LOMBARD ODIER
LOMBARD ODIER DARIER HENTSCH

Predictors of Success in a Greening World

December 2021

In partnership with

ssee

UNIVERSITY OF OXFORD

This document has been prepared by:

Pia Andres, Grantham Research Institute and
Department of Geography and Environment,
London School of Economics

Joris Bucker, Institute for New Economic Thinking,
School of Geography and the Environment, University of Oxford

Dr Matthew Ives, Institute for New Economic Thinking,
Smith School of Enterprise and the Environment, University of Oxford

Dr Penny Mealy, Smith School of Enterprise and the Environment,
University of Oxford and and SoDa Labs, Monash Business School

Dr Kevin Tang, Oxford Sustainable Finance Group, Smith School of Enterprise
and the Environment, University of Oxford

Dr Michael Urban, Lombard Odier

Dr Matthew McCarten, Oxford Sustainable Finance Group,
Smith School of Enterprise and the Environment, University of Oxford

Sugandha Srivastav, Smith School of Enterprise and the Environment,
University of Oxford

Prof Cameron Hepburn, Smith School of Enterprise and the Environment,
University of Oxford

Important information. Please read the important information at the end of the document. Note all data used in this report are based on the most recent data computed based on the baci database (Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version). - we are using the most recent data ie 1995-2019, HS92 nomenclature).

Abstract

The transition to a green economy is shifting the global competitiveness landscape. As more countries, regions, and corporates commit to net zero targets, capabilities need to adapt to meet the changes in demand for products and skills. At the time of publication, total government COVID-19 recovery spending exceeded USD$3.4 trillion, of which over USD$0.5 trillion were allocated to green recovery spending, creating new stimulus and new opportunities for the green transition.

Who are the likely winners and losers from this transition? This report makes use of cutting-edge research to identify the emerging global trends in green competitiveness, examine some countries in detail, and identify how governments might take advantage of these green prosperity opportunities. Overall, we find that a number of countries are actively capitalising on the growing green products market, particularly Germany, China, the US, Italy and Austria, and that early leaders on key renewable generation technologies, such as Germany and China, are most likely to gain from the global transition to net zero. We examine seven case studies in more detail: China, the US, Brazil, Australia, the UAE, Switzerland, and Singapore. These countries provide a broad range of green growth archetypes, from leading exporters to those being left behind in the race to a greening world. The detailed findings contained in the report are likely to be of value to governments, corporates, civil society, and investors.

We offer further insights into investment implications at the corporate level, specifically in relation to the wind and solar industries. Overall, we find that Asian wind and solar firms tend to be more domestically oriented, whereas Western firms are more dependent on global trade. Thanks to a buoyant domestic market and strong export prospects, Chinese wind and solar firms are likely to consolidate their leading position, while supply chains risks and trade tensions could be key destabilisers for the United States and its wind and solar firms. In Europe, we find interesting and promising results for Spain and Italy.

Contents

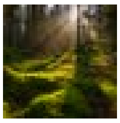
3 Abstract

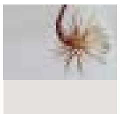
8

Executive Summary

Background and key findings 9

Key Terms 21

3

Introduction

27

2. Emerging winners in a greening world

The green imperative 28

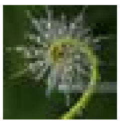
What is a green product? 29

Measuring green competitiveness 32

Which countries are currently well placed to succeed in the green economy? 38

Which countries have the greatest green product growth potential? 40

Which countries have the greatest green energy potential? 42

52

3. Greening the COVID-19 recovery

Why is a green covid recovery important? 54

A global comparison between countries' green indices and green recovery spending 54

Clean vs traditional stimulus spending post-COVID19 56

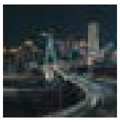
Green recovery and green complexity 58

Spending on renewables 60

Big spending in the pipeline? The US infrastructure deal and the EU green deal 62

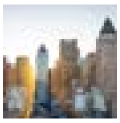
64 

4. Country Case Studies

68 

China case study

At a glance: policy ambition and green complexity 69
Trends in green competitiveness 74
Trends in green energy 78
Policy and economic environment 82
Made in China 2025 84
Environmental credentials and policy ambition 85
Green strengths and opportunities 86
Summary 89

90 

United States of America case study

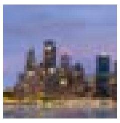
At a glance: policy ambition and green complexity 91
Trends in green competitiveness 94
Trends in green energy 99
Green strengths and opportunities 102
Policy and economic environment 104
Environmental credentials and policy ambition 106
The Build Back Better Plan and US green recovery spending 107
Summary 109

112

Brazil case study

At a glance: policy ambition and green complexity 113
Trends in green competitiveness 114
Trends in green energy 117
Policy and economic environment 119
Environmental credentials and policy ambition 122
Green strengths and opportunities 123
Summary 125

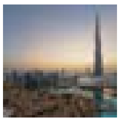
126



Australia case study

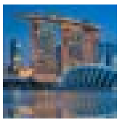
At a glance: policy ambition and green complexity 127
Trends in green competitiveness 130
Trends in green energy 133
Policy and economic environment 135
Environmental credentials and policy ambition 136
Green strengths and opportunities 137
Summary 139

140



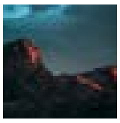
United Arab Emirates case study

At a glance: policy ambition and green complexity 141
Trends in green competitiveness 144
Trends in green energy 148
Policy and economic environment 150
Operation 300bn 151
Environmental credentials and policy ambition 152
Summary 155

156 

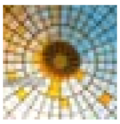
Singapore case study

At a glance: policy ambition and green complexity 157
Trends in green competitiveness 160
Trends in green energy 164
Policy and economic environment 167
Environmental credentials and policy ambition 168
Green strengths and opportunities 169
Summary 171

172 

Switzerland case study

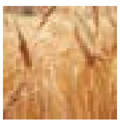
At a glance: policy ambition and green complexity 173
Trends in green competitiveness 176
Trends in green energy 180
Policy and economic environment 182
Environmental credentials and policy ambition 183
Green strengths and opportunities 184
Summary 185

186 

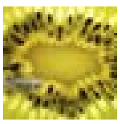
5. What could this mean for companies and their investors?

212 

6. Conclusion

216 

7. Appendix

226 

8. References

Executive Summary

Background

As environmental challenges such as climate change, biodiversity loss, air pollution, and plastic contamination become increasingly pressing, countries around the world are pledging to transition to more sustainable energy and production systems. Capital allocation in the era of climate change will play a key role in shaping such pathways, determining which industries survive, thrive, and come to define the new industrial landscape. Equally, the risk and return profiles of financial investments are increasingly shaped by this transition. This environment of evolving comparative advantage poses a key question: which countries, regions and economic assets are poised to appreciate in value, and which are set to decline? The world is in the midst of a new green industrial revolution, and industries, investors and governments that actively invest in and foster high-growth, climate compatible industries have much to gain.

This report makes use of cutting-edge research to identify which countries are specialising in high-growth green industries; which countries are laggards, and the extent to which countries have used the COVID-19 pandemic to gain from a “green recovery”. Regions that manage to capture market share and high value components of relevant supply chains will likely be best placed to benefit economically, while those that continue to focus on and specialise in declining dirty sectors risk being left with stranded assets.

To define a set of globally traded “green” products, we use a list of 295 products, based on environmental goods lists compiled by the WTO, the OECD, and APEC. This report uses the Green Complexity Index (GCI) to measure the number and complexity (a proxy for technological sophistication) of the green products that a country has exported competitively.

Research further suggests that industrial development is often path-dependent: countries and regions are significantly more likely to develop competitiveness in products and services that require similar capabilities to those they already produce. Therefore, identifying products that are closely related to a country’s existing capabilities can provide insights into what those future paths might look like.

The Green Complexity Potential (GCP) measures each country’s average relatedness to complex green products it does not yet export competitively and is a strong predictor of future GCI. We build on these ranking analyses through a case study approach, diving deeper into the green competitiveness profiles of Australia, Brazil, the US, the UAE, China, Switzerland, and Singapore.

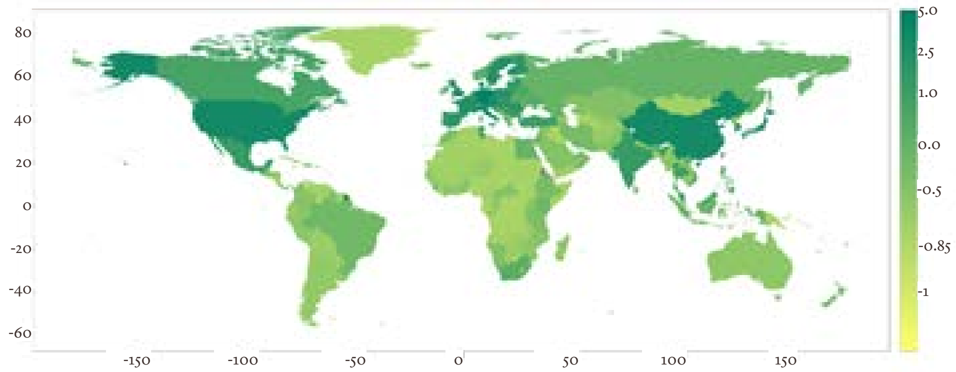
Key findings

As the world wakes up to the possibilities of a greening global economy, we see green competitiveness spread unevenly around the world (Figure 1). Europe, North America, China, Japan, and India are among the most highly ranked regions for green complexity; Africa, Australia and parts of South America rank lowest. Germany currently holds top rank in GCI (and has done so throughout the last two decades), followed by Italy, Austria, and the US.

The opportunities to benefit from the transition to the green economy are numerous and varied across countries. While countries that have built up strong manufacturing and technological capabilities, such as Germany, the US and China, are currently well placed to benefit from the green transition, many countries have competitive strengths and endowments that could allow them to capitalize on the burgeoning demand for green products, technologies, and energy over the coming years. The largest sub-categories of green products by trade value are renewable energy, efficient consumption of energy technologies, carbon capture and storage, and wastewater management and potable water treatment. Given the considerable future growth likely in clean energy technologies, and the global abundance of renewable energy potential, the countries most likely to gain from the clean energy transition are those who manufacture and export equipment for renewable energy generation and integration - such as solar panels, wind turbines, electrolysers, and batteries.

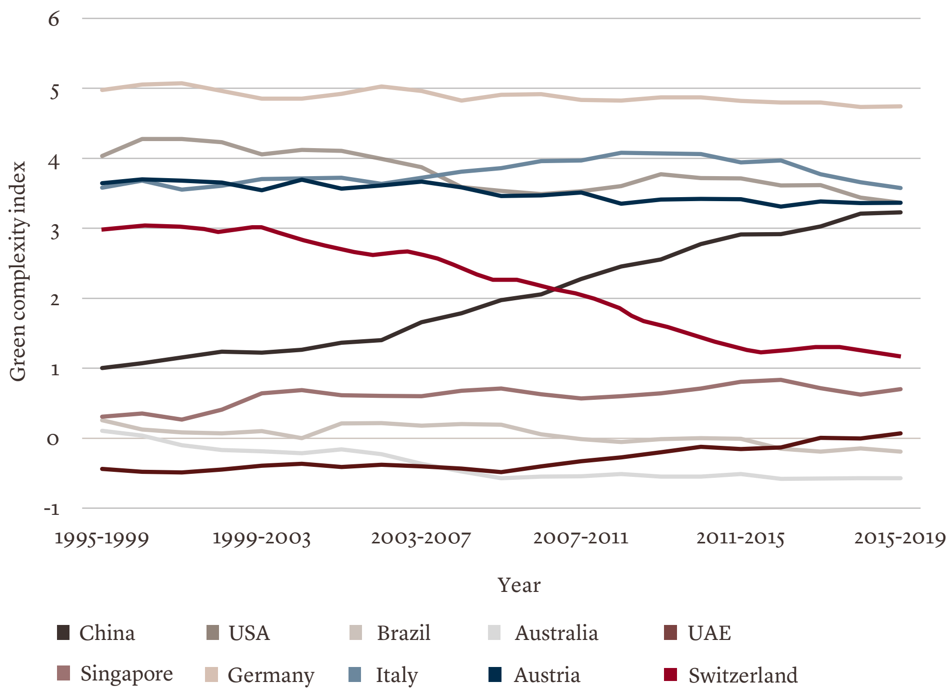
Among the countries analysed in the case study section of this report, the US ranks highest, but is running a very close race with China, which has seen a dramatic increase in its GCI over the course of the period (Figure 2). Singapore and the UAE have increased their GCI slightly. Brazil, Australia, and Switzerland have all lost green competitiveness over the past 25 years.

Fig. 1: World map with countries coloured according to their Green Complexity Index (GCI). Note the logarithmic colour scale.



Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

Fig. 2: GCI through time for the countries assessed in this report as well as the top 3 ranked countries - Germany, Italy, and Austria.



Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

China

China's rise to prominence in manufacturing is exceeded by its green manufacturing export expansion. These developments are thought to be driven by its cheap labour force, but also by well targeted industrial strategies to grow domestic energy security and strengths in key clean technology such as renewables and energy storage. China is blessed with some of the highest renewable energy potential of all countries, but with a large population and increasing GDP per capita it is unlikely to be a major green energy exporter.

United States of America (US)

The US has the world’s largest economy, with vast natural wealth and a track record as one of the world’s great innovators. While the US currently supplies much of its own substantial green product market, it has seen a gradual decline in its green complexity and green complexity potential in exports over the study period, mirroring the decline in its overall economic complexity. However, the country remains highly competitive in global comparison and has immense green energy potential, more than enough to become a green energy exporter. President Biden’s efforts to prioritise climate action and to pass legislation expanding electric public transport and a clean electricity grid may contribute to providing the country with the green post-COVID stimulus it needs.

Brazil

Brazil has strong renewable energy endowments, but has experienced a general decline in green competitiveness and potential since the turn of the century. This decline in Brazil's green potential means its probability of moving into new more complex green products has fallen, suggesting that reversing this negative trend in green competitiveness may become increasingly difficult. On a more positive note, Brazil has leveraged its local hydro, wind, and solar resources to grow a local wind turbine manufacturing industry and competitive strengths in the export of hydraulic turbines.

Australia

Australia has seen a long-term decline in its green competitiveness, but has immense potential in its natural renewable energy endowments and access to minerals critical to the more materials-based green energy transition. Although it is currently lagging in its capacity to export green complex products, it could leverage these natural advantages to carve out an advantage in the green economy going forward.

The United Arab Emirates (UAE)

While a major exporter of hydrocarbons, the UAE has actively pursued a diversified industrial strategy that appears to have resulted in an increase in its green competitiveness over the last decade. It now has competitiveness in a selection of green products, such as limestone materials and manganese oxides, which are both used in wastewater management; and parts and accessories for surveying instruments, which have important applications for environmental monitoring. The UAE does not have an overabundance of renewable potential given its sparsely populated land mass, but its proximity to the greening EU economy, high solar irradiance, and low solar costs make it a good candidate for capturing some of the green energy export market.

Singapore

Singapore recently overtook Germany to become ranked second to Japan in the economic complexity of its exports, but this has not translated into green competitiveness. Singapore is also lacking in renewable resources, with only a small land mass and relatively low wind speeds. It does, however, have competitive strengths in some complex green products, such as chromatographs and microtomes, which are technologies commonly used for monitoring air pollution or assessing environmental influences.

Switzerland

Switzerland already utilises a large amount of renewable energy and has a significant role in green finance, but its green export competitiveness has been falling in recent years, suggesting it is not capturing the opportunities available in a growing green EU market. Switzerland has enough renewable potential to transition relatively easily to supplying all its own energy needs from green resources, and to even export locally. Switzerland also has strengths in some complex green products, such as railway parts and biogas equipment, and the potential of making gains in the growing wind turbine industry.

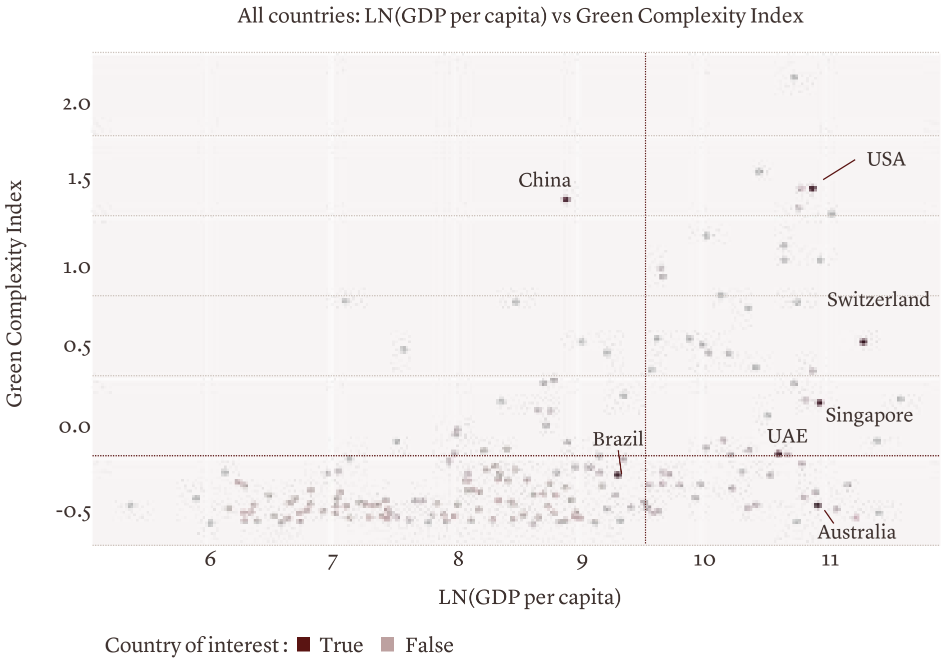
The global diversity shown by these examples is explained to some extent by the fact that green competitiveness appears to have a clear positive correlation with income level (Figure 3). Most countries with below-average GDP per capita also rank below average in GCI, such as Brazil. Countries with high GCI tend to be higher income, such as the US or Singapore. Nevertheless, there are low- and middle-income countries with above-average GCI, such as China, and high-income countries with relatively low GCI, such as Australia and the UAE.

The green competitiveness landscape is thus incredibly diverse, but by no means static. The investment and policy choices countries make in the short term will play a significant role in shaping their capacities to be leaders or laggards in the green economy over the longer term. The COVID-19 pandemic and associated recovery spending present a unique opportunity for countries to invest in green R&D and low-carbon infrastructure, upgrade their technological capabilities and support their workforce to take advantage of new green jobs and transition out of dwindling, emissions-intensive industries. Our analysis shows that not all countries are seizing this opportunity. While countries such as China, the US, Germany, Denmark, France, Spain, South Korea, and the UK currently rank highly in GCI and are also spending a significant proportion of their recovery spending on green initiatives, other countries ranking highly in GCI such as Italy, Czechia and Romania are spending relatively little on their green recovery. While it remains to be seen whether green recovery spending translates into greater green competitiveness in global markets, such differences in policy stances towards green spending and investment could drive significant changes in countries' capacities to benefit from the green transition going forward.

Political ambition and trade relationships will also shape future green competitiveness. Brazil’s green competitiveness is declining, whilst a pivot away from fossil fuel and mineral exports for the UAE and Australia will require strong political leadership to unlock their green potential. China, whilst a leader in green product manufacturing, must deal with the threat of international climate regulation if it does not make its energy mix cleaner with appropriate carbon prices and other regulations. Partisan politics in the US have hindered progress and tensions with China are likely to continue to affect trade, although the Biden administration’s commitment to tackling climate change is suggestive of a friendlier climate for green investments. Switzerland has a global role to play in green finance and may take advantage of its proximity to the rapidly greening EU. Singapore has also yet to realise its potential as a “green services hub”, leveraging its reputation as a well-functioning bureaucracy and international financial centre.

Although the pathways towards green competitiveness vary geographically and technologically, with early leaders showing clear advantages, there is ample potential for interesting new dynamics to emerge in a post-pandemic world. Investment in green technologies is not without its challenges: renewable energy projects in particular have high capital costs and carry significant risk in many developing countries. Yet, these technologies have also exhibited remarkable learning rates which has led to cost declines and rapid growth.

Fig. 3: GCI against income {LN(GDP per capita)} for all countries. LN=Natural Logarithm.

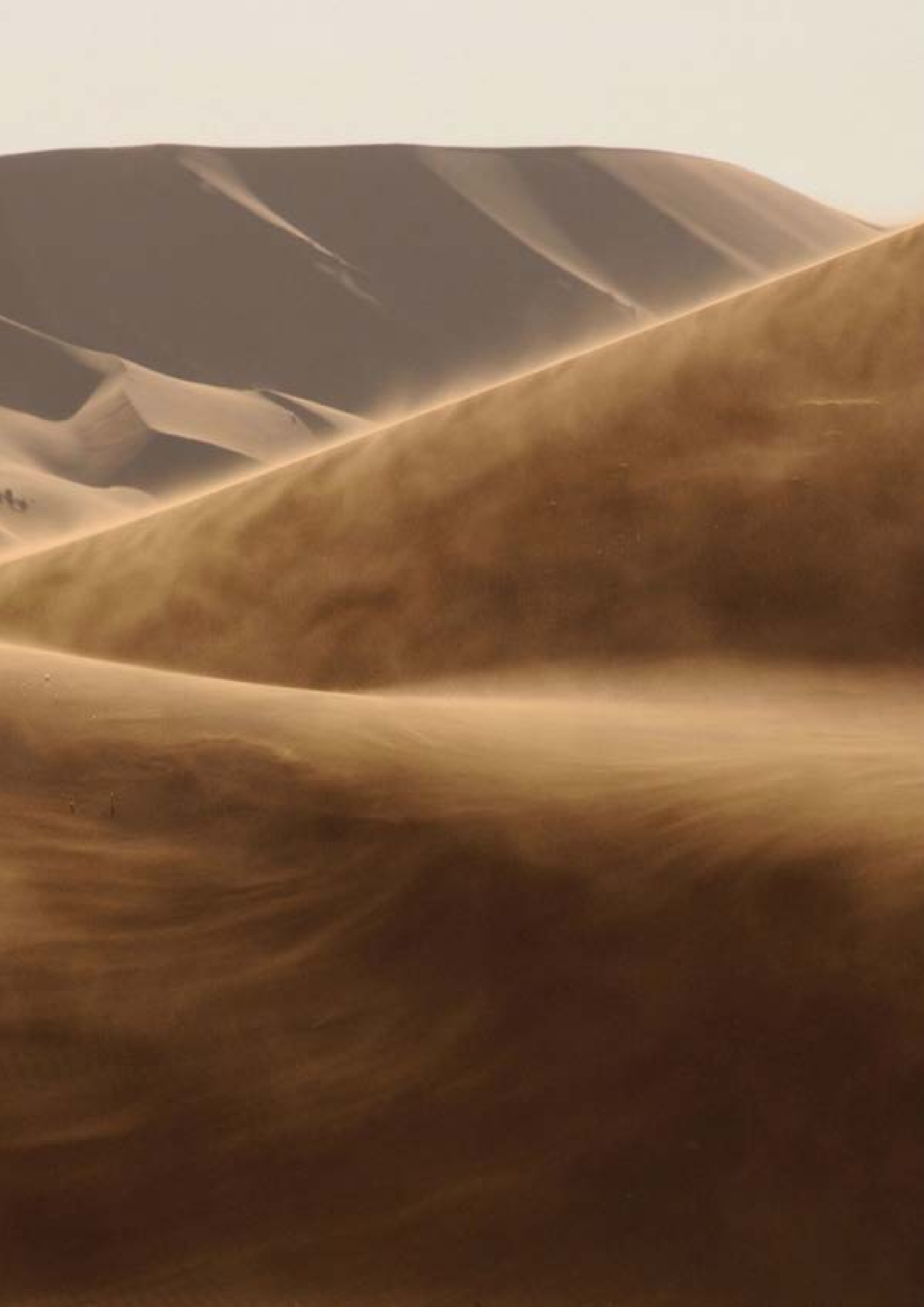


Source: World bank GDP data 2019 in current US dollars sourced on 25 June 2021 from https://data.worldbank.org/indicator/NY.GDP.MKTP.KD

It is likely that products which are complementary to renewable energy, such as batteries and electrolysers for green hydrogen, will also grow substantially in the years to come. The fate of the hydrocarbon sector is also clear. Most hydrocarbon generators, if not already uneconomic, are set to become more expensive than low-carbon alternatives in the next 5-10 years.

To curate portfolios that will maximise value, investors may need to disentangle short term noise from long term trends. As this report shows, a global green race is underway, in which early movers will be rewarded and laggards risk losing global competitiveness. Such findings are likely to be of value to governments, corporates, civil society, and private sector investors.

The urgency of increasing investment into renewable energy sources has been highlighted by the recent European gas crisis. Although some commentators blame climate policies for extreme price rises, they could also be seen as a result of too little investment in renewable energy capacity, rather than too much. GCI and GCP rankings can help investors to identify which countries are developing, and are likely to develop, their green industries. But what information can we offer to those making investment decisions at the corporate level?

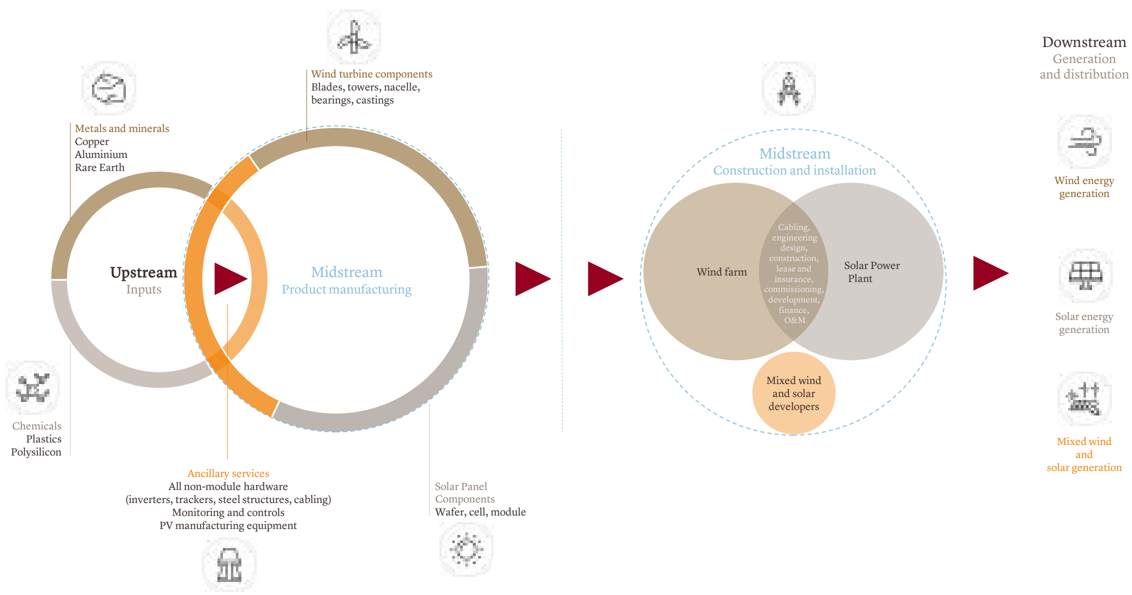


Building on the our earlier findings, we use a case study approach to answer this question by carrying out an in-depth analysis of the wind and solar industry—two sources of clean energy that are critical to the climate transition and are projected to continue their cost declines by recent University of Oxford research, thereby offsetting inflationary pressures. We first recalculate CI and CP scores for each country based on a subset of green products related to the wind and solar industry. Denmark, Finland, Estonia, and India show higher rankings in CI (Complexity Index) for wind and solar relative to their GCI rank overall. China and Italy rank highly in both wind and solar CI and CP (Complexity Potential), without significant movement in the rankings. Spain, France, Turkey, and Poland also all rank highly in wind and solar related CP.

We build on these country-level findings by developing a sample of corporates across the wind and solar value chain (Figure 4), consisting of pureplay wind and solar companies.

Most companies are concentrated in midstream activities, involving the manufacturing of wind and solar products, and Chinese and US companies dominate the sample. Interestingly, Asian wind and solar companies (Chinese, Japanese, Indian and Thai) generate most of their revenues domestically, whilst North American and European companies generate a higher proportion abroad. This highlights the importance of considering multiple sources of data when analysing the green competitiveness landscape, as results based on trade data may not reflect opportunities in domestically oriented economies.

Fig 4: Wind and solar value chain



Analysing the wind and solar industries through both the country-level and corporate-level lens offers several interesting implications for investors. In general, China is clearly playing an increasingly central role in the wind and solar landscape. It is also worth noting that China's dominance in supplying raw materials, such as aluminium and rare earth metals, presents significant supply chain risks for companies in the US and Europe, who rely on Chinese imports to drive production. Interestingly, currently peripheral European countries in high value wind and solar products may play a key role in the energy transition. Italy, Spain, and Turkey, for example, have high CP ranks and are developing trailblazing domestic wind and solar companies.

Key terms

- **Revealed Comparative Advantage (RCA)**
  A measure of the relative advantage of a certain country in exporting a certain product. An RCA of a country-product pair of 0.5 means that the country exports half of what is expected, given the global average exports of that product and the country's total export value. A country exports a product competitively if it has RCA > 1 for that product.

- **Product Complexity Index (PCI)**
  A proxy for technological sophistication. Products which are more complex tend to open up better diversification paths for countries which export them.

- **Economic Complexity Index (ECI)**
  An index that ranks countries according to the similarity of their export baskets. Countries with high ECI tend to specialize in products with high Product Complexity Index (PCI) - see above for definition.

- **Green Complexity Index (GCI)**
  An index that captures the number and the complexity of green products a country is currently exporting competitively.

- **Green Complexity Potential (GCP)**
  The Green Complexity Potential (GCP) measures each country's average proximity to complex green products it does not yet export competitively. It is a strong predictor of future GCI.

- **Green Energy Potential (GEP)**
  The total renewable energy potential of a country in terms of access to hydro, biomass, solar and wind resources. The focus of this study is on country's technical potential, which is a subset of a country's geographical potential. The geographical potential is the energy flux theoretically extractable in areas that are considered suitable and available for this production; that is to say, in areas which are not excluded by other incompatible land cover/use and/or by constraints set on local characteristics such as elevation and minimum average wind speed. The technical potential is the geographical potential after the losses incurred during the conversion from the extractable primary energy flux to secondary energy carriers or forms (electricity, fuel) are taken into account.

- **Proximity between a country and a product**
  The average proximity between the product and all products the country has competitive export capabilities in. This is a highly correlated with the probability with which a country will develop new export capabilities in this product.

- **Proximity between products**
  The probability that two products are both exported with comparative advantage by the same country. This is a proxy for the relatedness or similarity of two products within the product space.

1. Introduction

1. Introduction

How capital is allocated in the era of climate change will determine not only humanity's progress towards addressing the climate crisis, but also which industries and companies will survive, thrive, and come to define the new industrial landscape. The changing risks associated with continuing climate change are expected to affect the valuation of many assets: some assets will not be able to withstand physical climate risks; other assets may be subject to new regulation as well as liabilities that change their economic calculus. Asset managers, banks, financiers, and advisors are faced with a new challenge of preserving portfolio value in an era where the old rules of what constitutes a good investment need updating. In this environment of evolving comparative advantage, the key question is: which countries, regions and economic assets are poised to appreciate in value, and which are set to decline?

The transition to a net-zero emissions economy will undoubtedly shift the global competitiveness landscape. Demand for zero-emissions technologies will increase further as regulation, political will, and the impacts of climate change compel societies to demand and adopt cleaner modes of production and operation. Perhaps more importantly, the demand for carbon-intensive products will fall as the costs of clean technologies continue their decline and the social and economic license to operate in a polluting manner erodes.

The world is in the midst of a new green industrial revolution, driven by mega-trends that include a groundswell of climate activism, which has compelled major economies all over the world to adopt net-zero targets; learning curves which are placing renewable energy amongst the cheapest sources of electricity in the world; automation, which is enhancing our capacity to dynamically optimise and integrate intermittent technologies; electrification, which is transforming transport; and a geopolitical push to reduce dependence on imported fossil fuels. These trends point in the direction of a smarter, greener, more efficient, and potentially cheaper economy. Recent modelling efforts show that if solar photovoltaics, wind, batteries, and hydrogen electrolysers continue to follow their current exponentially increasing deployment trends for another decade, we will achieve a near net-zero emissions energy system within 25 years[1]. This extraordinary transformation assumes that the growth in deployment of these technologies witnessed over the past two decades is maintained for only one more decade. As such, there is much to gain by fostering high-growth, climate compatible industries[2].

1 Way et al. 2021
2 Mealy and Teytelboym 2020

China's early and aggressive entry into the market for solar panels is just one example of how decisive policy coupled with pre-existing industrial capabilities can allow a country, in a short space of time, to capture the lion's share of a growing global market early in the product lifecycle. There are clear lessons to be learned from China's strategic dominance in solar, and in Europe, from the Danish firm Ørsted's dramatic growth from deploying offshore wind technologies. Can these experiences be re-created elsewhere, and how can investors get a clearer sense of the global green competitiveness landscape? Answering these questions is the objective of this work.

This report makes use of cutting-edge research to identify which countries are specialising in high-growth green industries; which countries are laggards; and the extent to which countries have used the COVID-19 pandemic to gain from a "green recovery". Our measures of green competitiveness are based on research by Mealy and Teytelboym (2020)[3,4] to develop measures of competitiveness in producing "green" products. They capture the number and complexity of green products that countries are currently exporting competitively, as well as the relative ease with which they are likely to increase their green complexity in the future. "Complexity" is a proxy for technological sophistication, and products which are more complex tend to be associated with higher income and open up better diversification paths for countries that produce and export them.

The report complements this global green competitiveness analysis with seven country case studies for a range of major economies: China, the US, Brazil, Australia, Switzerland, the United Arab Emirates, and Singapore. These case studies combine a data-driven approach with a qualitative analysis of the local policy environment, barriers to finance, natural resource endowments, and economic structure. The results of this analysis carry important implications for investment strategy, industrial policy, and government spending. While all countries have some form of green comparative advantage or potential, some are much further ahead in the green race than others.

Following on from the case studies, we also offer insights into investment implications at the corporate level, specifically in relation to the wind and solar industries. This discussion seeks to overlay a company-level perspective onto the country-level green competitiveness results, by analysing a sample of the largest wind and solar companies, the majority of whom are active in complex midstream manufacturing activities.

3 Mealy and Teytelboym 2020.
4 Who in turn built on work by Cesar Hidalgo, B. Klinger, A.-L. Barabasi, and R. Hausmann. 2007. "The Product Space Conditions the Development of Nations." Science 317(5837) <https://doi.org/10.1126/science.1144581>.

2. Emerging winners in a greening world

- The green imperative
- What is a green product?
- Measuring green competitiveness
- Analysis of recent and past trends in green volumes
- Which countries are currently well placed to succeed in the green economy?
- Which countries have the greatest green energy potential?

2. Emerging winners in a greening world

The green imperative

As environmental challenges such as climate change, biodiversity losses, air pollution, and plastic contamination become increasingly pressing, countries around the world are pledging to transition to more sustainable energy and production systems. Given the myriad of environmental challenges, this requires changes along multiple dimensions, such as reducing greenhouse gas emissions, adapting to a changing climate, improving extraction practices, promoting a circular economy, and many more.

Achieving these goals requires, in many cases, the use of new technologies. One of the most intuitive examples is the production of energy, which traditionally involves the burning of fossil fuels. To produce energy in a “cleaner” way, we must turn to new technologies such as solar panels and wind turbines for electricity; hydrogen and batteries for energy storage and mobility; geothermal energy and heat pumps for heating, new biodegradable and recyclable materials, and so on. This implies that global demand for products associated with this major transition will increase as more and more countries take steps towards net zero and “greening” their economies. The transition to a more sustainable economy thus presents an enormous opportunity for producers of “green” products. Companies and regions that manage to capture market share and high value components of such supply chains will be best placed to benefit economically[1], while those that continue to focus and specialise in declining sectors risk being left behind holding stranded assets[2].

In this section of the report, we explore trends in global trade of “green” technologies within the harmonised commodity description and coding system (an international nomenclature for the classification of products). We also analyse a range of countries for their competitiveness in producing and exporting green technologies: the United States, Switzerland, Australia, Brazil, Singapore, China, and the United Arab Emirates. We do not identify declining sectors, nor are we able to measure the sustainability of the upstream production processes of these products. Rather, we focus on which countries have been successful in producing the technologies required to transition to a greener economy, and which countries have the potential to capture the most economic benefits from doing so in the future.

---

1 Cesar Hidalgo, B. Klinger, A.-L. Barabasi, and R. Hausmann. 2007. “The Product Space Conditions the Development of Nations.” Science 317(5837) <https://doi.org/10.1126/science.1144581>.

2 J. F. Mercure et al., ‘Macroeconomic Impact of Stranded Fossil Fuel Assets’, Nature Climate Change, 2018 <https://doi.org/10.1038/s41558-018-0182-1>.

What is a green product?

A product might be considered green if the use of non-renewable energy and materials and the creation of waste are minimised in its production. Alternatively, a product could be regarded as green if it provides environmental benefits in its use. That is, the manufacture of the product could involve non-renewables and waste, but the product itself is a required input into an environmental use case, such as reducing pollution, or supplying renewable energy. We deliberately employ the latter definition of "green products" for this study as it provides a better understanding of those products that are likely to create the greatest export earnings potential in a greening world. It should be noted that this does not exclude the possibility that such products can also be used for an unrelated or even a polluting purpose. However, this "dual-use" problem is not considered a major concern for our purposes, which are to understand which countries are well-placed to meet increasing demand for such technologies in the transition to a cleaner global economy.

To this end, we use a list of 295 products from the Harmonised System's 6-digit level to identify "green" trade. This list is based on environmental goods lists compiled by the WTO, the OECD, and APEC (see Mealy & Teytelboym3 for more detail). The products are further assigned to 19 (not mutually exhaustive) "green categories". Table 1 provides this list of 19 categories with an example product for each category[4,5]. Using this list of products, we compile a panel dataset of countries' green exports and competitiveness between 1995 and 2019, as detailed in the next section.

---

[3] Penny Mealy and Alexander Teytelboym, 'Economic Complexity and the Green Economy', Research Policy, 2020, 103948 <https://doi.org/10.1016/j.respol.2020.103948>.

[4] Pia Andres and Penny Mealy, 'Green Transition Navigator', Retrieved from Www.Green-Transition-Navigator.Org, 2021.

[5] To demonstrate how our green goods classification compares to other definitions of sustainability, we provide a mapping of our 19 categories to the six environmental goals set out in the "EU taxonomy for sustainable activities" in the Appendix.

Table 1: 19 green product categories used in this analysis

Category	Example product	Environmental benefit
Air Pollution Control	Condensers for steam or vapour power units.	Used to cool gas streams to temperatures which allow the removal of contaminants, e.g. volatile organic compounds (VOC) like benzene.
Clean Up or Remediation of Soil and Water	Centrifuges not elsewhere specified (Oil Skimmer).	Equipment used to remove oil floating on water and is commonly used for oil spill remediations.
Cleaner or More Resource Efficient Technologies and Products	Parts for domestic non-electric thermic appliances (parts of solar stoves).	Parts are used in the maintenance and repair of solar stoves.
Efficient Consumption of Energy Technologies and Carbon Capture and Storage	Auxiliary plant for steam/vapour generating boilers (multiple ex-outs including (i) soot removers, (ii) super-heaters and economisers with a stream or other vapour production, (iii) auxiliary plant for use with steam generating boilers and super-heated water boilers).	Components of industrial air pollution control plant (e.g., soot removers) help minimise the release of pollutants into the atmosphere. This equipment is also used to support waste heat recovery processes in waste treatment, or renewable energy resource recovery applications.
Energy Efficiency	Air conditioners not elsewhere specified with reverse cycle refrigeration (Energy efficient air conditioning machines which conform to the energy efficiency standard and are so certified by the authority in destination country. Also have applications in geothermal heat pump systems).	Energy efficient air conditioners use less electricity and produce less emissions. Geothermal pump systems transfer heat available in land and water masses to heat or cool buildings.
Environmental Monitoring Analysis and Assessment Equipment	Monoculars, telescopes, etc.	Applications in environmental monitoring, analysis, and assessment equipment.
Environmentally Preferable Products based on End-Use or Disposal Characteristics	Parquet panels and tiles, of wood (bamboo building products).	Renewable bamboo-based products are substitutions of wooden necessities. Since bamboo is characterized by a short growing cycle, these environment-friendly products can save a great deal of water, soil and air resources.
Gas Flaring Emission Reduction	Industrial furnace, oven, incinerator non-electric not elsewhere specified (waste incinerators; heat or catalytic incinerators).	Used to destroy solid and hazardous wastes. Catalytic incinerators are designed for the destruction of pollutants by heating polluted air and oxidation of organic components.
Heat and Energy Management	Supported catalysts, nickel based.	Heat/energy savings and management.

Category	Example product	Environmental benefit
Management of Solid and Hazardous Waste and Recycling Systems	Sheet/film not cellular/reinforced polymers of ethylene (HDPE or flexible membrane landfill liners and/or covers for methane collection; plastic and polyethylene geomembranes for soil protection, water tightness, anti-erosion of soil...).	Membrane systems have multiple uses including (i) to line landfills to prevent leachate (water run-off) from contaminating groundwater resources, (ii) to cover landfills and prevent methane from escaping into atmosphere and (iii) for the reinforcement and protection of soil, including under oil refineries, gas stations etc.
Natural Resource Protection	Binder or baler twine, of sisal or agave.	More biodegradable than synthetic fibre alternatives and made from a renewable resource. When used in fishing nets that include use of turtle excluder devices, reduces turtle mortality by 90-100 per cent.
Natural Risk Management	Photogrammetrical surveying instruments, appliances.	Photogrammetry is an aerial remote sensing technique which forms the baseline of many Geographic Information Systems (GIS) and Land Information Systems (LIS), which are important for monitoring and managing natural risks such as floods or earthquakes.
Noise and Vibration Abatement	Air or gas compressors, hoods (industrial hoods; aerators; blowers; and diffusers).	Air handling equipment. Transport or extraction of polluted air, corrosive gases, or dust.
Renewable Energy	Towers and lattice masts, iron, or steel (prefabricated modular type joined by shear connectors of towers for wind turbine).	Used to elevate and support a wind turbine for the generation of renewable energy.
Resources and Pollution management	Air compressors mounted on wheeled chassis for towing (air compressors used in the transportation or extraction of polluted air, corrosive gases, or dust).	Air handling equipment. Transport or extraction of polluted air, corrosive gases, or dust.
Waste Management, Recycling and Remediations	Mats, matting and screens, vegetable plaiting material (from coconut fibre/coco-coir).	Used for soil erosion as a soil cover, biodegradable from waste.
Wastewater Management and Potable Water Treatment	Limestone materials for manufacture of lime or cement.	Used in chemical recovery systems for wastewater management.
Water supply	Mineral and aerated waters not sweetened or flavoured.	Potable water supply and distribution.
Others	Distilling or rectifying plant (distilling apparatus for desalination systems, biogas refinement equipment and solvent recycling plants).	Desalination plants remove salt from water and are important in conditions of water scarcity. Biogas refinement equipment "upgrades" biogas resulting from organic matter to give it the same properties as natural gas. Allows the recovery and reuse of solvents, (e.g., solvents used in the printing, painting or dry-cleaning industries).

Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

Measuring green competitiveness

Industrial development is often path-dependent[6]; this is supported by empirical evidence showing that countries and regions are significantly more likely to develop competitiveness in products and services which require similar capabilities to those they already possess[7]. There is further evidence to suggest that countries which specialise in more technologically sophisticated products tend to enjoy greater income and growth[8].

To capture these phenomena, we employ an approach first introduced by Hidalgo et al.[9] and extended by Mealy and Teytelboym[10] to measure competitiveness in exporting green products. The proximity of a product to a country's current capabilities is strongly associated with the probability that this country will develop competitiveness in this product in the future (if it does not already export it competitively)[11]. We use the algorithm developed by Hidalgo et al.[12] to calculate the Product Complexity Index (PCI), which is a proxy for technological sophistication[13]. This report will also occasionally refer to the Economic Complexity Index (ECI), which measures the overall complexity of a country’s export basket.

The product space can be visualised as a network of products (Figure 1), some of which are closer to each other and some of which are further apart. It shows that more technologically sophisticated activities, such as producing machinery or chemicals, are in the denser “core”, while agriculture or resource extraction are in the periphery. This difference in density implies that specialising in sectors which are located in the core opens up new proximate industrial diversification paths which are both more numerous and higher in complexity[14].

---

6 M Grubb, Jean Charles Hourcade, and K Neuhoff, Planetary Economics: Energy, Climate Change and the Three Domains of Sustainable Development, Planetary Economics (London, UK, 2014) <https://doi.org/10.4324/9781315857688>.

7 Cesar Hidalgo et al. ‘The Product Space Conditions the Development of Nations’, Science, 317.5837 (2007) <https://doi.org/10.1126/science.1144581>; Frank Neffke, Martin Henning, and Ron Boschma, ‘How Do Regions Diversify over Time? Industry Relatedness and the Development of New Growth Paths in Regions’, Economic Geography, 87.3 (2011) <https://doi.org/10.1111/j.1944-8287.2011.01121.x>.

8 Cesar Hidalgo, B. Klinger, A.-L. Barabasi, and R. Hausmann. 2007. “The Product Space Conditions the Development of Nations.” Science 317(5837) <https://doi.org/10.1126/science.1144581>; Ricardo Hausmann, Jason Hwang, and Dani Rodrik, ‘What You Export Matters’, Journal of Economic Growth, 12.1 (2007) <https://doi.org/10.1007/s10887-006-9009-4>.

9 Cesar Hidalgo, B. Klinger, A.-L. Barabasi, and R. Hausmann. 2007. “The Product Space Conditions the Development of Nations.” Science 317(5837) <https://doi.org/10.1126/science.1144581>.

