal for the take up of

[9] Weitzman (2007) further argues that high carbon prices "would do more to unleash the decentralized power of capitalistic American inventive genius on the problem of researching, developing, and finally investing in economically efficient carbon-avoiding alternative technologies than all of the piecemeal command-and-control standards and patchwork subsidies making the rounds in Washington these days".

[10] A REC is created for every megawatt-hour of renewable electricity generated and delivered to the utility grid and it generally includes the following: type of renewable resource, location of renewable resource, date stamp or vintage of generation, emissions profile of the generating resource, unique identification number (Critchfield, 2015). The concept refers to the fact that when the power provider fed the energy into the grid, he receives a REC that can be sold in the market as an energy commodity (see Holt and Bird, 2005).

unfamiliar technologies and because of imperfect information. Moreover, carbon tax rates have been too low, do not internalize all externalities and therefore do not correspond to the social cost of carbon, whose estimation may vary considerably (Semieniuk and Yakovenko, 2020; Smith and Braathen, 2015; Stern, 2006).[11] Lastly, and above all, even if the price signal allows the market to adjust, 'pricing is not sufficient to achieve on its own the scale and speed of decarbonisation required to stabilise global temperature at safe levels' (Zenghelis, 2016).
Carbon markets therefore need to be complemented by government regulations to work more effectively. Government regulations (such as energy efficiency standards, product prohibitions and voluntary agreements) ensure that certain targets can be met and lead to higher incentives for low carbon innovation. As best stated by Chang (2019: minute 14.08), "necessity is the mother of invention. Technologies are developed when there is great urgency, but carbon markets do not force firms to innovate: it enables some of the dirty polluters to postpone innovation." Regulations provide such urgency to innovate. This view is confirmed by the fact that the highest decrease in emissions at the European level are attributed not to carbon taxes but to a series of other policy measures (Haites et al., 2018). For instance, in the EU, the regulation progressively phasing out incandescent bulbs between 2009 and 2012 (European Commission, 2008) has enabled LED costs to fall by 85% since 2009 because government support enabled people to switch their consumption towards LED, which created a mass market at which point private firms could exploit scale economies to produce goods at lower cost (Chang, 2019; Hyperikon, 2018). LED lights have now reached a market share of 31% of all light bulbs in Europe (Hyperikon, 2018). In similar perspective, Zenghelis (2018) also puts forward the effects that government subsidies have on the innovation and deployment process of wind turbines and solar cells and found that the price of solar cells and wind turbines respectively fell by 83% and 35% since 2010.

In the remainder of this paper, we attempt to move the debate on climate change mitigation beyond the dichotomy of market-based versus non market-based solutions, and beyond the unidimensional emphasis on single instruments to solve the climate crisis. A key shortcoming in existing approaches lies in the fact that both market-based mechanisms and/or regulations are often portrayed as solving several issues ranging from consumer behaviour, ensuring the sustainability of production processes, to incentivizing low carbon innovation. In contrast, we argue that a more holistic approach is needed to target different components of climate change mitigation more efficiently. Our main contribution is therefore to shed light on three main dimensions that can help compartmentalize the wide array of 'green' policy instruments, their objectives, time horizon, strengths, and limitations. Our matrix further shows that both market-based mechanisms and regulations cut across these three different dimensions, as they can be used to achieve different policy goals, but that they need to be accompanied by broader and complementary policies to ensure their sustainability. The next sub-sections further discuss some of those three dimensions of GIP.

3.1. *First dimension of GIP: Consumption-focused approaches to climate change mitigation*

The first dimension features a rather reductionist view of green industrial policies as

[11] Between 2007 and 2012, actual emissions subject to a carbon tax increased and continued to increase during the next five years while the tax rate was constant (Murray and Rivers, 2015; Haites et al., 2018).

policies that favour “green consumption”. This level of analysis tends to put responsibility at the level of individuals and that as consumers, and therefore entails policies that seek to influence consumer behaviour, which can involve both market-based mechanisms (e.g. fees and taxes that increase the cost of carbon-intensive goods and activities) and regulations (such as product prohibitions). The core concern of these policies is ‘how to make people buy greener’ while completely overlooking the production processes of the goods and services. This is not to say that policies that aim to change consumer behaviour are not necessary. However, despite their benefits, several issues can be identified and consumer behaviour is unlikely to change if:

(i) Consumers (or policy-makers) have imperfect information of the environmental impact of some products over others (e.g. electric car that rely on fossil fuel-based electricity generation, and that can have a higher carbon footprint than hybrid or diesel cars). Indeed, a key assumption of arguments advocating for carbon markets is perfect information. For the emission target to be achieved, consumers need to be aware of their carbon emission reduction costs. McKinsey (2009) reveals that many emission reductions options like installing LED lighting or insulation retrofits (both commercial and residential) already have negative costs and net economic benefits over time. However, few households have captured this potential to date as a result of a range of market failures, including principle-agent problems, stemming from the imperfect information available to those who would benefit from given solutions.[12] In this perspective, Simon (1956) refers to the notion of *satisficing*, whereby decision making is costly: whereas economic man maximises, looking for the best alternative among all available, Simon (1956) argues that, due to the costs and complexity of undergoing change, human beings tend to satisfice, keeping the option that is good enough.