10 Penny Mealy and Alexander Teytelboym, ‘Economic Complexity and the Green Economy’, Research Policy, 2020, 103948 <https://doi.org/10.1016/j.respol.2020.103948>

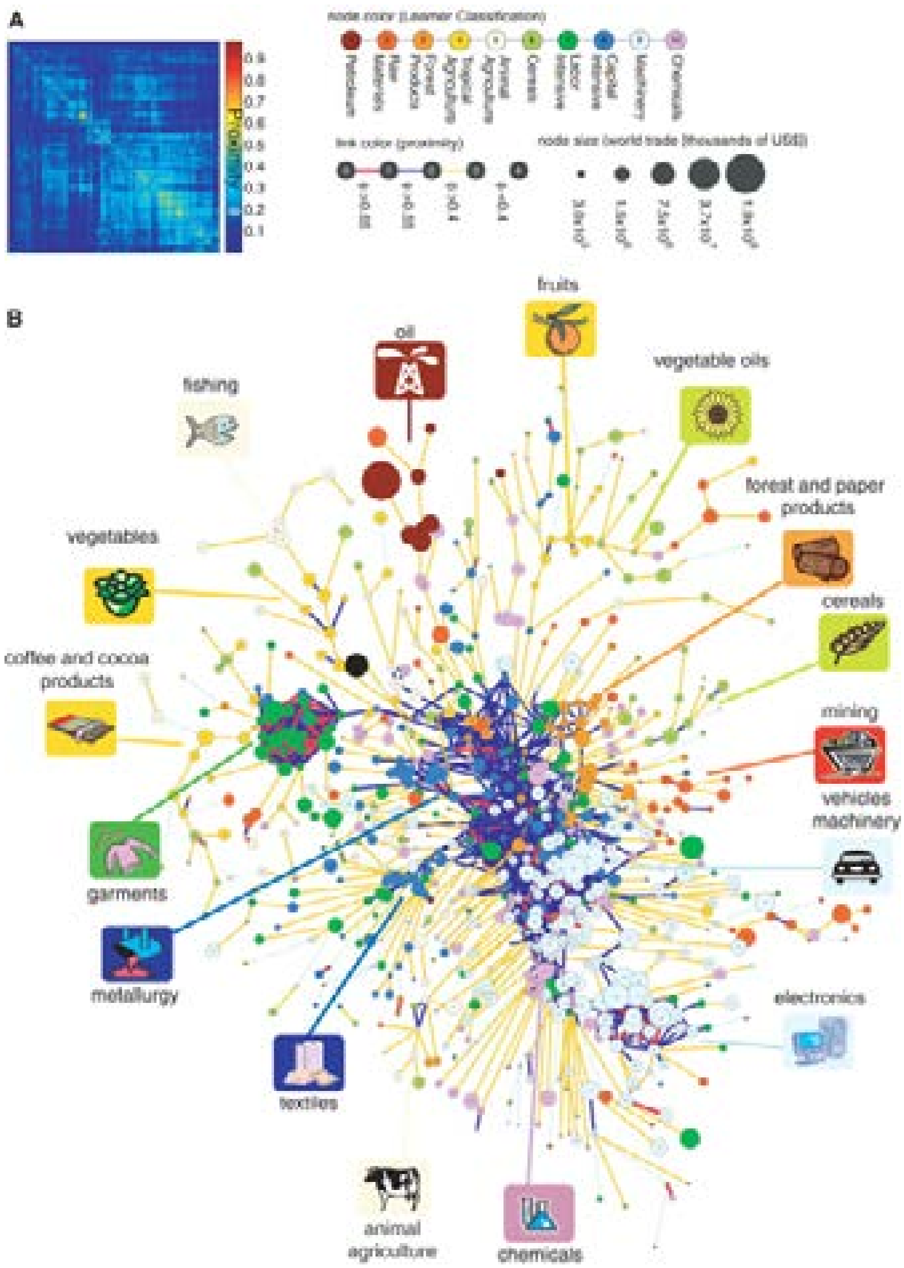
11 Cesar Hidalgo, B. Klinger, A.-L. Barabasi, and R. Hausmann. 2007. “The Product Space Conditions the Development of Nations.” Science 317(5837) <https://doi.org/10.1126/science.1144581>.

12 Ibid.

13 The Product Complexity Index (PCI) and the Economic Complexity Index (ECI) are dimensionality reduction algorithms which are calculated conjointly. PCI ranks products according to the similarity of the countries which export them, while ECI ranks countries according to the similarity of their export baskets. Countries which are higher in ECI tend to be higher-income, grow faster, and export products which are high in PCI. PCI is used as a proxy for technological sophistication. Intuitively, products which are high in PCI are those located in the denser core of the product space (Figure 3: the product space). C. A. Hidalgo and R. Hausmann, ‘The Building Blocks of Economic Complexity’, Proceedings of the National Academy of Sciences, 106.26 (2009) <https://doi.org/10.1073/pnas.0900943106>; Penny Mealy, J. Doyne Farmer, and Alexander Teytelboym, ‘Interpreting Economic Complexity’, Science Advances, 5.1 (2019) <https://doi.org/10.1126/sciadv.aau1705>.

14 Cesar Hidalgo, B. Klinger, A.-L. Barabasi, and R. Hausmann. 2007. “The Product Space Conditions the Development of Nations.” Science 317(5837) <https://doi.org/10.1126/science.1144581>.

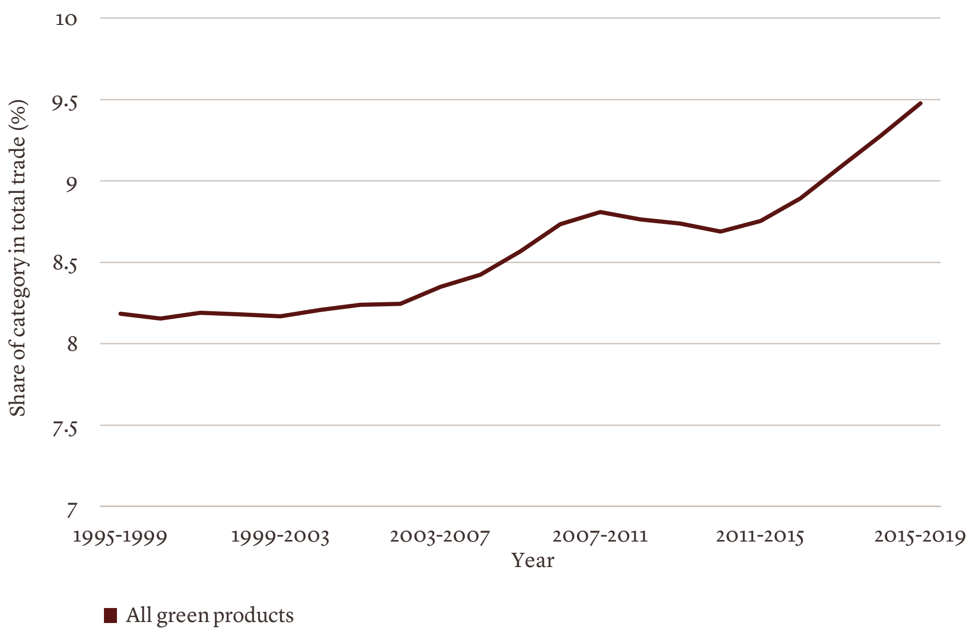
Fig 1: The product space



Source: Hidalgo, C.A., Klinger, B., Barabási, A.L. and Hausmann, R., 2007. The product space conditions the development of nations. Science, 317(5837), pp.482-487. Reprint with permission.

We apply the approach of Mealy and Teytelboym[15] here and combine these measures of complexity with the WTO, OECD, and APEC lists of traded green products to develop indices of green complexity (at times referred to as "green competitiveness"). We use two key metrics to assess countries' progress in capitalising on the growing green product market. The Green Complexity Index (GCI) measures the number and complexity of green products that a country has exported competitively. It constitutes a composite measure of green competitiveness. Due to the aforementioned path dependency often observed in industrial development, identifying products that are closely related to a country's capabilities can provide some insight into what those future paths might look like. The Green Complexity Potential (GCP) measures each country's average proximity to complex green products that it does not yet export competitively. It has been shown to be a significant predictor of a country's future GCI[16]. To prevent our analysis from being skewed by short-term fluctuations in trade, we use annual average values over rolling 5-year periods (1995-1999, 1996-2000, etc). For more detail on the mathematical representation and interpretation of PCI and ECI, please refer to the Appendix and Mealy et al. 2019[17].

Fig. 2: Change in share of green products in global trade



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

15 Mealy and Teytelboym, 2020.
16 Mealy and Teytelboym, 2020.
17 Penny Mealy, J. Doyne Farmer, and Alexander Teytelboym. 2019. "Interpreting Economic Complexity." Science Advances 5(1).

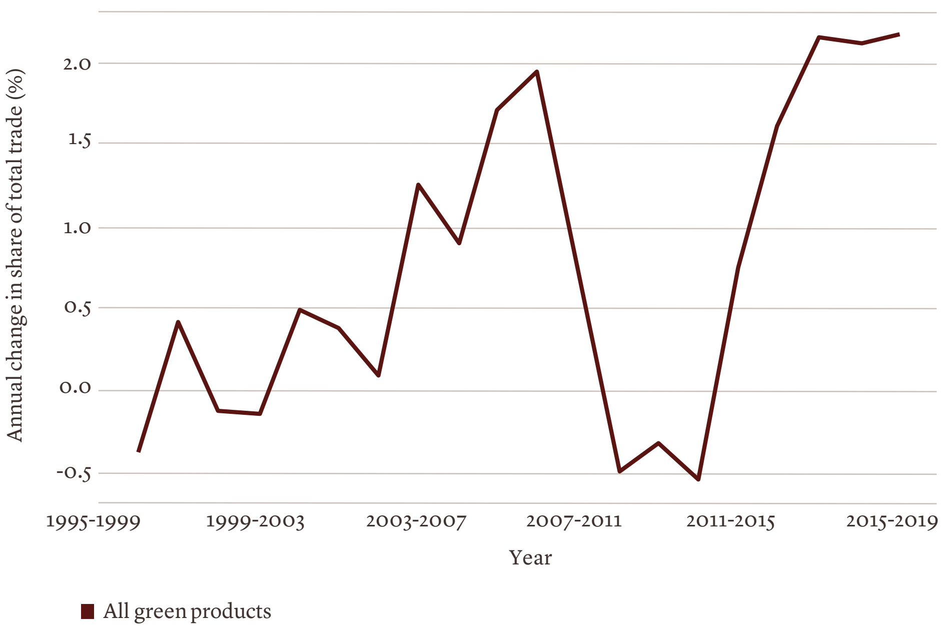
Analysis of recent and past trends in green trade volumes

The share of green products in global trade has increased from roughly 8.2% in 1995-1999 to 9.4% in 2015-2019 (Figure 2). This upwards trend recovered around 2010, following a slight dip after the global financial crisis. Note that the decline following the global financial crisis in 2009 is relative to total export volume and thus in addition to the absolute decline in export volume. Most striking is the positive trend in the share of green trade over the last 4 years, showing a rate of increase slightly above 2% since 2013-2017. If global green share continues to grow at this rate it could make up roughly 17-18% of total trade by mid-century.

While this is a modest increase, we might expect green products to increase in significance even more rapidly as renewable technologies become even more competitive[18], and as countries around the world start to implement net-zero-CO2 emissions targets, COP26-revised ambitions, and the UN Sustainable Development Goals.

Among the countries analysed in this report, the importance of “green” in country-level exports is uneven (Figure 4).

Fig. 3: Change in share of green products in global trade



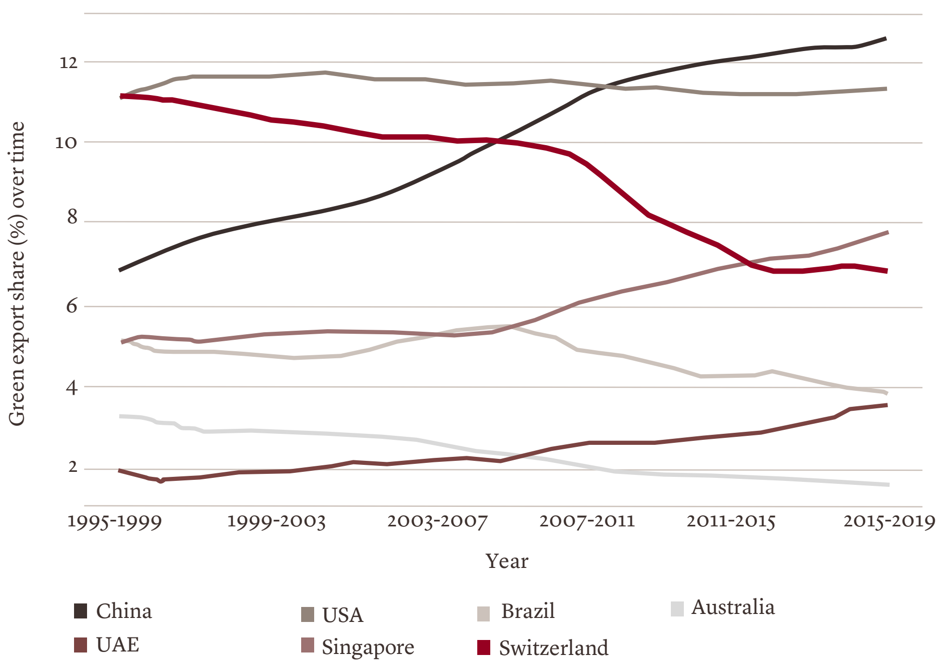
Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

[18] Rupert Way and others, Empirically Grounded Technology Forecasts and the Energy Transition, 2021 <https://www.inet.ox.ac.uk/publications/no-2021-01-estimating-the-costs-of-energy-transition-scenarios-using-probabilistic-forecasting-methods/>.

The share of green products in US exports has remained around 11% throughout the period, while China's green share increased from 7% to about 12% between 1995 and 2019. Singapore also shows an increasing trend, from 5% to 8%, as do the United Arab Emirates (albeit from a much lower starting point). Conversely, Switzerland, Brazil, and Australia have seen a decline in the share of their exports that are classified as "green".

Within the set of products which are defined as "green", the most significant sub-categories are renewable energy (currently 3.53% of total trade and 37.28% of green trade); efficient

Fig 4: Green export share (%) over time for key countries assessed in this report

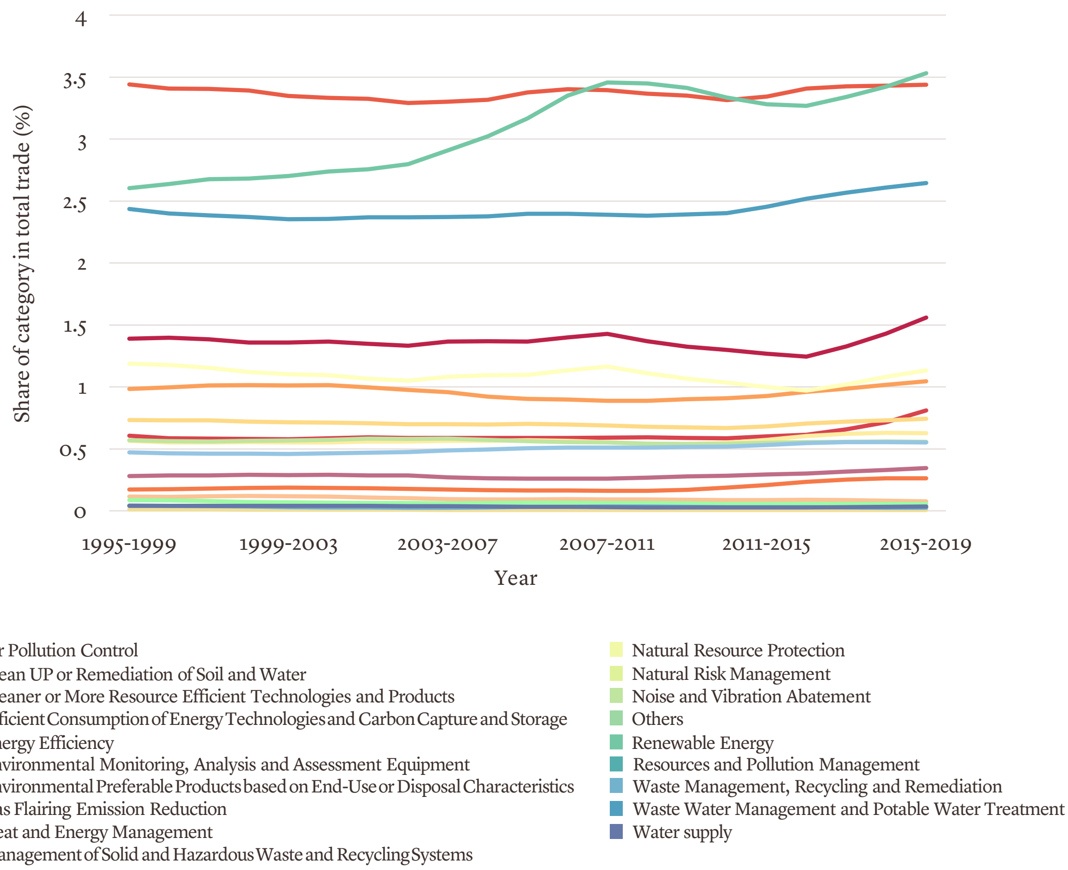


Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

consumption of energy technologies and carbon capture and storage (3.44% of total trade and 36.28% of green trade); and wastewater management and potable water treatment (2.65% of total trade and 27.92% of green trade) (Figure 5).

Renewable energy technologies (which include products such as wind turbines and solar panels) have increased their share of global trade volumes by close to 1 percentage point and may grow more rapidly in the future as the world transitions to clean energy and net zero[19].

Fig. 5: The share of green product categories in global trade from 1995-1999 to 2015-2019



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

[19] M.C. Ives et al, A New Perspective on Decarbonising the Global Energy System, Oxford University Smith School of Enterprise and the Environment, 2021 <www.energychallenge.info>.

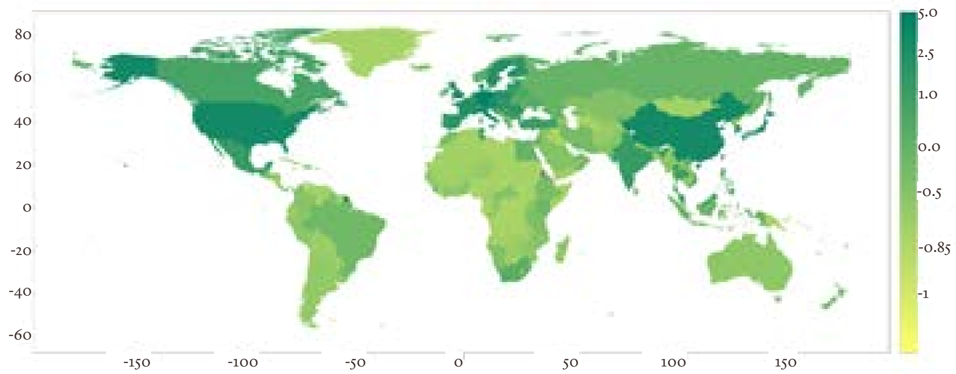
Which countries are currently well placed to succeed in the green economy?

Green competitiveness is currently spread unevenly around the world (Figure 6). Europe, North America, China, Japan, and India rank highly among regions for green complexity; Africa, Australia and parts of South America rank lowest. Germany currently holds top rank in GCI[20] (and has done so throughout the last two decades), followed by Italy, Austria, and the US. Among the countries analysed in this report, the US ranks highest, but is currently in a tight race with China, which has manufactured a dramatic increase in its GCI over the course of the period (Figure 7). Singapore and the UAE have increased their GCI slightly. Brazil, Australia, and Switzerland have all unfortunately lost green competitiveness over the past 15 years.

The disparity between countries that is shown in Figure 6 is explained to some extent by the fact that green competitiveness appears to have a clear positive correlation with income level, as shown in Figure 8.

Most countries with below-average GDP per capita also rank below average in GCI, such as Brazil. Countries with high GCI tend to be higher-income, such as the US, Switzerland, or Singapore. Nevertheless, there are low- and middle-income countries with above-average GCI, such as China, and high-income countries with relatively low GCI, such as Australia and the UAE.

Fig. 6: World map with countries coloured according to their Green Complexity Index (GCI). Note the logarithmic colour scale.

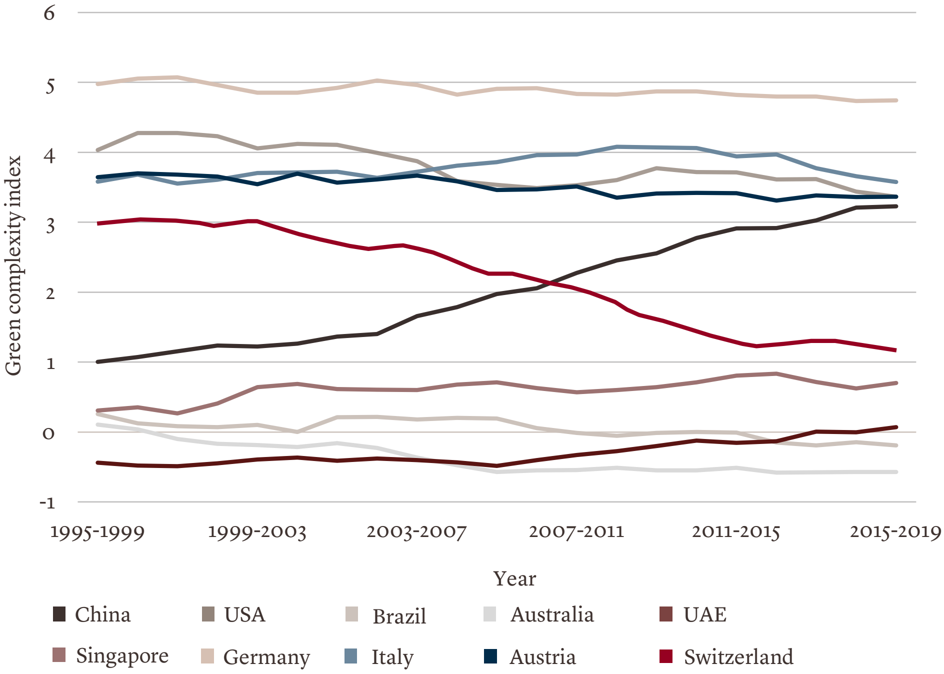


Source: Andres, P and Mealy, P (2021) *Green Transition Navigator.* Retrieved from www.green-transition-navigator.org.

---

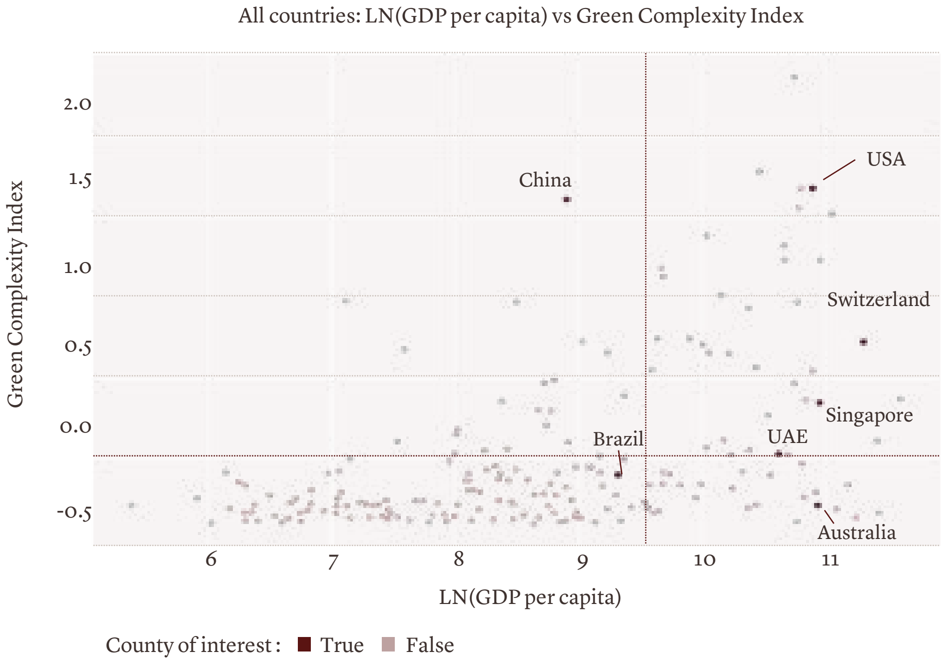
[20] The top 10 countries by GCI in most recent period are Germany, Italy, Austria, US, China, Japan, Denmark, Czech Republic, United Kingdom, France, and Sweden.

Fig. 7: GCI through time for the countries assessed in this report as well as the top 3 ranked countries - Germany, Italy, and Austria



Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

Fig. 8: GCI against income {log(GDP per capita)} for all countries



Source: World bank GDP data 2019 in current US dollars sourced on 25 June 2021 from https://data.worldbank.org/indicator/NY.GDP.MKTP.KD

Which countries have the greatest green product growth potential?

The Green Complexity Potential (GCP) provides a measure of a country's proximity to green products that it is not yet competitive in (and those products' PCI). It is a strong predictor of future GCI for that country. Figure 9 shows a world map of GCP by country[21]. The difference between high and low scoring countries is even larger than for the GCI (Figure 7, on previous page) and shows very different patterns. Asia's exports are getting greener, as are southern Europe's, while large parts of Europe and North America are ranked somewhat lower by GCP than they are by GCI. Africa and South America have diverging regions. China currently ranks first in the world on GCP, followed by Italy and Spain.

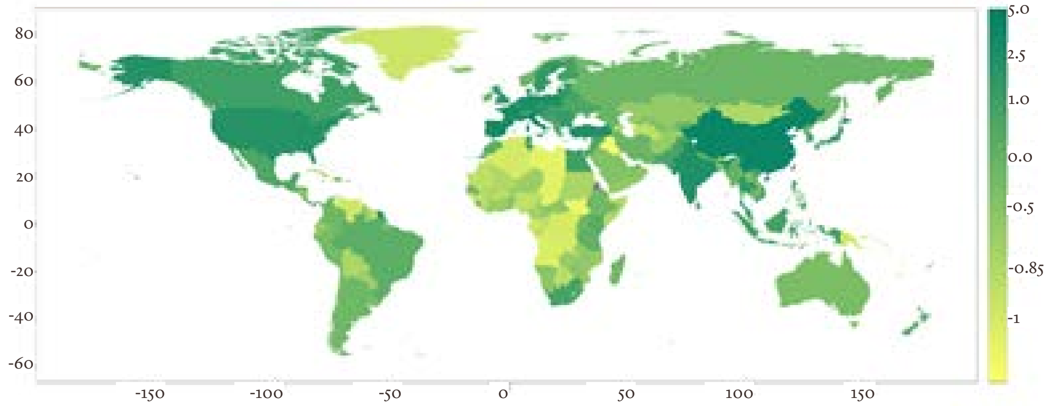
Among the countries considered in this report, GCP has been increasing steadily for China, while staying stagnant for the US and Singapore (Figure 10). The UAE have seen a slight uptick in GCP, predicting a potential further increase in green competitiveness. As with their GCI rankings, GCP has declined for Brazil, Australia, and Switzerland[22].

In the absence of policy action to counter-act these trends, all three countries may experience further declines in GCI in the future.

21 The top 10 countries by GCP are China, Italy, Spain, France, Germany, Turkey, Poland, India, Austria, and the Netherlands.

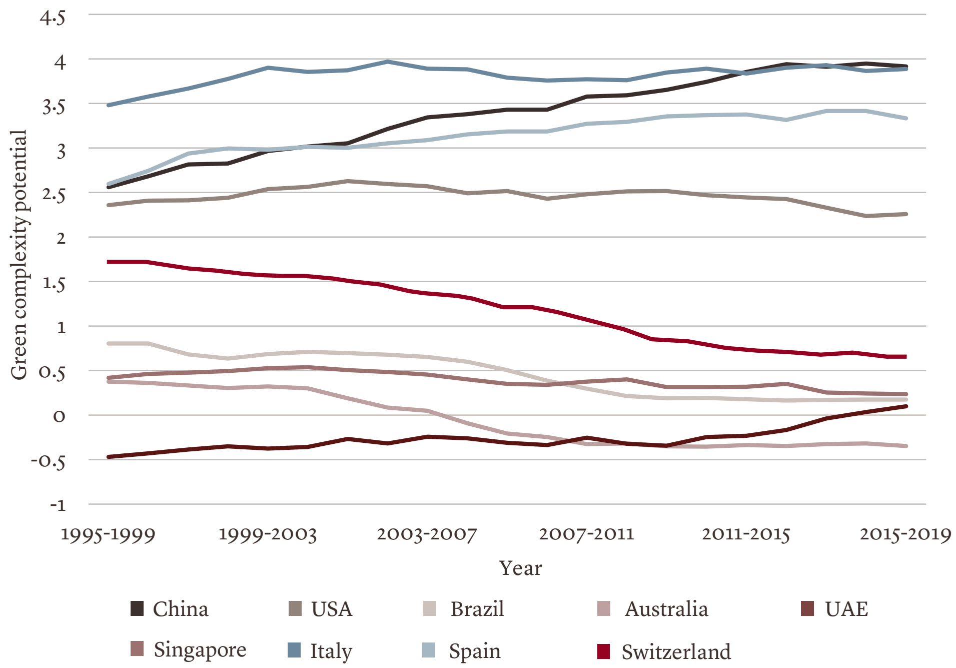
22 Switzerland is combined with Liechtenstein in the Green Transition Navigator used for GCI, GCP and its RCA as both countries report trade data conjointly to UN Comtrade..

Fig. 9: World map with countries coloured according to their Green Complexity Potential (GCP). Note the logarithmic colour scale.



Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

Fig. 10: Green Complexity Potential through time for the countries examined in this report, as well as Italy and Spain who along with China make up the top three ranked countries; and Germany, which holds top rank in GCI.



Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

Which countries have the greatest green energy potential?

With the recent pledges from China, India, Australia, and the new US administration, about 135 countries have declared a Net Zero or Carbon Neutrality goal, covering 88% of global greenhouse gas emissions, 90% of the world's GDP and 85% of the world's population[23]. As the energy sector is considered one of the easiest to decarbonise, and the largest source of emissions (nearly three quarters of global greenhouse gas emissions)[24], it is the sector where the greatest progress towards these goals has already taken place. Europe, the UK, and the US have all seen a gradual decline in emissions since 2010 despite continuing growth in GDP[25]. Much of this progress has come from fuel switching from coal to gas, but renewables such as solar and wind have seen impressive growth in recent years[26].

With growing confidence in continued demand for green energy products has come an impressive increase in new investment in projects to meet this demand. The Asian Renewable Energy Hub (AREH) along the north coast of Western Australia (WA) is currently in its planning stage. With a capacity of 26GW it will, if completed, rank as the world's largest energy development project, topping even China's 22 GW Three Gorges Dam development. The AREH project plans to export most of its energy production to Indonesia and Singapore through high voltage submarine power cables and as green ammonia (hydrogen-based fuel).

Similar large scale green energy projects are also in planning in the northern hemisphere, with a $5 billion-dollar green hydrogen production facility planned for NEOM, Saudi Arabia[28]. When operational, it will be powered by 4 GW of solar, wind and storage and plans to produce roughly 650 tons per day of green hydrogen for export to Europe and globally, most likely to meet the growing demands for clean transport fuels in busses and heavy goods vehicles.

Given recent persistent declines in the cost of renewables[29], countries are looking to green energy production not only for export opportunities but as a means of reducing their own dependence on imports of fossil fuels. Most recently, India's Prime Minister Narendra Modi announced a National Hydrogen Mission for the country.

---

23 Net Zero Tracker, Accessed 14/11/2021 https://www.zerotracker.net/ .
24 Hannah Ritchie and Max Roser (2020) - "CO_2 and Greenhouse Gas Emissions". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions'.
25 William F. Lamb and others, 'A Review of Trends and Drivers of Greenhouse Gas Emissions by Sector from 1990 to 2018', Environmental Research Letters, 2021 <https://doi.org/10.1088/1748-9326/abee4e>.
26 Lamb and others.
27 https://asianrehub.com/.
28 https://www.ammoniaenergy.org/articles/saudi-arabia-to-export-renewable-energy-using-green-ammonia/
29 J.D. Farmer and François Lafond, 'How Predictable Is Technological Progress?', Research Policy, 45.3 (2016), 647–65 <https://doi.org/10.1016/j.respol.2015.11.001>.

India now has some of the lowest solar costs “in history”[30] which will be leveraged, along with the country’s large land mass, to produce low-cost green hydrogen and ammonia, and hopefully to build an Indian electrolyser manufacturing capability[31]. The proposal involves making it mandatory for Indian fertiliser plants and oil refineries to purchase green hydrogen, thereby creating domestic demand and reducing the nation’s dependence on fossil fuels.

Renewable energy increasingly appears to be playing a central role in decarbonising the energy sector. However, mitigating emissions through renewables will require a) the electrification of a greater part of the energy sector, and b) the use of energy storage in the form of batteries and green fuels, such as green ammonia and e-methanol. Producing clean energy will require both sufficient clean energy sources (e.g., solar radiation or wind), and the equipment to harness it for human use.

Within our list of 295 “green” products, 62 relate to renewable energy – these include products such as “towers and lattice masts, iron or steel” which are used to “elevate and support a wind turbine for the generation of renewable energy”; “hydraulic turbines, water wheels” with different power levels and parts thereof, used for hydropower generation; photosensitive/photovoltaic/LED semiconductor devices – i.e., solar photovoltaic cells; and others[32]. Our dataset therefore allows us to identify which countries are well-placed to competitively export this equipment to meet these growing markets.

As more and more countries transition to net zero, they will need increasing amounts of such equipment from domestic production or imports. Countries which produce clean energy or relevant equipment will therefore likely enjoy increase global demand for their exports. Our analysis shows that renewable energy has gained the most in terms of share of global trade values in recent decades (Figure 5).

Renewable energy is a key consideration in any strategy to carve out a competitive advantage in a net zero economy. Countries must consider which parts of the value chain are feasible for them to capture given existing comparative advantage; but also, which are high in value added. Given input-output linkages as one driver of agglomeration economics, a comparative advantage in producing energy from a renewable source may be a “way in” to higher value-added parts of the supply chain (such as manufacturing technologically sophisticated equipment). This is particularly relevant in cases where transport costs matter.

---

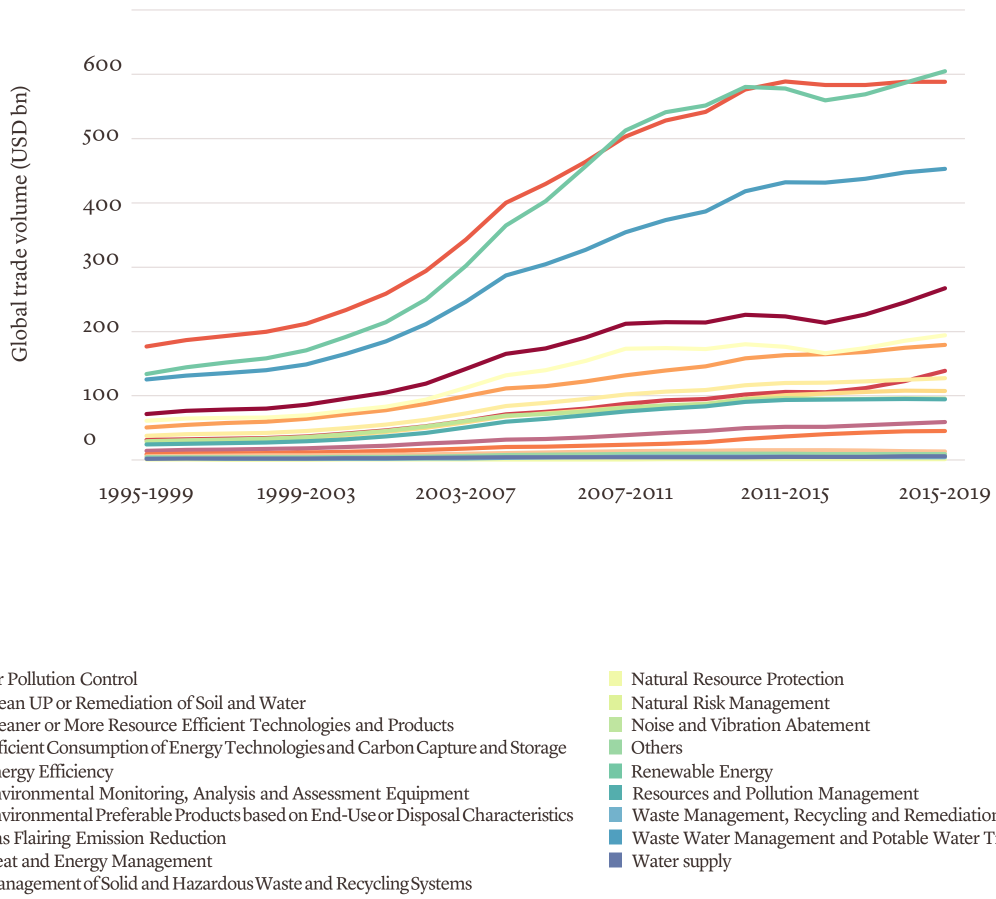
30 IEA, World Energy Outlook 2020, 2020, MML.

32 Electrolysers are the main technology used to generate hydrogen from water.

32 Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

With renewable energy exports growing from $133bn in 1995-1999 to $604bn in 2015-2019 (Figure 11) and demand for green fuels also growing, the question arises as to which countries are most likely to benefit from the decarbonisation of global energy.

Fig. 11: Global trade volume for green products (USD billions)



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

To answer this question, we must first look at the renewable energy potential available around the world. The potential availability of renewable energy sources varies over time and location. This variation is not only caused by climatic or resource characteristics, but also by topography, land cover/land use, labour costs, access to finance, and political support. The geographical and technical potential[33] for energy from solar and wind from renewables does not appear to be a limiting factor globally, with estimates of global solar resources ranging from between 1,500 and 50,000 EJ/yr (onshore and offshore wind resources ranging from between 1,000 and 3,000 thousand EJ/year; bioenergy between 34 and 1,270 EJ/yr; and hydropower between 30 and 52 EJ/yr)[34]. Utilising some of these energy sources will exclude others in certain locations[35], but the combined total global technical potential is at least between 3 to 50 times greater than current global primary energy demand, which lies at around 600 EJ[36].

With such enormous global potential, the question then moves on to which countries might have a competitive advantage in terms of their access to these renewable resources. China, Brazil, and the US have the world's largest hydro and biomass resources, both of which provide valuable dispatchable energy generation. However, these resources are dwarfed by the combined solar and wind potential of the planet, and they do not appear to have the same potential for declining costs shown by solar and wind[37].

---

33 The geographical potential is the energy flux theoretically extractable in areas that are considered suitable and available for this production i.e. in areas which are not excluded by other incompatible land cover/use and/or by constraints set on local characteristics such as elevation and minimum average wind speed; the technical potential is the geographical potential after the losses of the conversion from the extractable primary energy flux to secondary energy carriers or forms (electricity, fuel) are taken into account Bert J M de Vries, Detlef P van Vuuren, and Monique M Hoogwijk, 'Renewable Energy Sources: Their Global Potential for the First-Half of the 21st Century at a Global Level: An Integrated Approach', Energy Policy, 35.4 (2007), 2590–2610 <https://doi.org/10.1016/J.ENPOL.2006.09.002>.

34 Bert J M de Vries, Detlef P van Vuuren, and Monique M Hoogwijk, 'Renewable Energy Sources: Their Global Potential for the First-Half of the 21st Century at a Global Level: An Integrated Approach', Energy Policy, 35.4 (2007), 2590–2610 <https://doi.org/https://doi.org/10.1016/j.enpol.2006.09.002>; Patrick Moriarty and Damon Honnery, 'What Is the Global Potential for Renewable Energy?', Renewable and Sustainable Energy Reviews, 16.1 (2012), 244–52 <https://doi.org/https://doi.org/10.1016/j.rser.2011.07.151>; Elise Dupont, Rembrandt Koppelaar, and Hervé Jeanmart, 'Global Available Wind Energy with Physical and Energy Return on Investment Constraints', Applied Energy, 209.July 2017 (2018), 322–38 <https://doi.org/10.1016/j.apenergy.2017.09.085>; Elise Dupont, Rembrandt Koppelaar, and Hervé Jeanmart, 'Global Available Solar Energy under Physical and Energy Return on Investment Constraints', Applied Energy, 257.October 2019 (2020), 113968 <https://doi.org/10.1016/j.apenergy.2019.113968>; Hans-Holger Rogner and others, 'Energy Resources and Potentials', Global Energy Assessment (GEA), 2012, 425–512 <https://doi.org/10.1017/cbo9780511793677.013>; Kelly Eurek and others, 'An Improved Global Wind Resource Estimate for Integrated Assessment Models', Energy Economics, 64 (2017), 552–67 <https://doi.org/10.1016/j.eneco.2016.11.015>; Stephanie Searle and Chris Malins, 'A Reassessment of Global Bioenergy Potential in 2050', GCB Bioenergy, 2015, 328–36 <https://doi.org/10.1111/gcbb.12141>.

35 de Vries, van Vuuren, and Hoogwijk, 'Renewable Energy Sources: Their Global Potential for the First-Half of the 21st Century at a Global Level: An Integrated Approach'.

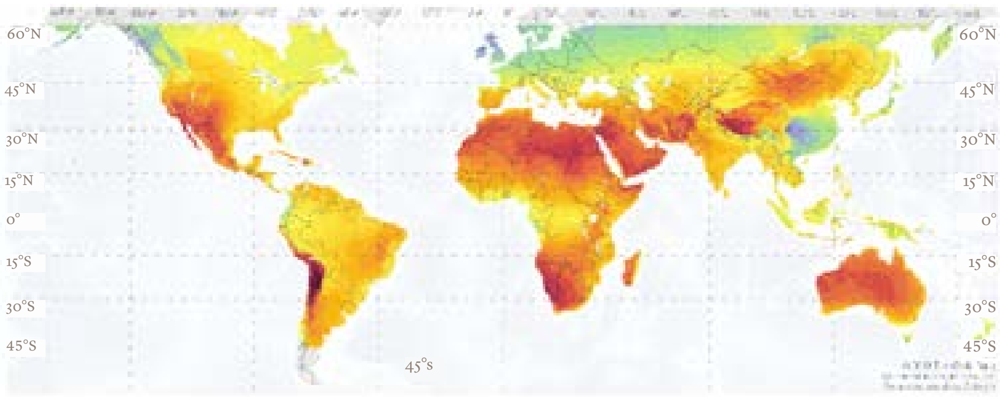
36 IEA, MML.

37 Way and others.

The distribution of solar and wind resources also appears to be quite variable on a global scale, with solar irradiance highest in the tropical regions (Figure 12), and wind potential, particularly offshore which has the greater energy potential, highest in the temperate regions (Figure 13). Given this apparent abundance of solar and wind resources, how much each will contribute to the energy mix in any given country at any point in time will depend on the economic viability of these resources in comparison to alternative sources of energy – their economic potential[38].

Global estimates of the economic potential of renewables have concluded that most countries will have access to sufficient cost-effective solar and wind resources to meet their domestic electricity demands when the local levelized costs for these technologies go below 10c/kWh[41].

Fig 12: A map of estimated solar photovoltaic (PV) power generation potential expressed as kWh/kWp (kWp=kilowatt potential)[39].



Long-term average of photovolaic power potential (PVOUT)
Daily totals: 2.0 2.4 2.8 3.2 3.6 4.0 4.4 4.8 5.2 5.6 6.0 6.4
kWh/kWp
Yearly totals: 730 876 1022 1168 1314 1461 1607 1753 1899 2045 2191 2337

Source: https://globalsolaratlas.info[40]

[38] The economic potential is the technical potential up to an estimated production cost of the secondary energy form, which is competitive with a specified, locally relevant alternative. A flexible way to represent the economic potential is in the form of the energy production potential as function of the production cost, the so-called long-run supply cost curve - de Vries, van Vuuren, and Hoogwijk, 'Renewable Energy Sources: Their Global Potential for the First-Half of the 21st Century at a Global Level: An Integrated Approach'.

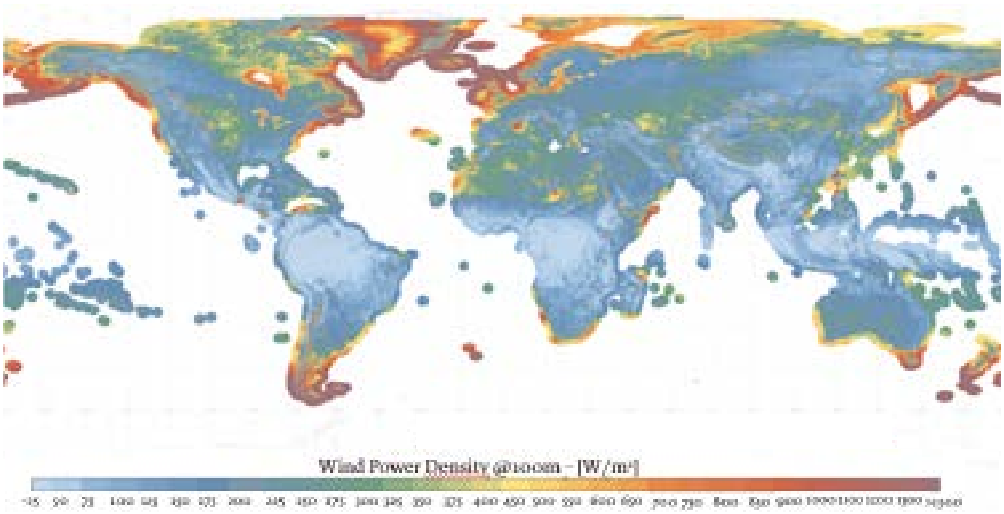
[39] Fig 12 represents the long-term average of yearly/daily potential electricity production from a 1 kW-peak grid-connected solar photovoltaic (PV) power plant.

[40] Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info

With about 75% of the world's population living in regions where the levelised cost of solar PV is now already at or below 12c/kWh[42], and given solar costs have declined consistently at around 10% per year since 1980[43], it appears that most countries will have access to this domestic economic potential well before 2030.

This consistent and rapid decline in solar costs potentially explains the exponential increase in solar deployment, (Figure 14)[44] which is likely to overtake hydropower as the primary source of green energy before the end of this decade.

Fig. 13: A map of global wind power density potential expressed as W/m2 at 100m height.



Source: https://globalwindatlas.info/[45]

---

41 de Vries, van Vuuren, and Hoogwijk, 'Renewable Energy Sources: Their Global Potential for the First-Half of the 21st Century at a Global Level: An Integrated Approach'.

42 World Bank, Solar Photovoltaic Power Potential by Country, 2020 <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/466331592817725242/global-photovoltaic-power-potential-by-country> [accessed 30 November 2020].

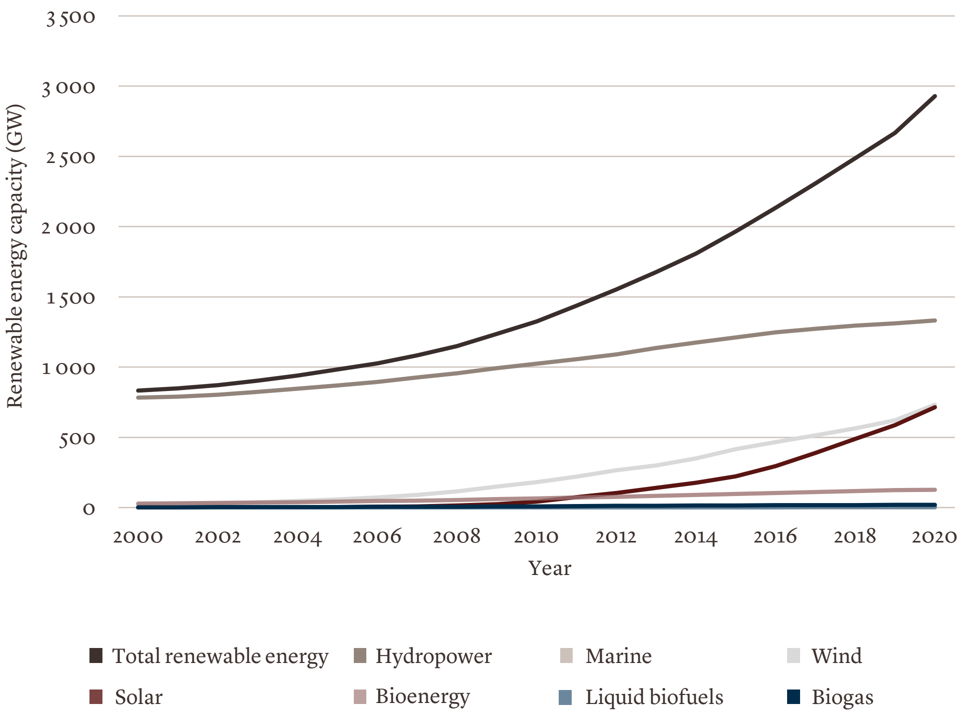
43 Farmer and Lafond 2016.

44 See Way et al. (2021) Figure 1 for a clearer graphical representation of the exponential increase in deployment of solar and wind over the last two decades.

45 Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info

The most compelling implication of this global potential for renewables and the steady decline in their costs is that the countries most likely to gain from the clean energy transition are those which manufacture and export equipment for renewable energy generation and integration - such as solar panels, wind turbines, electrolysers, and batteries[46]. Based on current export data, (Figure 15) this would include China, Germany, the United States, Japan, South Korea, and Italy.

Fig. 14: Global renewable energy generation by source



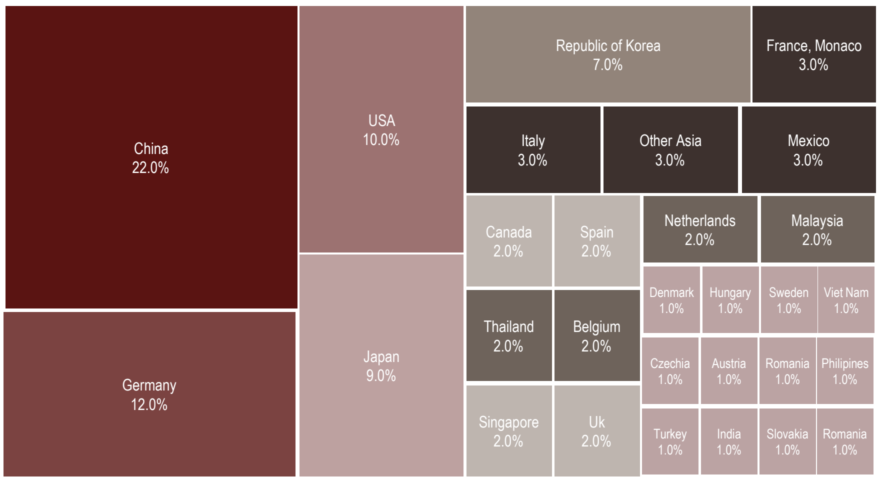
Source: IRENA (2021), Renewable Capacity Statistics 2021; & IRENA (2020), Renewable Energy Statistics 2020, The International Renewable Energy Agency, Abu Dhabi.

[46] Note that these are not the only technologies that make up the renewable energy product category, but they are the most predominant.

Each of these countries (along with Denmark) were early adopters of renewable technologies – suggesting that early efforts to decarbonise can translate into green export competitiveness and growth.

In the short term, there will also be opportunities for countries that possess a natural advantage, such as those countries which already have access to sufficient solar and wind at costs below 10c/kWh (e.g., India, Australia, China, Chile, and Brazil), to not only meet their own clean energy goals but to potentially export low-cost green energy at a premium to regions facing either long-term or short-term limits (e.g., Europe, Japan, and Singapore).

Fig. 15: Largest exporters of Renewable Energy products from 2015-2019



Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

Table 2 provides estimates of the current economic potential for each of the major renewable energy sources for a range of countries, including the seven countries included as case studies in this report. The potentials for each renewable resource are combined[47] in an estimate of total economic generation potential per capita, which is then compared with each country's current average energy usage per capita, to provide an indication of the green energy export potential for each country. The countries in Table 2 are separated by a black line above which are those countries who possess much higher per capita green energy generation potential than the current highest average annual energy usage per capita (89 MWh/yr/cap). This demarcation separates our seven case study countries between Australia, Brazil, Switzerland, and the United States, which have an overabundance, and the UAE, China, and Singapore, which are either close to or below this global maximum average annual energy usage. Such differences in green energy potential will be discussed in more detail for each of these case study countries in Section 4, with a focus on solar potential, given its enormous energy potential and expected continuing declines in costs[48].

Having access to sufficient economic potential for renewable energy does not necessarily mean a country will capitalise on this potential. There will be social and political, as well as technical, barriers to the widespread adoption of renewable technologies in many countries, that might slow or limit the uptake of renewables. However, the list of new major green energy export investments on the horizon suggests that examining differences between countries' green energy potential might provide insights as to which countries are most likely to seize the opportunity presented by renewables.

[47] Utilising some energy sources will exclude others in certain locations (de Vries et al., 2007a). See Appendix for details on how these generation sources are combined.
[48] Farmer and Lafond; Way and others.

Table 2 - Estimates of current technical potential of renewable resources per person compared with current average annual per capita usage for a range of countries, including the seven countries used as case studies in this report.

	Generation potential (EJ/yr)								
	Onshore wind)	Off-shore wind	Solar PV	Hydro	Bio-energy	Est. Total	Population (millions)	Average annual energy usage per capita (MWh/yr/cap)	Total generation potential per capita (MWh/yr/cap)
Australia	230	89	8	<1	8	319.0	25	64	3,408
Norway	5	41	7	1	1	48.0	5	68	2,508
Canada	38	121	104	2	3	225.0	37	89	1,687
Russia	107	123	47	5	10	170.1	144	57	327
US	130	25	174	1	11	200.6	329	79	169
Brazil	80	25	16	3	14	108.0	209	17	141
Japan	4	23	40	<1	<1	62.5	127	40	137
Switzerland	<1	-	4	<1	<1	4	9	34	130
U.A.E.	<1	<1	3	–	<1	3.2	10	89	94
South Africa	28	12	7	<1	1	18.8	58	31	91
China	117	35	218	6	16	376	1,402	26	74
Singapore	<1	<1	1	0	<1	1	6	60	53
Global	**2,005**	**1,134**	**1,008**	**30**	**100**	**3,169**	**7,566**	**58**	**116**

Source: See Appendix for Data

The horizontal line above the UAE is close to the current maximum average annual energy usage per capita. All countries above this line have more green energy potential than would be required for them to consume energy at this current maximum average.

3. Greening the COVID-19 recovery

› Why is a green COVID-19 recovery important?

› A comparison between countries' green indices and green recovery spending

› Clean vs traditional stimulus spending post-COVID-19

› Green recovery and green complexity

› Spending on renewables

› Big spending in the pipeline? The US infrastructure deal and the EU green deal

3. Greening the COVID-19 recovery

Why is a green COVID-19 recovery important?

The research by Mealy and Teytelboym used extensively in this study has provided evidence that countries which rank highly in GCI also tend to have lower emissions, higher green patenting rates, and higher environmental policy stringency – even after controlling for per capita GDP[1]. Moreover, they observe a “green get greener effect”, meaning that it seems to be easier for countries with advanced green production capabilities to diversify into new green export opportunities[2].

Their evidence further suggests that countries that provided more targeted green stimulus packages after the Global Financial Crisis of 2008 tended to experience greater GCI gains in the following years[3]. Building on this pioneering work, we examine in this section the proportion of COVID-19 recovery spending different countries dedicate to the green economy, with the idea that given the enormous sums in current recovery spending plans, these programmes may well influence the green competitiveness of countries over the next decade.

A global comparison between green indices and green recovery spending

COVID-19 represents a global health crisis that has directly impacted the lives of millions around the world. Its health impacts and the subsequent attempts by governments to limit the deleterious public health consequences has led to an economic emergency, affecting the livelihoods of many. Indeed, many governments have had to cope with the trade-off between lockdowns to protect their population and health services, and opening up economic activities to allow people to earn a living[4,5]. In the short term, predominantly higher-income countries countries have been able to provide liquidity for both businesses and individuals to minimise the economic harm of lockdowns and other measures to curtail the pandemic. Recovery spending, on the other hand, is aimed at stimulating longer term and structural re-growth[6].

The Oxford University Economic Recovery Project[7], housed within the Smith School of Enterprise and the Environment at the University of Oxford, investigates the extent to which these fiscal spending plans have prioritised greener alternatives over maintaining current practices.

1 Mealy and Teytelboym (2020)
2 Mealy and Teytelboym (2020)
3 Mealy and Teytelboym (2020)
4 Anton Pichler and others, ‘In and out of the UK Lockdown: Propagation of Supply and Demand Shocks in a Dynamic Input-Output Model’, 2020.
5 e.g., The Economist, ‘How to Assess the Costs and Benefits of Lockdowns’, The Economist, July 2021 <https://www.economist.com/finance-and-economics/2021/07/01/how-to-assess-the-costs-and-benefits-of-lockdowns>.
6 Cameron Hepburn and others, ‘Will COVID-19 Fiscal Recovery Packages Accelerate or Retard Progress on Climate Change?’, Oxford Review of Economic Policy, 36.Supplement_1 (2020), S359–81 <https://doi.org/10.1093/oxrep/graa015>.
7 Brian O’Callaghan and others, Global Recovery Observatory, Oxford University Economic Recovery Project, 2020 <https://recovery.smithschool.ox.ac.uk/tracking/> [accessed 25 June 2021].

Austria, for example, provided liquidity support to its airlines in return for targets on greenhouse gas reductions[8]. Other countries have prioritised renewable energy projects over more traditional infrastructure spending, such as South Korea's recovery investment in smart grid and renewables technologies[9]. The Recovery Project has gathered data on the 50 largest economies as well as an additional 39 emerging market and developing economies[10], put together in the Global Recovery Observatory[11]. For the following analysis, we use data that was available in September 2021 which includes spending plans up to June 2021. Green recovery spending plans announced afterwards or those still being formed are not taken into consideration. The data set is periodically updated and refined, and assessments of what policies are deemed green and count towards recovery spending is done transparently but can be open to interpretation in some cases.

8 Philipp Grüll and Sarah Lawton, 'The Green Compromise in the Austrian Airlines Bailout', Euractiv.Com, 10 June 2020 <https://www.euractiv.com/section/aviation/news/the-green-compromise-in-the-austrian-airines-bailout/>.
9 Sarwat Chowdhury, 'South Korea's Green New Deal in the Year of Transition', UNDP Blog, 2021 <https://www.undp.org/blogs/south-koreas-green-new-deal-year-transition> [accessed 10 August 2021].
10 Oxford University Economic Recovery Project and others, Global Recovery Observatory: Draft Methodology Document, 2021 <https://recovery.smithschool.ox.ac.uk/wp-content/uploads/2021/03/20210201-Global-Recovery-Observatory-Draft-Methodology-Document-.pdf> [accessed 10 August 2021].
11 Available online via https://recovery.smithschool.ox.ac.uk/tracking/

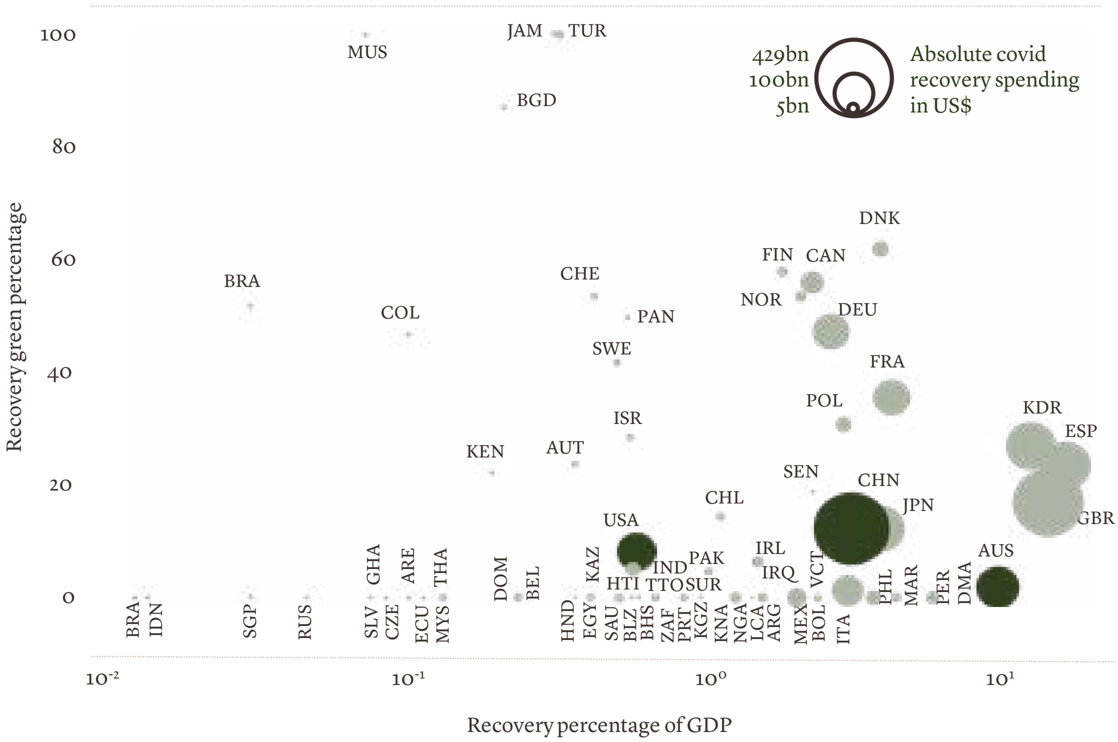
The large discrepancy between countries in terms of the amounts reserved to spend on recovery and the proportion that is green is shown in Figure 16. While some countries have plans to spend up to 10% of GDP on COVID-19 recovery, such as Spain, South Korea, and Australia, others barely reach 0.1%, such as Russia, Singapore, or the UAE. Brazil, despite reserving less than 0.1% of GDP for recovery spending, has pledged over 50% of that amount for green causes. Jamaica, Turkey, and Mauritius are the only three countries that aim to spend their entire recovery budget on green projects, with Bangladesh close behind at 87% green of total recovery spending. The Nordic countries of Norway, Denmark, and Finland spend above 50% on green projects, with total recovery spending at around 2-3% of GDP, while Germany reaches 45% green projects. Switzerland reaches over 50% as well, although on a much smaller total spending plan. China has pledged 12% of its recovery spending to green projects. Until the passing of the recent Infrastructure Bill, the US had pledged less than 10% to green projects. Besides Brazil, all countries we discuss in-depth in this report have used less than 15% of their recovery spending for building a green economy. Both the UAE and Singapore have no green spending plans in their limited recovery spending portfolio. This means that these countries have not (yet) revealed plans to leverage any COVID-19 recovery spending for green investment, but it does not necessarily mean they did not invest in a greener future. For example, Singapore released its Green Plan 2030, which marks a much needed step to green their economy independently of COVID-19[12,13,14].

Clean vs traditional stimulus spending post-COVID-19

It has been suggested that a sustainable recovery could be sufficient to address climate change[15], given the large sums of money involved[16]. However, of the money that is earmarked for long term recovery, only 21% is deemed green[17]. The IEA released a report based on the same dataset, amended with data of their own. Their model estimates that current spending plans only meet 35% of the emission reductions necessary to put countries on a 2050 net-zero emissions pathway. Advanced economies meet about 60%, whereas emerging and developing countries meet only 20%[18].

12 Robert Carnell and Prakash Sakpal, Singapore Green Plan 2030 – Important Steps towards a Sustainable Future, 2021 <https://think.ing.com/articles/singapore-green-plan-2030-important-steps-towards-a-sustainable-future/#a3>.
13 For more on Singapore, see the case study in Section 4. Carnell and Sakpal, 2021.
14 For more on Singapore, see the case study in Section 4.
15 Hepburn et al. 2020.
16 The IEA IEA, Sustainable Recovery Tracker report used the same dataset and estimated that current spending plans only meet 35% of emission reductions necessary to put countries on a 2050 net-zero emissions pathway. Advanced economies meet about 60%, whereas emerging and developing countries meet only 20%. Source IEA, Sustainable Recovery Tracker (Paris, France, 2021) <//www.iea.org/reports/sustainable-recovery-tracker>.
17 https://recovery.smithschool.ox.ac.uk/tracking/ , as of May 25th, 2021
18 IEA, Sustainable Recovery Tracker, 2021.

Fig 16: Covid recovery spending by various countries around the world.
Size of countries denotes absolute recovery spending in US dollars, x axis denotes the recovery spending as percentage of GDP (note the log scale) and the y-axis the percentage of recovery spending that is green. Countries that have no green recovery spending plans have their labels rotated vertically to aid readability.



Source: Note - figure uses slightly different definitions and therefore deviates slightly from figure on Global Recovery Observer https://recovery.smithschool.ox.ac.uk/tracking/

However, some countries do show sustainable leadership, including northern European countries, Spain, and South Korea[19]. Directing COVID-19 recovery funding toward green spending as opposed to neutral or fossil-fuel projects has multiple economic implications on top of decreasing greenhouse gases (GHGs). It provides more future-proof stable jobs[20], minimising fossil fuel stranded asset risk, and directing the economy toward a green growth path[21]. However, emerging market economies appear to suffer from relatively high interest rates and debt constraints[22], limiting their green recovery potential. In this report, we have stressed the path-dependency of development and diversification. Investment in long-lasting fossil-fuel based infrastructure can mean locking an economy into fossil fuels for the foreseeable future, increasing existing inertia of fossil-fuel based energy systems and the risk of asset stranding[23].

Green recovery spending, on the other hand, if significant enough, can accelerate a country's progress and allow its economy to thrive in a world that makes progresses towards net zero targets.

Green recovery and green complexity

The GCI and GCP of all countries are plotted against their green share of recovery in Figure 17. While their spending is small in absolute terms, Brazil and Switzerland are the only two case study countries that plan to spend a significant share of recovery investment on green projects. Other relatively low GCI/GCP countries (Australia, Singapore, and the UAE) barely spend anything on green recovery, while the US and China have green recovery plans of about 9-12% of total recovery spending.

---

19 Brian J. O'Callaghan and Em Murdock, Are We Building Back Better? Evidence from 2020 and Pathways to Inclusive Green Recovery Spending - Summary for Policymakers, 1386 <https://wedocs.unep.org/bitstream/handle/20.500.11822/35282/AWBBB_ES.pdf> [accessed 10 August 2021].

20 Robert Pollin and others, Green Growth A U.S. Program for Controlling Climate Change and Expanding Job Opportunities, 2014; Heidi Garrett-Peltier, 'Green versus Brown: Comparing the Employment Impacts of Energy Efficiency, Renewable Energy, and Fossil Fuels Using an Input-Output Model', Economic Modelling, 61 (2017), 439–47 <https://doi.org/10.1016/j.econmod.2016.11.012>.

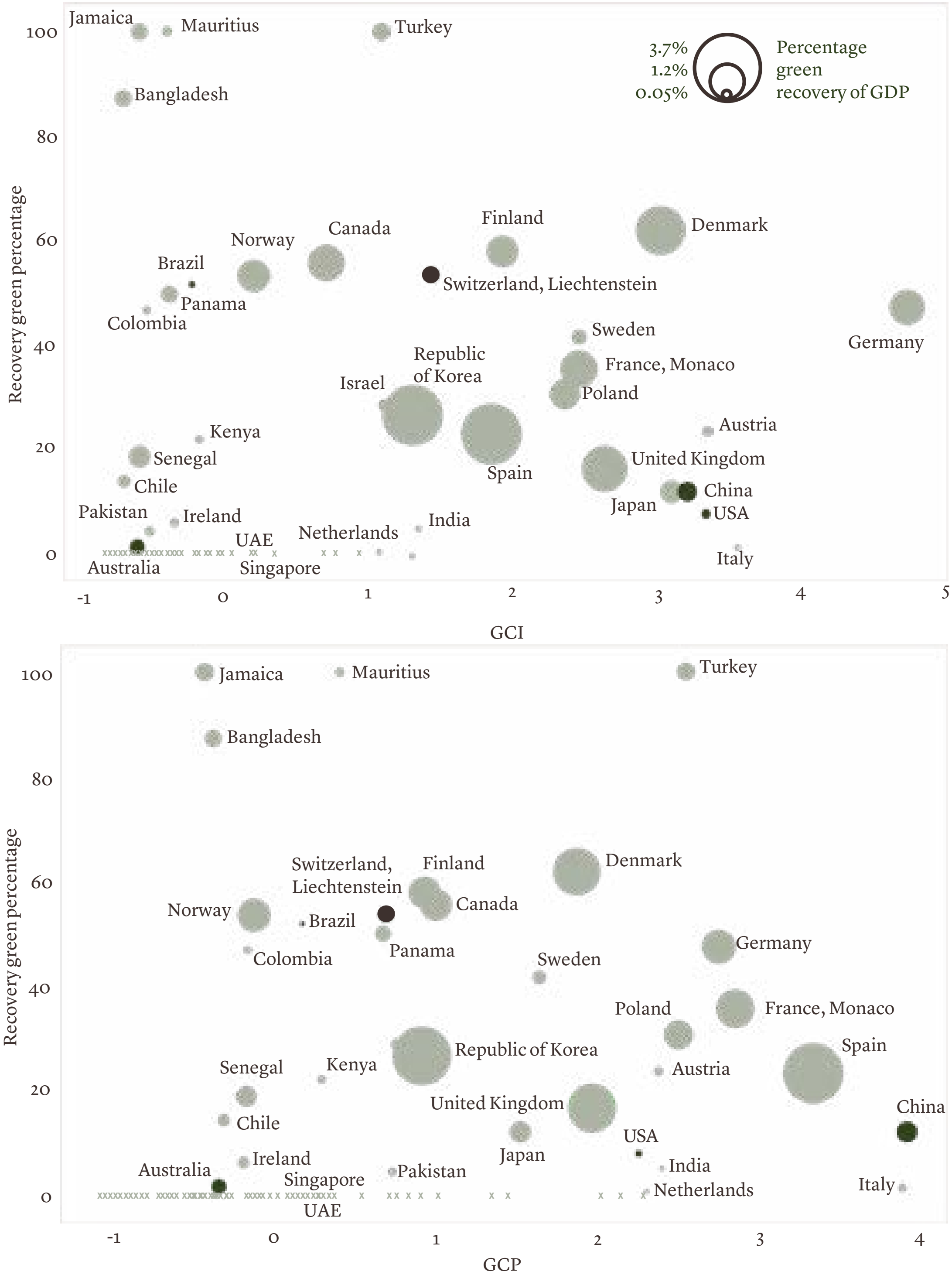
21 Hepburn et al. 2020.

22 O'Callaghan and Murdock; Ulrich Volz and others, Debt Relief for a Green and Inclusive Recovery Debt Relief for a Green and Inclusive Recovery A Proposal (Berlin, 2020).

23 Galina Alova, 'A Global Analysis of the Progress and Failure of Electric Utilities to Adapt Their Portfolios of Power-Generation Assets to the Energy Transition', Nature Energy, 5.11 (2020), 920–27 <https://doi.org/10.1038/s41560-020-00686-5>; Alexander Pfeiffer and others, 'Committed Emissions from Existing and Planned Power Plants and Asset Stranding Required to Meet the Paris Agreement', Environmental Research Letters, 13.5 (2018) <https://doi.org/10.1088/1748-9326/aabc5f>; Conor Hickey and others, 'Can European Electric Utilities Manage Asset Impairments Arising From Net Zero Carbon Targets?', SSRN Electronic Journal, 2020 <https://doi.org/10.2139/SSRN.3531724>.

24 In Figure 17 the dark green countries are the case study countries. The crosses (x) indicate Singapore and the UAE, who both spend zero on renewables, as well as the countries with these 3-digit codes: 'CRI', 'CUB', 'CZE', 'DMA', 'DOM', 'ECU', 'SLV', 'ATG', 'GHA', 'GRD', 'ARG', 'GTM', 'GUY', 'HTI', 'HND', 'IDN', 'IRN', 'IRQ', 'KAZ', 'KGZ', 'BHS', 'MYS', 'MEX', 'MNG', 'MAR', 'BRB', 'NIC', 'BEL', 'NGA', 'PRY', 'PER', 'PHL', 'PRT', 'ROU', 'RUS', 'RWA', 'KNA', 'LCA', 'VCT', 'BOL', 'SAU', 'SGP', 'VNM', 'ZAF', 'SUR', 'THA', 'TTO', 'ARE', 'EGY', 'BLZ', 'BFA', 'URY', 'VEN'.

Fig. 17[24]: GCI and GCP vs Percentage green spending of recovery. Size of countries indicates percentage of green spending of GDP



Source: Global Recovery Observer https://recovery.smithschool.ox.ac.uk/tracking

Turkey, although it scores relatively low on GCI, has high GCP and has intentions to spend a large portion of its recovery spending on green recovery, potentially enabling it to reach its green complexity potential faster than others. Many EU countries seem to be spending a good portion on green recovery, but some barely spend any, such as Italy, the Netherlands, Portugal, and Czechia. Many low-GCI/GCP countries across the world do not intend to spend any of their COVID-19 recovery on green projects.

Green recovery spending as percentage of GDP is presented in Figure 18[25]. Brazil (green recovery spending equals 0.015% of GDP) announced some green spending but its recovery spending is relatively small as a percentage of GDP. Australia (0.16%), with its modest green spending but large recovery spending is placed in the centre, well above the US (0.05%) and not far from China (0.36%). All of these countries, however, stay far below the top spenders Spain (3.7%) and South Korea (3.2%).

We identify 4 categories of countries[26] as shown in Figure 18. A number of EU countries plus Canada, South Korea, China, and Turkey are shown as "leading green spenders", owing to their high GCI score and above average green recovery spending. Other European countries, including Switzerland, as well as the US, Israel, India, Malaysia, Thailand, Mexico, and Singapore, also have a high GCI score, but spend less than average on their green recovery. We group these countries in a category called "falling behind". A third category, gaining momentum, includes Jamaica, as well as Senegal and Panama, all featuring a low GCI score but more than average spending on green recovery. While this approach does have obvious methodological drawbacks, this might indicate that these countries are better placed to improve on green metrics and may jump ahead compared to their peer countries. The final category, "missed opportunities", is made up of countries that have a low GCI score, and spend below average or even nothing on green recovery. This group of countries includes Australia, Brazil, the UAE, and many developing and emerging economies in our sample. Note that this categorisation may change as countries announce new recovery green spending packages, and we should be cautious to draw conclusions too early.

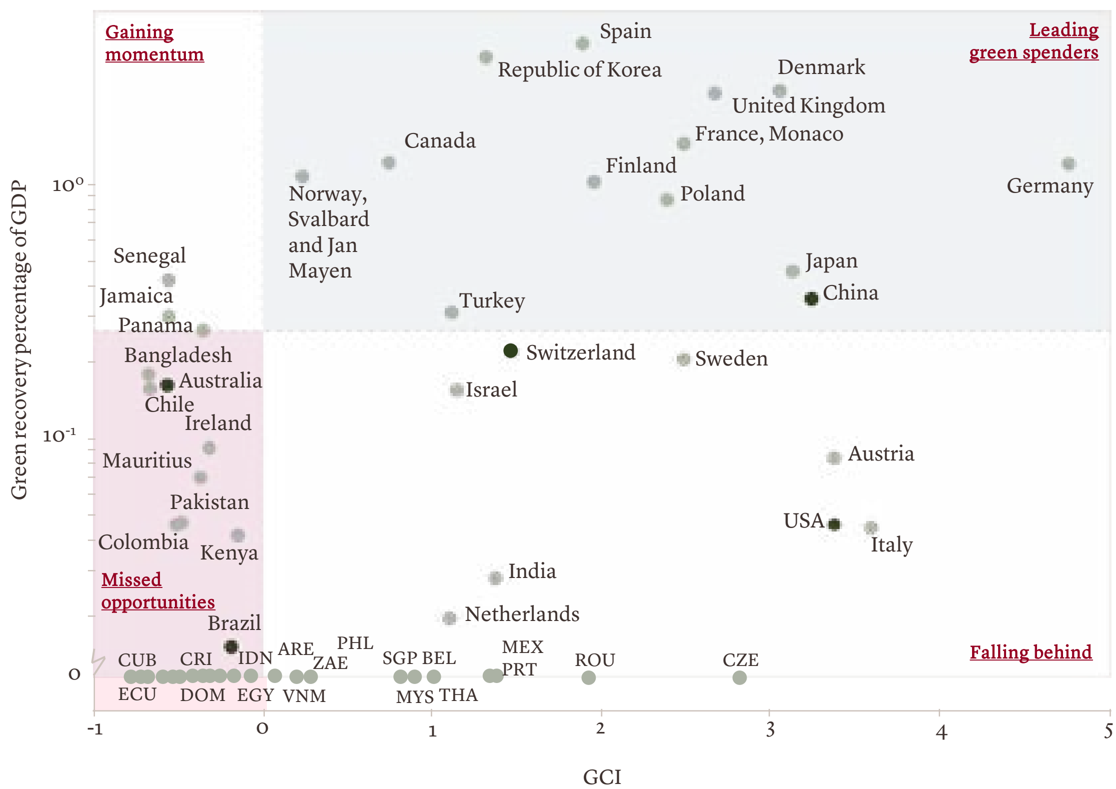
Spending on renewables

Renewable energy projects in our recovery spending dataset come in various forms, such as subsidies for rooftop solar installations, or loan guarantees for large-scale wind farms. Figure 4 visualises how much countries intend to spend on renewable energy projects. Emergent economies Bangladesh, Colombia, and Brazil are reserving a large proportion of their recovery spending on renewables, as well as Norway and Canada.

25 Note that it uses a logarithmic scale to distinguish between the different countries.

26 Note that only spending agreed by national governments is classified by the Oxford Economic Recovery Project. Any spending plans that are still being made or negotiated on May 25th (e.g. the Biden administration's American Jobs Plan) have not been considered here yet.

Fig. 18[27]: GCI and GCP vs Percentage green be spending of GDP. Note the log scale on the y-axis.



Source: Global Recovery Observer https://recovery.smithschool.ox.ac.uk/tracking.

[27] In Figure 18, the UAE (ARE), Singapore (SGP) and selected other countries are added underneath as their recovery spending plans include zero green projects. The full ist of country codes of countries with zero green recovery spending: 'CRI', 'CUB', 'CZE', 'DMA', 'DOM', 'ECU', 'SLV', 'ATG', 'GHA', 'GRD', 'ARG', 'GTM', 'GUY', 'HTI', 'HND', 'IDN', 'IRN', 'IRQ', 'KAZ', 'KGZ', 'BHS', 'MYS', 'MEX', 'MNG', 'MAR', 'BRB', 'NIC', 'BEL', 'NGA', 'PRY', 'PER', 'PHL', 'PRT', 'ROU', 'RUS', 'RWA', 'KNA', 'LCA', 'VCT', 'BOL', 'SAU', 'SGP', 'VNM', 'ZAF', 'SUR', 'THA', 'TTO', 'ARE', 'EGY', 'BLZ', 'BFA', 'URY', 'VEN'

Interestingly, countries that spend heavily on renewables tend to have lower GCI and GCP scores. Looking at a different measure, among the countries in our database, Norway, South Korea, and Canada spend the largest fraction - all above 0.75% of their GDP - on renewable energy projects. Given the declines anticipated in renewable energy costs this may well help them transition their economies faster towards net zero.

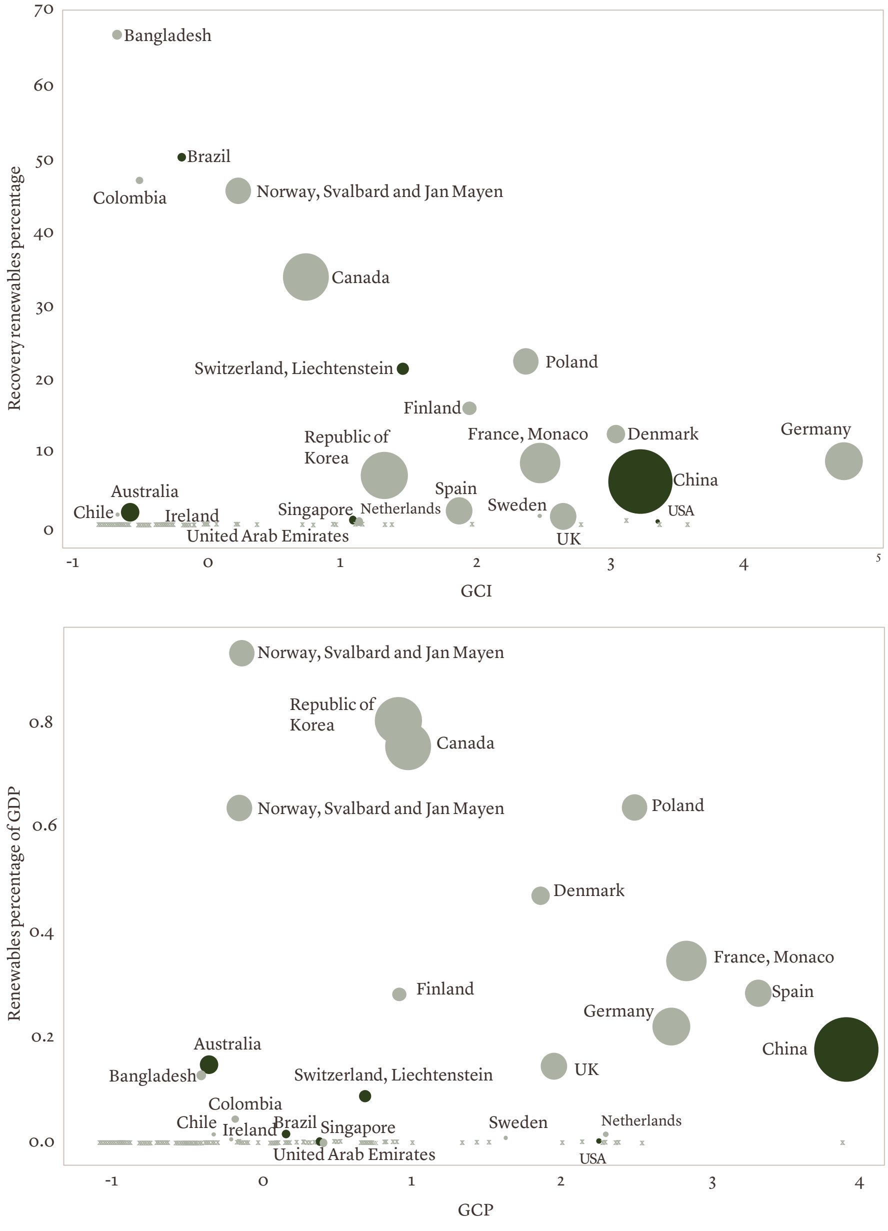
Big spending in the pipeline? The US infrastructure deal and the EU green deal

The US government on November 5th passed a large infrastructure and investment plan for the coming 8 years, which would include green infrastructure investment into renewable energy projects, as well as more conventional maintenance of highways and bridges[28]. While the original $2 trillion American Jobs Plan has been scaled back, the US congress approved the bipartisan infrastructure bill of about $550 billion (the headline of $1 trillion USD includes renewal of ongoing infrastructure spending). About 38% of the new spending (roughly $214 billion or 1.0% of GDP) can be classified as green. If this were included in the COVID-19 recovery spending, it would bring the US into the middle realm of the Leading green spenders[29]. Another bill that is currently being negotiated, the Build Back Better Act, currently has a headline figure of $550 billion spending on clean energy investments[30].

The recently announced plans for the EU green deal will enter the country-level negotiation phase this year and was therefore not taken into consideration for this report[31]. The EU green deal will be financed by one third of the combined EU's 1 trillion-euro seven-year budget (2021-2028) and 750 billion NextGenerationEU Recovery Plan (2021-2023), highlighting the need for a green COVID-19 recovery. This would raise the full EU's green spending by about 4% as a percentage of GDP in Figure 18. Taking only the NextGenerationEU funding into account would mean a rise of 1.7%.

[28] White House, American Jobs Plan (Washington, DC, 2021) <www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/>.
[29] See the US case study in Section 4, for more information
[30] House Committe on the Budget, 'The Build Back Better Act: Transformative Investments in America's Families & Economy', 2021 <https://budget.house.gov/publications/report/build-back-better-act-transformative-investments-america-s-families-economy> [accessed 8 November 2021].
[31] European Commission, European Green Deal (Brussels, 2021) <https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en>.

Fig 19[32]: GCI vs Percentage renewables spending of total recovery spending, and GCP vs Percentage renewables spending of GDP. Country size indicates absolute value of renewables spending plans.



Source: Global Recovery Observer https://recovery.smithschool.ox.ac.uk/tracking

32 In Figure 19 the size of the countries represents the absolute spending on renewables as part of covid recovery. In dark blue the case study countries. The crosses (x) indicate Singapore and the UAE, who both spend zero on renewables, as well as the countries with these 3-digit codes: 'CRI', 'CUB', 'CZE', 'DMA', 'DOM', 'ECU', 'SLV', 'ATG', 'GHA', 'GRD', 'ARG', 'GTM', 'GUY', 'HTI', 'HND', 'IDN', 'IRN', 'IRQ', 'KAZ', 'KGZ', 'BHS', 'MYS', 'MEX', 'MNG', 'MAR', 'BRB', 'NIC', 'BEL', 'NGA', 'PRY', 'PER', 'PHL', 'PRT', 'ROU', 'RUS', 'RWA', 'KNA', 'LCA', 'VCT', 'BOL', 'SAU', 'SGP', 'VNM', 'ZAF', 'SUR', 'THA', 'TTO', 'ARE', 'EGY', 'BLZ', 'BFA', 'URY', 'VEN'.

Country Case Studies

› China

› United States of America

› Brazil

› Australia

› United Arab Emirates

› Singapore

› Switzerland

4. Country Case Studies

We are now presenting a range of countries in more detail. The seven countries are chosen for their interest and importance to the finance community, their economic strength, their regional importance, and as examples of contrast in terms of green complexity, green energy potential and green recovery spending (Table 3).

Table 3: The contrasting elements of the seven case study countries

Country	GCI	GDP/Capita	Green Recovery Archetypes	GEP	Region
China	Higher	Lower	Leading spender	Med	East Asia
USA	Higher	Higher	Falling behind	High	North America
Brazil	Lower	Lower	Missed opportunity	High	South America
Australia	Lower	Higher	Missed opportunity	High	Oceania
UAE	Higher	Higher	Falling behind	Med	Middle East
Singapore	Higher	Higher	Falling behind	Low	South-East Asia
Switzerland	Higher	Higher	Falling behind	High	Europe

Source: GCI from Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

With their diverse backgrounds, these countries represent a variety of archetypes, challenges, and opportunities.

Two of our case study countries, Brazil and Australia, have lower than average GCI scores; the rest are above average. The US, Brazil, Switzerland, and Australia all have enough potential in green energy resources to produce more than double their own energy needs. China, the UAE, and Singapore do not have enough to meet their current needs. Brazil and China are part of the BRICS countries of major emerging economies. They are economic and regional powerhouses, but their GDP per capita is still significantly lower than that of developed economies.

In contrast, Switzerland, Singapore, and the UAE are among of the highest-income countries on the planet. However, only China is planning to spend more than average on a green recovery, the others less, although that may be in part due to separately announced plans (Singapore), or by policy that is still being developed (the US). Together, these countries represent about 43% of global green export value, with the majority coming from China (19%) and the US (10%).

Each country faces unique challenges and opportunities. China is a leading green manufacturer and wants to transform into a top green innovator as well. The US still has a higher GCI than China, but has dropped slightly in the rankings and is trying to find a strategy to remain at the top, with ambitious plans being negotiated. Brazil has enormous green energy potential but has been dropping in GCI rank and has recently neglected some of its most important natural resources. Australia and the UAE are both facing a challenge to move away from their fossil fuel dominated exports and carbon intensive industries. Singapore has limited natural resources on its own and is already looking to import green energy from abroad. Switzerland has almost 100% carbon free electricity but missed out on expanding its green product manufacturing base in its COVID-19 recovery plans. We begin with China.


解放碑步行街欢迎您！
国家级步行街改造提升试点街

China case study

Policy ambition and green complexity

Over the past decade, China has become the world's largest manufacturing economy. Not surprisingly, China is also the world's largest emitter of greenhouse gases. However, its global dominance in manufacturing is mirrored, and even surpassed, by its clean technology production capabilities.

China currently ranks 42nd in economic complexity and 5th in green complexity, reflecting this strategic focus on clean energy products. Its first place in green complexity potential also indicates China is well-placed to rise or remain near the top of the green complexity rankings in the years to come.

China's not only dominates exports of clean energy technology, but it also has the world's largest installed capacity of solar (255 GW) and wind (288 GW). China's president Xi Jinping announced in September 2020 at the United Nations General Assembly that China would aim for emissions to peak before 2030 and to become carbon neutral before 2060[1], increasing its 2016 Nationally Determined Contributions (NDC)[2] commitment.

China's national industrial strategy is aimed at reaching the technological frontier. *Made in China 2025*, announced in 2015 as a major piece of industrial policy, identifies ten industries for which China aims to become the world leader by 2025. The chosen industries include both green vehicles and rail transport technology. Its focus on high tech industries may raise both its economic and green complexity ranking[3]. Recently, China's 14th 5-year plan (for 2021-2025) was approved and emphasises a similar set of industries. It also outlines plans for more

1 Xi Jinping, 'Statement by H.E. Xi Jinping President of the People's Republic of China at the General Debate of the 75th Session of The United Nations General Assembly', Ministry of Foreign Affairs of the People's Republic of China, 2020 <https://www.fmprc.gov.cn/mfa_eng/zxxx_662805/t1817098.shtml>.

2 Nationally determined contributions (NDCs) are at the heart of the Paris Agreement and the achievement of these long-term goals. NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. The Paris Agreement (Article 4, paragraph 2) requires each Party to prepare, communicate and maintain successive nationally determined contributions (NDCs) that it intends to achieve. Parties shall pursue domestic mitigation measures, with the aim of achieving the objectives of such contributions.

3 State Council of The People's Republic of China, '"Made in China 2025" Plan Issued', 2015 <http://english.www.gov.cn/policies/latest_releases/2015/05/19/content_281475110703534.htm>.

scientific and technological self-reliance and stronger collaboration between industry and research institutions[4].

Beyond its country borders, China exerts economic influence though bilateral and multilateral projects. A major example of this is the Belt and Road Initiative (BRI), a large infrastructure development strategy, planned in 2015 to be worth a cumulative 6 trillion USD[5] , with a major focus on 68 Asian, African, and European countries. Energy is one of the priority areas of the BRI. Although renewables are an increasing part of the strategy, as much as 90% of energy loans by six major Chinese banks on the BRI programme have gone to fossil fuel infrastructure in the period 2014 – 2018[6]. For pure electricity generating projects this was about two thirds of the total, with, with one third going to renewables, predominantly hydropower. In 2019, coal accounted for 40% of China's overseas plant capacity, 27% for hydro and 11% for other renewables[7]. Since 2019 there have been signs that some coal projects will be put on hold in favour of more renewable projects, as renewable energy prices have continued to fall, and countries try to align their policies with their Paris commitments[8]. In September 2021 China also pledged to stop building new coal energy plants abroad, although at the time of writing the details of this pledge are still to be determined[9]. In another show of international green leadership ambition, China is to host the UN Biodiversity Conference COP15 in spring 2022[10].

4 Smriti Mallapaty, 'China's Five-Year Plan Focuses on Scientific Self-Reliance', Nature (NLM (Medline), 2021), 353–54 <https://doi.org/10.1038/d41586-021-00638-3>.

5 Lihuan Zhou and others, Moving the Green Belt and Road Initiative: From Words to Actions, 11 August 2018 <https://www.wri.org/research/moving-green-belt-and-road-initiative-words-actions> [accessed 19 August 2021].

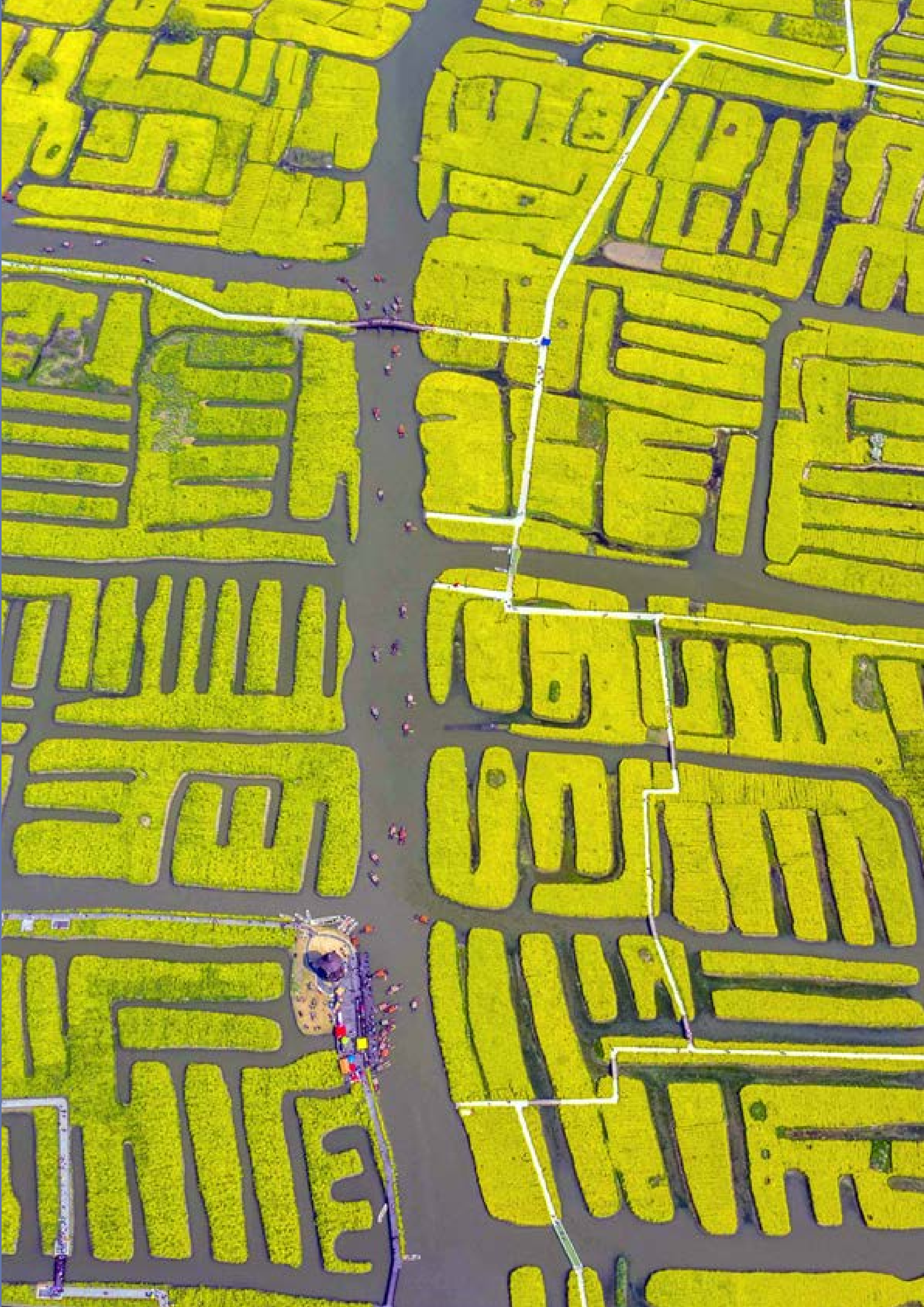
6 Zhou et al. 2018.