(ii) Consumers find it more costly to reduce carbon emissions than buying their rights to pollute by paying for carbon permits or carbon taxes that are too low. The cost of changing consumption towards “greener” goods and services can be higher than paying carbon taxes (as evidenced by the cost and length of train journeys that is often higher than flights to the same destination; or green mortgages in a context where energy efficient housing remains more costly than non-energy efficient one). Furthermore, the inducement of changes in consumption behaviour is less likely to include high-income groups, which have been identified as the higher CO_2 emitters (Knight et al. 2017; Gore, 2015; Yang et al. 2017) and are paradoxically the ones who can afford to secure and maintain their carbon-intensive consumption patterns and lifestyle by “buying” their right to pollute. As a result, the 1st dimension of GIP can have a discriminatory impact on low-income groups if they neglect issues of income distribution. This aspect is well reflected by the *‘gilet jaunes’* movement that has started in 2018 in France in the aftermath of rising fuel prices to support climate change. The protests were partly motivated by the idea that the working class and the poor were being forced to pay for a problem that they perceived to be caused by

[12] Here, the principal-agent problem stems from the fact that those who are responsible for installing - or covering the costs of installing - energy efficient solutions (e.g. landlords or buildings) may not act in the interest of those who may benefit from energy efficiency solutions (e.g. tenants benefiting from lower energy bills, or society as a whole benefiting for lower CO2 emissions). This departure of the principal’s interest from the agent’s interest constitutes an ‘agency cost’.

multinational corporations (Atkins, 2018; Rubin and Sengupta, 2018).

(iii) Even in the cases of product prohibitions, the success of regulations can be highly dependent on the pre-existence of quality alternatives that consumers can fall back to. Bans can be met with resistance in the context where individuals feel that such policies infringe on their individual freedoms, which is more likely to happen when the quality of green consumption alternatives are lower than the standards consumers are used to.

For the reasons listed above, consumption-focused policies need to be accompanied by policies to provide sustainable and quality alternatives to consumers. The case of Ecuador in section 4.1 is very representative of such an issue. In order to mitigate climate change, we may therefore need solutions that go beyond what mainstream economists have advocated for to date. For that purpose, this paper now turns towards what we have identified as the second and third dimensions of green industrial policy.

3.2 Second dimension of GIP: Resource efficiency-focused approaches to climate change mitigation.

This approach essentially views climate change mitigation as the challenge of producing the same goods but with less resources and CO_2 emissions, by improving the environmental sustainability of existing productive activities and value chains (See Ponte, 2019 for instance). This dimension emphasizes firm-level responsibility for CO_2 emissions and pollution more broadly, and therefore entails policies that aim to influence firms' behaviour. This dimension is particularly relevant considering that 90 firms worldwide are responsible for two thirds of GHGs (Goldenberg, 2013). The majority of these are part of the so-called "dirty industries" such as iron and steel, non-ferrous metals, industrial chemicals, pulp and paper, and non-metallic mineral products (OECD, 1997; see also Shan and Wang, 2019).

The 2nd level GIP encompasses what some stakeholders refer to as 'green manufacturing', which is "primarily about changing business and manufacturing practices, as well as the mindset of stakeholders, to mitigate the industrial impact on climate change and other environmental concerns" (Tricoire, 2019). The notion of 'green manufacturing' emphasises sustainable practices within manufacturing facilities, across the supply chain, such as the development of environmentally friendly materials; the decarbonization of energy; innovation for resource efficiency and for extending the life cycle of goods within a circular economy framework (ibid.).
The role of 2nd dimension of GIP is justified in terms of a collective action problem in resource efficiency. Indeed, industrialists might incur a loss of competitiveness by adopting resource efficiency measures and consequently would only do it if: (i) other competitors also do it; (ii) consumer preferences (and therefore consumer demand) shift towards sustainable products; (iii) there are public incentives and subsidies for increasing resource efficiency. As a result of such a collective action problem, regulations and policy interventions are needed in order to align the interests of firms with wider principles of low-carbon growth.

For instance, firms may find it more costly to reduce carbon emissions through the adoption of new technologies than buying their rights to pollute by paying for carbon permits or carbon taxes for instance, especially when these are set too low. In those instances, carbon markets legitimize pollution rather than incentivize changes in production patterns.

There are two main ways through which firms can be pushed to improve efficiency. Firstly, the circular economy is based on the principles of reducing waste and pollution, keeping production and materials in use, and regenerating natural systems (Ellen MacArthur foundation, 2019). The need for the circular economy arises from the fact that 62% of all the global GHG are emitted during extraction, processing and production of goods and that so far only 9% of used material is circular rather than extracted (ibid.). Circular economy efforts are different from anti-consumerism, as they endorse consumption but through re-use, repair and renting. [13]

Secondly, an increase in production efficiency through the reorganisation of production processes and the adoption of new technologies is considered to be one of the most important and cost-effective means for mitigating emissions from industrial activities (Worrell et al., 2009). This approach is attractive because it enables us to link the two objectives of increasing energy efficiency and increasing productivity, thereby reducing cost per unit. Nonetheless, it is problematic for important reasons that tend to be overlooked. Worrell et al. (2009) undertook an assessment of the most energy-intensive industries (e.g. iron and steel, chemicals, petroleum refining, minerals, pulp and paper) and reviewed technologies such as steam generation, energy recovery. They find that in countries such as South Korea, firms in the steel industry introduced continuous production processes (over batch processes) to reduce heat loss, increasing recovery of waste energy and process gases, scrap pre-heating, etc. However, they point out that what is feasible in terms of energy efficiency in the South Korean steel industry or in pharmaceutical industrial parks in Denmark is not necessarily feasible in other countries, especially developing ones. Advocating for the replicability of these experiences therefore seriously underestimates the considerable efforts and costs in terms of retrofitting processes that firms have to undertake with technological and organisational innovations. A further example on a more general level regards fourth industrial revolution (4IR) technologies that are increasingly observed as a way to increase sustainable production. While the recent debate on the 4IR puts forward the benefits of new technologies in terms of enhancing productivity, improving control over processes and predictive maintenance, the application of such technologies requires a continuous process of *retrofitting* within production systems, and the development of new production capabilities (Andreoni and Anzolin, 2019).

Policies at the 2nd GIP level may also have different impacts across sectors because not all industries offer the same prospects for retrofitting or waste/pollution reduction under existing technology (Allwood et al. 2019). Greening our economies may therefore require not only to shift the way in which we produce goods but also a change in some of goods we produce and consume. 2nd level GIPs are therefore complementary with 1st but also 3rd level GIPs because their success is heavily reliant on the strength of low carbon innovation ecosystems that can provide cost-reduction and low emissions solutions to firms in their production processes. The next section further turns towards the role of green industrial policy in promoting and supporting the development and the diffusion of green technologies.

[13] See Schröder et al. (2020) for an investigation of circular economy initiatives in Latin America.

3.3 Third dimension of GIP: Innovation- and production-oriented approaches to climate change mitigation.

This third approach views climate change mitigation as something that is above all based on the transformation of the productive structure of an economy towards low-carbon manufacturing. Several scholars have emphasised the role of innovation-driven industrial policies in the context of climate change (see Anadon et al. 2016; Barrett, 2009; Conchado et al. 2016; Doblinger et al. 2019; Mercure et al., 2016; Naudé, 2011). Barrett (2009) refers to the need for a "global climate-technology revolution" while Naudé (2011) argues that achieving a low-carbon revolution is clearly impossible without innovation and technological change. In that perspective, it appears that evolutionary, developmentalist and neo-Schumpeterian traditions offers relevant perspectives on innovation and technological capabilities that can inform our third dimension of green industrial policy (See Andreoni and Chang, 2017; Cimoli et al. 2009; Lee, 2013; Nelson and Winter, 1982).

For instance, in the case of energy transition, GIP3 policies would go beyond mere renewable energy adoption and deployment measures but would also entail the promotion of the production of equipment that directly feeds into renewable energy value chains. The case of Chinese wind energy sector provides very clear evidence of such policies. When China started to develop its wind energy capacity, its policy-makers faced a critical trade-off between a *fast-track development*, which implies the installation of the greatest number of turbines in the shortest possible time through the imports of wholly assembled wind turbines; and a *slow-track development*, which seeks to develop a domestic manufacturing capability base for wind turbines (Lema and Ruby, 2006). After the initial adoption of the *fast track development* during the 1980s with high reliance on duty free imports, China's choice of the slow-track model since the 2000s has enabled the building up of technological capabilities, and consisted in the adoption of local content requirements for wind turbines, support for local R&D activities and technological acquisition, as well as demand-side and supply-side policies (ibid.).
Another instance of successful GIP3 (or 'slow-track' development) is offered by the case of Brazil, where the Brazilian National Development Bank (BNDES) played an important role in supporting the wind turbine manufacturing industry by offering competitive financing for wind power installations (at rates well below market levels) while imposing local content requirements (Hochstetler, 2020). The various local content requirements slowed the actual introduction of wind power until after 2009, but eventually contributed to a substantial national industry as they became "the most effective guarantor of ongoing localized production of electricity components" (ibid.:129).

It should be acknowledged that innovation is often path-dependent on productive capabilities (Andreoni, Chang, and Labrunie, forthcoming; Nelson & Winter, 1982; Dosi, 1988). It can be argued that innovation in green technologies requires the existence of an array of capabilities at different levels (both individual and collective), especially in manufacturing sectors with high spillovers to the rest of the economy.[14]
This is evidenced amongst the above-mentioned cases of developing countries that have

[14] Mealy and Teytelboym (2019:4) further show that ''countries that currently export a significant number of green complex products are well placed to diversify into other green complex products in the futures.

managed to successfully develop green technologies and integrate high value-added segments of the renewable value chains.[15] China was already industrialising before emerging as the dominant low-cost producer of photovoltaic cells and modules; while in Brazil, the success of the wind turbine manufacturing sector relied on the ability to leverage the pre-existing domestic capabilities in aircraft manufacturing (Hochstetler, 2020). In addition, the Chinese case - and the Brazilian case, albeit to a lesser extent – may be peculiar given the unusually large size of the domestic markets and the relatively high state capacity to design and implement a coherent set of policies, As a result, a key concern that remains is: should any country embark on our third dimension of green industrial policy? Can 3rd level GIP only be attempted by relatively large countries with advanced productive capabilities?

The case of perovskite solar cells development in Poland provides interesting insights in terms of the role of policy inputs for low carbon innovation even in the context of initially lacking related productive capabilities and high risks and upfronts costs.[16] [17] A Polish company, Saule Technology (ST) is among the first companies in the world scaling up PSC production through a low and cheap temperature method to manufacture flexible solar cells. Besides initial investments from foreign entrepreneurs, ST developed thanks to the financial support (of EUR 6 million) from the Polish National Centre of Research and Development, and the European Union (over EUR20 million). Such R&D funding was non-repayable, which was crucial in sustaining the company throughout the early stages of commercialization, and allowed the company to buy the expensive machinery used in the first production line (such as cleanrooms and inkjet printers). The exposure to European mechanisms also stimulated interactions between ST and suppliers from different sectors, which generated knowledge spillovers and allowed the company to be "up-to-date with top-notch research and create important contacts." (David Forgacs, personal communication, 23/03/2020). The availability of long-term, patient, and non-repayable R&D funding is therefore essential to stimulate low carbon innovation, especially when profits from innovation can only be expected far into the future. In the above-mentioned example, ST had been making losses for six years, (which was *necessary* to develop the actual state of the art in low-cost PSCs), which confirms the argument that a critical ingredient for the early stage development of technologies is patient, long-term, and committed finance (Mazzucato, 2013).