7 Xinyue Ma, Understanding China's Global Power (Boston, MA, 2020) <https://doi.org/10.1038/s41586-019-1368-z>.

8 Christian Shepherd, 'China Turns Its Back on Bangladesh BRI Coal Projects', Financial Times, 2021 <https://www.ft.com/content/30840645-58d2-4da5-be05-f476623677d2> [accessed 19 August 2021].

9 Azi Paybarah, 'China Says It Won't Build New Coal Plants Abroad. What Does That Mean?', The New York Times (New York, 22 September 2021) <https://www.nytimes.com/2021/09/22/world/asia/china-coal.html>.

10 The first part of the COP15 will take place online in October 2021. See https://www.un.org/en/food-systems-summit-2021-en/un-biodiversity-conference



China at a glance

1,402,000
Population (thousands)

14,722,730
GDP (current US$, millions)

17,312
GDP / capita (US$, PPP)

5
GCI rank

42
ECI rank

1
GCP rank

18.74 %
Global share of green exports

12.58 %
Share of green in total exports

Electric floor lamps
Highest RCA green product

Optical devices
Most complex competitve

2060
Net zero target

1.4°C
Temp change since 1961

0.5 (rank: 11/230)
CO_2 intensity (kg/PPP$ GDP)

26
Avg energy use (MWh/yr/cap)

50
Global Energy Potential (MWh/yr/cap)

32
Climate risk index rank

85
Extreme risk index rank

12 % (131/213)
Renewable energy consumption

12 %
Share of green in covid recovery

Trends in green competitiveness

China's share in global green exports increased from 3.42% in 1995-99 to 18.74%. Its share of green imports increased as well, but to lesser extent: from 2.87% at the start of the period to 8% during the most recent period. China is a net exporter of green goods (reflecting its dominance in global manufacturing exports more broadly).

China's GCI rank increased from 25th to 5th over the course of the study period, while its GCP rank increased from 7 to 1. This indicates that China not only increased its green export share, but also moved into relatively complex green technologies. Its high Green Complexity Potential in particular indicates that China is well-positioned to further increase its global green competitiveness in the future. Renewable energy technologies are China's most important green export, as well as import. Global market concentration in this category, as measured by the Hirschmann-Herfindahl Index "HHI"[11] is 0.08, which suggests fairly low supply vulnerability. However, for some individual products within the category, market concentration is much higher: for example, the HHI for solar panels is 0.18. However, this primarily reflects China's own dominance in producing solar panels (it currently captures 38% of global solar panel exports).

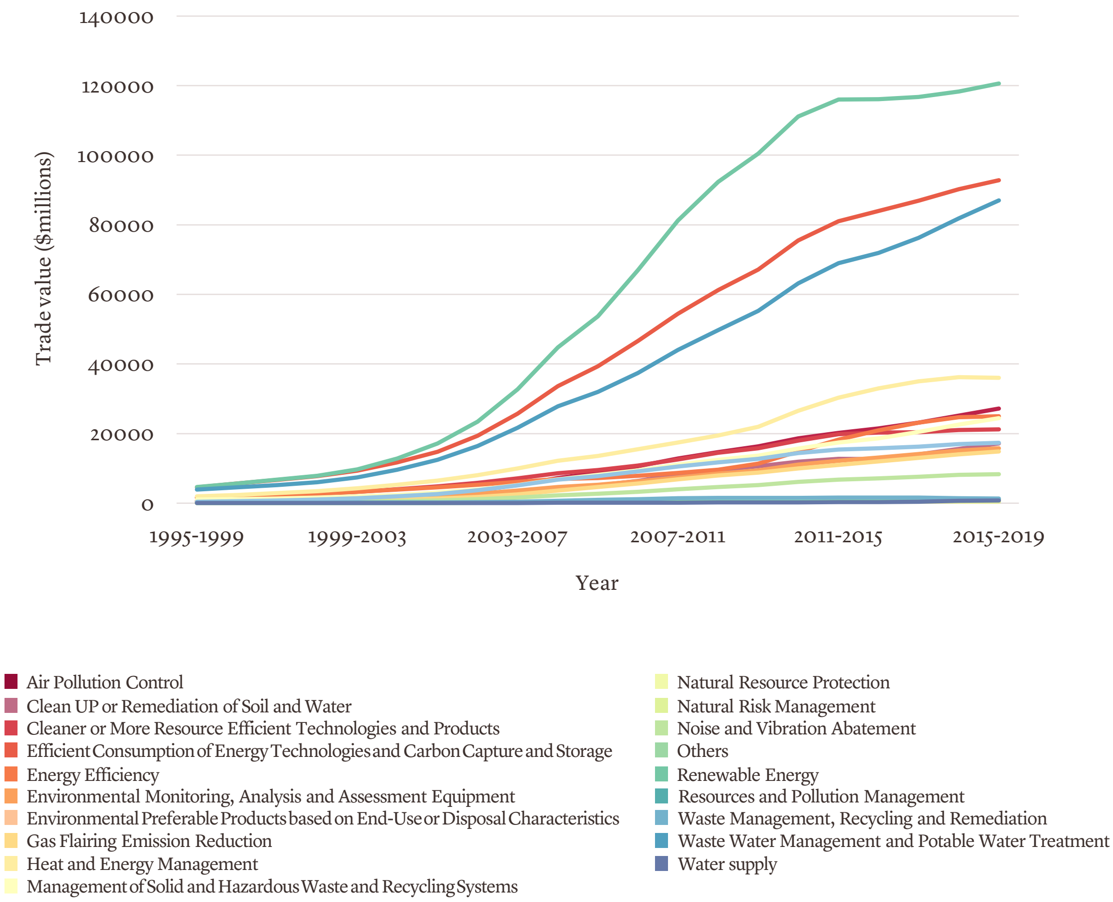
Export values increased in many categories over the course of the study period, but especially in more complex ones. The top three categories are renewable energy, followed by efficient consumption of energy technologies and carbon capture and storage and wastewater management and potable water treatment.

As Figure 21 shows, China's average proximity to green products has increased for all environmental categories. This indicates that China's productive capabilities are increasingly aligning with those required to competitively produce green technologies. This is also captured by its high rank in Green Complexity Potential.

Figure 22 shows importers' shares in China's green exports for those countries whose share is at least 2%. The United States are by far the most significant green export market for China, with a share of 15.6%; followed by Hong Kong (7.4%), Japan (6%) and Germany (4.2%). This is broadly in line with the pattern observed for China's exports overall: the US is the biggest importer (16.7%), followed by Hong Kong (10.4%) and Japan (5.9%) (Figure 23).

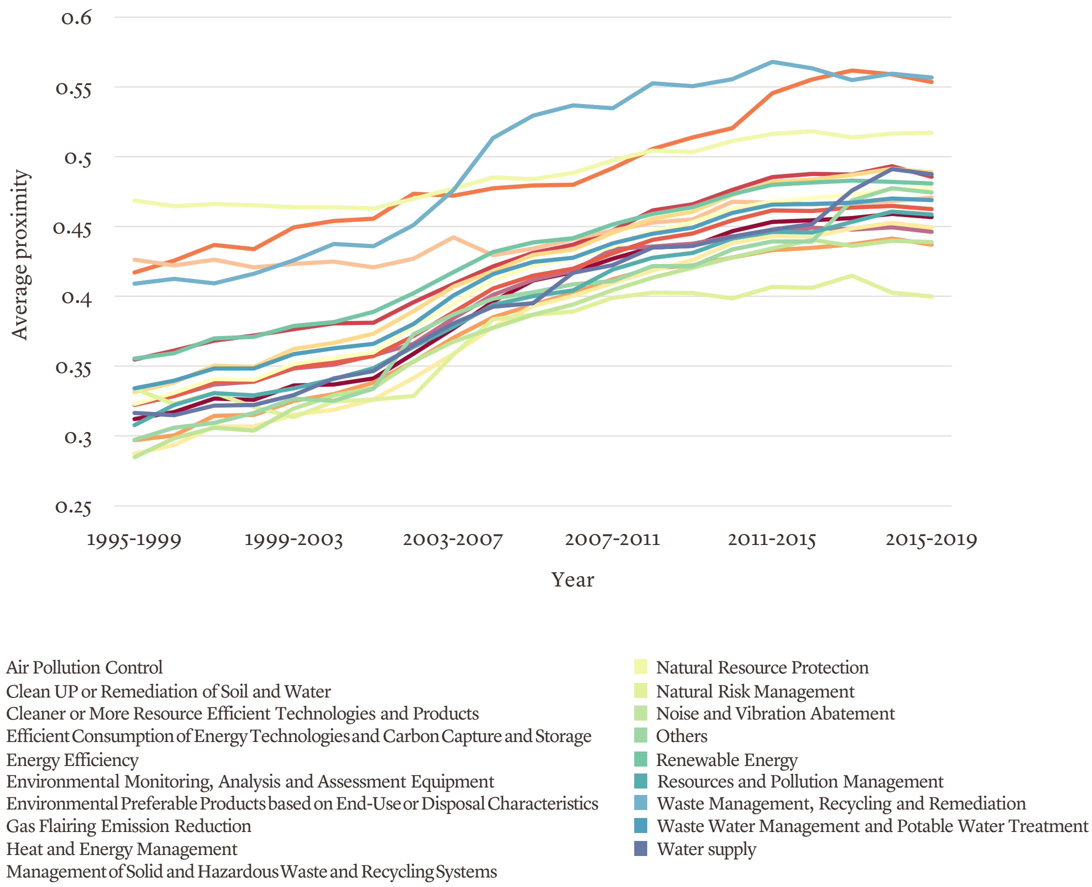
[11] The Hirschmann-Herfindahl Index provides a measure of market concentration based on countries' global market shares and is used to determine market competitiveness.

Fig 20: Export value over time by environmental category, China.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Fig. 21: Average proximity over time by environmental category, China.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Fig. 22: Largest importers of China's green exports. Only countries that import >2% of Chinese exports are shown separately.

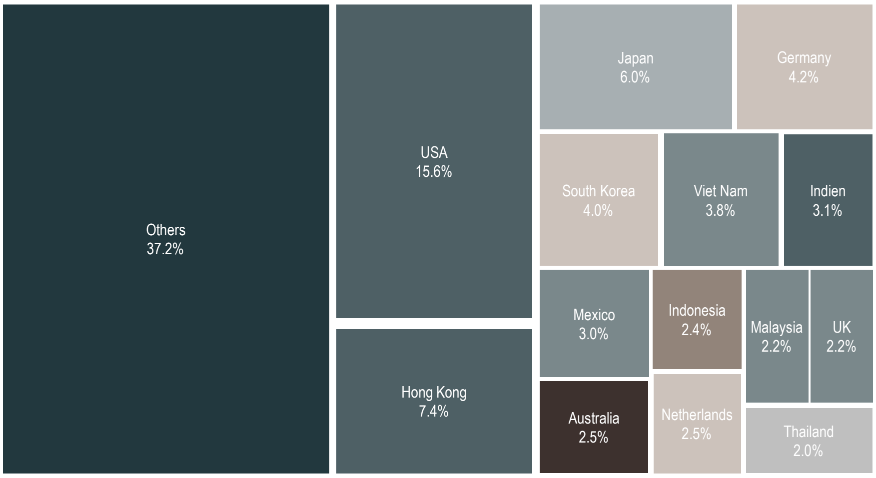
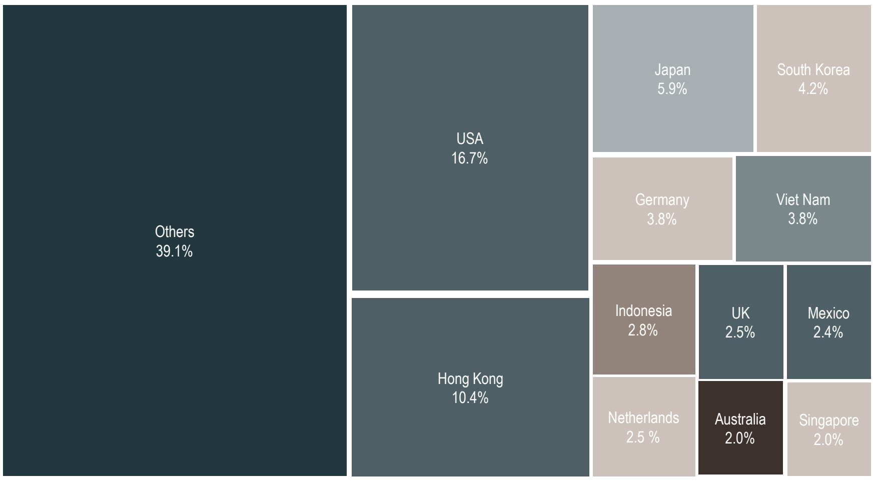


Fig. 23: Largest importers of China's overall exports. Only countries that import >2% of Chinese exports are shown separately.



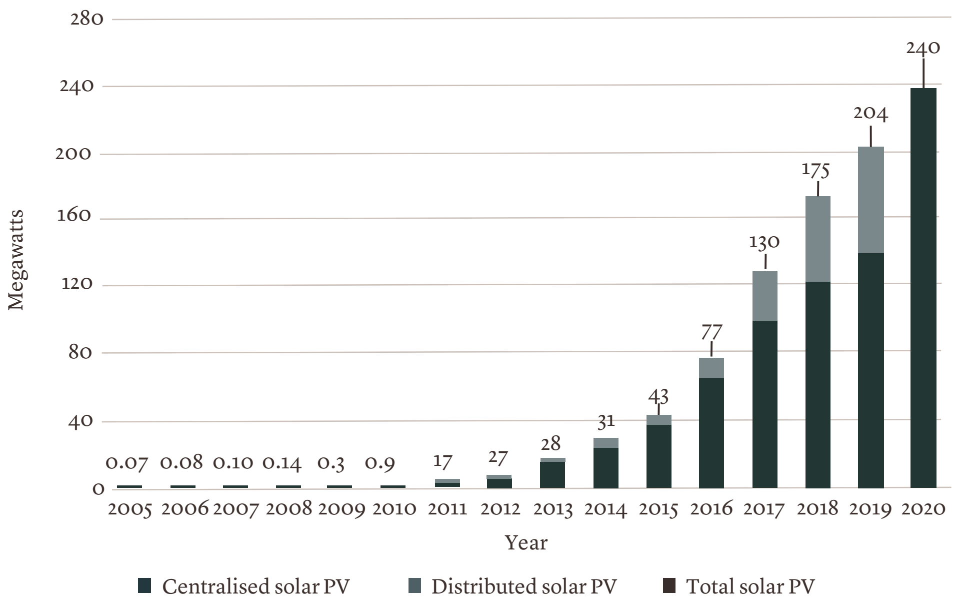
Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Trends in green energy

The growth in demand for solar PV since 2000, mostly from Europe (following Germany's *Energiewende* programme) generated sufficient growth in demand by 2009 for China and other low-cost manufacturing regions to enter the PV supply market, supported by targeted manufacturing subsidies. At this point, PV module prices fell dramatically, halving in less than 2 years, with concurrent rapid increases in deployment, particularly in China (Figure 24).

Further supported by a large domestic market incentivised by their own Feed-in-Tariff scheme, China has successfully grown its solar photovoltaics production capacity such that it now dominates this rapidly growing and potentially enormous market. Currently, 22% of all exports of renewable energy technology originate in China, followed by Germany, which produces only 12% of world exports. Besides being a very successful export strategy, the move into solar technologies was part of a long-standing effort by the Chinese government to increase domestic energy generation capacity. Beginning in the 2001 to 2005 '10th Five-Year' plan and continuing with subsequent five-year plans, China has tripled its hydro capacity (Figure 25) with over half (51%) of the hydro capacity installed in 2012 taking place in China. In September 2013, China introduced the influential Air Pollution Action Plan which subsequently led to an almost exponential growth in low carbon energy generation - mostly in hydro, solar, and wind. China currently has the highest renewable energy generation capacity of all

Fig. 24: Solar capacity in China 2005-2020.



Source: Trends and contradictions in China's Renewable Energy Policy https://www.energypolicy.columbia.edu/research/commentary/trends-and-contradictions-china-s-renewable-energy-policy#_edn13

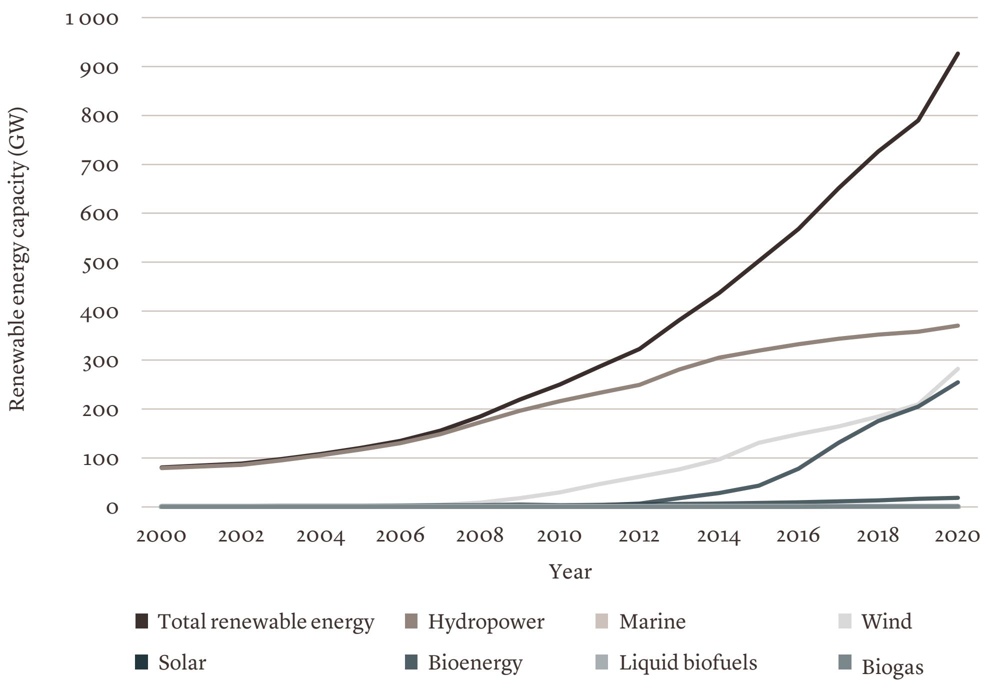
countries at over 900GW (Figure 25) - three times that of the United States, which is in second place(~300GW). China's estimated green energy potential is below its current energy demands, but with the richest hydropower resources in the world (17% of the global capacity) and the second largest technical generation potential for solar (Figure 26), it is well placed to increase its domestic renewable energy capacity. Despite a recent downturn in renewable investments during the COVID-19 pandemic, China is still predicted to have sufficient installed capacity of solar for the foreseeable future[12] in the coming years (SolarPower Europe, 2018). However, this will be shaped heavily by an ongoing contradiction within the power sector between long-term market-oriented reforms on the one hand and short-term administrative planning on the other[13].
As it has one of the highest green energy potentials of any country in Asia, China may also develop an export strategy for green energy to capitalise on any short-term green premia created in local countries with aggressive net zero targets.

---

[12] SolarPower Europe, Global Market Outlook For Solar Power / 2018 - 2022, 2018, https://www.solarpowereurope.org/wp-content/uploads/2018/09/Global-Market-Outlook-2018-2022.pdf

[13] SIPA Center on Global Energy Policy; Columbia University, Trends and Contradictions in China's Renewable Energy Policy, Date accessed: 03/11/2021, https://www.energypolicy.columbia.edu/research/commentary/trends-and-contradictions-china-s-renewable-energy-policy#_edn13.

Fig. 25: China's renewable energy generation capacity (GW) by energy source



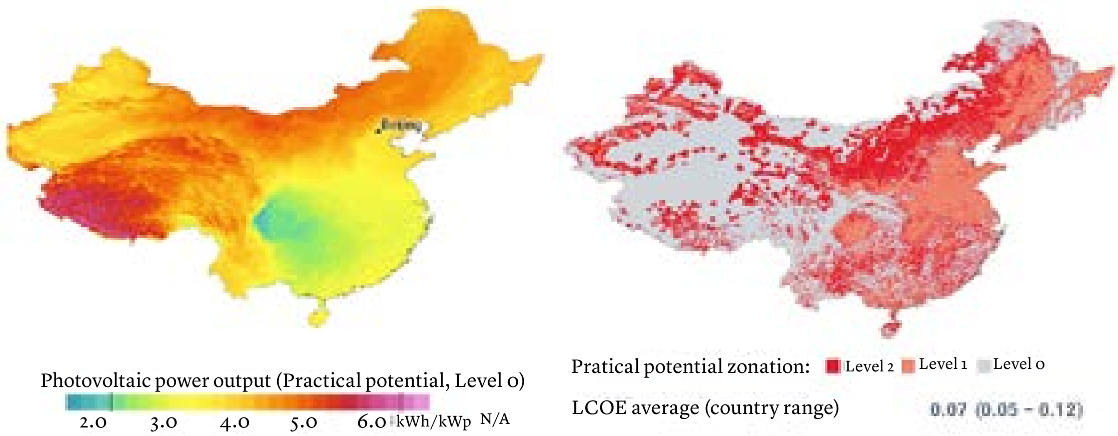
Source: IRENA (2021), Renewable Capacity Statistics 2021; & IRENA (2020), Renewable Energy Statistics 2020, The International Renewable Energy Agency, Abu Dhabi.

Table 4: Estimates of China's current technical potential for annual renewable energy generation which is used to calculate its per capita renewable energy potential in comparison with its current average annual per capita usage.

China	
Onshore wind generation potential (EJ/yr)	117
Offshore wind generation potential (EJ/yr)	35
Solar PV generation potential (EJ/yr)	218
Hydro generation potential (EJ/yr)	6
Bioenergy generation potential (EJ/yr)	16
Est. Total generation potential (EJ/yr)	376
Population (millions)	1,402
Average annual energy usage per person (MWh/yr/cap)	26
Total generation potential per person (MWh/yr/cap)	74

Source: See Appendix for Data Sources

Fig. 26: Estimates of solar photovoltaic potential (kWh/kWp) and practical potential zonation used to determine the China's economic potential for solar. The practical potential zonation of the land is based on topography, usage, and proximity to human settlement



Source: https://globalsolaratlas.info/

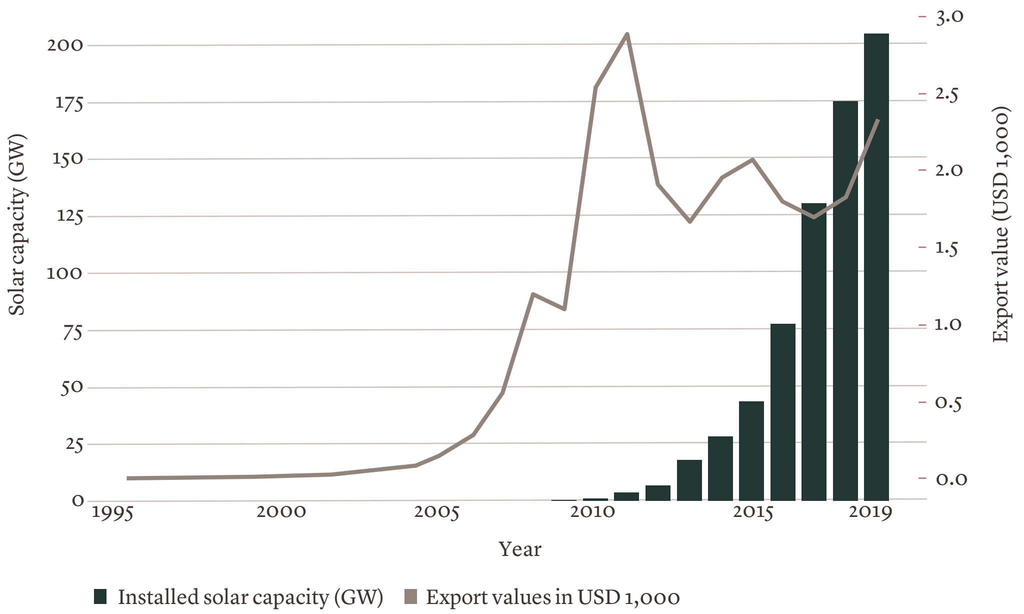
Policy and economic environment

While there has been an increased focus on green technologies in China's exports, the country's rise to prominence in manufacturing green technologies partly reflects its expansion of manufacturing exports more broadly. It is now the largest manufacturing economy in the world, having surpassed the United States in 2010.

In 2016, China captured 23.6% of world manufacturing output. The focus of Chinese manufacturing shifted from upstream to mid- and downstream products over the past decade, and thus towards products which are higher in complexity. Moreover, changes in policy allowed private enterprises to gain in significance and capture market share from state-owned enterprises[14]. China's manufacturing boom is thought to have been the result of its ability to take advantage of cheap labour resources, successfully support target sectors, and use aggressive measures to bring about technology transfer, such as by making it a condition of market access for foreign companies[15].

These industrial policy practices have led to trade tensions with the rest of the world, and in particular the US. Examples include the US-China trade war over solar panels in 2012[16] and an escalating tit-for-tat tariff war launched by former US President Donald Trump in 2018[17]. Despite ongoing tensions, China and the US surprised the world with a

Fig. 27: The green bars show installed solar capacity in GW. The line shows export values for solar panels in USD 1,000.



Source: NEMET, G. F. (2006): "Beyond the learning curve: factors influencing cost reductions in photovoltaics," Energy policy, 34, 3218–3232, Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version)..

new pledge at the recent COP26 to collaborate on Enhancing Climate Action in the 2020s.

Green energy technology has formed a key part of China's industrial strategy since its tenth 5-year plan of 2001-2005, which aimed to "[promote] new energy and renewable energy like solar PV and wind" as a principal target[18]. We can observe China's exports of renewables and other green energy technologies start to increase exponentially in the early 2000s.

For example, it is now the world's largest manufacturer of solar panels, batteries, and electric vehicles. Support for clean energy policies has at times been contingent on local content requirements – for example, 70% local content was required for projects to be eligible for wind tenders in 2003-2009.

There was also a local content eligibility requirement for grants from the Special Fund for Wind Power Manufacturing from 2008-2011[19]. China's push to manufacture clean tech has tended to precede a push for deployment of these technologies – for example, the value of China's exports of solar panels peaked in 2011 (prior to the US and the EU imposing anti-dumping duties on these exports), while solar photovoltaic generation capacity was only just beginning to increase around that time.

---

[14] Kerry Liu, 'Chinese Manufacturing in the Shadow of the China–US Trade War', Economic Affairs, 38.3 (2018), 307–24 <https://doi.org/10.1111/ecaf.12308>.

[15] Kerry Liu 2018.

[16] Llewelyn Hughes and Jonas Meckling, 'The Politics of Renewable Energy Trade: The US-China Solar Dispute', Energy Policy, 105 (2017), 256–62 <https://doi.org/10.1016/J.ENPOL.2017.02.044>.

[17] Kerry Liu 2018.

[18] IEA, 'The 10th Five-Year Plan for Economic and Social Development of the People's Republic of China (2001-2005)', IEA/IRENA Renewables Policies Database, 2021 <https://www.iea.org/policies/1736-the-10th-five-year-plan-for-economic-and-social-development-of-the-peoples-republic-of-china-2001-2005?page=4&q=China> [accessed 19 July 2021].

[19] OECD, 'Overcoming Barriers to International Investment in Clean Energy', in Green Finance and Investment (Paris, France: OECD Publishing, Paris, 2015) <https://doi.org/10.1787/9789264242661-18-en>.

Made in China 2025

"Made in China 2025" is an industrial strategy aimed at helping China move further towards the technological frontier. It includes some clean technologies, such as electric vehicles, and aims to improve sustainability by reducing energy and water use, as well as emissions, per unit of output. It also targets new information technologies, biomedicine, and other high-tech sectors. Policies aimed at achieving these goals include emissions targets, targeted subsidies, preferential credit, insurance products and other measures to facilitate financing activities of firms engaged in relevant activities, as well as financial support for foreign investment. Made in China 2025 also includes an "internationalisation" pillar. This refers to efforts to set up bilateral capacity cooperation agreements, establish "overseas R&D centres", and encourage the acquisition of foreign technology companies by Chinese firms[20].

China is currently facing the risk of a middle-income trap. Its growth was slowing before COVID-19, due in part to its ageing population and reduced supply of cheap labour. It has been very successful in scaling up low-cost manufacturing of existing technologies; however, its R&D expenditure as a percentage of GDP still lags behind other manufacturing economies[21], and while the share of patents originating in China – a common proxy for innovative output – has been on the rise, high quality patents such as triadic patent families are still lagging[22]. The "Made in China 2025" strategy aims to upgrade technological and innovative capabilities in high-tech sectors, which may cause existing trade tensions to further intensify[23].

Environmental credentials and policy ambition

Notwithstanding its strong capabilities to manufacture cleaner technologies, China performs poorly on metrics such as manufacturing industry energy consumption per unit of GDP, and coal continues to make up the lion's share of its energy mix (57.64% in 2019, followed by oil which accounts for nearly 20%[24]). However, it has recently increased its policy ambition, setting a carbon neutrality target for 2060 and specifying several sustainability goals in its aforementioned "Made in China" strategy. Its carbon emissions trading scheme is also expected to become operational in 2021, following ten years of preparation and pilot projects[25].

According to the University of Oxford's Global Recovery Observatory, with $429 USD in total of planned projects as of May 2021 China has presented one of the most ambitious post-COVID-19 recovery plans. About 12% of this can be deemed green, similar to the US and Japan, but this is much lower than leading countries. Combined, their green plans make up about 0.3% of China's GDP. Owing more to the absolute size of the recovery package than its green credentials, that is enough for China to be included in the *leading green spenders* category of countries with high GCI and more than average spending as percentage of GDP on green recovery.

---

[20] Kerry Liu, 2018.

[21] Kerry Liu, 2018.

[22] China Power Team, Is China Leading in Global Innovation? China Power. Updated January 28, 2021. Accessed July 19, 2021., 2019 <https://chinapower.csis.org/china-innovation-global-leader/>.

[23] Kerry Liu, 2018.

[24] Hannah Ritchie and Max Roser, 'China: Energy Country Profile', Our World in Data, 2021 <https://ourworldindata.org/energy/country/china> [accessed 19 July 2021].

[25] Hongqiao Liu, 'In-Depth Q&A: Will China's Emissions Trading Scheme Help Tackle Climate Change?', Carbon Brief, 2021 <https://www.carbonbrief.org/in-depth-qa-will-chinas-emissions-trading-scheme-help-tackle-climate-change>.

Green strengths and opportunities

China's NDC has recently called for further R&D spending in renewable energy and related technologies, including desalination and climate change risk assessment methodology[26]. Some environmental monitoring technology is highly complex and close to China's current strengths, such as exposure meters, or electrical measurement instruments and their components (Figure 28). Figure 28 divides all green products into those which China exports competitively, with RCA>1 ("Current Strengths"); and those which it does not currently export competitively, with RCA<1 ("Potential Opportunities"). The horizontal axis shows the products' proximity to China's current productive capabilities, which is correlated with the probability that China will develop competitiveness in those products in the future where it does not already have it. The vertical axis shows Product Complexity Index (PCI). PCI is a proxy for technological sophistication. For some countries, including China, there is a trade-off between transitioning into "proximate" versus "complex" new products. If those products which are high in complexity tend to be relatively further away from existing capabilities, it will be riskier for them to transition into products which are more likely to open up greater diversification opportunities.

One of China's "Made in China 2025" target industries is green vehicles. Policies have been in place for Chinese consumers to buy hybrid and electric cars since 2009, and in 2035 all new vehicles sold must be electric, hybrid, or fuel-cell driven, according to a Ministry of Industry and Information Technology guided report[27]. Electric and hybrid vehicles represent about 5% of new car sales today and perhaps 20% in 2025, making it already the world's largest EV market in absolute numbers[28].

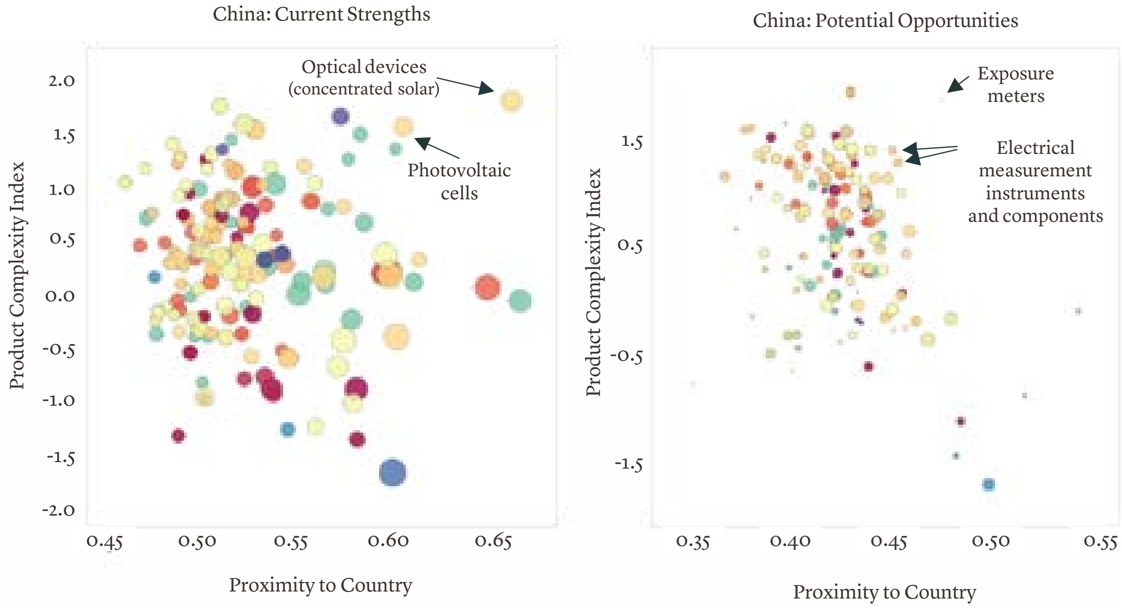
In our dataset, China's share of global export of new energy vehicles (which includes gas powered vehicles besides electric, hybrid, and hydrogen-powered ones), is only 1%, compared to 12-25% for Germany, Japan, and the US - all three countries with large automotive sectors. China has not yet developed competitive export capabilities

[26] NDRC, China's Intended Nationally Determined Contribution: Enhanced Actions on Climate Change (Beijing, 2015) <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/China First/China's First NDC Submission.pdf>.

[27] Shunsuke Tabeta, 'China Plans to Phase out Conventional Gas-Burning Cars by 2035', Nikkei Asia, 27 October 2020 <https://asia.nikkei.com/Business/Automobiles/China-plans-to-phase-out-conventional-gas-burning-cars-by-2035>.

[28] The Economist, 'What Is China's Five-Year Plan? The Economist Explains', The Economist, 4 March 2021 <https://www.economist.com/the-economist-explains/2021/03/04/what-is-chinas-five-year-plan>; IEA, 'Reports: Electric Vehicles', IEA, 2020 <https://www.iea.org/reports/electric-vehicles>.

Fig. 28: China's green export products divided into current strengths and potential opportunities. Size of product indicates China's current RCA, colours represent product categories (see legend)



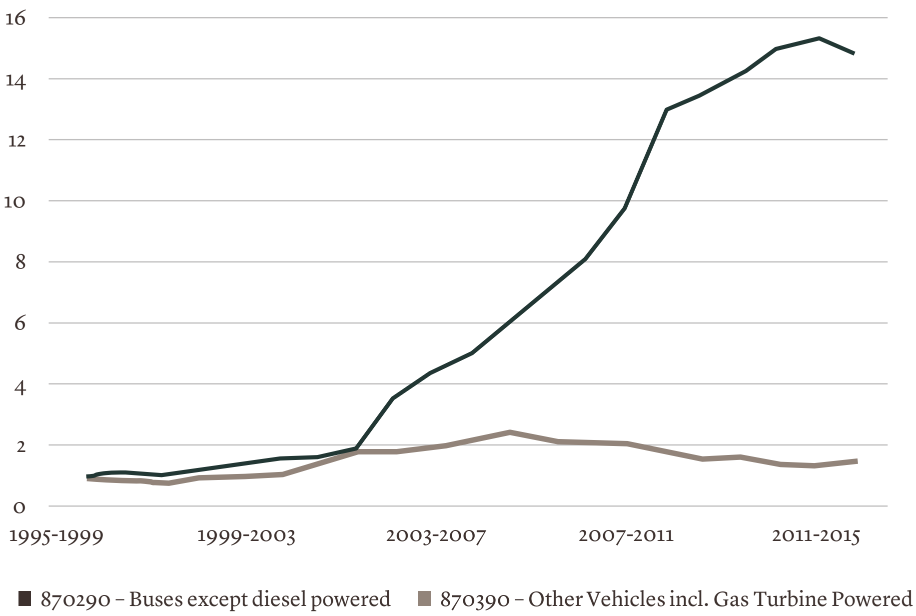
- Management of Solid and Hazardous Waste and Recycling Systems
- Natural Resource Protection
- Energy Efficiency
- Heat and Energy Management
- Gas Flairing Emission Reduction
- Efficient Consumption of Energy Technologies and Carbon Capture and Storage
- Environmental Monitoring, Analysis and Assessment Equipment
- Renewable Energy
- Noise and Vibration Abatement
- Resources and Pollution Management
- Waste Water Management and Potable Water Treatment
- Air Pollution Control
- Natural Risk Management
- Clean UP or Remediation of Soil and Water
- Cleaner or More Resource Efficient Technologies and Products
- Others
- Environmental Preferable Products based on End-Use or Disposal Characteristics
- Waste Management, Recycling and Remediation
- Water supply
- Bubbles are sized by RCA

Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

in this area, with RCA in alternative vehicles currently at 0.06 and proximity to current productive export capabilities comparatively low at about 0.4. Since 2017, EVs have their own export code (separated from other "new energy" vehicles), but this is not reflected in our longitudinal data covering the period of 1995-2019 and therefore using the original 1992 version of the HS nomenclature. Tracking this new export code, we see that China was the 8th largest net exporter of EVs in 2020, with exports up 260% compared to the year before, now capturing 4.6% of global export markets for EVs[29,30].

Separately, our longitudinal dataset shows that China has export capabilities (RCA = 1.1 > 1) in environmentally friendly and less-polluting busses (those that don't run on diesel) and is a major player on its export market (Figure 29). But making busses is significantly less complex (product complexity index (PCI: 0.43) than new energy vehicles (PCI: 1.87). The question remains whether this will help improve China's EV capability for the next decade, or whether its EV demand will mostly met by imports from other countries.

Fig. 29: China's share in global exports of new electric vehicles (also includes gas powered)



Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

32 Daniel Workman, 'Electric Cars Exports by Country', World's Top Exports, 2021 <https://www.worldstopexports.com/electric-cars-exports-by-country/>.

33 Workman, Daniel, 'Electric Cars Exports by Country', World's Top Exports, 2021 <https://www.worldstopexports.com/electric-cars-exports-by-country/>

Summary

- China's rise to prominence in manufacturing green technologies exceeds its broader manufacturing and export expansion, but may partly reflect a shift towards more technologically sophisticated exports in general.
- These developments are thought to be driven by its ability to take advantage of cheap labour, as well as targeted industrial policy which includes industry-specific subsidies, preferential credit, and measures which aggressively target technology transfer, as well as protectionist provisions such as local content requirements.
- China is the world's largest emitter of green house gases, and its production processes for manufactured goods are considered very polluting.
- However, China has recently increased its environmental ambitions in raising its Nationally Determined Contribution under the Paris Agreement and setting a carbon neutrality target for 2060.
- The "Made in China 2025" strategy targets sustainability and some key green technologies such as electric vehicles, as well as digitalisation and high-tech industries more broadly.
- China has enormous green energy potential and access to very cheap solar resources, but due to its large population it might only export green energy in the short-term.
- Trade tensions between China and the rest of the world, especially the US, have been ongoing for years and intensified in 2018 under President Trump. At COP26, China and the US surprised the world with a new pledge to collaborate in the form of a US-China Joint Declaration on Enhancing Climate Action in the 2020s.
- While China has been very adept at technology adoption and manufacturing, it has not, so far, contributed much at the innovation frontier.
- Its ageing population and rising standards of living have led to a rapid increase in the cost of labour. With growth starting to slow, the question arises whether China can escape the middle-income trap and take the leap from technology adopter to frontier innovator.


Allianz

United States of America case study

Policy ambition and green complexity

The United States has a long history as a global innovator and boasts some of the most progressive and innovative green states in the world, such as California.

It is therefore not surprising that the US holds the 4th highest rank in Green Complexity Index (after Germany, Italy and most recently Austria) and rank 12th in Green Complexity Potential.

What is perhaps surprising is that its GCI and GCP have declined slightly since 1995, as has its manufacturing competitiveness overall.

The US currently captures about 10% of global green exports, a decline from 17% in 1995-99. Green products make up about 11% of its total exports.

The US is the world's second-largest emitter of greenhouse gases and has historically been hamstrung by climate and other environmental issues being highly politicised.

Former Republican President Donald Trump, who questioned the existence and threat of anthropogenic climate change and promised to bring back coal mining and manufacturing jobs, rolled back many of the previous administration's environmental protections and pulled the country out of the Paris Climate Accord.

The current Democrat Biden administration has worked hard to reverse many of these decisions since coming to power in January, re-joining the Paris agreement and recently setting targets to reach net zero greenhouse gas emissions by 2050 and to support clean energy technologies through the Glasgow Breakthrough Agenda at COP26.

The administration's economic agenda strongly ties the green transition to infrastructure investments and job creation. To what extent the current level of ambition can be realised remains to be seen.

United States at a glance

329,000
Population (thousands)

20,936,600
GDP (current US$, millions)

65,280
GDP / capita (US$, PPP)

4
GCI rank

8
ECI rank

12
GCP rank

10.18 %
Global share of green exports

11.34 %
Share of green in total exports

Rail locomotives (diesel-electric)
Highest RCA green product

Profile projectors
Most complex competitive

2050

Net zero target (proposed)

1.3°C

Temp change since 1961

0.24 (rank: 52/230)

CO_2 intensity (kg/PPP$ GDP)

79

Avg energy use (MWh/yr/cap)

169

Global Energy Potential (MWh/yr/cap)

-

Climate risk index rank

127

Extreme risk index rank

8.7 % (146/213)

Renewable energy consumption

8%

Share of green in covid recovery

Trends in green competitiveness

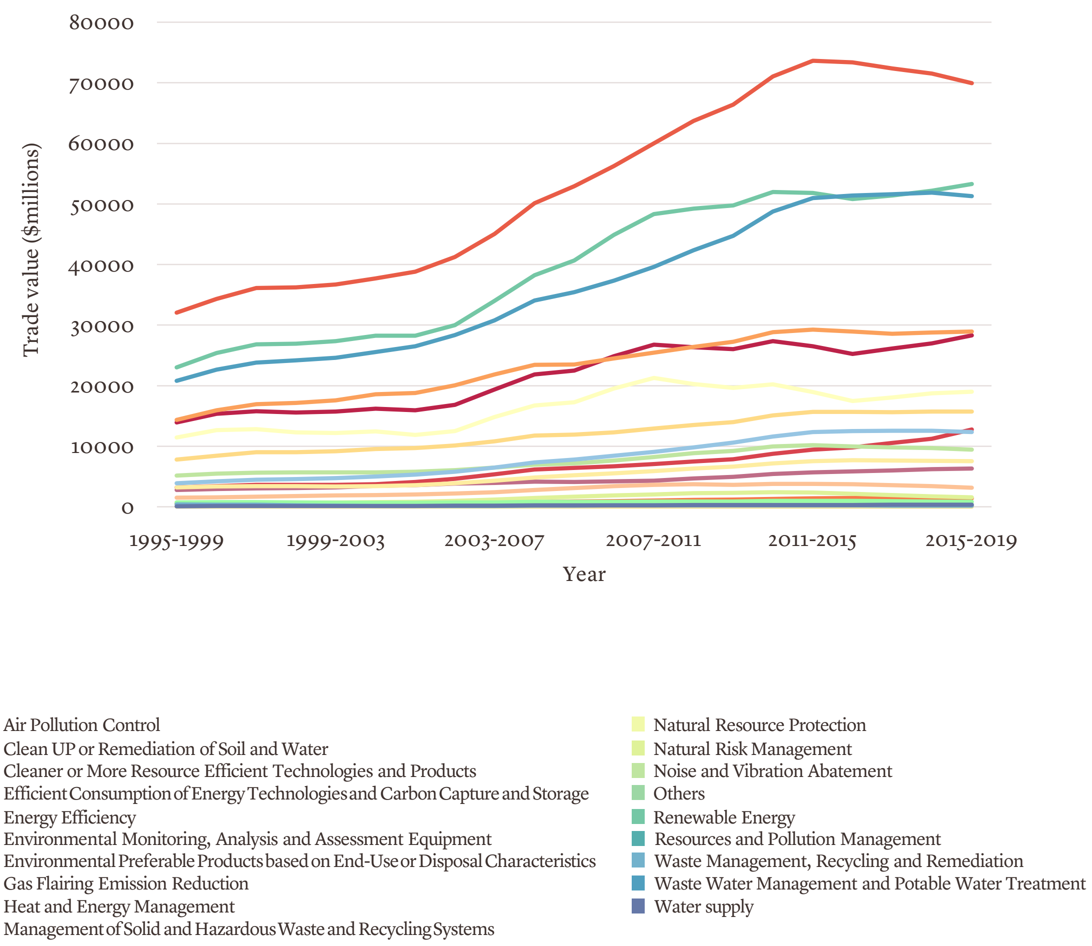
The United States' green competitiveness has been on a slowly declining trend. It held second rank in Green Complexity Index until 2003-2007, when it was overtaken by Italy. It was overtaken again by Austria in 2015-2019 and now holds rank 4. Its Green Complexity Potential peaked in 2005-2009 and has been declining ever since, to its current rank of 12. The US still has a large domestic green market that it is mostly met by domestic industry (Section 5), but in exports at least further declines in green complexity may lie ahead unless the new administration's policies manage to reverse this trend.

The United States' share in global exports of green products declined significantly over the course of the period: from 17.04% in 1995-1999 down to 10.18% in 2015-2019. Its share in green imports fluctuated somewhat, declining in the years leading up to the global financial crisis following its peak in 1998-2002, then reversing back to an upwards trend. It now stands at close to 14%, as it did at the start of the period. This makes the US a net importer of green goods.

Overall trade volume increased in many green categories, including products related to efficient consumption of energy technologies and carbon capture and storage; renewable energy; and wastewater management and potable water treatment (Figure 29). However, trade values have plateaued or even slightly decreased since around 2011-2015, even though green products continued to gain in importance as a share of global trade. This is reflected in the country's falling green competitiveness.