Nevertheless, beyond the EU context, the discussion regarding the role of developing countries in the context of energy transition has often focused on developing countries as consumers of green energy rather than producers of green energy technology, with a standard view that developing countries should pursue a fast-track policy rather than a

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15 Brazil and China and Brazil tend to be particularly competitive in industries with green innovation in contrast to most other developing nations (Fankhauser et al. 2019). China has indeed become the global leader in the production of photovoltaic, wind and solar thermal heating technologies, while Brazil has become the second largest producer of liquid biofuels for transport (after starting the industry in the 1960s).

16 The information presented in this section was gathered through two interviews with ST employees in July 2017 and October 2019, and through detailed documents available in the company website https://sauletech.com/

17 Perovskite Solar Cells (PSCs) belong to the third generation of photovoltaic technologies, whose production is much cheaper when compared to conventional silicon photovoltaics. Three main characteristics sparked the interest over this technology: its potential to be low processing costs, the mechanical properties that enable to fabricate perovskite on cheaper and more flexible types of materials, and the peculiarities of its value chain which is shorter (Song, 2017; Anzolin and Righetto, 2017; EPKI, 2019).

slow track one.[18] [19] This line of argument relies on a static approach to comparative advantage, which would tend to view green industrial policy (and industrial policy in general) as bearing high costs in developing countries that may not have the capabilities to compete in green technologies.
While emphasis is placed by neoclassical economists on the importance of specialization based on existing comparative advantages, a more comprehensive analysis of the acquisition of comparative advantages would take into account the role of learning, technological upgrading, productive capabilities, and the role of the state, responsible for shaping productive transformation away from 'low-quality' activities towards 'high-quality' activities (Andreoni and Chang, 2017; Cimoli et al., 2009). Consequently, in the context of green technological development, rather that accepting that countries have gotten where they are by exploiting their existing comparative advantages, the key question we should ask is how they have developed new capabilities and acquired new comparative advantages.

In this perspective, relevant insights can be drawn from the innovation economics literature. Several scholars have shown that state interventions play a key role in guiding innovation and industrial development (See Wade 1988 in the case of Taiwan; Amsden 1989 and Chang 1993 in the context of South Korea;, and Mazzucato 2013 in the context of the United States). Mazzucato (2016) also points out how government support has a key role to play in leading technological and industrial developments towards accomplishing certain "missions", such as climate change or energy transitions (ibid.).[20] It can be argued that the role of the State through the 3rd dimension GIP is justified in alleviating what could be perceived as a market failure in financing (low carbon) innovation. Although pioneers can gain significant sales advantages, head start in learning, and reputational advantage (as argued by Schumpeter, 1942), Boulding and Christen (2001) have found that they can at times incur even larger cost disadvantages than sales advantages, while firms that follow pioneers can have some cost advantages as they can learn from the mistakes and successes of their predecessors, reducing their own investment requirements and risks, potentially leading to a free rider problem. States may therefore have a key role to play in incentivizing "first movers" through R&D support and long-term (patient) capital for green technological development, diffusion and emulation.

18 Pegels and Altenburg (2020) also point out that the literature on green industrial development has been biased towards developed countries and has mostly ignored developing ones..

19 One line of argument emphasizes the fact that late industrializers, which may feature low levels energy access, can benefit by directly leapfrogging towards renewable energies, while early industrializers have to bear the cost of retrofitting and reconversion of the electricity grid towards renewable energies (Batinge et al. 2017; The Economist, 2017).

20 Semieniuk and Mazzucato (2019) have indeed shown that public financing was central in national energy transitions, such as in Iceland (from fossil to geothermal energy), Norway (to hydroelectricity), France (from oil to nuclear) and the United States (from conventional to shale gas).

4. The case study of Ecuador

This section applies our green industrial policy framework to a case study of Ecuador, showing the usefulness of applying a multidimensional approach to green industrial policy when analysing different climate change mitigation policies as well as their complementarity (or lack of).

The case of Ecuador during the Correa administration (2007-2017) has been selected as a case study because of its government's commitment to adopt climate change mitigation policies, its increasing consumption of renewables, as well as its critical integration in low-value added segments of wind turbine value chain, which makes it particularly relevant to discuss the need for policy complementarity across different dimensions of green industrial policy. The constitution of Ecuador states that the country "will adopt climate change mitigation policies" and promotes the development and adoption of clean technology. During the Correa administration (2007-2017), serious policy efforts were devoted towards transforming the country's energy matrix towards clean energies (hydro-electric and solar power in particular) and towards increasing energy efficiency (Nachmany et al. 2015). After a decline since the 1990s, renewable energies have once again surpassed non-renewable energies as the main source of electricity generation, going from 45% in 2010 to over 70% in 2017 (International Energy Agency, 2020). However, progress has been slower than anticipated and fell below the 93% target for renewables in the total energy mix by 2017.