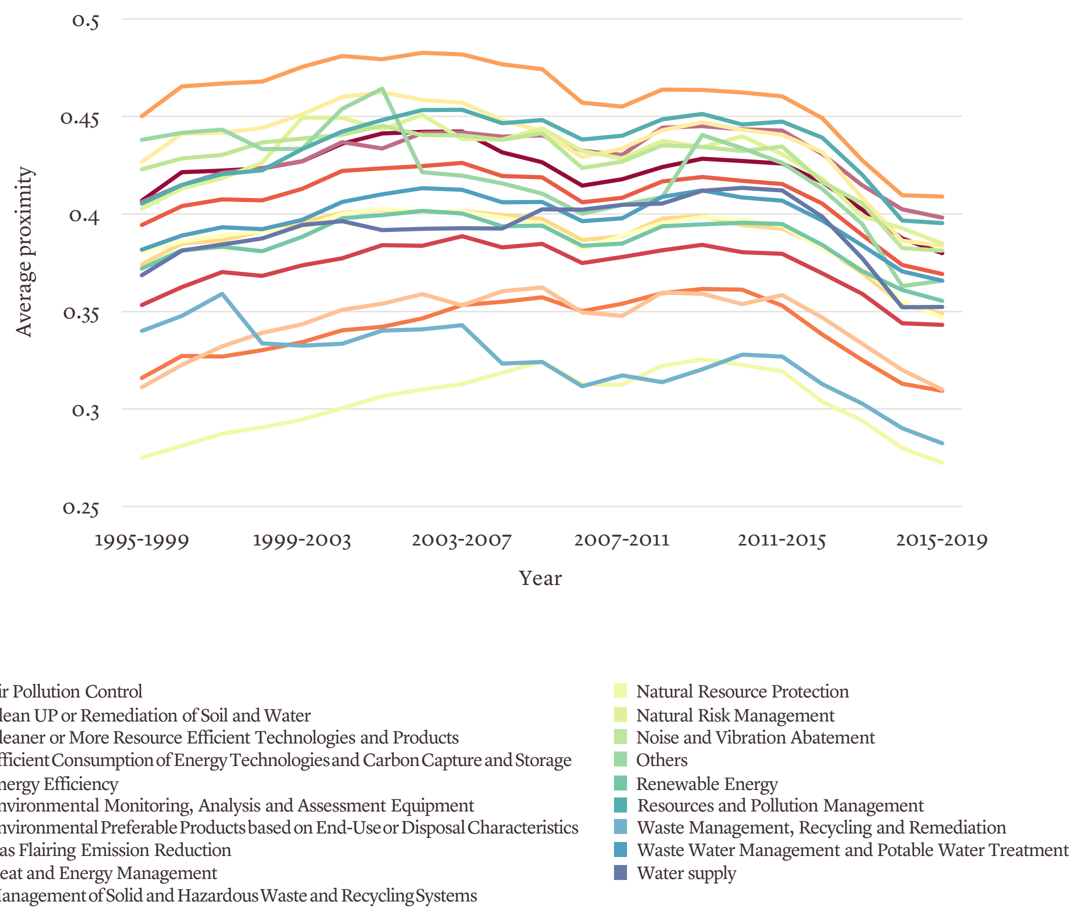
As is the case with overall GCP, average proximity to production capabilities in most green categories peaked during the early 2000s (Figure 30). It has been on a declining trend since then, apart from a brief recovery following the global financial crisis of 2008. Since around 2011-2015, this decline has been steeper than ever.

Fig29: Export value over time by environmental category, United States



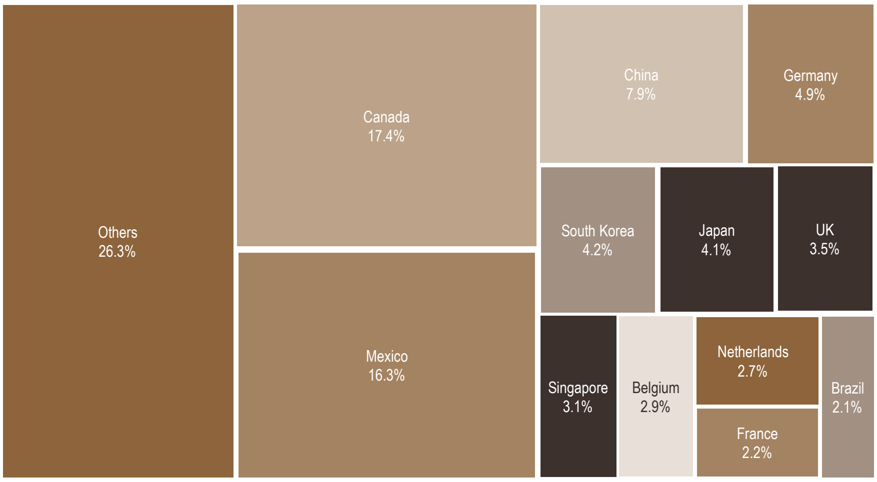
Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Fig. 30: Average proximity over time by environmental category, United States.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

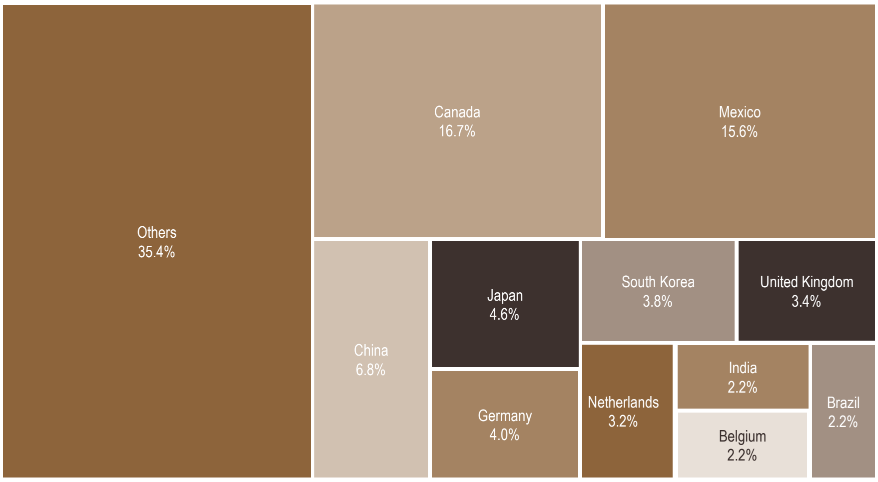
Fig. 31: Largest importers of US green exports. Only countries that import >2% of American exports are shown separately.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

In summary, our analysis implies that US' productive capacities are becoming less suited to producing clean technologies, relative to other countries. This is partly mirrored by a fall in overall economic complexity – with the US' rank in Economic Complexity Index after some fluctuation falling from 6 to 8 over the last two decades (1995-99 to 2015-19). The most important importers of green technologies produced in the United States are its immediate neighbours Canada (17.4%) and Mexico (16.3%) (Figure 31). Strikingly, while the US accounts for about 15.6% of China's green exports, China only accounts for 7.9% of green exports from the US. Figure 32 shows the distribution for overall exports, which paints a broadly similar picture.

Fig. 32: Largest importers of US overall exports. Only countries that import >2% of American exports are shown separately.

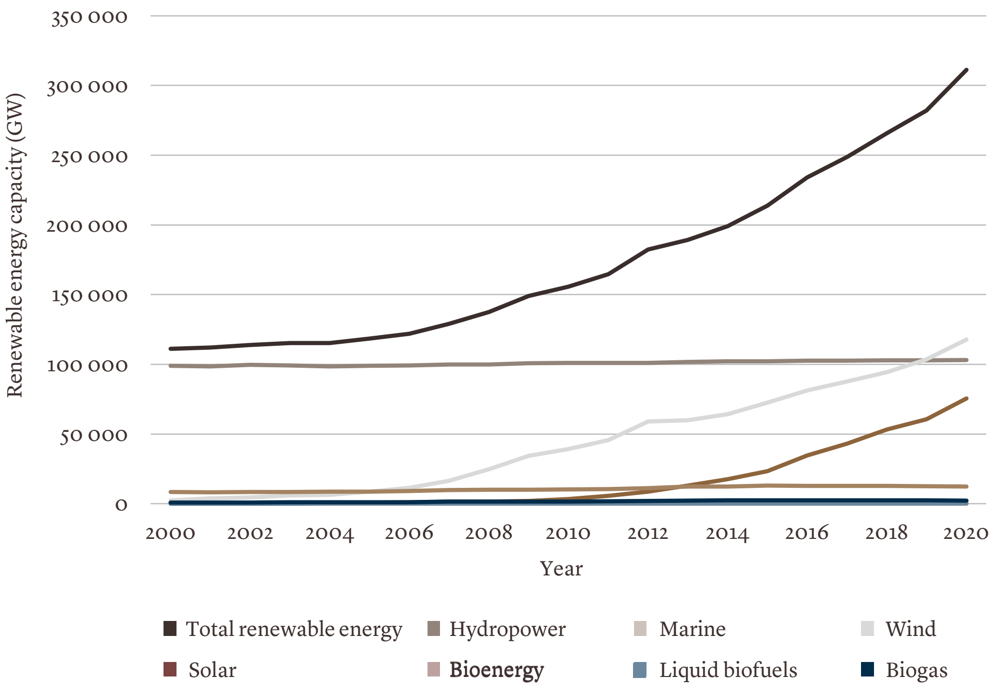


Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Trends in green energy

The US is one of a number of countries whose energy emissions intensity has declined since 2010[1]. Much of this progress has been the outcome of the switch away from coal in favour of fracking gas. Renewable energy capacity has also increased since the 1990's in the US and currently accounts for 8.71% of per capita energy, compared to 4.47% in 1995, with the state of California leading the way. The country did, however, start with a very high level of per capita emissions, with most of the country's energy mix still being made up by fossil fuels (83%) - close to the global average of 84%[2].

Fig. 33: USA's renewable energy generation capacity by source.



Source: IRENA (2021), Renewable Capacity Statistics 2021; & IRENA (2020), Renewable Energy Statistics 2020, The International Renewable Energy Agency, Abu Dhabi.

1 Lamb and others.

2 Hannah Ritchie and Max Roser, 'Energy', Our World in Data, 2020 <https://ourworldindata.org/energy> [accessed 19 August 2021].

The US is, however, blessed with some of the world's greatest technical potential for hydropower, biomass, solar, and wind. The relatively large population of 330 million is widely distributed over the land surface, giving it a high practical solar potential zonation[3] (Figure 34) and consequently high solar economic potential. Its current estimated green energy potential (170 MWh/yr/cap) is well above its very high average energy usage (79 MWh/yr/cap) and an average solar PV LCOE of 10c/kWh indicating considerable potential for expansion of green energy for both the domestic market and for export.

Most of the new renewable growth in the US is from onshore wind (Figure 33), although the US is predicted to have the third highest solar installations in the coming years, behind China and India, thanks to recent declines in costs for solar PV[4] and opportunities for further integration through improved grid interconnectedness across the country's

Table 5: Estimates of the US's current economic potential for annual renewable energy generation which is used to calculate its per capita renewable energy potential in comparison with its current average annual per capita usage

United States	
Onshore wind generation potential (EJ/yr)	130
Offshore wind generation potential (EJ/yr)	25
Solar PV generation potential (EJ/yr)	174
Hydro generation potential (EJ/yr)	1
Bioenergy generation potential (EJ/yr)	11
Est. Total generation potential (EJ/yr)	331
Population (millions)	329
Average annual energy usage per person (MWh/yr/cap)	79
Total generation potential per person (MWh/yr/cap)	279

Source: Appendix for Data Sources

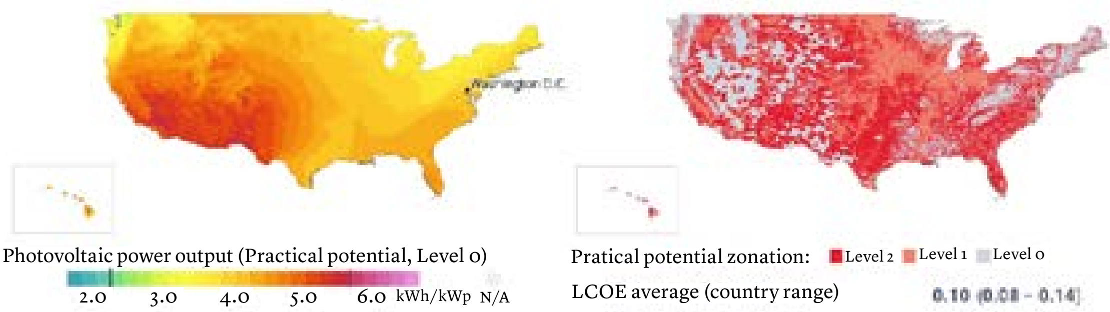
[3] The solar practical zonation excludes land with physical or technical constraints, such as rugged terrain, extreme remoteness, built-up environment, and dense forests, and 'soft' constraints, such as regulations related to protection of cropland and conservation areas.

[4] SolarPower Europe, 'Solar Power 2019–2023', Global Market Outlook, 2018, 94.

vast land mass[4]. As will be discussed below, should the Build Back Better Act currently before US Senate get passed, the US will become one of the largest investors in renewable capacity in the coming years.

The United States have a mix of existing strengths and new opportunities in the green economy (Figure 34)[6]. High complexity strengths highlighted on the plot include profile projectors (which are used in the measurement, recording, analysis and assessment of environmental samples or environmental impact), and cleaner vehicles such as hybrids or EVs. The latter are a clear strategic priority for the Biden Administration and the Breakthrough Agenda from COP26.

Fig. 34: Estimates of solar photovoltaic potential (kWh/kWp) and practical potential zonation used to determine the US's economic potential for solar.



Source: https://globalsolaratlas.info/

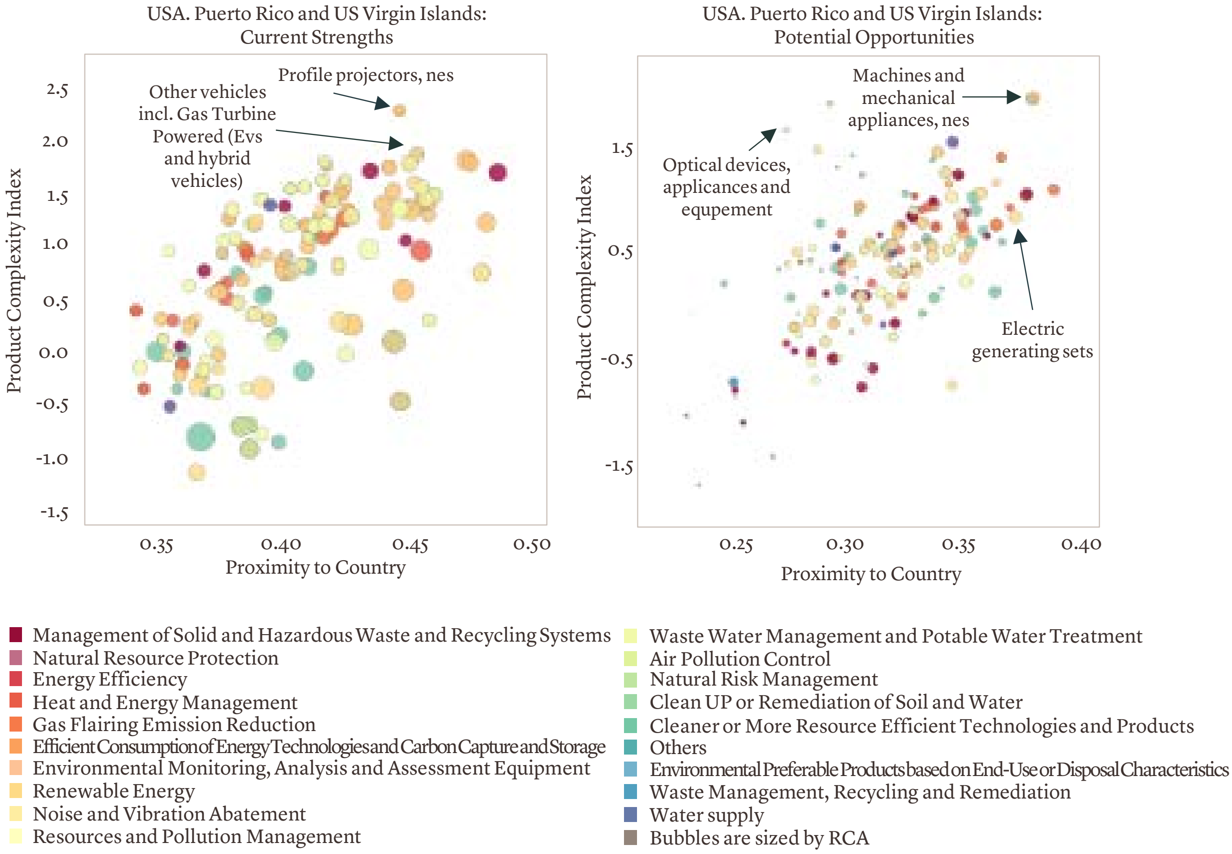
5 Patrick R. Brown and Audun Botterud, 'The Value of Inter-Regional Coordination and Transmission in Decarbonizing the US Electricity System', Joule, 2021, 115–34 <https://doi.org/10.1016/j.joule.2020.11.013>

6 For a more in-depth explanation of how to read this figure, please refer to the section Green strengths and opportunities within the China case study.

Green strengths and opportunities

There is a positive correlation between complexity and proximity, which implies that products which would be easier for the US to develop a new competitive advantage in, are also higher in complexity - opening up a greater number of new (complex) diversification opportunities (Figure 35). High complexity opportunities for the US include machines and appliances designed for a wide range of areas of environmental management including waste, wastewater, drinking water production and soil remediation; and electric generating sets used in the production of renewable energy. Figure 35 also highlights optical devices, appliances, and equipment at the top left. This product category includes solar heliostats, which orient mirrors in concentrated solar power systems to reflect sunlight on to a CSP receiver. This product group is highlighted as an example of one that is high in complexity but low in proximity, implying that the US could gain from producing this product but is unlikely to easily develop a competitive advantage. In contrast, this is China's most complex competitive product, demonstrating how the green indices might be used for industrial policy.

Fig. 35: United States' green export products divided into current strengths and potential opportunities. Size of product indicates country's current RCA, colours represent product categories (see legend)[7]



Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

[7] For an in-depth explanation of how to read this figure, please refer to the section Green strengths and opportunities within the China case study.

Policy and economic environment

The past few decades have seen a decline in US manufacturing employment which is well-documented in the literature and is usually attributed to offshoring (especially to China) and/or to automation[8]. Manufacturing employment has been on the decline since the 1970s, with 2 million jobs lost between 1980 and 2000; however, this trend accelerated rapidly after 2000. Five and a half million manufacturing jobs were lost between 2000 and 2017, a substantial share of which occurred even before the great recession[9]. Real value added in manufacturing nevertheless continued to increase until the early 2000s, reaching a peak just before the global financial crisis of 2008[10]. This "decoupling" of employment and value added was primarily driven by computers and electronic products, such as semiconductors[11].

The US, like many – especially rich – countries, has experienced a sectoral shift towards services. A decline in manufacturing employment and, more recently, manufacturing output growth, is not necessarily a negative trend. High-skilled services, such as software engineering, are arguably highly sophisticated and high in value added. Our methodology for measuring complexity does not capture this, as it is based on manufacturing exports. However, manufacturing has historically provided important employment opportunities to low-skilled workers. Charles et al.[12] argue that the fall in manufacturing employment has driven substantial declines in employment rates among prime-age workers, accompanied by higher opioid use in those affected. Moreover, they find that manufacturing itself has become increasingly capital-intensive and high-skilled, implying that erecting trade barriers to prevent offshoring and support American manufacturers may not help low-skilled workers.

The structural shifts in the US economy that have transpired over the past few decades have resulted in political tensions which arguably contributed to the election of

---

8 Teresa C. Fort, Justin R. Pierce, and Peter K. Schott, 'New Perspectives on the Decline of US Manufacturing Employment', Journal of Economic Perspectives, 32.2 (2018), 47–72 <https://doi.org/10.1257/jep.32.2.47>.

9 Kerwin Kofi Charles, Erik Hurst, and Mariel Schwartz, 'The Transformation of Manufacturing and the Decline in US Employment', NBER Macroeconomics Annual, 33 (2019), 307–72 <https://doi.org/10.1086/700896>.

10 Fort et al., 2018.

11 Fort, Pierce, and Schott; Susan N Houseman, Understanding the Decline of U.S. Manufacturing Employment, Upjohn Institute Working Paper, 2018 <https://doi.org/10.17848/wp18-287>.

12 Charles, Hurst, and Schwartz, 2019.

former President Donald Trump in 2016 and continue to loom large in US political discourse. Concerns over the competitiveness of US manufacturing, the effects of climate policy thereon, offshoring to China, and loss of employment in polluting sectors such as coal mining and fracking, continue to be highly divisive and pose a potential political barrier to the transition to a net zero economy. The Biden administration has adopted a "Green New Deal" style rhetoric as part of their Build Back Better Plan, linking the greening of the economy to infrastructure investment and job creation and promises to revive American manufacturing. Policies such as the "Buy American" provision in public procurement indicate that the administration is not opposed to protectionist measures, and ongoing trade tensions with China are likely to continue.

Environmental credentials and policy ambition

The US are the world's second-largest emitter of greenhouse gases, having been overtaken by China in 2006[13]. Climate policy in the US has depended largely on the current administration's stance on the issue. The Obama era saw multiple policies aimed at reducing greenhouse gas emissions, such as the Clean Power Plan; renewable energy tax credits; the creation of ARPA-E; or the signing of the Paris climate accord. President Trump, who famously called climate change a "hoax", spent much of his tenure rolling back environmental protections[14] and pulled the United States out of the Paris agreement, which the current President Biden promptly re-joined[15] .

The American Clean Energy and Security Act of 2009, which attempted to introduce a cap-and-trade system, was blocked by the Senate after passing through Congress. As of today, the United States still do not have a national carbon price. However, some states have responded by cooperatively introducing their own: the Regional Greenhouse Gas Initiative (RGGI) was established in 2019. RGGI is a carbon trading system covering the power sector in Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, Vermont, and Virginia.

The Biden administration has made climate change a priority. President Biden has pledged to half greenhouse gas emissions by 2030[16] and reach net zero by 2050[17]. The Biden Climate Plan is strongly tied to infrastructure investments, economic inclusion, and job creation, as we will set out in more detail in the following section.

---

[13] Hannah Ritchie and Max Roser, 'CO2 and Greenhouse Gas Emissions', Our World in Data, 2020 <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions#citation> [accessed 19 August 2021].

[14] Nadja Popovich, Livia Albeck-Ripka, and Kendra Pierre-Louis, 'The Trump Administration Rolled Back More Than 100 Environmental Rules. Here's the Full List.', The New York Times, 20 January 2021 <https://www.nytimes.com/interactive/2020/climate/trump-environment-rollbacks-list.html> [accessed 19 August 2021].

[15] Oliver Milman, 'Biden Returns US to Paris Climate Accord Hours after Becoming President', The Guardian, 20 January 2021 <https://www.theguardian.com/environment/2021/jan/20/paris-climate-accord-joe-biden-returns-us> [accessed 19 August 2021].

[16] The White House, 'FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies', White House Statements and Releases, 2021 <https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/> [accessed 19 August 2021].

[17] Biden Harris Democrats, 'The Biden Plan for a Clean Energy Revolution and Environmental Justice', Battle for the Soul of the Nation, 2021 <https://joebiden.com/climate-plan/> [accessed 19 August 2021].

[18] The White House, 'FACT SHEET: The American Jobs Plan', White House Statements and Releases, 2021 <https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/> [accessed 19 August 2021].

The Build Back Better Plan and US green recovery spending

In Section 3, we discussed countries' plans to spend on green recovery post COVID-19. Any policy that was still being negotiated in the national parliaments was excluded from the analysis.

The Biden administration began with significant ambition: the American Jobs Plan announced in March 2021 could have added green spending worth 2% of GDP. The American Jobs Plan was eventually incorporated into the $1 trillion Infrastructure Investment and Jobs Act (of which $550 billion is new spending), passed by the Senate in August 2021 and by the House in November. Based on a rough breakdown, about 20% of this can be deemed green (mainly investment in EVs, railway transportation, and clean electricity)[18].

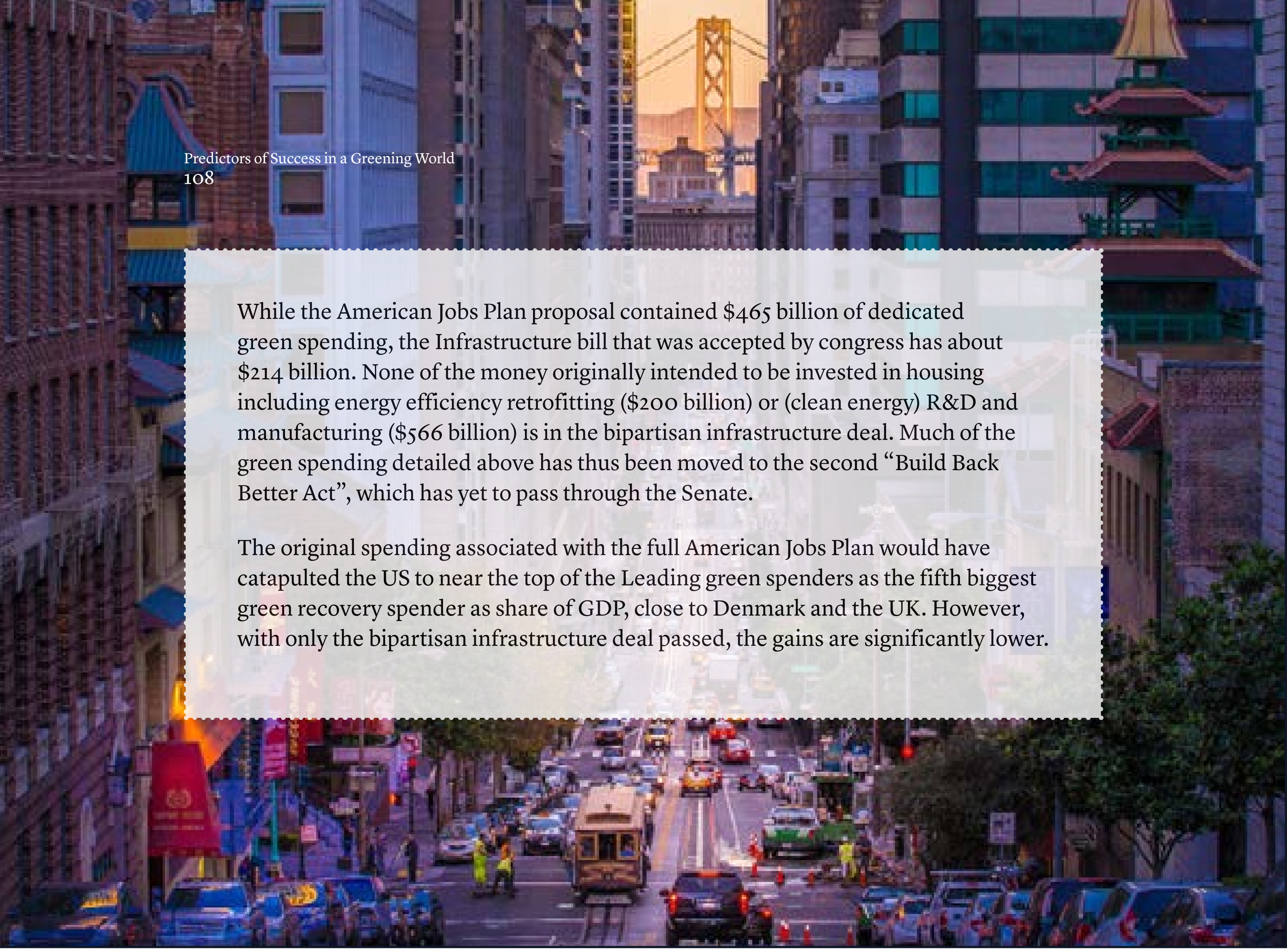
A further $2.2 trillion Build Back Better Act was passed in the House of Representatives along party lines, but has yet to pass through the Senate. This second bill is aimed at securing better social welfare provisions, including much of Biden's American Families Plan, and to support his recent commitments on climate change. This latter component, which will include significant spending on renewables and reducing methane emissions, will likely have the greatest impact on the US's green competitiveness.

A breakdown of some of the key green components of only the recently passed Infrastructure Investment and Jobs Act are as follows:

EVs: The Infrastructure bill contains $7.5 billion for EV infrastructure and a further $7.5 billion for electric and clean busses and ferries. This is about 10% of the figure originally envisioned by the Biden administration for electric vehicle investment as a whole. Some of the remainder is to be included in the Build Back Better Act.

Clean electricity: The recently passed Infrastructure bill aims to spend $73 (original plan: $100) billion on the electricity grid, energy efficiency, and renewable energy, to put the US electricity system on a pathway toward carbon-free electricity by 2035. An additional $21 billion is planned for plugging former oil and gas wells and cleaning up abandoned mines.

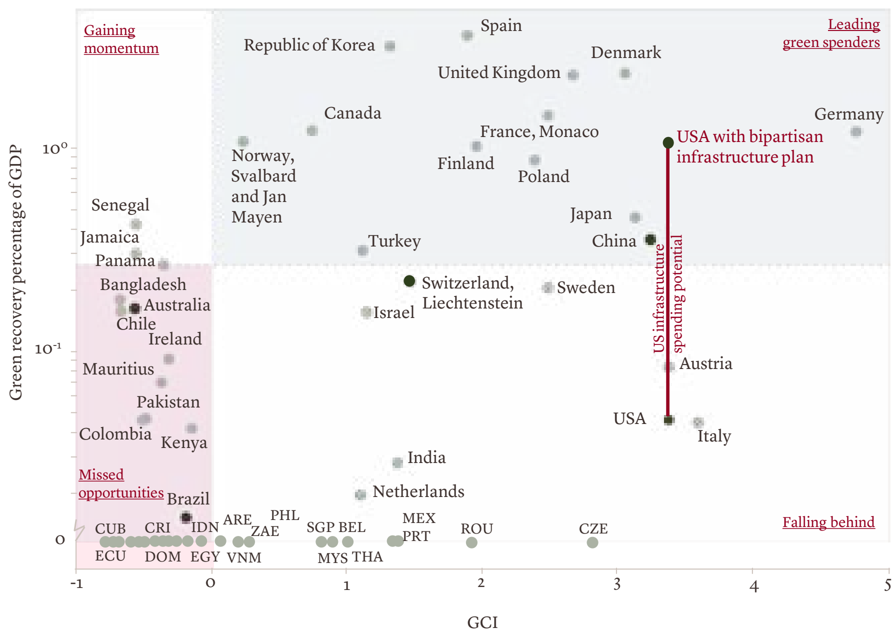
Public transport: $39 billion will go to modernising and upgrading the large repair backlog of the Department of Transportation, as well as expanding the public transit network. A further $66 billion will be spent on modernising and expanding passenger railway and electrifying freight rail transport. This is scaled back from the original $85 + $80 billion package respectively.



While the American Jobs Plan proposal contained $465 billion of dedicated green spending, the Infrastructure bill that was accepted by congress has about $214 billion. None of the money originally intended to be invested in housing including energy efficiency retrofitting ($200 billion) or (clean energy) R&D and manufacturing ($566 billion) is in the bipartisan infrastructure deal. Much of the green spending detailed above has thus been moved to the second "Build Back Better Act", which has yet to pass through the Senate.

The original spending associated with the full American Jobs Plan would have catapulted the US to near the top of the Leading green spenders as the fifth biggest green recovery spender as share of GDP, close to Denmark and the UK. However, with only the bipartisan infrastructure deal passed, the gains are significantly lower.

Figure 36 shows the impact of the bipartisan infrastructure deal, which still puts the US squarely in the Leading green spenders corner.
Reproduction of figure 18, including the potential impact of the recently passed bipartisan infrastructure deal. Note that the y-axis is logarithmic.



Source: Global Recovery Observer https://green-transition-navigator.org

Summary

- US green complexity and green complexity potential have declined slightly over the study period, as has its overall economic complexity.
- However, the country remains highly competitive in global comparison, with a GCI rank of 4 and a GCP rank of 8.
- The United States has substantial green energy potential, more than enough to meet future domestic demands and even become a green energy exporter.
- President Biden has made climate change one of his top priorities and pledged to half greenhouse gas emissions by 2030 and reach net zero by 2050.
- The bipartisan infrastructure deal aims to expand and electrify public transport and build a clean electricity grid. It includes ambitious public infrastructure investments and promises to generate employment for American workers, although it misses many other investments originally planned by the Biden administration.
- The administration is presenting a firm stance on China, emphasising the importance of supply chain resilience, and aiming to boost American manufacturing using policies such as the “Buy American” provision for public procurement.

Brazil

Policy ambition and green complexity

Despite a proud history of technological progress, particularly in aviation, Brazil stands out in modern times for its relatively low investment in R&D, combined with economic and political volatility, high levels of corruption, and low capacity of industries to generate innovation[1]. Such problems have no doubt contributed to its declining ECI, GCI and GCP rankings.

The current Bolsonaro government has been widely criticised for its poor environmental record. However, Brazil updated its NDC[2] in 2020 with a new intermediate target. Compared to 2005 levels, Brazil wants to lower its emissions by 37% in 2025 and by 43% in 2030[3]. This was written with a long-term goal of carbon neutrality by 2060.

As Brazil is able to produce much of its electricity from hydropower, a large part of the country's emissions are from agriculture (33%), land-use change (e.g. deforestation) (23%) and transport (15%)[4] . Accordingly, Gurgel, Paltsev, and Breviglieri[5] argue that the 2030 goal could be achieved quite cheaply at 0.7% of GDP in 2030, mostly through reducing deforestation and changes to agricultural practices. After 2030, though, more ambitious policy changes, such as a carbon pricing mechanism, might be necessary to remain on track. Gramkow and Anger-Kravi[6] also believe that with the right mix of green stimulus, paid for by a carbon tax, Brazil could increase economic growth while lowering emissions from a business-as-usual baseline. However, as noted in Section 3, Brazil has allocated only a fraction of its GDP to spend on stimulus following the COVID-19 pandemic. Nonetheless, the small amount it has allocated for recovery has been over 50% green, with a focus on renewable energy projects. This was still quite little spending, and consequently Brazil has ended up in the *falling behind* category.

1 Marisa Moser, Mauri Aparecido de Oliveira, and Ricardo Luiz Pereira Bueno, 'Comparison between Brazil and the 30 Most Innovative Countries in the World', EMAJ: Emerging Markets Journal, 7.2 (2018), 19–28 <https://doi.org/10.5195/emaj.2017.141>.

2 Nationally Determined Contribution

3 UNFCCC, 'Federative Republic of Brazil First Nationally Determined Contribution towards Achieving the Objective of the United Nations Framework Convention on Climate Change (Updated Submission)', 2020 <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Brazil First/Brazil First NDC (Updated submission).pdf>.

4 USAID, Greenhouse Gas Emissions in Brazil, USAID, 2018.

5 'The Impacts of the Brazilian NDC and Their Contribution to the Paris Agreement on Climate Change', Environment and Development Economics, 24.4 (2019), 395–412 <https://doi.org/10.1017/S1355770X1900007X>.

6 Camila Gramkow and Annela Anger-Kraavi, 'Developing Green: A Case for the Brazilian Manufacturing Industry', Sustainability 2019, Vol. 11, Page 6783, 11.23 (2019), 6783 <https://doi.org/10.3390/SU11236783>.

Brazil at a glance

212,560
Population (thousands)

1,444,733
GDP (current US$, millions)

15,076
GDP / capita (US$, PPP)

93
GCI rank

76
ECI rank

72
GCP rank

3.83 %
Share of green in total exports

0.50 %
Global share of green exports

Binder twine, sisal
Highest RCA green product

Refrig compressors
Most complex competitive

2050

Net zero target (proposed)

1.2°C

Temp change since 1961

0.14 (rank: 120/230)

CO_2 intensity (kg/PPP$ GDP)

17

Avg energy use (MWh/yr/cap)

141

Global Energy Potential (MWh/yr/cap)

27

Climate risk index rank

123

Extreme risk index rank

44% (57/213)

Renewable energy consumption

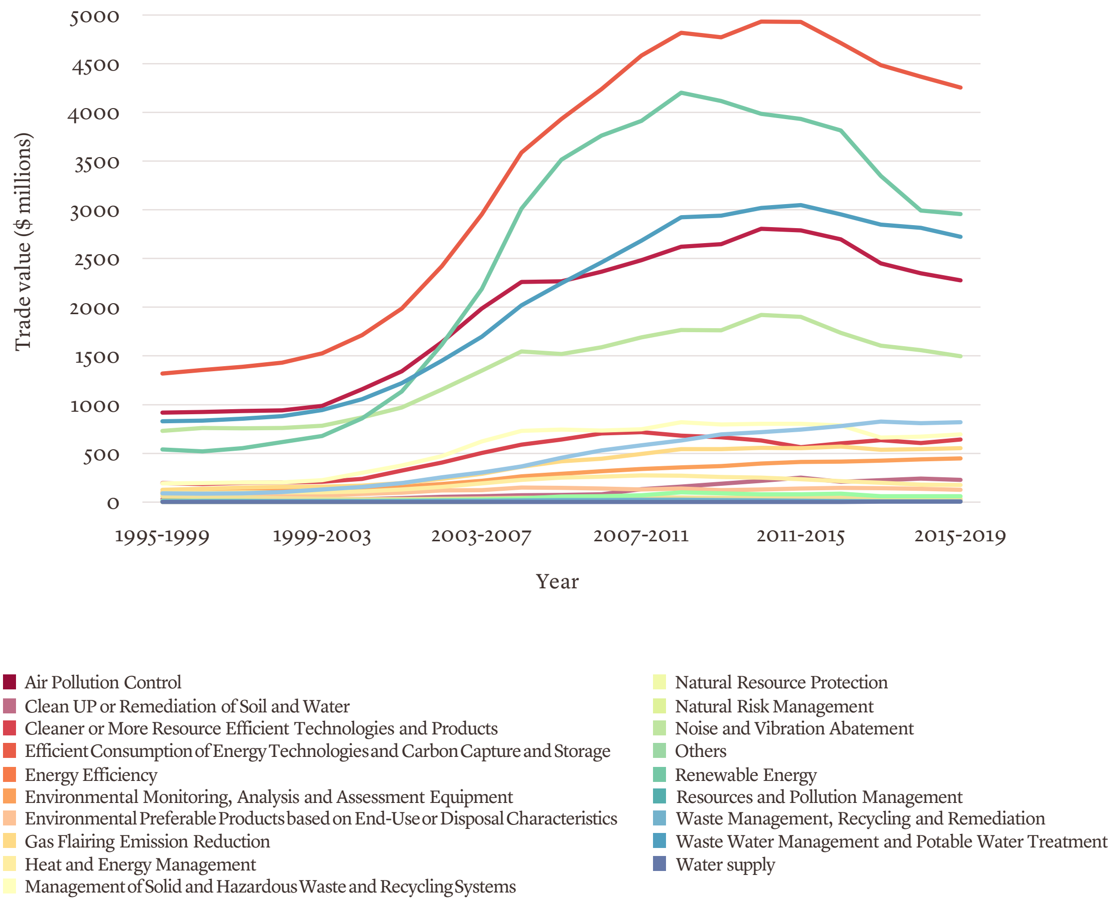
-

Share of green in covid recovery

Trends in green competitiveness

Both Brazil's green competitiveness and its green competitiveness potential have seen a declining trend over the course of the study period. Its GCI declined from rank 48 to rank 93 and GCP fell from rank 43 to rank 72, suggesting that GCI is likely to fall further in the future. As can be seen in Figure 36, Brazil increased its absolute trade volume in green products in almost all categories from 1995 until the 2011-2015 period. Between then and the 2015-2019 period, total trade volumes dropped in Brazil's top 5 categories: Efficient Consumption of Energy Technologies and Carbon Capture and Storage, Renewable Energy, Wastewater Management and Potable Water Treatment, Air Pollution Control, and Noise and Vibration Abatement.

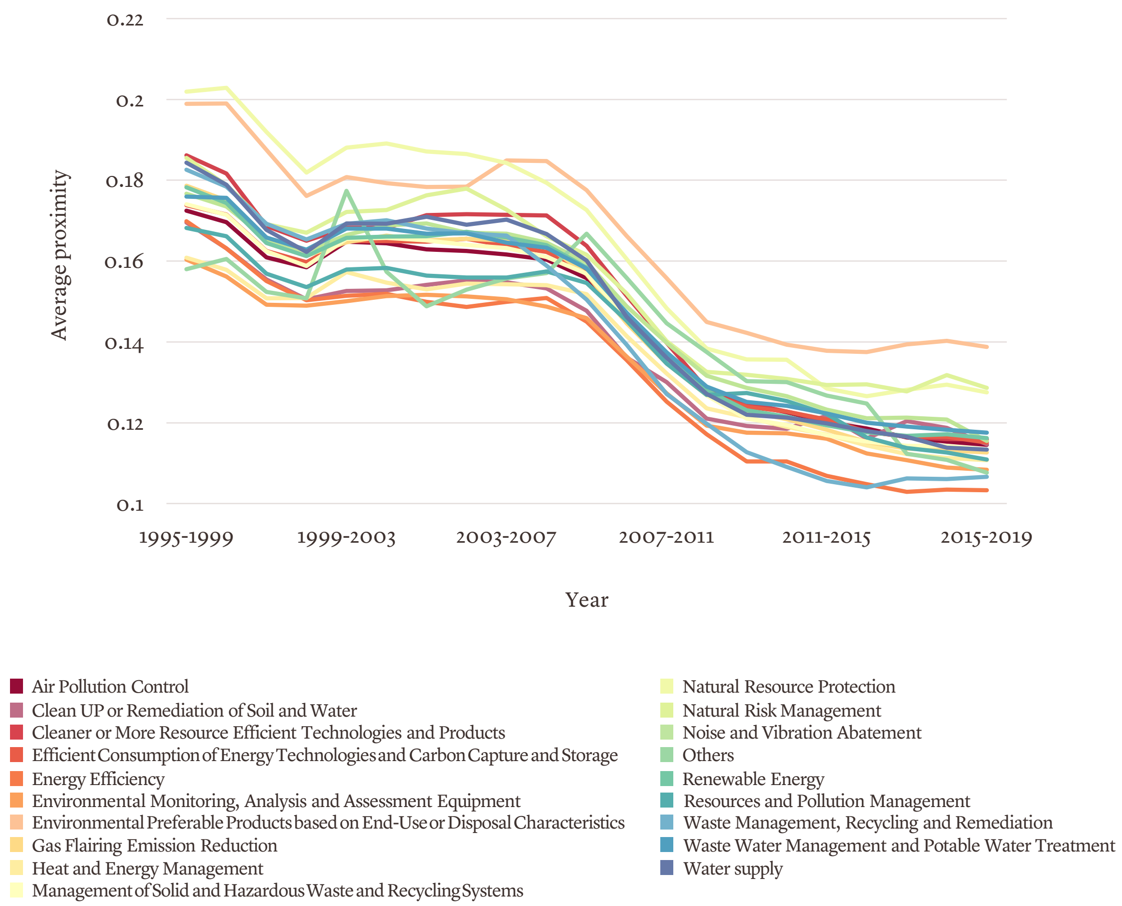
Fig. 36: Export value over time by environmental category, Brazil



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Over the same period, from 1995 onward, the average proximity of green products to Brazil's productive capabilities has declined, as is shown in Figure 37. This implies that green growth opportunities might be harder to attain than was once possible. The steepest declines occurred between the 2003-2007 and 2011-2015 time periods, which corresponds to the time frame of the great financial crisis and its recovery period. The US is by far the largest importer of Brazilian green products, importing almost 30% of the total. A breakdown of other countries importing more than 2% of Brazil's export is visualised in Figure 38. The second largest importer is Argentina with just over 9% of the total, followed by the Netherlands which imports 7.8% of Brazil's green exports.

Fig. 37: Average proximity over time by environmental category, Brazil



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Fig. 38: Largest importers of Brazilian green exports. Only countries that import >2% of Brazilian exports are shown separately.

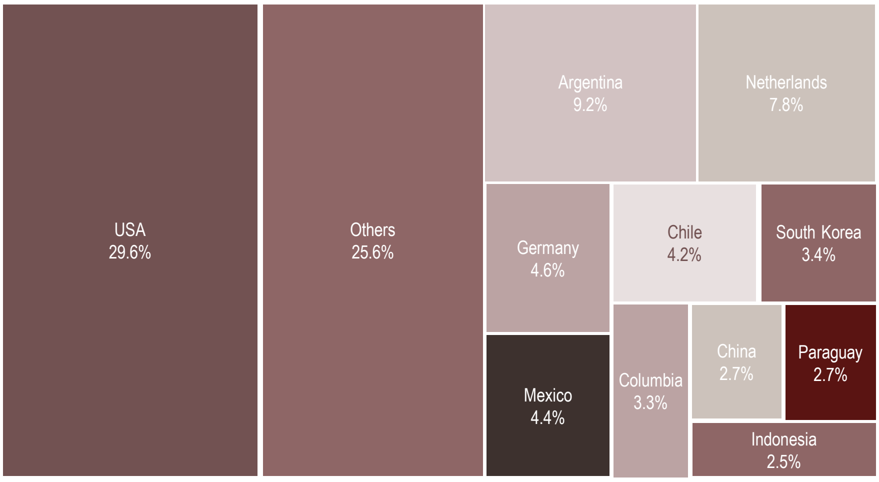
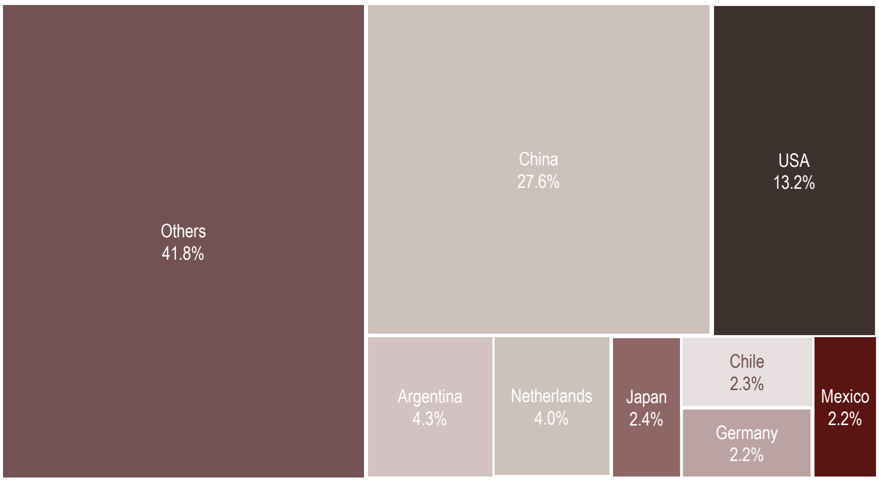


Fig. 39: Largest importers of Brazilian overall exports. Only countries that import >2% of Brazilian exports are shown separately.



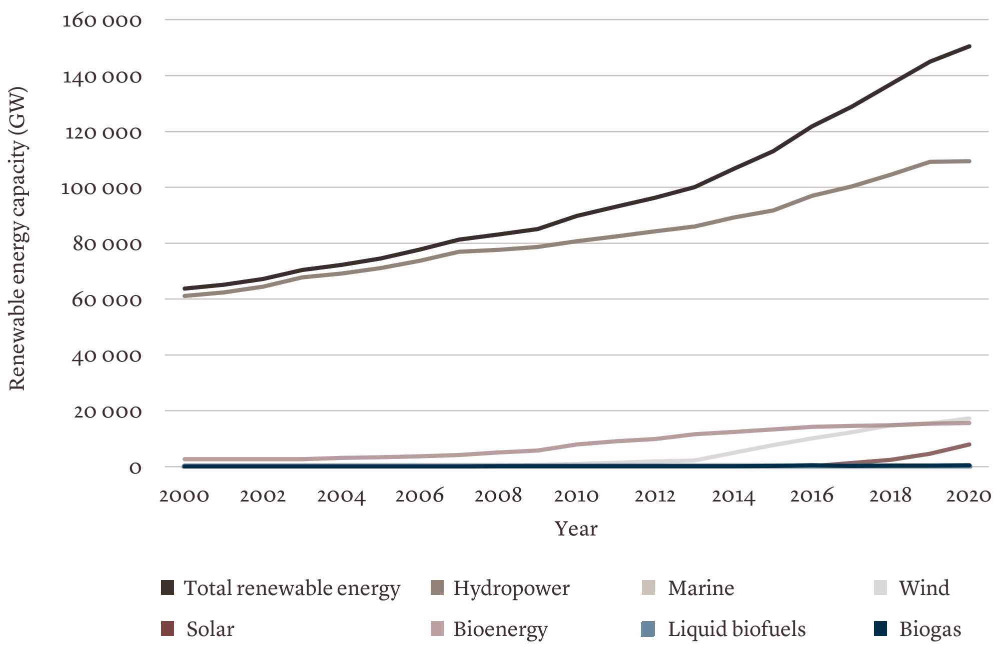
Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

The distribution of importer shares for Brazil's overall exports differs from those for its green exports (Figure 39). China constitutes a much more significant share of overall exports, at 27.6%, while the US's and Argentina's shares are much smaller (13.2% and 4.3%, respectively). Overall, green exports seem to be more locally concentrated and a much smaller share is captured by countries with a share of 2% or less (25.6%, compared to 41.8% for overall exports).

Trends in green energy

Brazil has very large renewable energy potential and some of the highest levels of renewable energy generation in the industrialised world thanks to their investment in hydropower[7] and quotas on biofuels for transport[8]. Brazil is second only to China in its hydropower generation capacity, and second only to the US in bioenergy generation (Figure 40). The Brazilian government has invested significantly in growing a domestic wind turbine manufacturing capability which has supplied much of its current wind capacity. Solar PV has also begun to grow significantly in Brazil mainly due to utility-scale installations, but with significant distributed solar coming online thanks to increasing competitiveness of the net-metering regulation throughout the country[9]. Newly added solar capacity amounted to 390 MW in 2018. This doubled in 2019 and almost doubled again in 2020 despite the COVID-19 pandemic.

Fig. 40: Brazil's renewable energy generation capacity by source



Source: IRENA (2021), Renewable Capacity Statistics 2021; & IRENA (2020), Renewable Energy Statistics 2020, The International Renewable Energy Agency, Abu Dhabi.

7 Eduardo Von Sperling, 'Hydropower in Brazil: Overview of Positive and Negative Environmental Aspects', Energy Procedia, 18 (2012), 110–18 <https://doi.org/10.1016/j.egypro.2012.05.023>.

8 Searle and Malins, 2015.

9 IRENA, Future of Solar Photovoltaic: Deployment, Investment, Technology, Grid Integration and Socio-Economic Aspects (A Global Energy Transformation: Paper), International Renewable Energy Agency, 2019, NOVEMBER <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019.pdf>; SolarPower Europe, 'Solar Power 2019–2023', Global Market Outlook, 2018, 94.

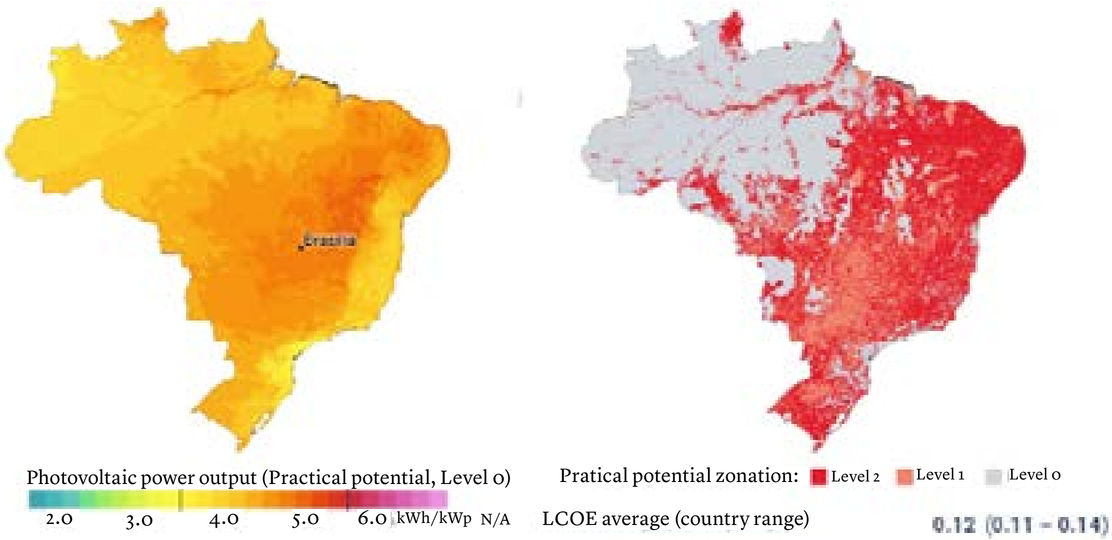
Brazil's highest potential in the short-term is from wind (Table 4), which would explain its significant investment in wind capacity over the last decade. Solar potential is limited in part due to large sections of the country (particularly the Amazon basin) being excluded from the level 1 zonation used to determine solar potential (Figure 41).

Table 6: Estimates of Brazil's current technical potential for annual renewable energy generation which is used to calculate its per capita renewable energy potential in comparison with its current average annual per capita usage.

Brazil	
Onshore wind generation potential (EJ/yr)	80
Offshore wind generation potential (EJ/yr)	25
Solar PV generation potential (EJ/yr)	15
Hydro generation potential (EJ/yr)	3
Bioenergy generation potential (EJ/yr)	14
Est. Total generation potential (EJ/yr)	123
Population (millions)	213
Average annual energy usage per person (MWh/yr/cap)	17
Total generation potential per person (MWh/yr/cap)	161

Source: See Appendix for Data Sources

Fig. 41: Estimates of solar photovoltaic potential (kWh/kWp) and practical potential zonation used to determine Brazil's economic potential for solar.



Source: https://globalsolaratlas.info/

Policy and economic environment

Brazil's own development bank, BNDES, is one of the largest state-owned development banks in the world and works quite efficiently. Its presence in the country has been called an industrial policy asset[10]. It has played a major role in many industrial policy strategies in the past. However, the implementation of an industrial policy is a particularly difficult task in Brazil, due to a litany of past failures and the resistance of many actors[11]. Such problems were only exacerbated by the recent Lava Jato investigation into corruption, involving the government and state-owned enterprises, notably its energy firm Petrobras[12].

A stable factor in Brazil's industrial policy of the past twenty years has been local content requirements (LCRs)[13] for the renewables market. Brazil is one of the largest markets for renewables that has a LCR[14], and has the largest wind energy potential in the region[15]. Brazil implemented its LCR by restricting access to low-cost financing from BNDES to those manufacturers that use local inputs. Since then, about 70% of Brazilian wind and solar power capacity has been financed through BNDES[16]. The LCRs started in 2002, when the industry was still in its infancy, and have become more and more stringent over time. For wind turbines, as of 2006 all generating components (nacelle) must be sourced locally, and the blades and tower must contain at least 60% local content. These rules were changed again in 2019 with a lower LCR percentage but a renewed focus on other priorities, such as jobs and exports.

Many studies, including by the OECD and IRENA, have pointed out the effectiveness of the Brazilian LCRs in creating a local

10 Felipe Silveira Marques João Carlos Ferraz David Kupfer, 'Industrial Policy as an Effective Development Tool: Lessons from Brazil', in Transforming Economies: Making Industrial Policy Work for Growth, Jobs and Development, ed. by José M. Salazar-Xirinachs, Irmgard Nübler, and Richard Kozul-Wright (Geneva: ILO publishing, 2014), pp. 291–305 <http://www.ilo.org/global/publications/books/WCMS_315675/lang--en/index.htm> [accessed 19 August 2021].

11 Wilson Suzigan, Renato Garcia, and Paulo Henrique Assis Feitosa, 'Institutions and Industrial Policy in Brazil after Two Decades: Have We Built the Needed Institutions?', Economics of Innovation and New Technology, 29.7 (2020), 799–813 <https://doi.org/10.1080/10438599.2020.1719629>.

12 Eliza Massi and Jewellord Nem Singh, 'Industrial Policy and State-Making: Brazil's Attempt at Oil-Based Industrial Development', Third World Quarterly, 39.6 (2018), 1133–50 <https://doi.org/10.1080/01436597.2018.1455144>.

13 LCRs are used in many jurisdictions, in various forms and degrees. Brazil, India, and South Africa are the largest markets for renewables that have LCR policies in place Morgan Bazilian, Victoria Cuming, and Thomas Kenyon, 'Local-Content Rules for Renewables Projects Don't Always Work', Energy Strategy Reviews, 32 (2020), 100569 <https://doi.org/10.1016/J.ESR.2020.100569>.

14 Bazilian, Cuming, and Kenyon. 2020.

15 Andrew S. David and Dennis Fravel, U.S. Wind Turbine Export Opportunities in Canada and Latin America, Office of Industries Working Paper, 2012 <https://www.usitc.gov/publications/332/ID-032_final.pdf> [accessed 19 August 2021].

16 Bazilian, Cuming, and Kenyon, 2020.

manufacturing base for wind and solar power[17]. Local players were able to capture a large market share for less sophisticated parts of the supply chain, but Brazil continued to rely on foreign companies with local factories to produce high-end parts, such as the wind turbine's nacelle[18]. Partly to comply with the LCRs, many of these foreign companies have established subsidiaries in Brazil, spurring local manufacturing[19]. A downside of LCRs might be that realisation rates of renewable energy projects are lower in Brazil compared to other countries, which some have speculated is due to higher costs caused by LCRs[20].

In our export dataset we find that Brazil has increased its export values in five of the key intermediate products we track that can be used for wind turbines over time[21].

However, as can be seen in Figure 42, Brazil does not currently have a competitive advantage in any of them. It did have significant comparative advantage (close to 4) in steel towers; however, RCA in this product has seen a steep decline since 1995 and is now below 1. RCA for other components has fluctuated somewhat, but all remain below 1. This suggests that while LCRs have somewhat boosted local production, jobs, and even exports in these products, they have not yet enabled Brazil to become internationally competitive. The same is true for the solar energy products that are included in our dataset.

[17] U. E. Hansen and others, 'The Effects of Local Content Requirements in Auction Schemes for Renewable Energy in Developing Countries: A Literature Review', Renewable and Sustainable Energy Reviews, 127 (2020), 109843 <https://doi.org/10.1016/J.RSER.2020.109843>.

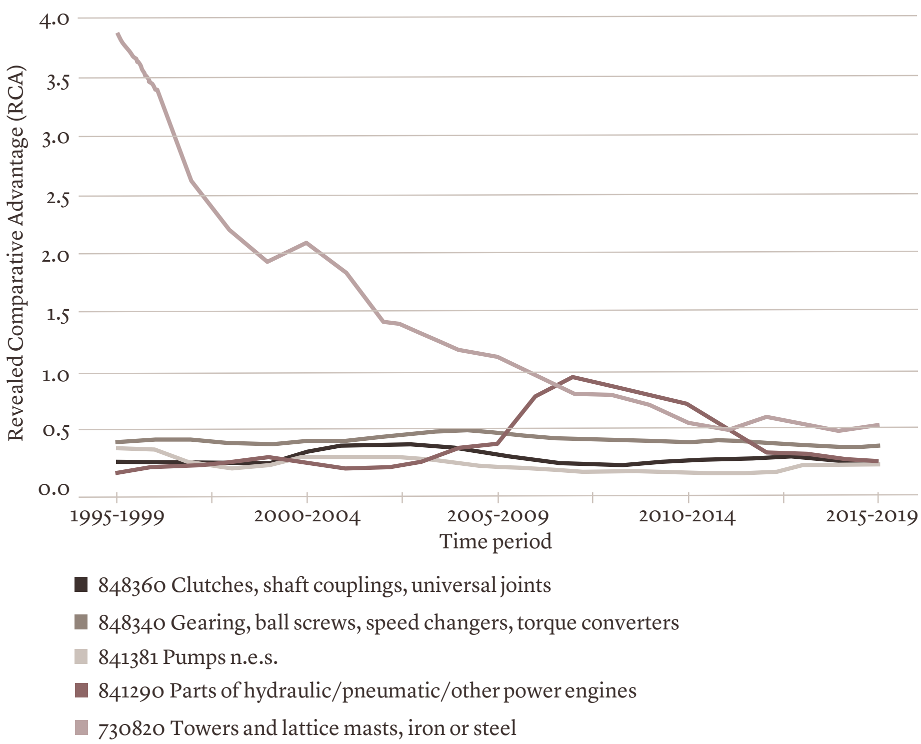
[18] Bazilian, Cuming, and Kenyon, 2020.

[19] David and Fravel, 2012.

[20] Benedict Probst and others, 'The Short-Term Costs of Local Content Requirements in the Indian Solar Auctions', Nature Energy, 5.11 (2020), 842–50 <https://doi.org/10.1038/s41560-020-0677-7>.

[21] 848360 Clutches, shaft couplings, universal joints; 848340 Gearing, ball screws, speed changers, torque converters; 841381 Pumps n.e.s.; 841290 Parts of hydraulic/pneumatic/other power engines; 730820 Towers and lattice masts, iron or steel. Note that we do not track all components that can be part of wind turbines.

Fig. 42: Five wind turbine intermediate products and their RCA through time for Brazil. Note that all intermediate products are generic and can be used for end uses other than wind turbines, and that not all wind turbine parts are covered.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Environmental credentials and policy ambition

Climate Action Tracker reports that Brazil's current policies are not consistent with its NDC and its 2060 net zero target, nor its Paris Agreement commitment to stop illegal deforestation in the Amazon by 2030. President Bolsonaro claims ambition to achieve carbon neutrality by 2050 rather than 2060, although official policy has not been yet amended[22]. Its NDC was updated in 2020 and confirmed its aim to reduce emissions by 37% by 2025 and by 43% by 2030, but by updating its carbon accounting for 2005, it increased its base year emission calculations, making the target less, rather than more, ambitious in practice. In fact, Brazil now allows itself to emit a third more greenhouse gases by 2030[23]. As mentioned above, solar and wind generation capacity are steadily increasing, which may be cause for some optimism; however, energy infrastructure planning continues to include fossil fuels such as coal and gas[24].

Deforestation in the Brazilian Amazon, which had been slowly creeping up from a low point in 2011, has accelerated dramatically since President Jair Bolsonaro took office in 2019. Prioritising economic gains from mining and agriculture, the current government has rolled back protective policies and weakened enforcement mechanisms against illegal deforestation[25]. In 2019, Norway and Germany halted their contributions to the Brazilian government's Amazon Fund, whose objectives were seen to have been undermined by the government's actions. Earlier this year, President Bolsonaro appeared to change his stance, declaring his intention to protect the Amazon, subject to receiving financial contributions amounting to around 20 billion US dollars from the international community. This has been widely met with criticism[26], but Brazil did surprisingly join the 100 nations that signed the global deforestation pledge at COP26, pledging to end and reverse deforestation by 2030.

[22] Reuters, Jake Spring, and Lisandra Paraguassu, 'Brazil's Bolsonaro, under U.S. Pressure, Vows Climate Neutrality by 2050', Reuters (Brasilia, 22 April 2021) <https://www.reuters.com/business/environment/bolsonaro-says-brazil-will-reach-climate-neutrality-by-2050-2021-04-22/>.

[23] The Economist, 'How Climate Targets Compare against a Common Baseline', The Economist (London, 7 August 2021).

[24] CAT, 'Country Summary: Brazil', Climate Action Tracker, 2020 <https://climateactiontracker.org/countries/brazil/> [accessed 27 July 2021].

[25] cf. Jonathan Watts, 'Amazon Rainforest "Will Collapse If Bolsonaro Remains President"', The Guardian (London, 14 July 2021); Ernesto Londoño, 'Bolsonaro's Sudden Pledge to Protect the Amazon Is Met With Skepticism', New York Times (New York, 21 April 2021) <https://www.nytimes.com/2021/04/21/world/americas/bolsonaro-climate-amazon.html>.

[26] Londoño, Ernesto, 'Bolsonaro's Sudden Pledge to Protect the Amazon Is Met With Skepticism', New York Times (New York, 21 April 2021) <https://www.nytimes.com/2021/04/21/world/americas/bolsonaro-climate-amazon.html>

Green strengths and opportunities

Over 15% of Brazil's energy demand is met by ethanol. While not originally a green policy but a sugarcane and energy price stabilisation tool, Brazil's ethanol industry was rebranded as an environmentally friendly industry in the early 2000's[27]. Brazil now accounts for 25% of global ethanol production. Flex-fuel cars, that can use gasoline, ethanol, or a mixture of the two, accounted for over half of Brazil's total cars by 2012. While biofuels have negative side effects, including potentially crowding out food crops, and in Brazil may indirectly contribute to deforestation of the Amazon rainforest, Brazilian sugarcane ethanol is seen as having one of the lowest carbon intensities of commercially available biofuels[28]. Because of its credentials as a low-carbon fuel, ethanol is also part of our list of green products. With a PCI of -1.12, it is the third most important green product of Brazil by revealed comparative advantage (RCA), behind sisal/agave binder twine (PCI: -1.73) and hydraulic turbines and water wheels > 10,000 kW (PCI: 0.08).

One challenge to flex-fuel cars might be the projected future dominance of electric vehicles, which appears to be the winning green vehicle strategy in much of Europe and the US[29]. While ahead of the green transportation curve right now, Brazil might struggle to reduce transportation emissions further and leverage its ethanol technology if it delays its EV development and deployment. This is doubly problematic as, in contrast to biofuels, batteries are expected to bring significant future energy efficiency and cost savings[30,31]. Sugarcane ethanol fuel could however, have potential for net-zero aviation[32].

---

[27] Green Industrial Policy: Concept, Policies, Country Experiences, ed. by Tilman Altenburg and Claudia Assmann (Geneva, Bonn: UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE), 2017) <https://www.die-gdi.de/buchveroeffentlichungen/article/green-industrial-policy-concept-policies-country-experiences/> [accessed 19 August 2021].

[28] Altenburg and Assmann, 2017.

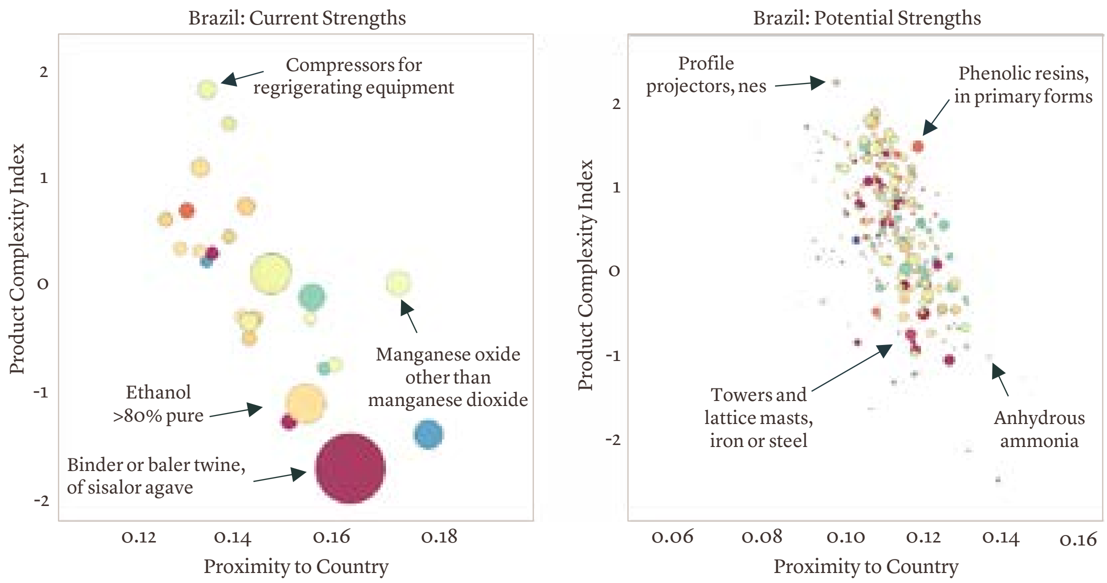
[29] Ewa Krukowska and Tara Patel, 'EU Aims to Have 30 Million Electric Cars on the Road by 2030', Bloomberg, 3 December 2020.

[30] Way and others, 2021.

[31] M. Grubb and others, 'Induced Innovation in Energy Technologies and Systems: A Review of Evidence and Potential Implications for CO_2 Mitigation', Environmental Research Letters, 2021 <https://doi.org/10.1088/1748-9326/abde07>.

[32] Deepak Kumar, Stephen P. Long, and Vijay Singh, 'Jet Fuel from Sugarcane? It's Not a Flight of Fancy', The Conversation, 21 November 2017 <https://theconversation.com/jet-fuel-from-sugarcane-its-not-a-flight-of-fancy-84493>.

Fig. 43: Brazil's green export products divided into current strengths and potential opportunities. Size of product indicates country's current RCA, colours represent product categories (see legend)[33]



- Management of Solid and Hazardous Waste and Recycling Systems
- Natural Resource Protection
- Energy Efficiency
- Heat and Energy Management
- Gas Flairing Emission Reduction
- Efficient Consumption of Energy Technologies and Carbon Capture and Storage
- Environmental Monitoring, Analysis and Assessment Equipment
- Renewable Energy
- Noise and Vibration Abatement
- Resources and Pollution Management
- Waste Water Management and Potable Water Treatment
- Air Pollution Control
- Natural Risk Management
- Clean UP or Remediation of Soil and Water
- Cleaner or More Resource Efficient Technologies and Products
- Others
- Environmental Preferable Products based on End-Use or Disposal Characteristics
- Waste Management, Recycling and Remediation
- Water supply
- Bubbles are sized by RCA

Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

[33] For an in-depth explanation of how to read this figure, please refer to the section Green strengths and opportunities within the China case study.

Summary

- Brazil's green competitiveness has seen a declining trend in recent decades: its global rank in Green Complexity Index fell from 48 to 93, while its Green Complexity Potential rank dropped from 43 to 72.
- The decline in Green Complexity Potential and average proximity to products across all green categories suggests that reversing this negative trend in green competitiveness will become increasingly difficult.
- Absolute export values in green products increased between 1995 and 2011-2015, but have since declined.
- Brazil's government has been subject to international criticism for its failure to combat deforestation in the Amazon region, which has increased dramatically since 2019.
- Brazil has considerable green energy potential and renewable energy capacity has grown significantly in the last decade, particularly in wind.
- Financing from Brazil's development bank for renewable energy projects has been contingent on Local Content Requirements, which are thought to have contributed to the establishment of a local manufacturing base for renewable generation equipment. This has led to an increase in local manufacturing and jobs, but our analysis indicates that Brazil has lost, rather than gained, international competitiveness in these components.

Australia

Policy ambition and green complexity

Australia, once self-referenced as the "smart country[1]", has seen a dramatic decline in its economic complexity (ECI) with a concurrent decline in GCI - currently ranking 125th in ECI, 157th in GCI and 112th in GCP. Australia's reliance on the extractive industry for its economic growth is a likely driver behind its low ranking in green complexity. Australia's rank in ECI, GCI and GCP has been on a downward trajectory since the start of our analysis: in the 1995-1999 period it ranked 60th for ECI and 57th for both GCI and GCP.

In its updated COP26 Nationally Determined Contribution (NDC) to the UNFCCC, Australia has committed to lowering greenhouse gas emissions by 26-28% below 2005 levels by 2030, confirming its previous 2015 submission[2], but with little explanation of how it will meet these reductions. Australia's prime minister, Scott Morrison, has very reluctantly agreed to a nationwide net zero target by 2050, but remains non-committal to actual climate change action[3]. Many of Australia's states and territories, however, have set binding net-zero targets and in general have set more ambitious goals of their own[4].

Only 1.6% of Australia's exports can be deemed green, capturing a total of just 0.23% of the global export market in green products, a share which has almost halved since our dataset began; it was 0.44% in the 1995-1999 period. Russia and Brazil, also resource rich countries with a similar sized economies, capture about double Australia's share. Spain, which has an equally sized but more diversified economy, has captured 1.55% of the global export market in green products.

Australia's energy consumption is still dominated by coal, accounting for about 56% of electricity production in 2019[5]. However, renewables are rapidly gaining through residential and community adoption, generally becoming a disruptive force for change. More than 27% of Australia's electricity is now sourced from renewables, up from 17% only four years ago, with falling electricity prices causing financial difficulties for incumbent technologies[6].

---

1 https://medium.com/@ashleyhamiltonrice/australia-the-smart-country-48dc740aca39 .

2 UNFCCC, 'Australia's First Nationally Determined Contribution towards Achieving the Objective of the United Nations Framework Convention on Climate Change (Updated Submission)', 2020 <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Australia First/Australia NDC recommunication FINAL.PDF>.

3 RNZ, 'Australia PM Refuses to Set "net Zero by 2050" Climate Target as Global Warning Issued', Radio New Zealand, 10 August 2021 <https://www.rnz.co.nz/news/world/448880/australia-pm-refuses-to-set-net-zero-by-2050-climate-target-as-global-warning-issued>.

4 Don Henry and Sangeetha Chandra-Shekeran, 'State Leadership on Emissions Reduction Is Crucial', University of Melbourne Pursuit, 3 May 2021 <https://pursuit.unimelb.edu.au/articles/state-leadership-on-emissions-reduction-is-crucial>.

5 Energy.gov.au, 'Australian Electricity Generation - Fuel Mix', Department of Industry, Science, Energy and Resources Website. <https://www.energy.gov.au/data/australian-electricity-generation-fuel-mix>.

6 Clean Energy Council, Clean Energy Australia Report 2021, https://assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2021.pdf

Australia at a glance

25,687
Population (thousands)

1,330,900
GDP (current US$, millions)

52,518
GDP / capita (US$, PPP)

157
GCI rank

125
ECI rank

112
GCP rank

1.60 %
Share of green in total exports

0.20 %
Global share of green exports

Aluminium Hydroxide
Highest RCA green product

Electric signal, safety controls
Most complex competitive

none

Net zero target

1.1°C

Temp change since 1961

0.31 (rank: 31/230)

CO_2 intensity (kg/PPP$ GDP)

64

Avg energy use (MWh/yr/cap)

3,408

Global Energy Potential (MWh/yr/cap)

19

Climate risk index rank

121

Extreme risk index rank

9.2% (143/213)%

Renewable energy consumption

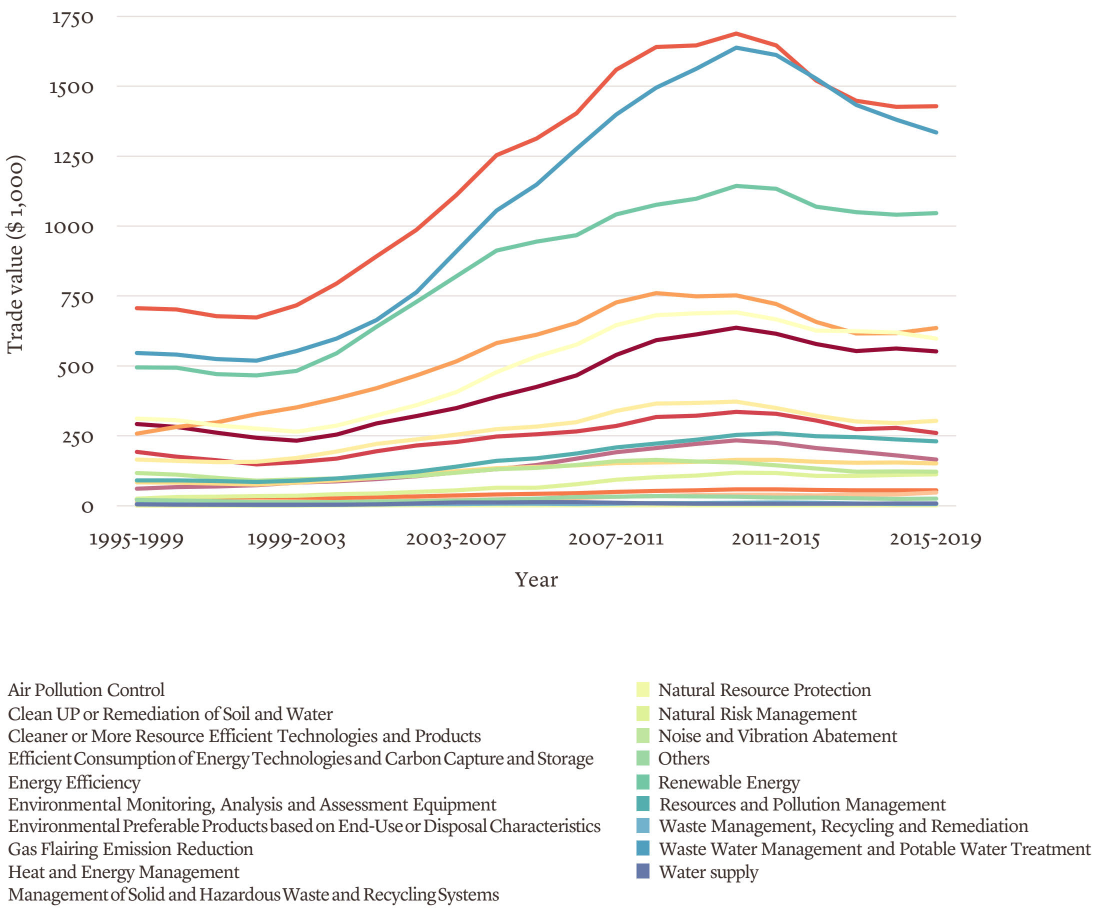
2 %

Share of green in covid recovery

Trends in green competitiveness

While its green complexity ranking dropped, Australia's absolute trade value did increase in almost all green product categories until the 2011-2015 period and declined since then for some. Its top three largest export categories are efficient consumption of energy technologies and carbon capture and storage, wastewater management and potable water treatment, and renewable energy, as shown in Figure 44.

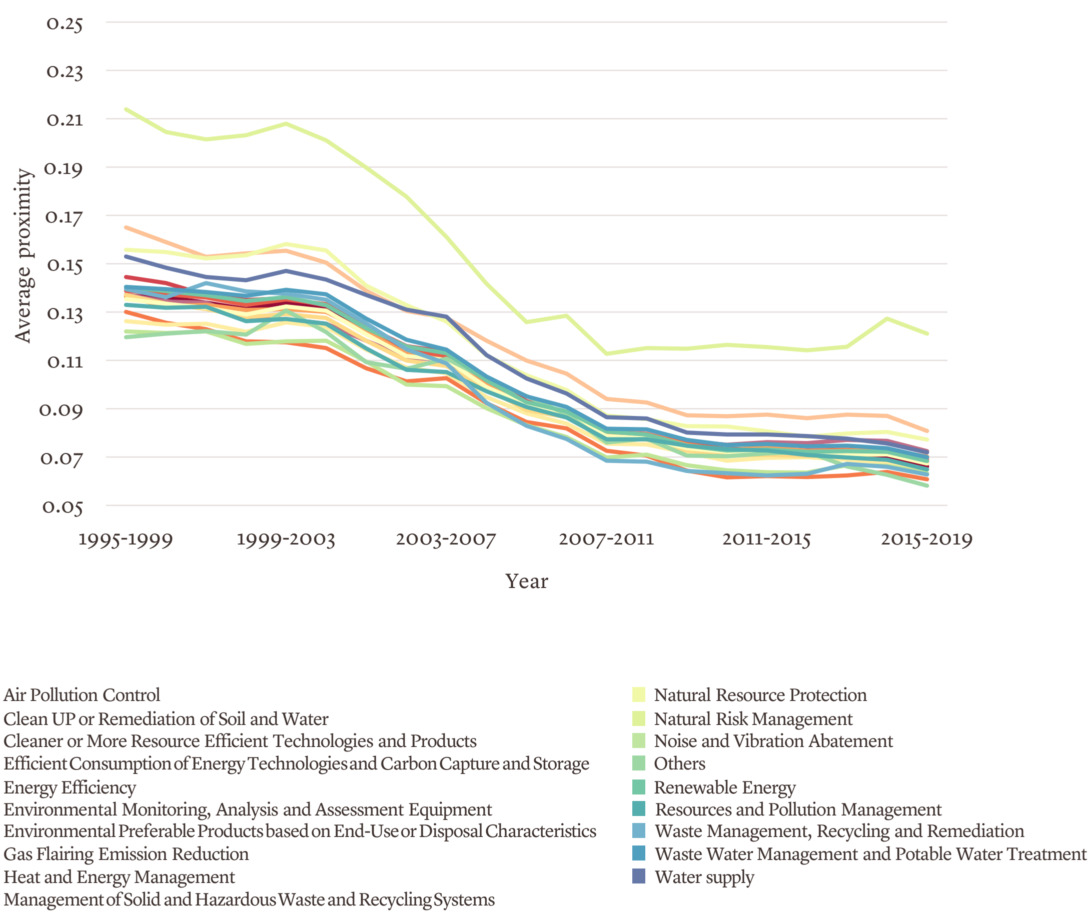
Fig. 44: Export value over time by environmental category, Australia



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version)

The average proximity of Australia's production capabilities to green products has been declining for all green categories since the early 2000s (Figure 45). This is reflected in its losses in GCI and GCP rank and implies that it is becoming increasingly harder for Australia to take advantage of the greening global economy.

Fig. 45: Average proximity over time by environmental category, Australia



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Fig. 46: Largest importers of Australian green exports. Only countries that import >2% of Australian exports are shown separately.

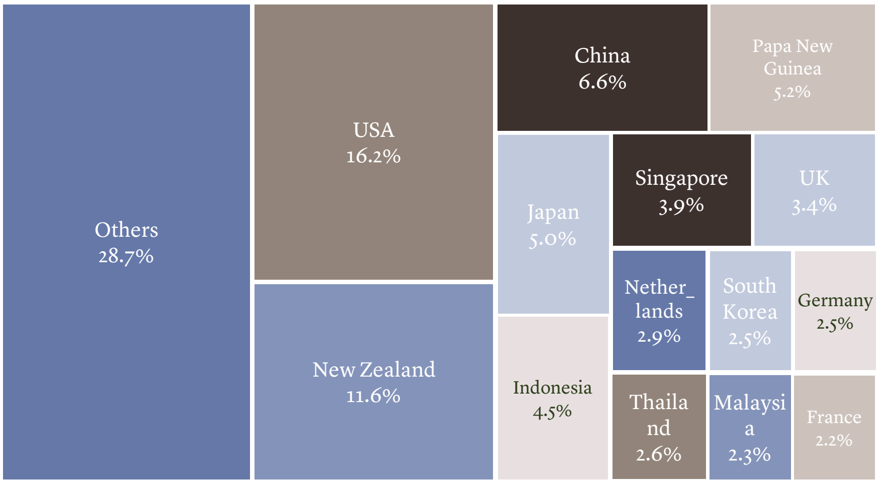
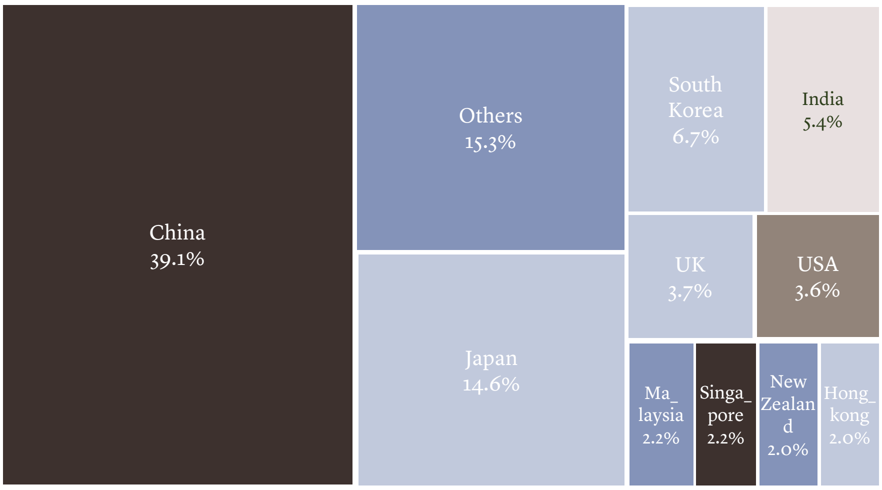


Fig. 47: Largest importers of Australian overall exports. Only countries that import >2% of Australian exports are shown separately.



Source:Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

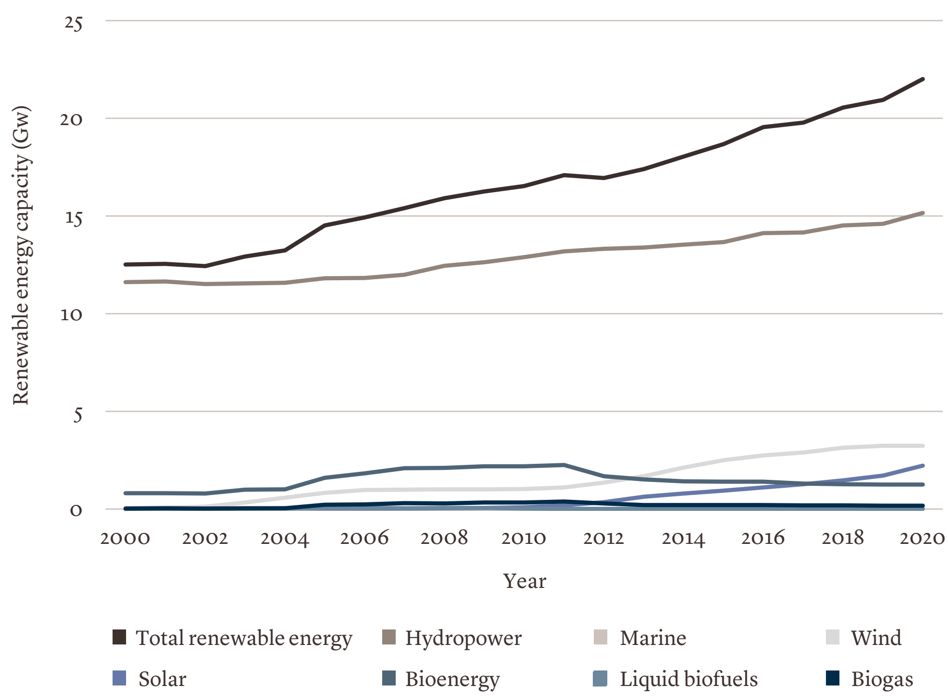
The US is the largest buyer of Australia’s green exports, followed by New Zealand, China, Japan, and other countries in the Asia Pacific region, as well as some European countries. Figure 47 visualises this breakdown.

Trends in green energy

Australia is a large, sparsely populated and mostly dry land mass that lies predominantly in the tropics and hence has an abundance of sunshine. However, it also has an abundance of land available for mining and large coal and gas resources. A significant percentage of the population are supportive of action on climate change, but the current conservative federal government appears to be prioritising the local fossil fuel industry, which provides significant export income. This has led to delays in investment to capitalise on the country's abundant renewable potential, with only a few independent states declaring binding net zero goals and supporting large-scale renewable projects.

Most of the growth of renewables over the last decade has been due to expansion of hydropower, with some wind and mostly distributed solar (Figure 48). Australia has only limited additional hydropower capacity, but abundant wind resources in the south; an average LCOE of less than 10c/kWh (USD) for solar; and continuing public pressure for action on climate change following some extreme national-scale wildfire events.

Fig.48: Australia's renewable energy generation capacity by source



Source: IRENA (2021), Renewable Capacity Statistics 2021; & IRENA (2020), Renewable Energy Statistics 2020, The International Renewable Energy Agency, Abu Dhabi.

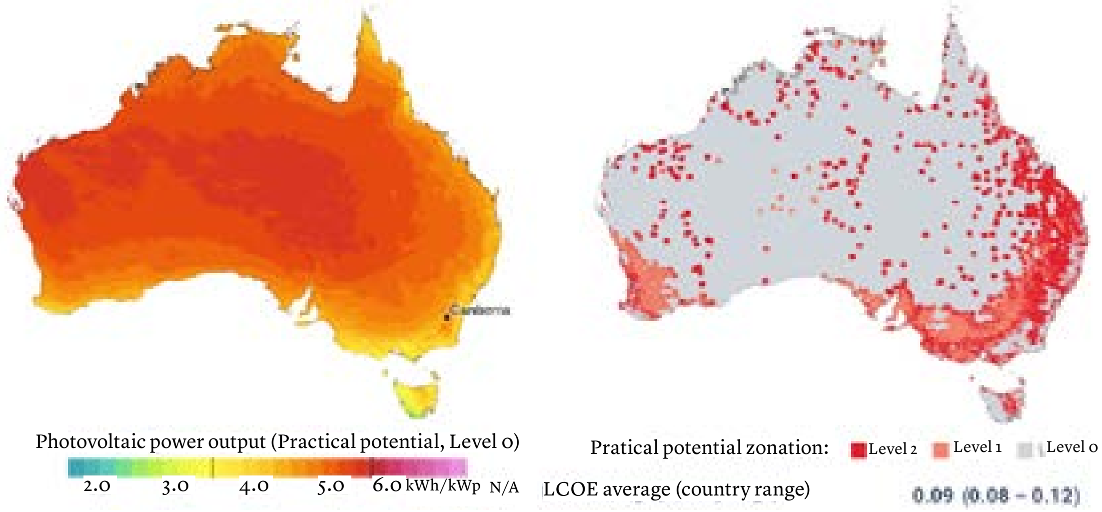
It will therefore be difficult to stem the tide of investment in renewables given the improving economics, growing local markets for green energy in Asia and the country's huge green energy potential (Table 7). With a high potential and relatively small population, Australia has the highest total generation potential per person of any country evaluated in this report, and is therefore one of the countries best placed to build a significant export industry for green energy.

Table 7. Estimates of current economic potential of renewable resources per person compared with current average annual per capita usage for Australia.

Australia	
Onshore wind generation potential (EJ/yr)	230
Offshore wind generation potential (EJ/yr)	89
Solar PV generation potential (EJ/yr)	8
Hydro generation potential (EJ/yr)	<1
Bioenergy generation potential (EJ/yr)	8
Est. Total generation potential (EJ/yr)	327
Population (millions)	26
Average annual energy usage per person (MWh/yr/cap)	64
Total generation potential per person (MWh/yr/cap)	3,496

Source: See Appendix for Data Sources

Fig. 49: Estimates of solar photovoltaic potential (kWh/kWp) and practical potential zonation used to determine Australia's economic potential for solar.



Source: https://globalsolaratlas.info/

Policy and economic environment

Australia's economy has grown every year from 1992 up until 2019, only to suffer a recession again in 2020 of just 2.4% in the COVID-19 pandemic[7]. Australia's extraction economy was fuelled to a large degree by high economic growth in China which has also seen a decline during the pandemic. Fossil fuels and other commodities accounted for nearly three quarters of Australia's export growth between 1995 and 2020[8].

Its current government has a lacklustre policy record on climate change action and greening its economy. Australia was one of the signatories to the 1998 Kyoto protocol, but for a long time opposed the ideas embodied in the climate action plan. It did not ratify the Kyoto protocol until 2007, an indication of the partisan nature of the country's actions on climate. A proposal to implement a carbon tax in 2008 faced criticism because it might lower Australia's competitiveness, but an emissions trading scheme was finally adopted in 2012 during a labour government. However, after just one year of operation it was repealed in 2013 by the newly elected conservative Abbot Coalition[9]. In the 2019 election that re-elected the Liberal conservative party into government, the opposition labour party proposed plans to cut emissions by 45% in 2030, and the Liberal party's strong rejection of that plan has been partly credited for their win[10].

In 2020, China, the largest importer of Australia's resources, imposed an unofficial ban on the use of Australian coal in its power plants[11]. While China has struggled to source its coal elsewhere, Australia has diverted shipments to other large coal users, including India and Brazil, after an initial slump in exports following the ban[12]. However, India's coal ministry has also recently claimed that it plans to eliminate coal imports by 2024[13].

---

7 Austrade, Why Australia Benchmark Report 2021, 2021 <https://www.austrade.gov.au/benchmark-report/resilient-economy>.

8 Connor MacDonald and Peter Sloman, 'Resource Extraction, Economic Growth, and the Climate Dilemma in Canada and Australia', The Political Quarterly, 91.4 (2020), 780–85 <https://doi.org/10.1111/1467-923X.12902>.

9 Kate Crowley, 'Up and down with Climate Politics 2013–2016: The Repeal of Carbon Pricing in Australia', Wiley Interdisciplinary Reviews: Climate Change, 8.3 (2017), e458 <https://doi.org/10.1002/WCC.458>.

10 MacDonald and Sloman.

11 Su-Lin Tan, 'China-Australia Relations: US Coal Continues to Fill Void Left by Ban on Australian Exports, Canberra Report Says', South China Morning Post (Hong Kong, 30 June 2021).

12 Rory Simington, 'Australian Coal Exports Bounce Back from China's Ban', Wood Mackenzie, 4 March 2021 <https://www.woodmac.com/news/opinion/australian-coal-exports-bounce-back-from-chinas-ban/>.

13 S&P Global Platts, https://www.spglobal.com/platts/en/market-insights/latest-news/coal/101321-coal-crisis-a-litmus-test-for-indias-resolve-to-eliminate-imports.

Environmental credentials and policy ambition

Australia's CO2 emissions per capita are among the highest in the world and, in 2018, were the highest among OECD countries together with Canada[14].

In its NDC and accompanying policy, Australia stresses the need for technological innovation to combat climate change. Its Low Emissions Technology Statement points to five priority areas for investment in Australia: clean hydrogen, energy storage, low carbon materials (steel and aluminium), carbon capture and storage, and soil carbon[15]. Many of these technologies are still in development and not yet tested at large scale, although it seems possible that clean hydrogen can take off on a relatively short term, given the country's renewable potential[16].

Australia has made plans to spend more than most countries on post-COVID-19 recovery, nearly 10% of GDP. That is the 4th largest in the University of Oxford Global Recovery Observatory dataset, behind only Spain, South Korea, and the UK. However, only a fraction of that has been allocated to green projects. Because of its low GCI and GCP scores, this means Australia has ended up in our *missed opportunities* section.

[14] Tan, Su-Lin, 'China-Australia Relations: US Coal Continues to Fill Void Left by Ban on Australian Exports, Canberra Report Says', South China Morning Post (Hong Kong, 30 June 2021)

[15] UNFCCC, 'Australia's First Nationally Determined Contribution towards Achieving the Objective of the United Nations Framework Convention on Climate Change (Updated Submission)'.