The case of Ecuador is also interesting given its (often overlooked) integration in low value-added segments of the wind turbine value chain. The country produces over 90% of global supply of balsa wood (Cañadas-López et al. 2019), which is a key component of many wind turbine blade cores (Dempsey, 2020).

Understanding the nature and objectives of Ecuador's green policies can be facilitated by applying our GIP matrix. As shown in table 2, most initiatives can be categorized as GIP1 or GIP2 policies, while lesser efforts were deployed at the GIP3 level. As a result, as further argued in the following subsections, Ecuador's energy transition has lacked an industrial transformation component. More worryingly, the lack of complementarity across various GIP dimensions in Ecuador has eventually stalled the country's energy transition. Our analysis therefore corroborates the findings in Fontaine et al. (2019) that the adoption of contradictory policy aims in Ecuador have led to the slowdown of the country's low-carbon energy transition.

The information contained in this section has mostly been gathered through fieldwork interviews with government officials from various ministries and public agencies, business executives, industry experts, academics, and civil society representatives in Ecuador in July-August 2019. Data was also gathered through the analysis of government reports, legislation, academic literature, and media articles.

Table 2: Classification of Ecuador’s green policies (GIP)

<table>
<tr><th></th><th>1st level GIP
(consumer-focused)</th><th>2nd level GIP
(firm-level resource efficiency)</th><th>3rd level GIP
(green technology development)</th></tr>
<tr><td rowspan="2">Transport-related CO2 emissions</td><td>Subsidies for EEV
Attempts to cut fuel subsidies</td><td></td><td rowspan="2">Prototypes of green technologies (e.g. solar boats) developed by a public R&D institute (IGEE).</td></tr>
<tr><td colspan="2">Quality requirements for exhaustion pipes for both private vehicles and transportation companies.</td></tr>
<tr><td rowspan="2">Non-transport related CO2 emissions</td><td colspan="2">Electric Law of 1996, providing import duty exemptions for solar, wind, geothermal & biomass equipment</td><td rowspan="2">Feed-in-tariffs (between 2000 and 2015) that are no longer active due to the lack of regulations to implement laws</td></tr>
<tr><td>Electric Cookers programme</td><td>Access to clean energy through public investment in renewable energy plants (PV, hydroelectric & geothermal).
OGE-EE project (associated gas management)
Galapagos Island Zero Fossil Fuels initiative</td></tr>
</table>

Table 3: Assessment of policies across the three GIP dimensions in Ecuador

	Policy Initiatives	Objectives	Outcomes	Explanations
GIP1	*Subsidies for energy efficient vehicles (EEVs)*	Tax breaks for the purchase of EEVs since 2015 to reduce transportation-related CO2 emissions.	Only 240 electric cars had been purchased as of 2018. CO2 emissions from transport have doubled between 2008 and 2018 and continued to increase since the scheme started	Both the offer and demand for EEVs have stalled due to the high cost of importing EEVs and the lack of complementary investment in electric batteries charging stations across the country.
GIP1	*The Electricity Cookers programme*	Shift consumption from subsidized LPG cooking fuel to induction cookstoves for 3 million families. Reduce Ecuador's energy-related CO2 emissions by 9%	Only 13% of the target was reached, while most of the cookers imported by the government remain unsold.	Fuel subsidies were still in place, reducing incentives for changes in consumer behaviour
GIP1	*Hoy no circula ('Don't drive today')*	Driving restriction policy during rush hours introduced in Quito in 2010 (under the name *Pico y Placa)* to mitigate traffic congestion, potentially curbing car-related CO2 emissions.	Traffic congestion has not reduced & the quantity of vehicles in Quito's province has doubled in the first eight years of the policy (GK, 2019). Consumers turned towards ride hailing platforms when they were prohibited from using their cars, which has reduced neither traffic nor traffic-related CO2 emissions.	High-income groups could afford buying new cars with different license plates to circumvent the driving restrictions This measure only addressed the symptoms of transport-related CO2 emissions (e.g. traffic congestion) rather than its root causes (e.g. lack of infrastructure for public transport & cycling routes)
GIP2	*Public investments in hydroelectric plants (since 2014)*	Increase access to sources of clean energy for firms and households.	Installed hydroelectricity capacity has doubled between 2014 and 2017. CO2 emissions from industry and electricity and heat producers have dropped in 2014-2017.	Public investments of USD10.5 billion in new hydroelectric power plants and a new electric transmission grid between 2014 and 2022
GIP2	*The OGE-EE project (since 2008)*	Improve resource efficiency in the petroleum sector and reduce CO2 emissions associated with gas flaring.	Reduction of CO2 emissions by 848.5 thousand tons between 2009-2015. 79 Households in the community benefited from this programme through access to electricity	As part of the project activities, Petroamazonas has trained more than 300 technical professionals on issues pertaining to gas management (UNDP, 2015) The budget for this programme was USD1.2 billion for the 2013-2017 period (UNDP, 2015). However, since 2014, the program has suffered budget cuts, which led to the exploration of alternative financing options
GIP3	*Creation of the IIGE (2018)*	Technological development and innovation to maximize resource efficiency	The development of several green prototypes that have not been commercialized. Technological innovation with low technological diffusion	Poor dialogue between different stakeholders. Lack of adequate financing Insufficient local human capital Volatility of demand for renewable energy technology.

4.1.1 GIP1 policies and the failure to change consumer behaviour

Several policy initiatives were implemented to incentivize consumers to reduce their CO2 emissions (see table 3). This section describes some of these initiatives, before assessing their success and limitations.[21]

Subsidies for energy efficient vehicles (EEVs): Transport-related CO2 emissions represented over 40% of Ecuador total emissions from fuel combustion as of 2014 (IEA, 2020). To curb transport-related emissions, the Ecuadorian government has offered tax breaks for the purchase of EEVs since 2015. However, both the offer and demand for EEVs have stalled, given the high cost of importing these vehicles. Only 240 electric cars (and 6581 hybrid vehicles) had been purchased during the three years following the introduction of the tax breaks (Castillo and Serrano, 2018). In addition, despite an apparent increase in the number of hybrid vehicles sold since 2016, the share of EEVs stalled at 2% of total vehicle sales since 2016 (AEDE, 2018) because the general sales of vehicles has also doubled since 2016. There is therefore reasonable ground to argue that the impact of the tax break, despite non-negligible, has been relatively limited and has not sufficed to curb transport-related emissions, which can contribute to explain why the government further exempted all electric vehicles from customs duties and taxes since June 2019. Nevertheless, it seems unlikely that this measure will have a large impact in terms of changing consumer preference towards EEVs if they are not accompanied by measures to tackle the persisting obstacles for the adoption of EEVs in Ecuador, such as the lack of complementary investment in electric batteries-charging stations and related infrastructure across the country (Vera et al. 2017). Even attempts to cut fuel subsidies in 2019 (that could have further incentivized the use of EEVs) failed as they did not contribute to providing sustainable alternatives to consumers, which partly explains the wave of protests that shook Ecuador in 2019.

The Electricity Cookers programme: The electricity cookers programme was implemented as part of the National Efficient Cooking Program (NECP), which aimed to shift consumption from subsidized LPG cooking fuel to induction cookstoves. The programme aimed to replace liquefied petroleum gas (LPG)-based cookers and residential water heating systems with electric systems for 3 million families and would have led to a reduction of 2.9 million tonnes CO2 emissions per year, which represents 9% of the total emissions of Ecuador's energy sector (UNFCCC, 2019). This program would also have had considerable public costs reduction effects since the LPG subsidy currently costs the government about USD700million per year (Martínez-Gómez-Gómez et al., 2017). In addition, over 83% of the LGP is imported, while cooking activities represent over 91% of Ecuador's LPG (ibid.).

The results of this programme were rather disappointing. Only around 389,000 electric cookers (less than 13% of the initial target) were installed. Meanwhile, most of the induction cookers that were imported from the government, at a cost exceeding

[21] There are other examples of 1st level GIP (such as the mandatory control of efficient exhaustion pipes for vehicles) cannot be further analysed in this paper due to space constraints. Overall, those examples also show that consumer behaviour is not likely to change through regulations if the cost of transition remains too high for consumers.

USD200 million, remain unsold (El Universo, 2019). This outcome can be explained by the fact that the incentives to shift consumption toward electricity did not suffice in a context in which cooking with LPG is strongly rooted in the habits of Ecuadorian households (Carrión and Carvajal-Pérez, 2015). On the one hand, under the NECP, consumers received a subsidy for electric cookers that covered the first 80 kWh, with a value of 0.04 USD/kWh (Martinez-Gomez et al., 2017). On the other hand, consumers were still benefiting from subsidized prices for LPG, which reduced the incentives to transition to electric cookers usage. Further adjustments would have been thus necessary to adjust the relative prices of electricity and LPG.[22]

4.1.2 GIP2 policies: successful efforts to improve resource efficiency with foreign technology

This is the dimension of Ecuador energy transition that has been the most successful. The main objectives of Ecuador's government through energy transition were to increase access to clean sources of energy for firms and households. This section discusses two important policy initiatives: the large-scale public investment in renewable energy plants and the Optimization of Power Generation and Energy Efficiency Program (OGE-EE) (see table 3).

Optimization of Power Generation and Energy Efficiency Program (OGE-EE): This programme, implemented in 2008 by the state-owned oil company PetroAmazonas, has addressed the challenge of capturing associated gas management as an alternative to gas flaring in the oil sector, but has also enabled to reduce the consumption of (largely imported) diesel, which has been used traditionally in the oil sector for electricity generation. This project has already achieved positive results with the reduction of 848,500 tons of CO_2 emissions between 2009 and 2015, which is equivalent to the emissions of 82,622 vehicles (Neira, 2016).

Public investments in hydropower plants: In order to increase access to clean energy for all the country's population, the government has invested over USD6 billion in hydropower plants and over USD4.5 billion in reinforcing the electric transmission and distribution to households (Martinez-Gomez et al. 2017). As a result of these investments, hydroelectricity generation almost doubled in four years, from about 11,000 GWh in 2014 to about 20,000 GWh in 2017. In the same time period, CO_2 emissions from electricity and heat production have dropped from 9MT (million tons) to 5MT, while CO_2 emissions from the industry sector dropped from 5MT to 3MT (IEA, 2020).

While Ecuador represents a relative success of renewable energy deployment, it appears that the national strategy has addressed energy transition from a consumption perspective while neglecting its potential industrial opportunities. Most of the machinery and equipment needed for the construction of renewable energy plants has

[22] One further interesting point is that the success of efficient cooking programmes relies on the availability of reliable power supply during cooking time (Banerjee et al., 2016; Martinez-Gomez et al. 2017). In that context, because the implementation of the NECP led to an anticipated increase in electricity demand, the government has invested over USD11 billion in a new hydroelectric power station, a new electric transmission grid and distribution infrastructure (Martinez-Gomez et al. 2017). Those investments, further discussed in section 4.1.2, reveal the need for complementarity across the different green policy dimensions.

been imported, while the locally procured goods and services mostly consisted in low value-added services such as the installation of metallic structures, repair and maintenance activities, which also only generate short-term employment.[23] Local content requirements were introduced to encourage the hiring of local personnel in 2013, but did not address the local procurement of goods and services.[24] In that context, referring back to section 3 of this paper, Ecuador has chosen the fast track rather than the slow track development strategy when it comes to renewable energy development. The next section further explains why Ecuador has not attempted to plug into higher value segments of the green technology value chains.