[16] Note that the production of green ammonia can be done with seawater using desalination which represents only a small fraction of the ammonia production costs.

Green strengths and opportunities

Australia's current strengths and opportunities are highlighted in Figure 50[17]. Australia only has few green strengths. Most of the higher PCI products that are Australia's strengths are either wastewater management and potable water treatment products or are a cleaner or more resource efficient alternative to mainstream practices. The green product with the largest revealed comparative advantage (RCA) in Australia, aluminium hydroxide, can be used in chemical recovery systems for wastewater management[18]. Australia's opportunities have very low proximity to the country's current capabilities, indicating a low probability of developing a competitive advantage, barring decisive action. In addition, opportunities with a high PCI have the lowest proximity.

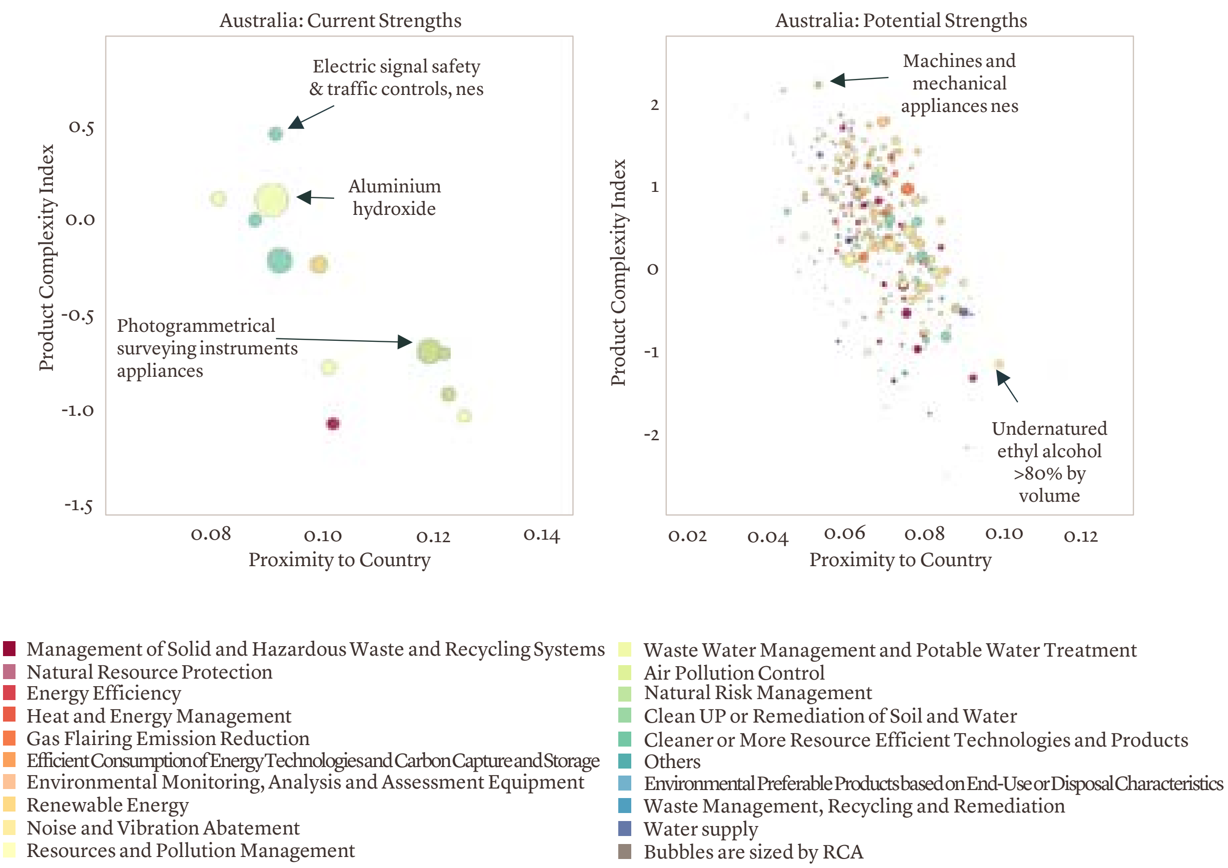
This means that products that are closest to Australia's current strengths, such as undenatured ethyl alcohol, could be comparatively easier to develop locally but are unlikely to provide significant future growth in product complexity and sophistication.

Even though Australia only has few green product export strengths, and a large share of its exports relies on fossil fuels and low-complexity resource extraction, Australia is seen by many as a potential green energy powerhouse. Its large land area, long coastline and abundant sunshine are significant assets for harnessing cheap wind power and solar energy. Indeed, there are major plans in place to make the northern states green energy hubs for export.

[17] For an in-depth explanation of how to read this figure, please refer to the section Green strengths and opportunities within the China case study.

[18] Aluminium hydroxide also has other end uses, such as in medicine and as a precursor for other aluminium products. We do not track the specific usage in every case. See Section 2. What is a green product? on page 15, for the definition of a green product.

Fig. 50: Current green strengths and opportunities of Australia.[19]



Source:Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

[19] For an in-depth explanation of how to read this figure, please refer to the section Green strengths and opportunities within the China case study.

Summary

- Australia has seen a significant decline in both its economic complexity and green complexity over the last two decades.
- Australia relies heavily on the export of fossil fuels and minerals for its economic growth, particularly exports to China.
- Australia is a high-income country, but has increasingly relied on low-complexity exports and therefore ranks low on the economic complexity index as well as the green complexity index and potential.
- Australia's current conservative government has a track record of stalling action on climate change.
- However, because of its vast land mass, ample wind resources, and low average solar costs, Australia has the highest green potential of all the countries evaluated in this report, and therefore has the potential to become a powerhouse for renewable energy exports in the future.

United Arab Emirates case study

Policy ambition and green complexity

As a major exporter of petroleum, the United Arab Emirates relies primarily on its extractive industry and therefore has relatively low manufacturing competitiveness. Accordingly, its green complexity ranking is low, with a GCI of 59 and a GCP of 75. However, both indices have seen a positive trend over the study period, suggesting that the UAE's productive capabilities are moving closer to those required to competitively produce complex green products.

The UAE's per capita emissions are among the world's highest. In 2020, the UAE submitted a nationally determined contribution (NDC) target of decreasing emissions by 23.5% by 2030[1]. As of 2019, fossil fuels still accounted for nearly 97% of the country's energy mix[2].

The UAE was the third-largest petroleum producer in OPEC in 2019 behind Saudi Arabia and Iraq and plans to continue increasing production of petroleum[3]. This strategy may backfire in the coming decade, increasing the country's risk of stranded assets in a future low-carbon global economy.

1 CAT, 'CAT Climate Target Update Tracker: UAE', Climate Action Tracker, 2020 <https://climateactiontracker.org/climate-target-update-tracker/uae/> [accessed 19 August 2021].

2 Ritchie and Roser, 'Energy'.

3 EIA, 'Country Analysis Executive Summary: United Arab Emirates', Independent Statistics & Analysis, 2020.

United Arab Emirates at a glance

9,890
Population (thousands)

421,124
GDP (current US$, millions)

69,957
GDP / capita (US$, PPP)

59
GCI rank

104
ECI rank

75
GCP rank

3.52 %
Share of green in total exports

0.46 %
Global share of green exports

Limestone materials
Highest RCA green product

Distilling or rectifying plant
Most complex competitive

none

Net zero target

1.6°C

Temp change since 1961

0.30 (rank: 32/230)

CO2 intensity (kg/PPP$ GDP)

89

Avg energy use (MWh/yr/cap)

94

Global Energy Potential (MWh/yr/cap)

130

Climate risk index rank

163

Extreme risk index rank

0.1% (196/213)%

Renewable energy consumption

2 %

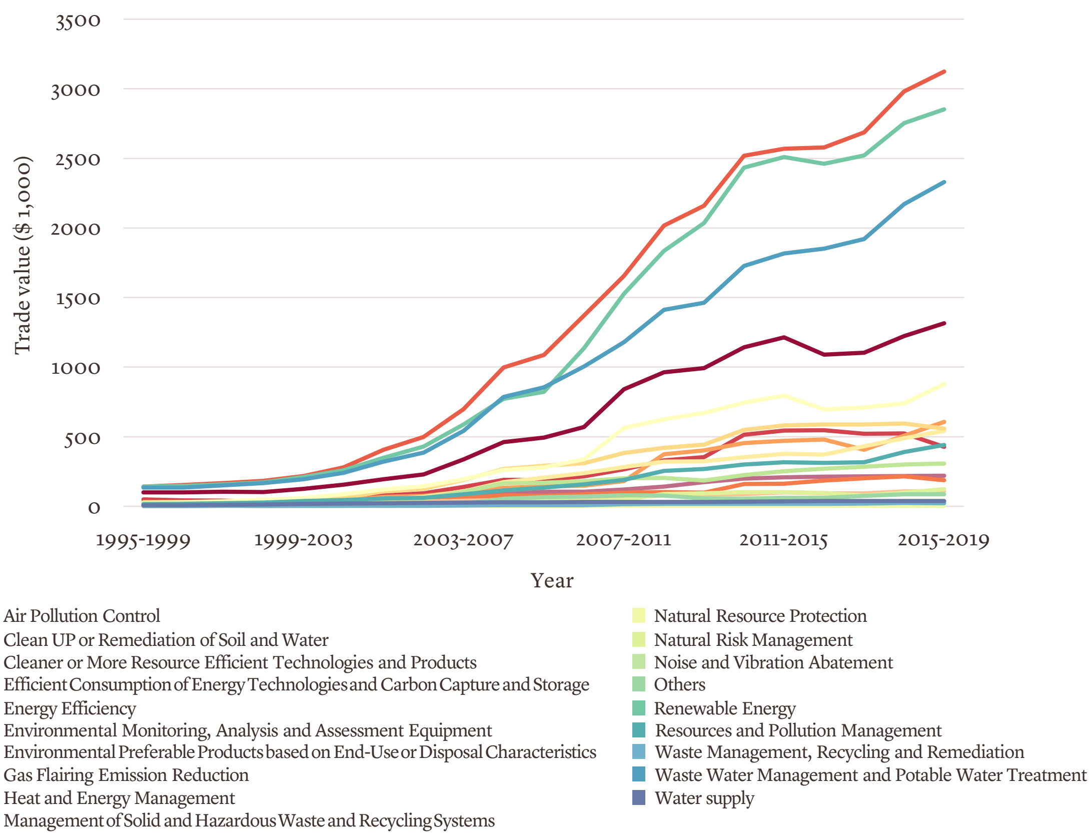
Share of green in covid recovery

Trends in green competitiveness

The United Arab Emirates rank relatively low in green competitiveness and overall complexity, but have increased their position considerably over the course of the study period. GCI has risen from its initial rank of 117 to its current rank of 59; GCP increased from 120 to 75.

Over the same period, overall ECI rose from rank 138 to 104. This is thought to be result of a long-term strategy for the UAE's led most publicly by Dubai, which has consistently progressed a pronounced diversification strategy[4].

Fig. 51: Export value over time by environmental category, United Arab Emirates

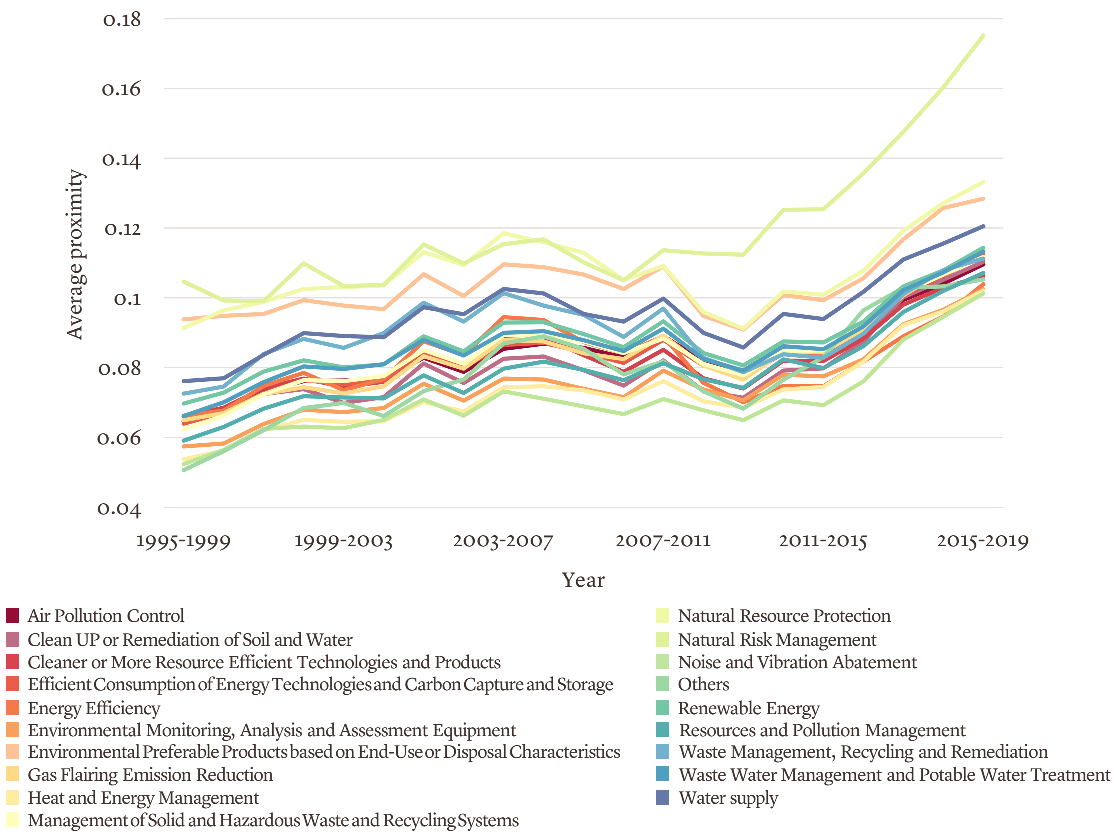


Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

[4] Seric & Tong, 2019, Progress and the future of economic diversification in the UAE, https://iap.unido.org/articles/progress-and-future-economic-diversification-uae.

Absolute trade values in most green categories have also increased at an accelerating rate since the early 2000's. The largest categories in terms of absolute trade are efficient consumption of energy technologies and carbon capture and storage; renewable energy, wastewater management and potable water treatment; and air pollution control. The share of green products in the UAE's overall exports has also risen, from 1.9% to 3.5%.

Fig. 52: Average proximity over time by environmental category, United Arab Emirates.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Average proximity of the UAE's productive capabilities to products within each category fluctuated between the start of the period and the early 2000s, but has been on a clear upwards trajectory since 2009-13. This trend is especially pronounced in the category "Natural Risk Management", which contains products the UAE seem to be particularly well suited to produce.

The largest importers of the UAE's green products are Saudi Arabia (15.3%) and Oman (14%), followed by India (8.5%) (Figure 53). Nearly a third of the UAE's green products are imported by countries with a share of less than 2% of its green exports.

Notably, the distribution of imported shares for the UAE's overall exports differs from that for green exports, with India (10.8%), Japan (9.7%) and Switzerland (6.1%) as the largest importers (Figure 54). This is likely driven by the large share of petroleum in overall exports, which Oman and Saudi Arabia have little need to import. The geopolitical implications of trade relations may therefore change if the UAE shift their export basket towards non-extractive, and especially towards green, industries.

Fig. 53: Largest importers of the UAE green exports. Only countries that import >2% of the UAE's exports are shown separately.

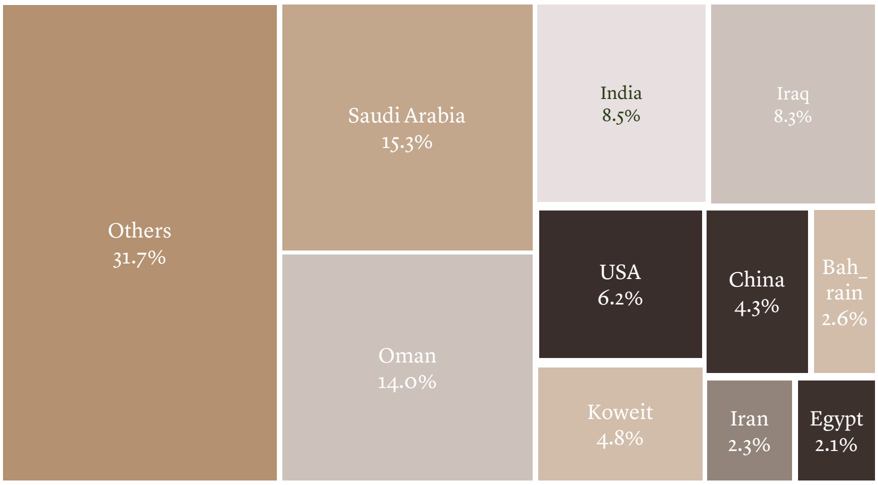
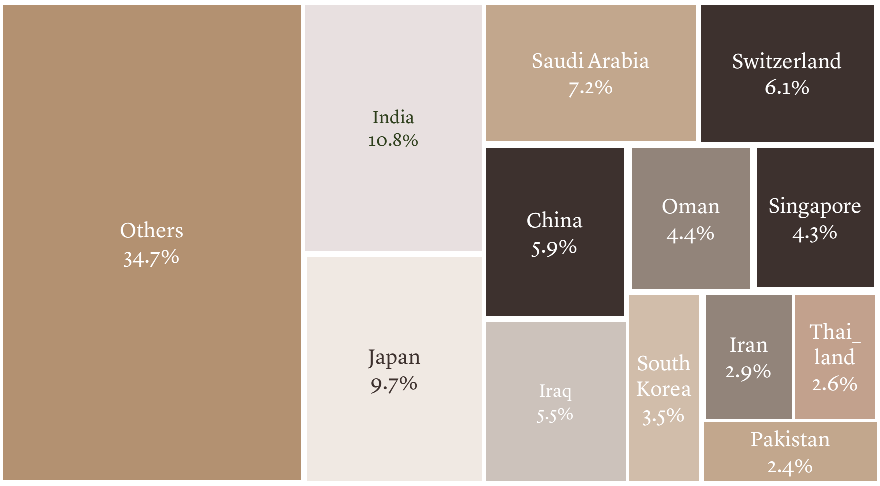


Fig. 54: Largest importers of the UAE overall exports. Only countries that import >2% of the UAE's exports are shown separately.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Trends in green energy

Table 8. Estimates of current technical potential of renewable resources per person compared with current average annual per capita usage for the UAE.

United Arab Emirates	
Onshore wind generation potential (EJ/yr)	<1
Offshore wind generation potential (EJ/yr)	-
Solar PV generation potential (EJ/yr)	3
Hydro generation potential (EJ/yr)	-
Bioenergy generation potential (EJ/yr)	-
Est. Total generation potential (EJ/yr)	3
Population (millions)	10
Average annual energy usage per person (MWh/yr/cap)	89
Total generation potential per person (MWh/yr/cap)	94

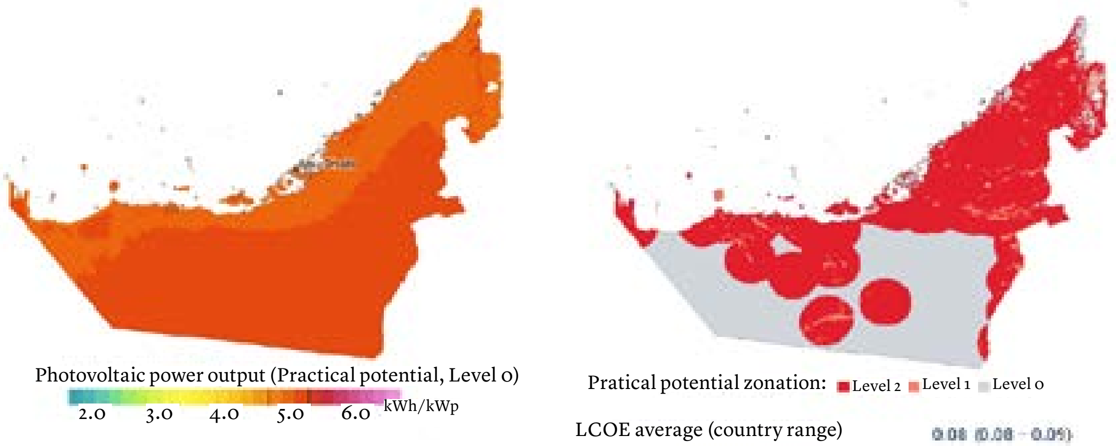
Source: See Appendix for Data Sources

The UAE has the seventh largest supply of proven oil reserves in the world[5] and so stands to lose much from a rapid transition away from fossil fuels. They are not as blessed in renewable resources, but have sufficient solar potential to meet their current high average annual energy usage per person.

It is possible that the UAE will try to develop a green energy export capacity, given its high irradiance levels and consequent low average costs for solar (Figure 55); its need to eventually diversify away from fossil fuels; and its proximity to the large increasingly green market of Europe.

5 UAE facts and figures, https://www.opec.org/opec_web/en/about_us/170.htm

Fig. 55: Estimates of solar photovoltaic potential (kWh/kWp) and practical potential zonation used to determine the UAE's economic potential for solar



Source: https://globalsolaratlas.info/

Policy and economic environment

The United Arab Emirates have historically relied largely on petroleum extraction as the main component of economic activity. However, the government's economic agenda includes stated aims to grow manufacturing capacity in sectors such as plastics, machinery, renewable energy equipment and others[6]. As a major oil producer, the UAE face a considerable threat of stranded assets in a world of declining renewable and electric vehicle costs and increasing ambition to transition to net zero around the world, rendering industrial diversification and upgrading an essential and pressing challenge.

[6] UAE, 'Operation 300bn, the UAE's Industrial Strategy', The United Arab Emirates' Government Portal, 2021 <https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/federal-governments-strategies-and-plans/the-uae-industrial-strategy> [accessed 19 August 2021].

[7] UAE, 'Operation 300bn, the UAE's Industrial Strategy', The United Arab Emirates' Government Portal, 2021 <https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/federal-governments-strategies-and-plans/the-uae-industrial-strategy> [accessed 19 August 2021].

Operation 300bn

Operation 300bn, the UAE government's main industrial strategy, was launched in March 2021 with the stated aim to develop the UAE's industrial sector and "raise [its] contribution to the GDP from AED 133 billion to AED 300 billion by 2031". The plan has 6 objectives, which include creating an attractive business environment for local and foreign investors in industry; supporting industrialisation and international competitiveness; and stimulating innovation. Its 11 target sectors include agriculture, pharmaceuticals, electronics, petrochemicals, and machinery, as well as hydrogen. The strategy is to be implemented by the Ministry of Industry and Advanced Technology and relies on the Emirates Development Bank (EDB) to provide financing to its target sectors[7].

Environmental credentials and policy ambition

The UAE emitted about 190 million tonnes of CO2 in 2019; a notable drop from its peak of nearly 240 million tonnes in 2015. In contrast, the United States emitted over 5 billion tonnes, and China, the world's largest emitter, over 10 billion tonnes in 2019. However, its per capita emissions are among the highest in the world. In 2016 it emitted roughly 21 tonnes of CO2 per person, putting it well ahead of the US (14.8 tonnes), let alone the global average of 4.9 tonnes[8].

The UAE is not an Annex-1 country[9] and therefore is not required to reduce its emissions as rapidly under the United Nations Framework Convention on Climate Change (UNFCC). However, it has ratified the Paris Agreement and pledged to take action to reduce emissions[10]. The UAE's NDC to the Paris Agreement originally contained no overall emissions reduction target, but merely a target to increase the share of renewables and nuclear in the energy mix to 24% by 2021[11]. It was updated in 2020 with a target to reduce emissions by 23.5% by 2030[12]. In 2019 (the most recent year for which data could be collected), renewables and nuclear energy accounted for only about 3% of the UAE's energy mix[13], suggesting that this target was not reached. The UAE's Energy Strategy 2050's stated aim is to increase the share of clean energy, which includes renewables as well as nuclear, to 50% of the energy mix by 2050, and to reduce energy consumption by 40% over the same timeframe[14].

The UAE has been slow to spend on green recovery after the COVID-19 pandemic. Even though it is a high income country, it has only made plans to spend around 0.1% of GDP on recovery, none of which has been deemed green by the University of Oxford's Global Recovery Observatory. This is potentially a missed opportunity, as the UAE has shown clear progress in increasing its GCI rank and its stated intentions to upgrade its manufacturing capabilities.

---

8 Ritchie and Roser, 'CO2 and Greenhouse Gas Emissions'.

9 Within the UNFCCC regime, the term "Annex I countries" refers to a list of countries that includes members of the Organisation for Economic Co-operation and Development (OECD) as well as economies in transition.

10 UAE, 'The UAE's Response to Climate Change', The United Arab Emirates' Government Portal, 2021 <https://u.ae/en/information-and-services/environment-and-energy/climate-change/theuaesresponsetoclimatechange> [accessed 19 August 2021].

11 CAT, 'Country Summary: UAE'.

12 CAT, 'CAT Climate Target Update Tracker: UAE'.

13 Ritchie and Roser, 'Energy'.

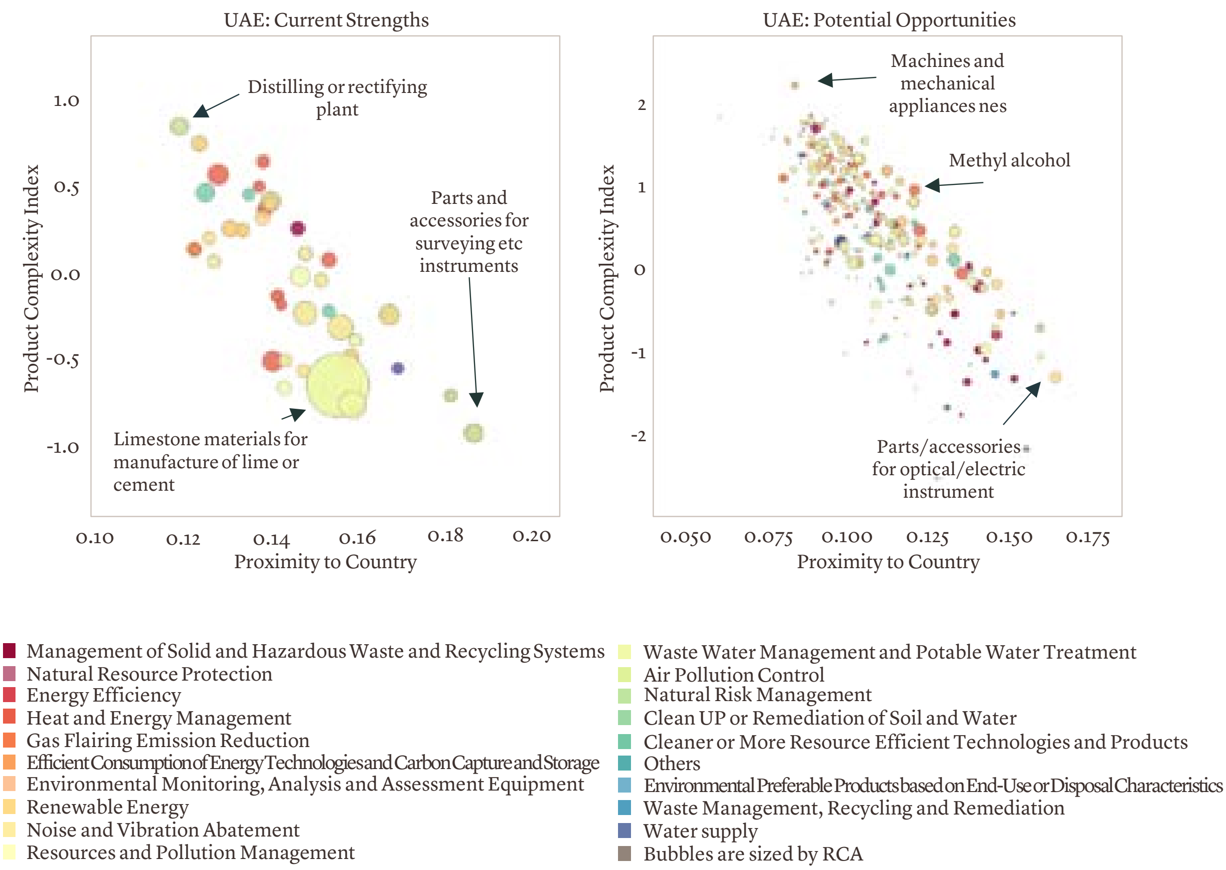
14 UAE, 'UAE Energy Strategy 2050', The United Arab Emirates' Government Portal, 2021.

The number of green strengths for the UAE are significantly exceeded by the number of potential opportunities (Figure 56). Overall proximity of its productive capabilities to green products is low, and there is a negative correlation between proximity and complexity. This implies an industrial policy trade-off between aiming for sophisticated products and aiming for those with a high chance of success. Nevertheless, the trends are encouraging.

A high complexity product the UAE exports competitively is distilling or rectifying equipment, which includes distilling apparatus for desalination systems, biogas refinement equipment and solvent recycling plants. The green product which the UAE export most competitively are limestone materials for manufacture of lime or cement, used in chemical recovery systems for wastewater management. This, however, is a product with a low complexity rank.

One of the easiest new opportunities for the UAE to transition into would be methanol made from renewable sources, which is low in technological sophistication but has huge growth potential. By contrast, machines, and mechanical appliances, which includes those used in a range of areas of environmental management such as waste, wastewater, drinking water production and soil remediation, ranks significantly higher in complexity. However, it is also very far from the UAE's existing capabilities and would be a more difficult and riskier prospect.

Fig. 56: The UAE's green export products divided into current strengths and potential opportunities. Size of product indicates the UAE's current RCA; colours represent product categories (see legend)[15]



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

[15] For an in-depth explanation of how to read this figure, please refer to the section Green strengths and opportunities within the China case study.

Summary

- The United Arab Emirates is one of the world's largest oil producers and, not surprisingly, scores relatively low in green (and overall) economic complexity.
- The country has one of the highest levels of per capita emissions globally, but due to its small population only accounts for a limited share of emissions overall.
- The UAE have seen gains in both green complexity and green complexity potential over time, suggesting the country's productive structure is becoming more suited to competitively producing complex green goods.
- The government's "Operation 300bn" industrial strategy aims to develop the country's manufacturing capabilities, including for renewable energy production.
- The UAE only has sufficient solar potential to meet their current high average annual energy usage per person, but it is possible it will try to develop a green energy export capacity given its low production costs; a need to diversify away from fossil fuels; and proximity to the large greening market of Europe.

Singapore case study

Policy ambition and green complexity

Singapore is one of the wealthiest places on earth, with a sophisticated economy (Economic Complexity Index - ECI rank of 2), but a much lower ranking in green complexity.

Singapore's nationally determined contribution (NDC) to the UNFCCC states the country's aim to peak its emissions by 2030[1]. Based on data up to 2017, Singapore was the worst performing rich country regarding action on climate change, and one of the worst overall, according to the Financial Times[2]. One of the reasons for this lack of progress is its limited renewable energy potential. Consequently, the country relied on natural gas for about 96% of its electricity generation in 2019[3].

Despite its strong response to the COVID-19 pandemic, none of Singapore's recovery spending spending was deemed green by the Oxford University recovery tracking project.

[1] UNFCCC, 'Singapore's Update of Its First Nationally Determined Contribution (NDC) and Accompanying Information', 2020 <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Singapore First/Singapore's Update of 1st NDC.pdf> [accessed 19 August 2021].

[2] Steven Bernard, 'Singapore Fails to Keep Pace with Wealthy Peers on Carbon Emissions', The Financial Times, 12 March 2021 <https://www.ft.com/content/a60e9464-a55d-4066-a839-46e334fde094> [accessed 19 August 2021].

[3] CAT, 'Country Summary: Singapore', Climate Action Tracker, 2020.

Singapore at a glance

5,686
Population (thousands)

340,000
GDP (current US$, millions)

98,526
GDP / capita (US$, PPP)

40
GCI rank

2
ECI rank

64
GCP rank

7.80 %
Green exports of total

1.44 %
Global share of green exports

Chromatographs, electrophoresis
Highest RCA green product

Profile projectors
Most complex competitive

none

Net zero target

1.4°C

Temp change since 1961

0.08 (rank: 160/230

CO2 intensity (kg/PPP$ GDP)

60

Avg energy use (MWh/yr/cap)

53

Global Energy Potential (MWh/yr/cap)

130

Climate risk index rank

159

Extreme risk index rank

0.7% (191/213)%

Renewable energy consumption

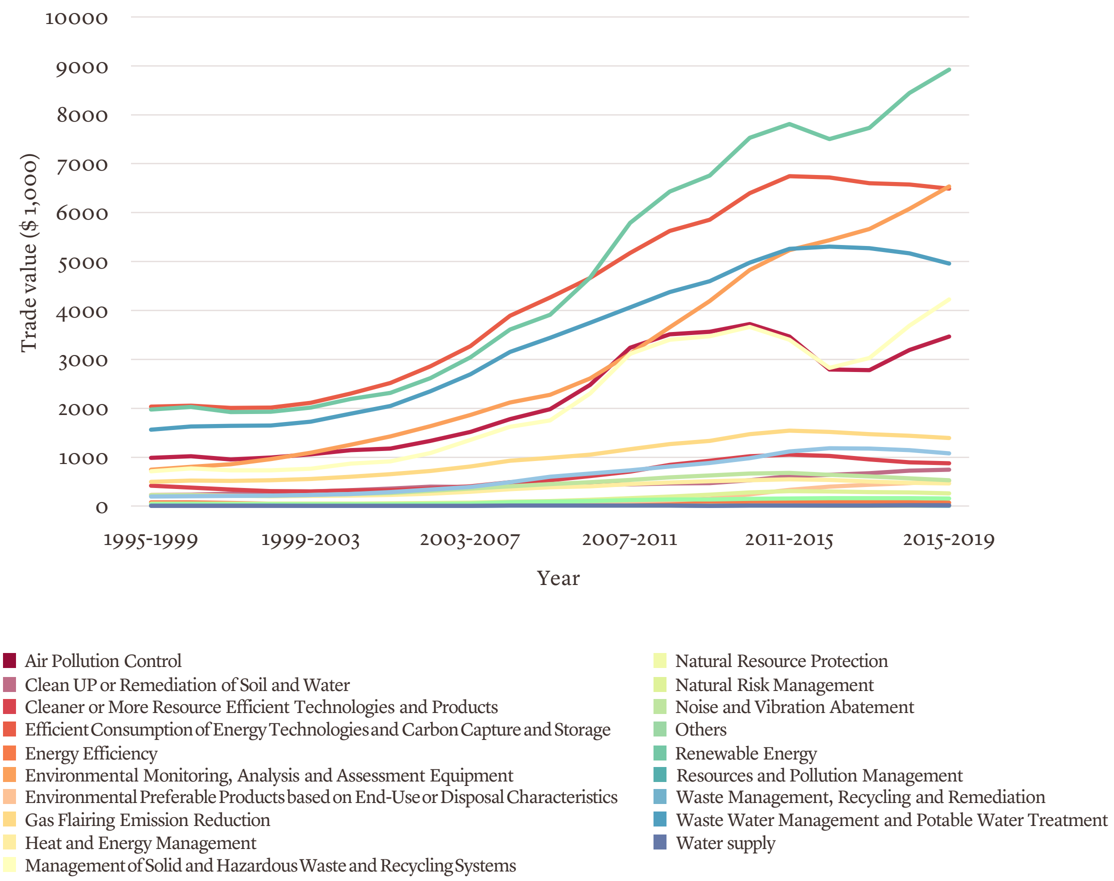
2 %

Share of green in covid recovery

Trends in green competitiveness

Singapore's GCI rank has increased marginally over the course of the study period – from 45 in 1995-99 to 40 in 2015-19. However, its GCP rank fell from 53 to 64. This stands in stark contrast to its ECI rank of 2 – which has risen from 43rd. Singapore has thus drastically improved its capability in producing complex products, but not, according to this analysis, complex green products. Absolute trade values increased over time, especially in the green categories of Renewable Energy; Environmental Monitoring, Analysis and Assessment Equipment; Efficient Consumption of Energy Technologies and CCS; Waster Water Management and Potable Water

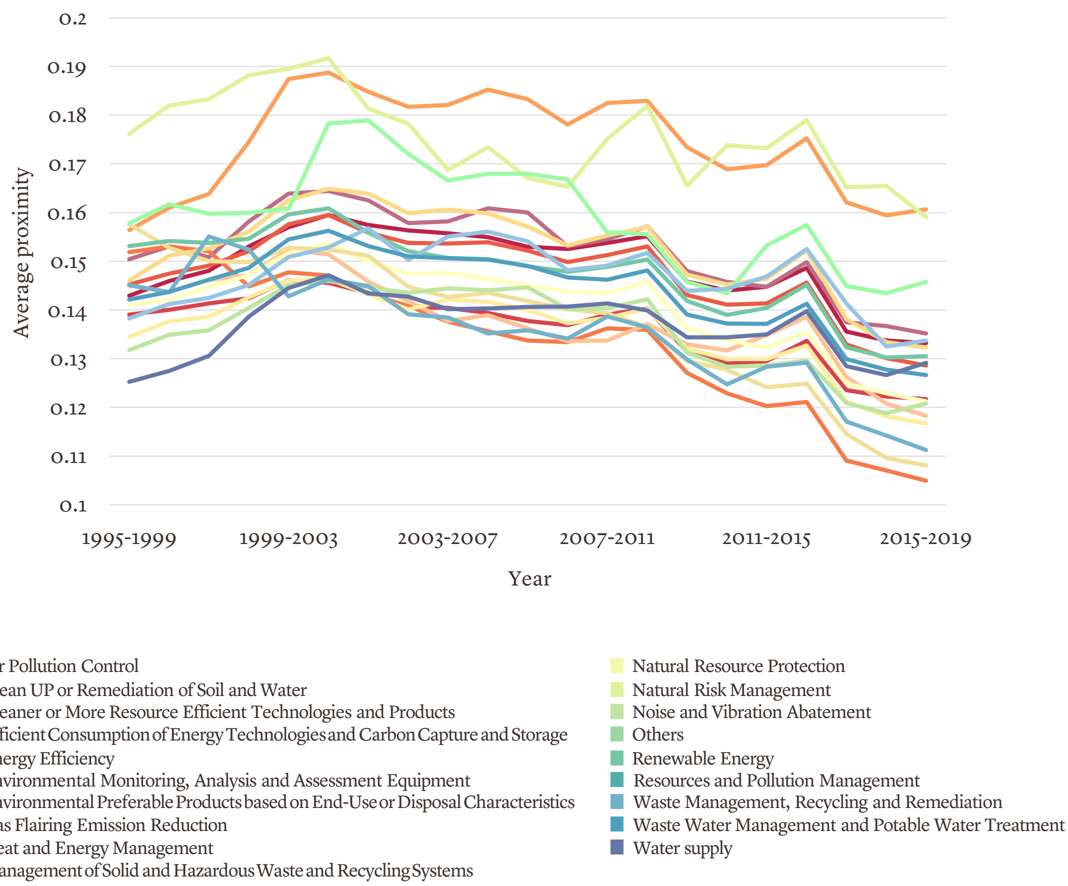
Fig. 56: Export value over time by environmental category, Singapore.



Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

Treatment; Management of Solid and Hazardous Waste and Recycling Systems; and Air Pollution Control. The share of green products in Singapore's overall exports has also increased, from 5.1% to 7.8% (Figure 56). However, this increase is smaller than the rise in green products as a share of global trade. The average proximity of Singapore's production capabilities to green products has been declining for all green categories since the early 2000s (Figure 57). This is reflected in its losses in GCI and GCP rank, and implies that it is becoming harder, rather than easier, for Singapore to develop a competitive advantage in the green economy.

Fig. 57: Average proximity over time by environmental category, Singapore

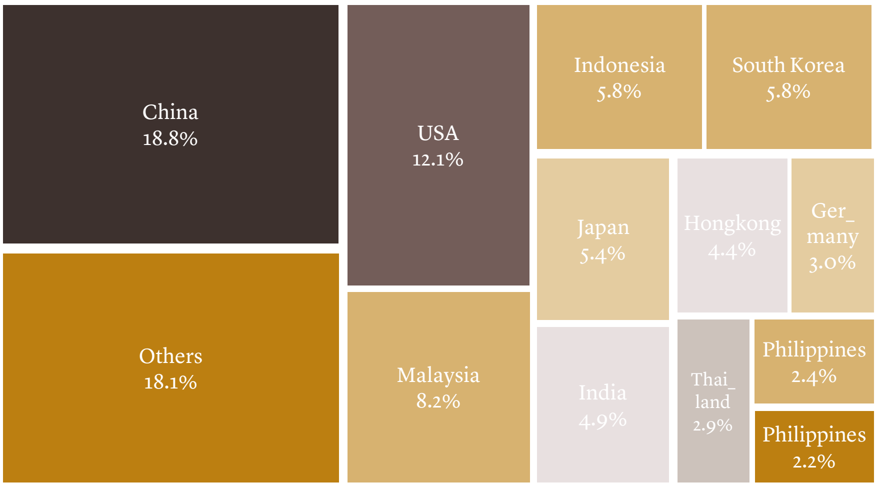


Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

The largest importers of Singapore's green products are China (18.8%) and the United States (12.1%). Several countries account for about 2-5% of Singapore's green exports, while only 18.1% of green export value goes to countries with less than a 2% share (Figure 58).

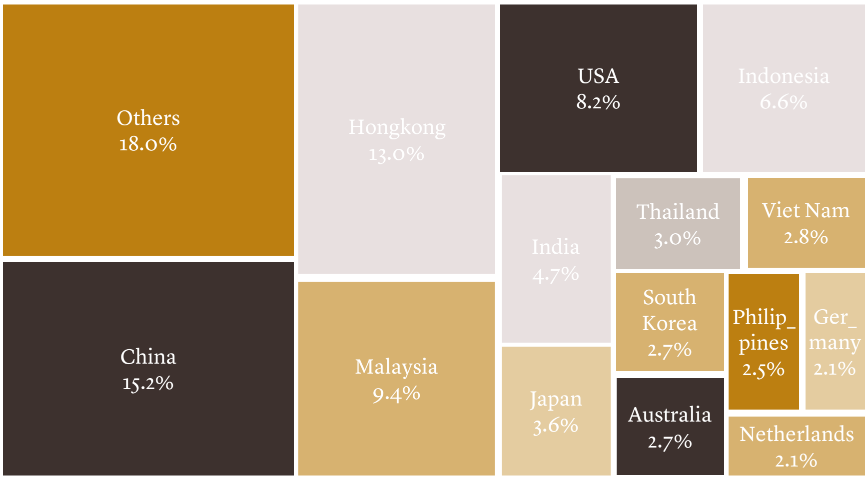
The distribution looks slightly different for overall export values: China (15.2%) remains the largest importer, but is followed by Hong Kong (13%), while Malaysia (9.4%) accounts for a slightly larger share than the US (8.2%) (Figure 59).

Fig. 58: Largest importers of Singapore's green exports. Only countries that import >2% of Singapore's exports are shown separately.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Fig. 59: Largest importers of Singapore's overall exports. Only countries that import >2% of Singapore's exports are shown separately.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

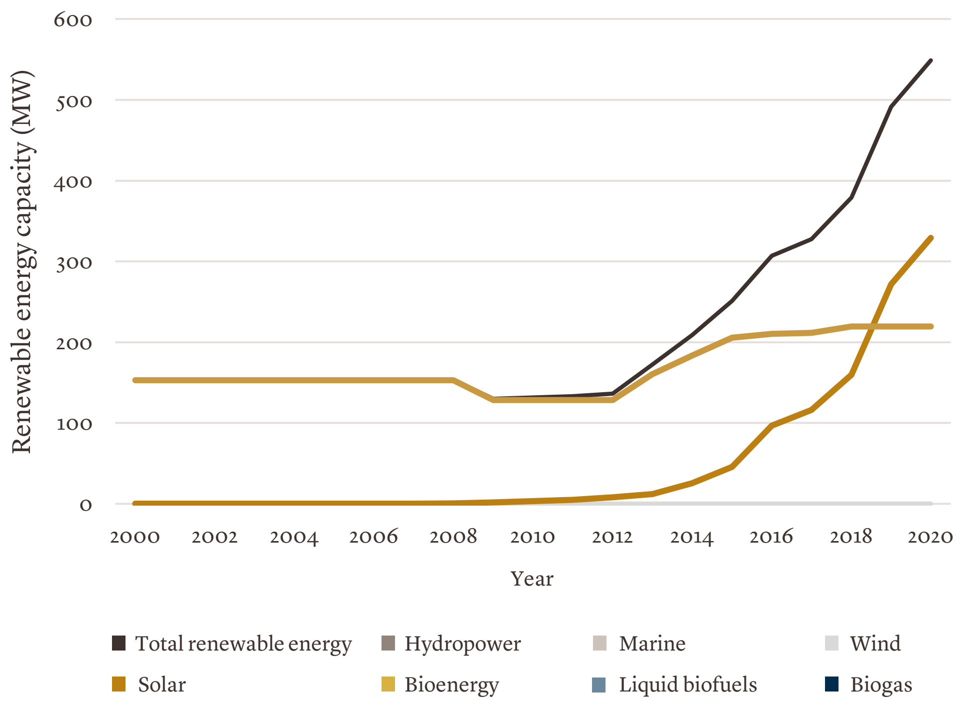
Trends in green energy

Singapore is a country that clearly has poor renewable energy potential relative to its population size. It has a high population density (8,400 people per km2), relatively high average energy use per person (60 MWh/yr/cap), quite limited access to renewable resources, and consequently very little current renewable generation (Figure 60).

Singapore and its surrounding waters do not experience winds consistently above 4 mph and so it is not considered to have any current economic wind energy potential. Moreover, it has no hydropower, and only a small bioenergy industry. There is some potential for solar energy, (Figure 61) but with limited available land it is unlikely much of this solar potential will be realised. Even if all of its green energy potential of 53 MWh/yr/cap were utilised it would still not be able to meet its current energy demands without a significant improvement in the energy efficiency of solar.

Consequently, Singapore is looking to secure significant amounts of green energy from Australia in the near future. As mentioned in Section 2. G, two major projects currently in their planning phases - the Asian Renewable Energy Hub and the Australia–ASEAN Power Link - are set to deliver around 20GW of green energy, or 20% of Singapore's current energy demand, in the form of green ammonia (hydrogen) or as electricity transferred through high voltage direct current underwater cables.