4.1.3 GIP3 policies: modest efforts towards a productionist and innovation-driven agenda

The Ecuadorian Constitution of 2008 established the responsibility of the state to promote scientific and technological research to achieve energy efficiency and to promote the development of low carbon technological practices (see art. 15, 387 and 413). Some efforts in that direction were attempted through a public institution, the Institute of Geology and Energy Research (*Instituto de Investigación Geológico y Energético*-IIGE), as shown in table 3.[25] As part of its mission, the IIGE aims to generate knowledge on energy efficiency and the use of low carbon technologies. It also aims to develop prototypes that have a high potential for industrial implementation. While it has successfully developed several 'green' prototypes (such as solar boats and jatropha biodiesel), it appears that the diffusion of such technologies has been limited. These prototypes were never commercialized nor scaled up, due to the presence of several obstacles. Such obstacles, which were identified through fieldwork interviews with various stakeholders in Ecuador (such as public officials, business executives, and representatives of renewable energy industry associations), include the following:

- **Poor dialogue** between different stakeholders, such as public agencies, higher education institutions, banks and local innovators (despite the fact that the IIGE's mission statement clearly acknowledges the need for links with academia, private businesses for knowledge exchange).
- **Lack of resources for R&D** support from public institutions. The budget of the IIGE is rather limited (less than USD 4million in 2018). The IIGE relied on funding from the Ecuadorian government and a grant from the Spanish government. The IIGE only consists of about 30-40 staff, most of which are trained abroad.
- **Lack of financing** for scaling up low carbon solutions, due to a risk-averse behaviour from bankers, which have little knowledge on low carbon innovation.
- **Lack of trust for local innovation** with a widespread view of local firms as technology users rather than technology providers.

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[23] While jobs in construction services of renewable energy plants are typically generated locally, their duration may be significantly lower than jobs in manufacturing, R&D and innovation, which is why technological dependence may become an obstacle to unleashing the wider socioeconomic benefits of energy transition (IRENA, 2020).

[24] CONELEC 001/13 established that 100% of non-qualified personnel and 50% of technical staff (not including administrative staff) during construction and operation of renewable energy projects must be Ecuadorian (IRENA, 2015).

[25] The IIGE was created in 2018 from the merger of two institutes (INIGEMM and INER) that were respectively created in 2009 and 2012.

- **Volatility of demand** for renewable energy technology in a context where most of the demand is driven by public procurement, which is influenced by commodity price volatility.
- **Insufficient local human capital** needed for leading and scaling up low carbon innovation.

The above-mentioned factors are intrinsically intertwined, which shows the need for a comprehensive and holistic approach to 3rd level green industrial policy. It should be mentioned that such factors are not limited to green industries as they have contributed to hinder the broader industrial development of Ecuador, which has not been able to adopt a truly coherent industrial policy in recent decades (Jaramillo, 2016). The difficulty of implementing industrial policies in Ecuador is also an outcome of the lack of strong developmental social coalitions between the government and the business elite (Mejía-Acosta and Polga-Hecimovich, 2011).

One question therefore remains: should Ecuador really attempt 3rd level GIP? Why should the country not remain a mere consumer of green technology, given the potential risks of failure and opportunity costs associated with low-carbon innovation policies in developing countries with little related productive capabilities?

Just as any industrial policy, green industrial policy does present real risks and challenges. However, such costs need to be weighed against the alternatives, which are likely to be far riskier and more costly in the long run because of the context of climate change (Lebdioui, 2020). Indeed, the future of trade in developing countries such as Ecuador is intrinsically linked to climate change: Ecuador is highly dependent on the exports of fossil fuels, which are at risk of becoming stranded assets as the world decarbonises its economic systems; and agro-commodities (such as cacao or shrimp production), where productivity is particularly vulnerable to fluctuations in temperature and precipitation (Elgouacem et al. 2020; Lebdioui, 2020). Firms in Ecuador and other developing countries will also need to anticipate and adapt to green trade standards as consumer demand shifts towards more sustainable products in key markets. For those reasons, the accumulation of productive capabilities towards the export of green goods and services remains an important agenda, even – and especially— in developing countries that may seemingly have little pre-existing related productive capabilities.

5. Key findings and their policy implications

Our study intended to untangle the interconnections between green consumption and green production and address the role of industrial policy into the climate change and sustainable development agenda. There are two main findings from our study:

1. A greener consumption is necessary but can hardly be achieved without green manufacturing and innovation. Green industrial policy therefore has a central role to play in the structural transformation towards a low carbon future.
2. There are three main dimensions of green industrial policy. A holistic and complementary approach is needed across these three dimensions in order to ensure a coherent and sustainable transition towards a low carbon economy.

The role of green industrial policy to tackle climate change in the long term.

In order to address the root causes of the climate crisis, the connections between 'green' consumption and 'green' production must be understood. So far, most discussions on climate change mitigation have focused on *consuming* less or differently, while neglecting the parallel need for *producing* differently, which mirrors a broader trend dominating anti-poverty policies that are oriented towards consumption, while ignoring production jobs (Amsden, 2012). Beyond individual consumption choices, however, a structural shift in productive structures and incentives is required.

The perceived performance and contributions in terms of climate change mitigation at the country level is also often measured in terms of low-carbon *consumption* (e.g. countries that rely on renewable energies for their energy consumption, such as Ecuador or Costa Rica), but much less attention has been given to the production of goods and equipment that can enable such "green" consumption. Climate change mitigation could therefore not be solely judged in terms of the end result (green consumption and low CO_2 emissions) but also in terms of ensuring the means (the innovation and production of green technologies) to achieve such goals. Because the production of low carbon technologies may involve carbon emissions, a paradigm shift is much needed. Simplistic country-level emissions reduction targets are likely to neglect that the CO_2 emissions stemming from industrial production of green technologies can be offset by their use somewhere else. For example, a country such China, which emits more CO_2 per capita than Ecuador, could appear prima facie a worst performer in terms of climate change mitigation. Nonetheless, it should be recognised that China is more actively developing green industries and low carbon technology that help speed up clean energy transitions in other countries.

Although there are still important challenges to the green growth paradigm (see Hickel and Kallis, 2019; and the debate between Hickel and Milanovic reviewed in Wuttke, 2019), it may be the most pragmatic path towards a low carbon economy because it holds the potential to gather broader political and social support across all income groups. To associate climate justice with social justice, a green transition must indeed be oriented towards creating employment and increasing social welfare.[26]

The need for a holistic approach across all three dimensions of green industrial policy

Against the backdrop of scholarly debates on the superiority of some policy instruments over others to reduce CO_2 emissions, our analysis contributes to evidence that there is no one-size-fits-all approach when it comes to climate change mitigation. We believe that the nature and urgency of climate change calls for a holistic approach both in terms of policy instruments and objectives. Market-based mechanisms, or policies aims at shifting consumer and firm behaviour more broadly, are important but need to be accompanied by other policy interventions at different levels to trigger a structural transformation towards a low carbon society.

By identifying the different dimensions in which green industrial policies can be situated, our study contributes to identify the potential synergies and complementarity between different climate change mitigation policy instruments. In contrast to the

[26] This perspective became integral part of the agenda of international institutions such as the OECD, the World Bank and the United Nations Environment Program, with each of them publishing flagship reports on green growth (Hickel and Kallis, 2019).

aforementioned Chinese experience, the case study of Ecuador reflects the limitations associated with the lack of consistency and complementarity among green policies.

Our research therefore supports and builds on the recent studies that underline the importance of "policy mixes", that is the coherence, combination and complementarity of various policy instruments to tackle the challenge of low carbon transition (e.g. Bahn-Walkowiak and Wilts, 2017; Del Rio, 2014; Fontaine et al. 2019; Rogge et al. 2017). Palage et al. (2019) also found that the balance and consistency between demand-pull policies (such as FITs and RECs), and supply-side policies are key features of successful low carbon innovation and deployment. The ability to provide demand push and supply pull policies within coherent policy packages across different transformational cycles (see Andreoni, 2016) is therefore particularly relevant in the context of green transitions.

A holistic approach to green industrial policy is also needed to maximize the socio-economic benefits of green transitions. Besides increasing access to low carbon solutions, green industries can generate wider socio-economic benefits. Our findings therefore support the recently growing scholarly research on the notion of co-benefits, that is the benefits of low-carbon transitions beyond those in the environmental domain (Anadon et al. 2016; Ansolabehere and Konisky, 2014; Pegels and Altenburg, 2020; Sovacool et al. 2020). These studies have highlighted how different policy instruments can be used to shape public opinion by lowering trade-offs amongst the diverse set of societal goals, such as welfare and environmental sustainability. Even in developing countries, early greening, rather than delaying actions (growing now and cleaning up later) can help bring about co-benefits, while gaining a foothold in the markets of the future, avoiding asset stranding (Pegels and Altenburg, 2020), and the risk of locking their economies onto energy-intensive pathways because energy systems are subject long-lived path dependence (Fouquet, 2016).

In that perspective, for countries aiming to seize the industrial, technological and employment opportunities that stem from green transitions, the third dimension of our green industrial policy matrix is of particular importance, and needs to be carefully timed, aligned and coordinated with first and second dimension policies.

However, it should be acknowledged that although the best green industrial policies would cut across all three dimensions in a coherent manner, the optimal balance and coordination across the three dimensions depends on several contextual factors across time and space. As highlighted in the different country experiences that are referred to in this paper, each country's political, social and economic characteristics, such as the starting composition of their productive structures, size of the domestic market, level of policy ambitions, developmental needs, and the strength of domestic social coalitions in support of a green agenda, deeply influence the ways in which policy-makers choose to tackle the various dimensions of green industrial policy, as well as the speed and scale of the decarbonisation process more broadly. Researchers and policymakers may draw informative lessons from studying the experiences of advanced economies (such as in the EU, Japan, South Korea, or the USA) and the large developing economies (such as Brazil or China), but such experiences may not often be easily replicable.[27] Countries attempting to develop green industrial capabilities in order to foster the

[27] Even in the case of India, Behuria (2020) argues that the country's position as a late, late industrializer in the renewable energy sector, combined with prevailing domestic political economy pressures, have made it extremely difficult to promote the manufacturing of solar panels and cells.

synergies between environmental sustainability and economic development therefore need to adapt their green industrial policies to their own economic, political and social context.

Conflict of Interest

The authors state that there is no conflict of interest.

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