Fig. 60: Singapore's renewable energy generation capacity (GW) by energy source



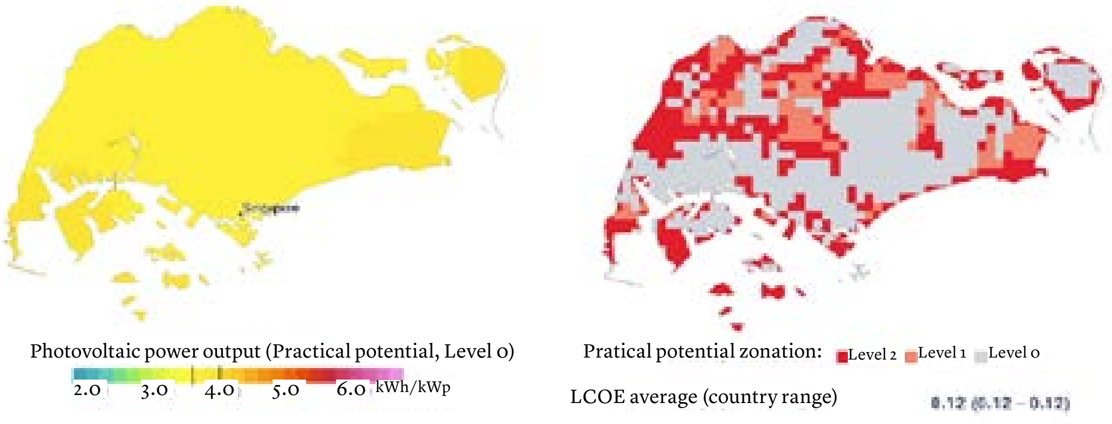
Source: IRENA (2021), Renewable Capacity Statistics 2021; & IRENA (2020), Renewable Energy Statistics 2020, The International Renewable Energy Agency, Abu Dhabi.

Table 9. Estimates of current technical potential of renewable resources per person compared with current average annual per capita usage for Singapore.

Singapore	
Onshore wind generation potential (EJ/yr)	<1
Offshore wind generation potential (EJ/yr)	<1
Solar PV generation potential (EJ/yr)	1
Hydro generation potential (EJ/yr)	-
Bioenergy generation potential (EJ/yr)	<1
Est. Total generation potential (EJ/yr)	1
Population (millions)	6
Average annual energy usage per person (MWh/yr/cap)	60
Total generation potential per person (MWh/yr/cap)	53

Source: See Appendix for Data Sources

Fig. 61: Estimates of solar photovoltaic potential (kWh/kWp) and practical potential zonation used to determine Singapore's economic potential for solar



Source: https://globalsolaratlas.info/

Policy and economic environment

As one of the four "Asian tigers" – along with Hong Kong, Taiwan, and South Korea – Singapore has seen rapid economic development since the 1990's. Taking advantage of its strategic position next to the Malacca Strain through which passes perhaps 40% of global trade, Singapore is an international trade success story, rising to rich country status in just a few decades after it gained independence in 1965[4].

Fairly soon after the Asian Financial Crisis, China took over as the Asian growth powerhouse. Consequently, Singapore has used its strong institutions and liberal policies to become a financial bridge between China and the rest of the world[5]. This exposes Singapore to the ups and downs of China's fortunes, and its policies toward international finance.

Singapore has also grown into a knowledge economy with some of the top universities in Asia. It prides itself on its advanced research, including in renewable energy technologies and other green innovation. Such innovations, however, are not reflected in the green complexity index or potential unless local companies are able to capitalise on these and export their products globally.

[4] https://www.economist.com/the-economist-explains/2015/03/26/why-singapore-became-an-economic-success

[5] https://www.economist.com/special-report/2019/12/05/after-half-a-century-of-success-the-asian-tigers-must-reinvent-themselves

Environmental credentials and policy ambition

In its NDC, Singapore seeks to peak emissions by 2030 below 65 Mt of CO2e, giving it ample room to increase emissions from their 2018 levels of 46 Mt[6]. Even without new policies these emission targets could be easily met, showing a clear lack of ambition[7].

Singapore explains its recent lack of ambition to earlier progress in shifting from oil to natural gas for electricity generation in the early 2000s, and a limited and eventually zero growth rate in the number of cars and motorbikes. Singapore is also densely populated and lacks natural renewable energy resources. Singapore has introduced a carbon tax in 2019 for industrial facilities as the first Southeast Asian nation. However, at 5 Singapore dollars (approximately 3.7USD) per ton, this is one of the lowest carbon prices in the world[8]. The price is expected to rise to about 10 or 15 Singapore dollars (approximately 7.5 – 11 USD) by 2030, but that has also been criticised by action groups and members of parliament as being unambitious[9].

Singapore's post-COVID-19 pandemic spending echoes its recent slow progress. According to the University of Oxford's Global Recovery Observatory, Singapore's plans so far have revealed less than 0.1% of GDP spending on recovery in total, none of which can be deemed green. One reason for its low green spending might be that this does not include Singapore's recently unveiled Green Plan 2030, which aims to get Singapore on track for meeting its Paris agreement goals. While the details of the Green Plan 2030 are still to be worked out, and without a net zero date pledge, nor any best-in-class ambition, it has nonetheless been welcomed as a good starting point[10,11]. Among other elements, the Green Plan 2030 includes increased solar energy deployment and investment in EV infrastructure, as well as investment in trees, parks, waste management, and green finance. Discussing the plan, Grace Fu, Minister for Sustainability and the Environment of Singapore, declared a need to incorporate sustainability in everything, including the COVID-19 recovery [12,13].

---

6 World Bank, 'Total Greenhouse Gas Emissions (Kt of CO2 Equivalent)', World Bank Data, 2020 <https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE> [accessed 19 August 2021].

7 CAT, 'Current Policy Projections: Singapore', Climate Action Tracker, 2020 <https://climateactiontracker.org/countries/singapore/current-policy-projections/> [accessed 19 August 2021].

8 Maria Hofbauer Pérez and Carla Rhode, 'Carbon Pricing: International Comparison', Ifo DICE Report I, Spring Volume 18 (2020).

9 Winston Chow, 'Singapore's Climate Action: It Is Time to Be More Ambitious', Research Collection School of Social Sciences. Paper 3173., 2020, 19–19 <https://ink.library.smu.edu.sg/cgi/viewcontent.cgi?article=4430&context=soss_research> [accessed 19 August 2021]; John Koh, 'Singapore MPs Call for Minimum 15-Fold Carbon Tax Increase by 2040', IHS Markit Net-Zero Business Daily News Research & Analysis, 2021 <https://ihsmarkit.com/research-analysis/singapore-mps-call-for-minimum-15fold-increase-in-carbon-tax-b.html> [accessed 19 August 2021].

10 Carnell and Sakpal.

11 Carnell and Sakpal.

12 Paritta Wangkiat, 'Green Recovery', Bankok Post (Bankok, 21 June 2021) <https://www.bangkokpost.com/business/2135711/green-recovery>.

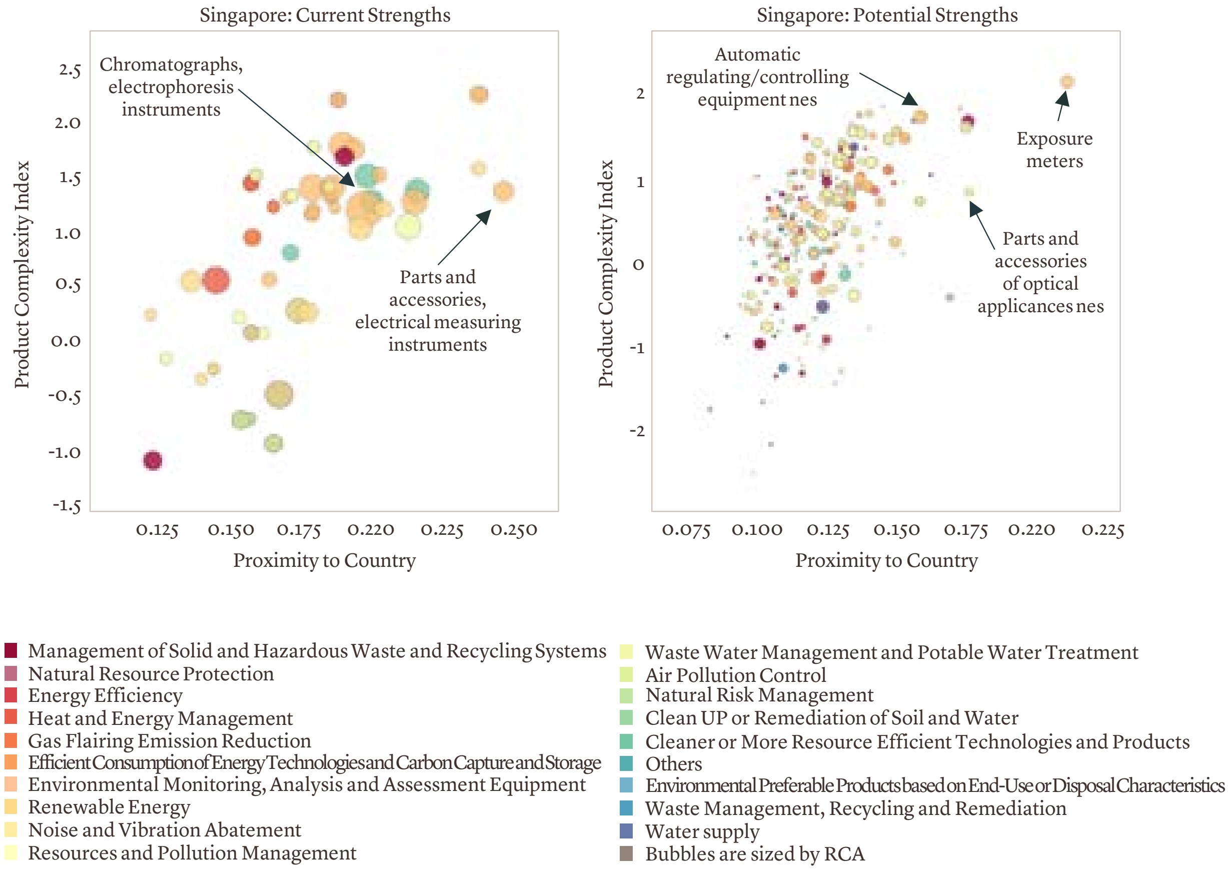
13 Wangkiat.

Green strengths and opportunities

Singapore's green strengths are vastly exceeded by the number of potential opportunities, as can be seen in Figure 62[14]. While there is a positive association between proximity and complexity, implying that the most technologically sophisticated products are also the ones it can transition into with the greatest ease, proximity overall is low, which is reflected in its relatively low GCP rank. The plot in Figure 62 highlights two of Singapore's competitive strengths: chromatographs and electrophoresis instruments, which are used for measurement and analysis of air- and water quality; and equipment for measuring electrical flow, used to identify electronic and electrical problems in equipment. New products which Singapore could develop a competitive advantage in with relative ease (compared to other green products) include exposure meters for controlling light sources and for measurements in agriculture, horticulture, and other natural resources applications; regulating/controlling equipment which includes solar heliostats; and parts for solar heliostats (labelled "parts and accessories of optical appliances").

[14] For an in-depth explanation of how to read this figure, please refer to the section Green strengths and opportunities within the China case study.

Fig. 62: Singapore's green export products divided into current strengths and potential opportunities. Size of product indicates Singapore's current RCA, colours represent product categories (see legend).[15]



Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org.

[15] For an in-depth explanation of how to read this figure, please refer to the section Green strengths and opportunities within the China case study.

Summary

- Singapore's economic growth can be attributed in no small part to its strategic position on major trade routes and its strong institutions.
- Singapore scores low on green complexity compared to its economic complexity ranking.
- While it has made progress in the past, Singapore’s current climate action policies have been criticised for lacking ambition.
- Singapore has high-ranking universities and prides itself on its green innovations, but such innovations are yet to be reflected in green complexity rankings as they require an ability to capitalise on these knowledge gains.
- With very limited green energy resources, Singapore is already looking to import green energy from other countries.

Switzerland

Policy ambition and green complexity

Switzerland[1] is one of the highest income countries on earth with a GDP per capita of over 70,000 USD[1]. This is also reflected in its high economic complexity (ECI) ranking of 5th.

It does not score as well on GCI and GCP and has, in fact, been dropping in the ranks[2].

Switzerland's legislature adopted a goal of net zero GHG emission by 2050 in 2019[3]; yet a key piece of legislation was voted down in a referendum in 2021.

Switzerland's nationally determined contribution to the UNFCCC (NDC) was updated in December 2020 and includes a 2030 target of 50% GHG reduction below 1990 levels.

This contribution is slightly more ambitious than previous submissions, in that a larger share of this goal will come from domestic reductions[4] rather than through the somewhat controversial purchase of overseas offsets.

---

[1] Switzerland GCI, GCP and RCA includes Liechtenstein due to their being combined in the underlying export trade data.

[2] At price point parity.

[3] CAT, 'Country Summary: Switzerland', Climate Action Tracker, 2020 <https://climateactiontracker.org/countries/switzerland/> [accessed 14 September 2021].

[4] UNFCCC, 'Switzerland's First Nationally Determined Contribution towards Achieving the Objective of the United Nations Framework Convention on Climate Change (Updated Submission)', 2020 <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Switzerland First/Switzerland_Full NDC Communication 2021-2030 incl ICTU.pdf>.switzerland/> [accessed 14 September 2021].

Switzerland at a glance

8,637
Population (thousands)

747,969
GDP (current US$, millions)

71,352
GDP / capita (US$, PPP)

23
GCI rank

5
ECI rank

47
GCP rank

6.90 %
Share of green in total exports

1.30 %
Global share of green exports

Railway & tramway & Bissel -bogies
Highest RCA green product

Machines & Mechanical appliances
Most complexe competitive

2050

Net zero target

2.3°C

Temp change since 1961

0.06 (rank: 177/230)

CO_2 intensity (kg/PPP$ GDP)

64

Avg energy use (MWh/yr/cap)

130

Global Energy Potential (MWh/yr/cap)

96

Climate risk index rank

155

Extreme risk index rank

25.3% (90/213)%

Renewable energy consumption

54 %

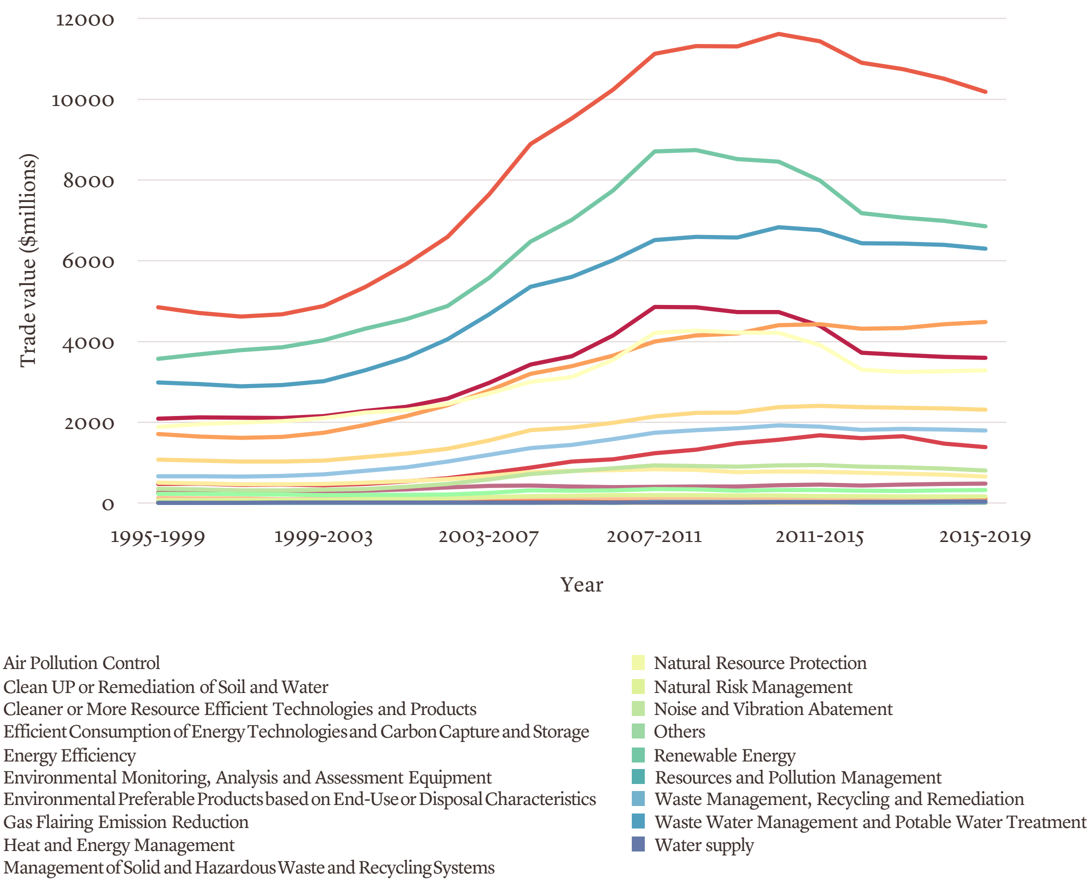
Share of green in covid recovery

Trends in green competitiveness

Switzerland has been declining in GCP since the mid-1990s and in GCI since the early 2000s. While the UK was on a similar trajectory in GCI from the mid 1990s until the mid 2000s, Switzerland was not able to keep its top 10 position. It now ranks 23rd in GCI and 47th in GCP.

Over the same period, absolute trade value went up in all green product categories, although many have slightly declined since a peak in the early 2010s. The largest export product by value are products in the category Efficient Consumption of Energy Technologies and CCS (see Figure 63). In line with its declining

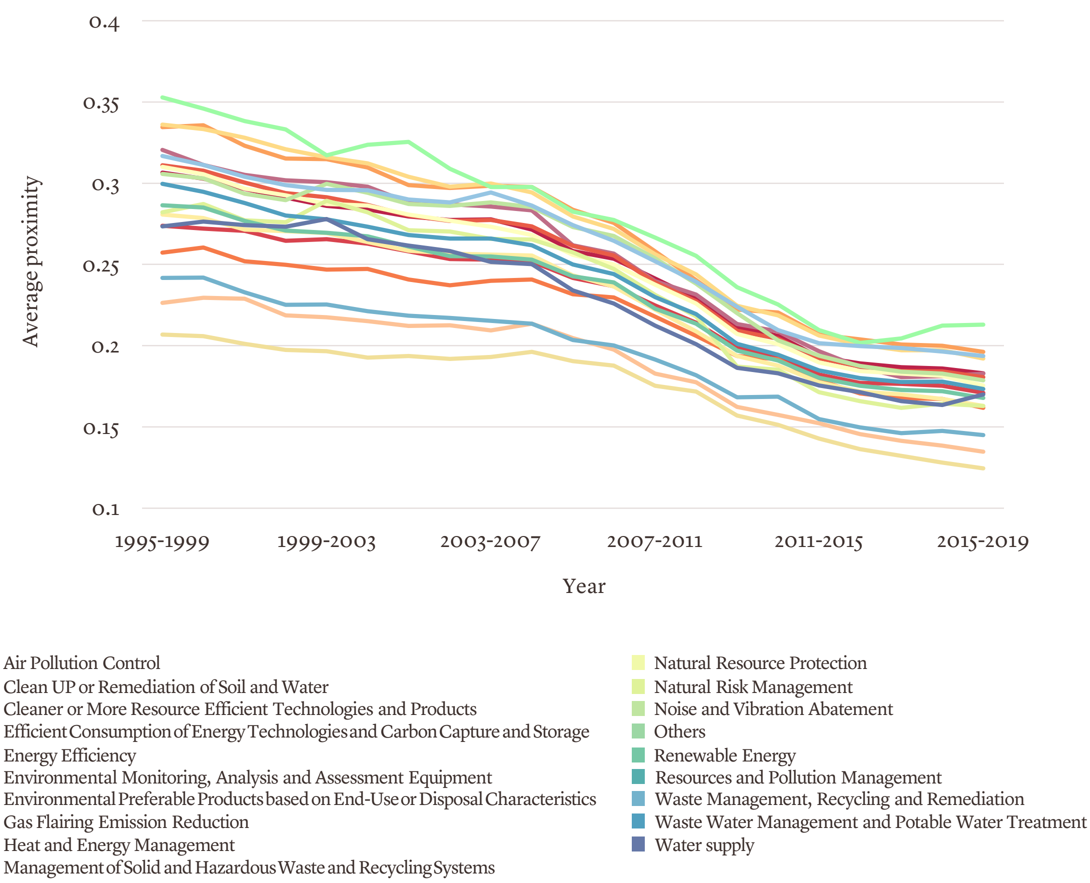
Fig 63: Export value over time by environmental category, Switzerland.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

GCI and GCP, the proximity of many green product categories to the Swiss economy has fallen, as is shown in Figure 64. There has, however, been a slight uptick in the category "Others" in recent years. This includes distilling apparatus for desalination systems, biogas refinement equipment and solvent recycling plants and machinery for treatment by temperature change, whose applications include biogas reactors and refinement equipment, among other environmentally relevant uses.

Fig 64: Average proximity over time by environmental category, Switzerland.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

Fig 65: Largest importers of Switzerland and Liechtenstein's green exports. Only countries that import >2% of Switzerland and Liechtenstein's exports are shown separately.

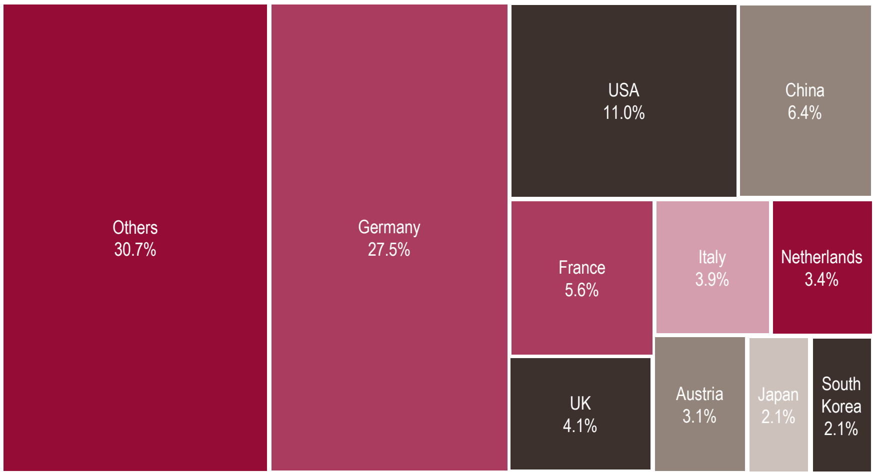
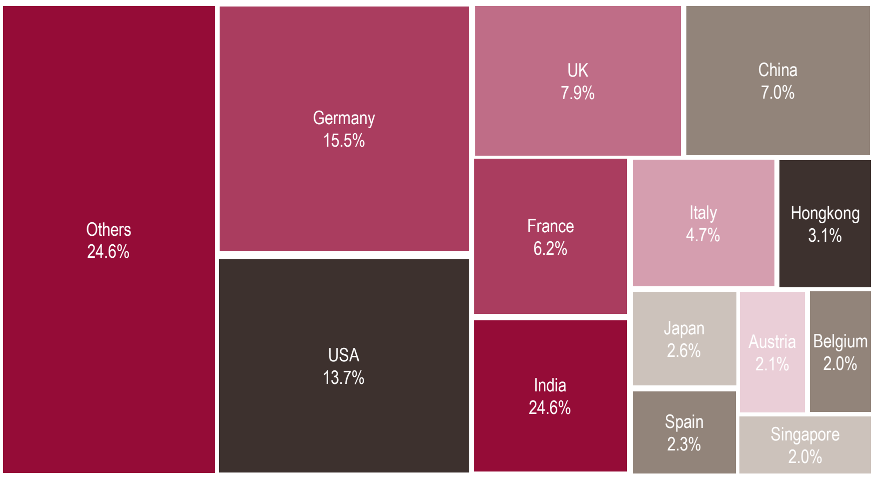


Fig 66: Largest importers of Switzerland and Liechtenstein's overall exports. Only countries that import >2% of Switzerland and Liechtenstein's exports are shown separately.



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

At 27.5%, Germany is the most significant importer of Switzerland[4]'s green exports. This is not surprising, given the two countries' geographic and cultural proximity, as well as the size of the German economy relative to that of other countries in the region. However, an analysis of overall import shares suggests that Germany is a particularly significant trading partner in green goods – more so than overall.

The United States account for the second-largest share at 11%, followed by China with 6.4%. Nearly a third of Switzerland's green exports are imported by countries with a share of less than 2%.

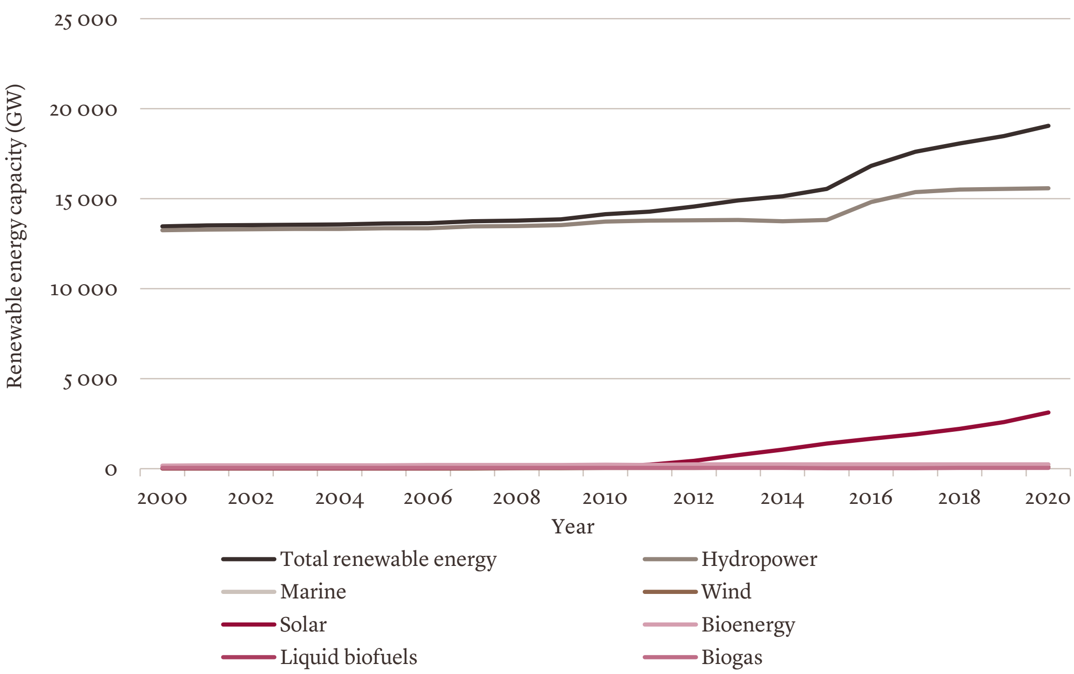
Importers' shares of Switzerland's overall exports differ somewhat from green exports. Germany remains the largest importer, but accounts for only 15.5%, which is only slightly more than half of its share of green exports. This indicates that Switzerland's green exports are significantly more dependent on Germany as a trading partner than is the case overall.[4]

The United States are still the second-largest importer, but account for a marginally higher percentage of 13.7%. They are followed by the United Kingdom (close to 8%) and China (7%). Countries with small import shares (less than 2%) account for about a quarter of Switzerland's exports.

Trends in green energy

Hydropower is the most important domestic source of renewable energy in Switzerland, with 59% (36.3 TWh/year) of domestic electricity production currently sourced from hydropower. Being a land-locked country, Switzerland has no offshore wind potential, so the next largest renewable resources available are solar, onshore wind, and bioenergy. This is reflected in the recent growth in solar PV shown in Figure 5, which is also indicative of relatively low costs and the reasonably large solar potential shown in Figure 67.

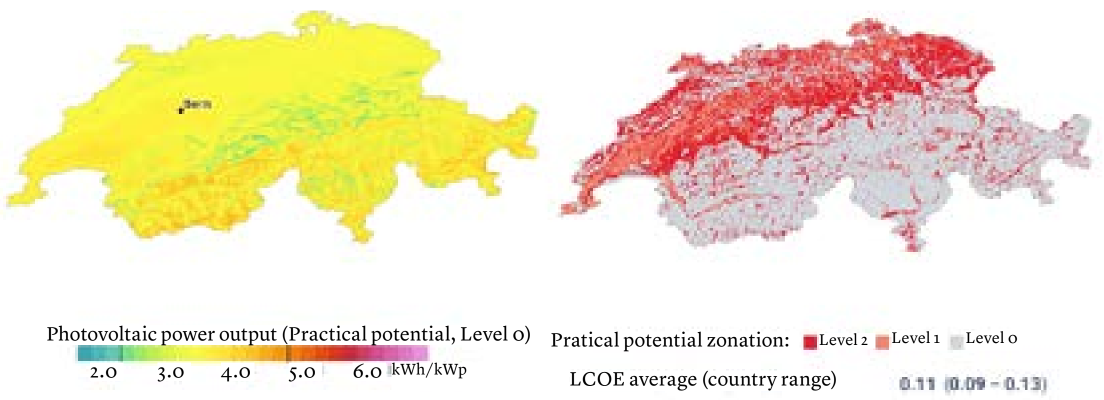
Fig 67: Switzerland's renewable energy generation capacity by source.



Source: IRENA (2021), Renewable Capacity Statistics 2021; & IRENA (2020), Renewable Energy Statistics 2020, The International Renewable Energy Agency, Abu Dhabi.

Switzerland's average annual energy usage per person is quite low compared to other countries of similar income, which is consistent with the European region (Table 10) . Hence the country's renewable per capita generation potential per person is much higher than current per capita demand, despite the country having only relatively low renewable potential. A scale up of renewables spending to match that of key regional competitors such as Germany could provide Switzerland with even greater energy security and the potential to export green energy to the growing EU market.

Fig 68: Estimates of solar photovoltaic potential (kWh/kWp) and practical potential zonation used to determine Switzerland's economic potential for solar.



Source: https://globalsolaratlas.info/

Table 10. Estimates of Switzerland's current technical potential for annual renewable energy generation which is used to calculate its per capita renewable energy potential in comparison with its current average annual per capita usage.

Switzerland	
Onshore wind generation potential (EJ/yr)	<1
Offshore wind generation potential (EJ/yr)	-
Solar PV generation potential (EJ/yr)	3.7
Hydro generation potential (EJ/yr)	<1
Bioenergy generation potential (EJ/yr)	<1
Est. Total generation potential (EJ/yr)	4.0
Population (millions)	9
Average annual energy usage per person (MWh/yr/cap)	34
Total generation potential per person (MWh/yr/cap)	130

Source: See Appendix for Data Sources

Policy and economic environment

Switzerland's economy is highly services-based, with a large financial industry and a strong tourism sector. On the manufacturing side, Swiss companies have a strong presence in the pharmaceutical industry, and food products via Nestlé, as well as niche high-end manufacturing such as watches and jewellery.

While Switzerland is not part of the EU, its relationship is governed via various treaties. Although Switzerland pulled out of negotiations of a landmark deal with the EU to formalise these bilateral treaties into a single agreement[4], the EU and Switzerland are largely aligned on their climate goals[5]. The European Green Deal, which was announced in late 2019 and is still being defined in detail, will impact Switzerland through many of its regulations. However, since both jurisdictions have emissions trading schemes in place that have been coupled since the beginning of 2020, Switzerland is exempt from a potential EU border adjustment tax[6].

[4] Hans von der Burchard, 'EU-Switzerland Relations Head for Trouble as Partnership Deal Unravels', Politico, 26 May 2021 <https://www.politico.eu/article/eu-switzerland-relations-head-for-trouble-as-partnership-deal-unravels/>.

[5] Mission of Switzerland to the EU, 'Environment and Climate – Stepping up Cooperation on Shared Challenges', 2021 <https://www.eda.admin.ch/missions/mission-eu-brussels/en/home/key-issues/enviroment-climate.html>.

[6] Mission of Switzerland to the EU, 'Environment and Climate – Stepping up Cooperation on Shared Challenges', 2021 <https://www.eda.admin.ch/missions/mission-eu-brussels/en/home/key-issues/enviroment-climate.html>.

Environmental credentials and policy ambition

Switzerland's updated NDC in 2020 was written with the amended CO2 act in mind as a key piece of legislation to help get Switzerland on a Paris agreement aligned pathway. It included, among other things, higher fossil fuel taxes and more expensive flight tickets. In June 2021, voters rejected this bill in a referendum, leaving Switzerland´s environmental minister to state that this would make reaching net zero in 2050 "very difficult[7]".

To reach its goal to decrease GHG emissions by 50% in 2030, Switzerland has made deals with Peru and Ghana to fund part of the reductions there that would count on Switzerland´s balance[8]. The deal with Peru was hailed as the first international agreement of its kind. This practice is allowed and governed by Article 6 of the Paris agreement, but still controversial and underutilised as exact rules for Article 6 were still being negotiated a deal on its formal rules was reached at the recent Glasgow COP26)[9].

Due in part to its natural endowments of renewable energy sources, Switzerland has an electricity system that is very low in carbon intensity. Almost 60% of domestic electricity production comes from its more than 600 hydroelectric power plants. Most of the remainder is accounted for by nuclear power plants.

In early 2020, almost 10% of vehicles sold were EVs, with the ambition to raise this to 15% by 2022. This is more than the EU average, although richer peers of Switzerland such as the Nordics are further ahead.

7 Peter Stubley, 'Swiss Voters Reject New Climate Law to Help Cut Carbon Emissions', The Independent (London, 14 June 2021) <https://www.independent.co.uk/climate-change/news/switzerland-referendum-climate-change-emissions-b1865193.html>.

8 Joe Lo, 'Peru and Switzerland Sign "World First" Carbon Offset Deal under Paris Agreement', Climate Home News, 21 October 2020 <https://www.climatechangenews.com/2020/10/21/peru-switzerland-sign-world-first-carbon-offset-deal-paris-agreement/>.

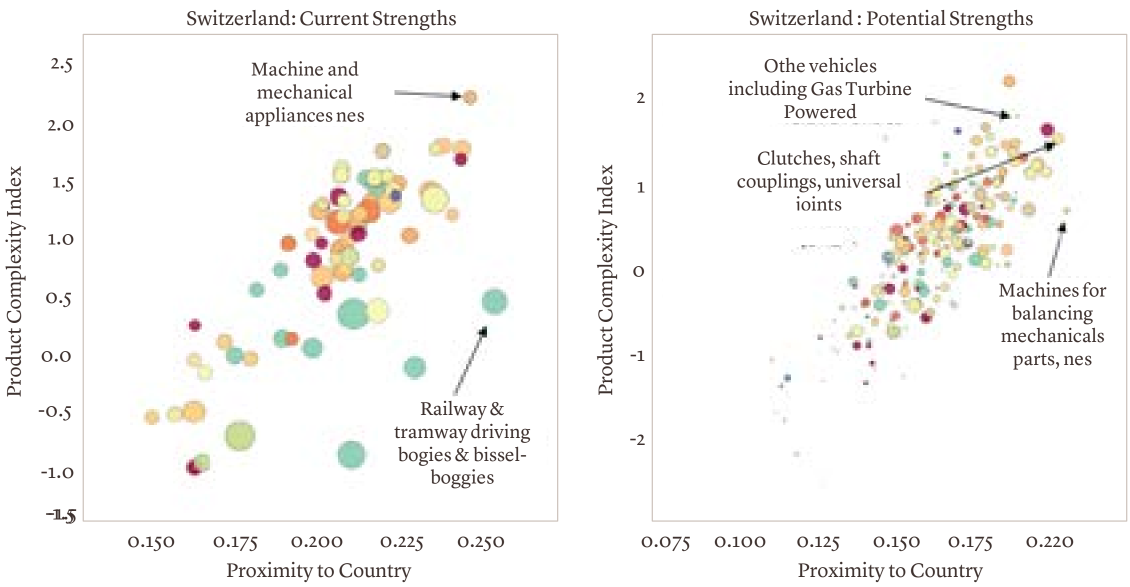
9 IISD, Delivering Climate Ambition Through Market Mechanisms: Capitalizing on Article 6 Piloting Activities, 2021 <https://sdg.iisd.org/commentary/policy-briefs/delivering-climate-ambition-through-market-mechanisms-capitalizing-on-article-6-piloting-activities/>.

Green strengths and opportunities

Figure 69 shows that Switzerland has a larger number of green opportunities than green strengths, and relatively low proximity to green production capabilities. However, the most proximate green products tend to be higher in complexity, which implies there is little tradeoff between complexity and the ease of transitioning .

Switzerland's green strengths include a number of railway parts, one of which is highlighted on the plot. High complexity green opportunities include parts for wind turbines (such as clutches, shaft couplings and universal joints) and cleaner vehicles, such as hybrids and EVs, in which Switzerland currently has very low RCA.

Fig 69: Switzerland's green export products divided into current strengths and potential opportunities. Size of product indicates Switzerland's current RCA, colours represent product categories (see legend)[10].



- Management of Solid and Hazardous Waste and Recycling Systems
- Natural Resource Protection
- Energy Efficiency
- Heat and Energy Management
- Gas Flairing Emission Reduction
- Efficient Consumption of Energy Technologies and Carbon Capture and Storage
- Environmental Monitoring, Analysis and Assessment Equipment
- Renewable Energy
- Noise and Vibration Abatement
- Resources and Pollution Management
- Waste Water Management and Potable Water Treatment
- Air Pollution Control
- Natural Risk Management
- Clean UP or Remediation of Soil and Water
- Cleaner or More Resource Efficient Technologies and Products
- Others
- Environmental Preferable Products based on End-Use or Disposal Characteristics
- Waste Management, Recycling and Remediation
- Water supply
- Bubbles are sized by RCA

Source: Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org..

[10] For an in-depth explanation of how to read this figure, please refer to the section Green strengths and opportunities within the China case study.

Summary

- Switzerland ranks highly in overall economic complexity, with a global ECI rank of 5th.
- However, its competitiveness in producing complex green products has declined dramatically over the period of this study, with GCI falling from 6 to 23 and GCP from 18 to 47 between 1995-1999 and 2015-2019.
- Products which Switzerland (and Liechtenstein) export competitively include railway parts and equipment used for biogas production.
- Switzerland (and Liechtenstein)'s green exports are highly concentrated: Germany accounts for close to 30%, which is almost twice its share in the region's overall exports.
- Switzerland has set a goal to reach net zero GHG emissions by 2050. However, given its current trajectory and policies it is difficult to argue it is on track to reach this goal.
- Switzerland has a much greater renewable energy potential than current energy demand needs and so a scale up of renewables spending to match that of key regional competitors such as Germany could provide Switzerland with even greater energy security and the potential to export green energy to the growing EU market.
- The country has put in place international agreements to outsource emission reductions to countries in the Global South, specifically Ghana and Peru, which is an unusual and controversial practice.

5. What could this mean for companies and their investors?

Investment opportunities in wind and solar

Is the transition to blame for the current energy crisis?

As countries have begun to recover from the COVID-19 pandemic, an energy crisis has gripped Europe. By October 2021, European gas prices had increased by about 500% from the beginning of the year. In the UK, prices of 60p per therm[1] at the beginning of the year rose 37% in 24 hours to trade at 400p per therm[1]. Energy bills are forecasted to rise by up to 30% next year, whilst by the 18th October sixteen smaller energy providers had gone out of business in the UK market as they struggled with rising costs.

While some have blamed this energy crisis on the energy transition, it is most likely a result of multiple factors including supply and demand dynamics, geographic and political factors, rather than merely the rising cost of carbon[2]. Such additional factors include low gas storage stocks, reduced gas supplies from certain geographies, a shortage in Liquified Natural Gas (LNG) deliveries linked to high demand from Asia following China's decision to ban imports of Australian coal following a political dispute, as well as lower than normal renewable output in Europe due to meteorological factors. Asian gas demand has risen due to cold weather and new policies on imports of coal, whilst LNG shipments have been sent to South America as droughts caused hydroelectric production to fall. In Europe, where natural gas demand fell by 1.9% in 2020, demand has rebounded post-pandemic as lockdowns have eased. Delayed maintenance at other European production facilities has further exacerbated supply chain shortages, as have lower wind energy production due to reduced wind speeds. Finally, and crucially, gas supplies from Russia have fallen. This is in part due to high Asian demand. Some commentators have suggested that Russia may also be purposefully limiting gas flows to the rest of Europe to strengthen its case for starting flows through the new Nord Stream 2 pipeline to Germany. In October this year, President Putin claimed that Russia "could deliver 10% more gas if Nord Stream 2 was approved"[3], hinting at the existence of additional stockpiles that were being deliberately withheld.

Some have argued that the excessive price rises are simply the result of a market responding to an "unusual confluence of economic forces"[4], and should soon reverse course. However, the crisis also presents an inflection point in the energy transition, as policymakers need to choose between two different responses.

The first response, that will likely be supported by many incumbent energy providers, is to blame renewables, encouraging a "popular revolt against climate policies" as households energy bills rise[5]. This was observed earlier in 2021, when the electricity grid in Texas failed due to freezing temperatures. Republican leaders blamed freezing wind turbines, when

[1] One therm is equivalent to 100,000 BTUs (British Thermal Unit) – the amount of heat needed to increase the temperature of one pound of water by one degree Fahrenheit.

[2] From January to November 2021 the EU carbon price has doubled (https://ember-climate.org/data/carbon-price-viewer/) while EU gas prices over this period have quadrupled. (https://www.euronews.com/2021/10/28/why-europe-s-energy-prices-are-soaring-and-could-get-much-worse)

[3] https://www.ft.com/content/e5f74353-73e5-4273-ae13-cc3d0985e606

[4] https://www.ft.com/content/f2ca6690-0390-4374-a9d5-29caf2d651dd

[5] https:////www.economist.com/leaders/2021/10/16/the-first-big-energy-shock-of-the-green-era

freezing components in thermal sources were also a major contributing factor; renewables only contributed 13% of power outages, according to analysis from the Electric Reliability Council of Texas[6]. In the current crisis, some argue that the phasing out of coal increases volatility, reducing the grid's capacity to draw on reliable sources of backup power when the wind does not blow, or when gas supplies run low. There is some credence to this view; as the energy transition towards renewables accelerates, coal and other sources of fossil fuel energy, traditionally seen as reliable sources of primary and backup power, are indeed being phased down. Under such pressure, some countries have considered controversial measures against renewables. For instance, Spain's now watered-down levy on "excess profits" from electricity companies would have taken from companies with a larger share of renewables (thus comparatively unaffected by rising gas prices yet benefiting from rising electricity costs) to "shield" consumers from rising electricity prices[7]. Meanwhile, many countries, including the UK[8], are temporarily ramping up coal output to alleviate short-term pressure.

The second possible response would be to stay the course on the transition and recognise that there will likely be short-term growing pains as the world undergoes a major transformation of the energy system. Gas might be needed as a bridge fuel to smooth the transition away from coal, especially across Asia, but this can lead to greater stranded assets, carbon lock-in[9], and unless there is further investment in ramping up LNG capacity to meet growing demand, the global shortfall in LNG capacity could rise from 2% of demand to 14% by 2030[10]. It could therefore be argued that extreme volatility in gas prices is a result of too little investment in clean energy and associated energy storage technologies. The more renewables and storage capacity is increased, the less need there is for fossil fuel sources such as LNG or coal to smooth the transition. Therefore, the speed of the transition from fossil fuels to green energy will determine the volatility of the energy supply-demand balance in the EU. Finally, in terms of long-term energy security, such volatility in fossil fuel prices is one key reason to transition to domestically generated renewable energy sources plus more transmission and storage[11] capacity which has shown to result in increased resilience in power systems and electricity grids[12,13,14].

Policymakers could therefore choose to address the gas crisis with even more aggressive

---

6 https://www.reuters.com/article/uk-factcheck-texas-wind-turbines-explain-idUSKBN2AJ2EI

7 https://www.ft.com/content/7d38b7da-0e33-4379-bffa-470b74e82a3f

8 https://www.bbc.com/news/business-58469238

9 Linus Mattauch, Felix Creutzig, and Ottmar Edenhofer, 'Avoiding Carbon Lock-in: Policy Options for Advancing Structural Change', Economic Modelling, 50 (2015), 49–63 <https://doi.org/https://doi.org/10.1016/j.econmod.2015.06.002>.

10 https://www.economist.com/leaders/2021/10/16/the-first-big-energy-shock-of-the-green-era

11 https://www.ren21.net/renewable-energy-resilient/

12 Dakota J. Thompson, Wester C.H. Schoonenberg, and Amro M. Farid, 'A Hetero-Functional Graph Resilience Analysis of the Future American Electric Power System', IEEE Access, 9 (2021), 68837–48 <https://doi.org/10.1109/ACCESS.2021.3077856>.

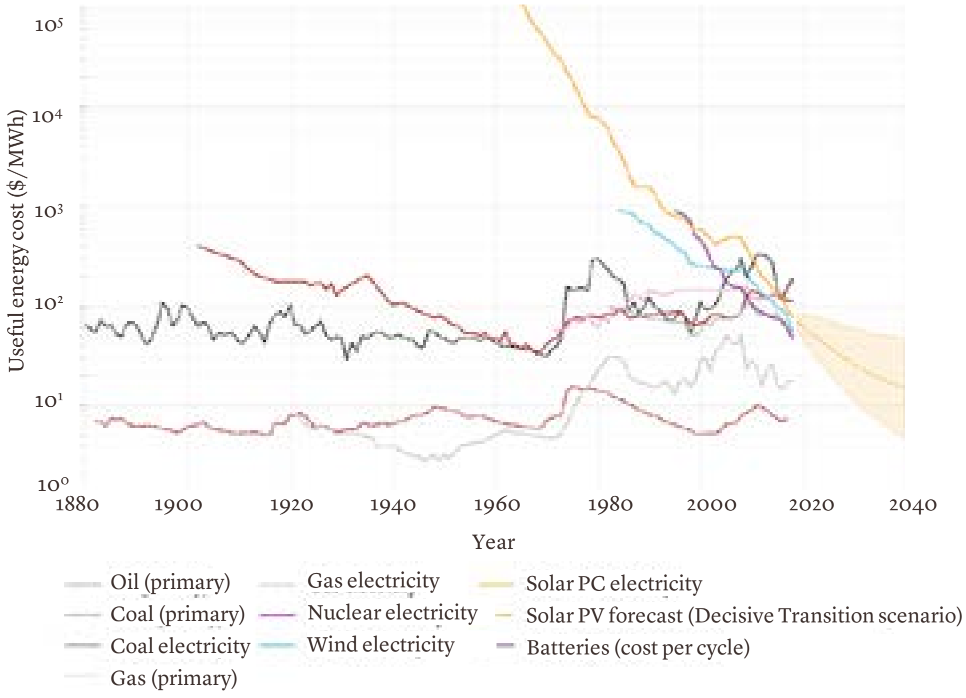
13 https://www.sciencedaily.com/releases/2021/05/210511123634.htm

14 NREL, 2019, Renewable Energy to Support Energy Security, https://www.nrel.gov/docs/fy20osti/74617.pdf

investment in the wind and solar industries. Renewables are no longer an expensive source of energy. On the contrary, wind and solar costs have dropped by 60% and 80%, respectively, over the past 10 years, owing to larger, more efficient wind turbines and the automation of solar product manufacturing (Figure 70). Such cost declines are expected to continue, and could prove to be profoundly disruptive for the global energy system[15]. Increased wind and solar capacity can support a wholesale shift away from gas towards electrification in domestic heating, industry, and power generation, as well as supporting the growing green hydrogen industry.

As the global economy ramps up its efforts to align with net zero, renewable sources of energy such as wind and solar are increasingly becoming deflationary forces. New modelling from the Oxford Institute for New Economic Thinking suggests a fast transition to a global energy

Fig 70: Long-run useful energy costs and prices of major energy supply technologies.



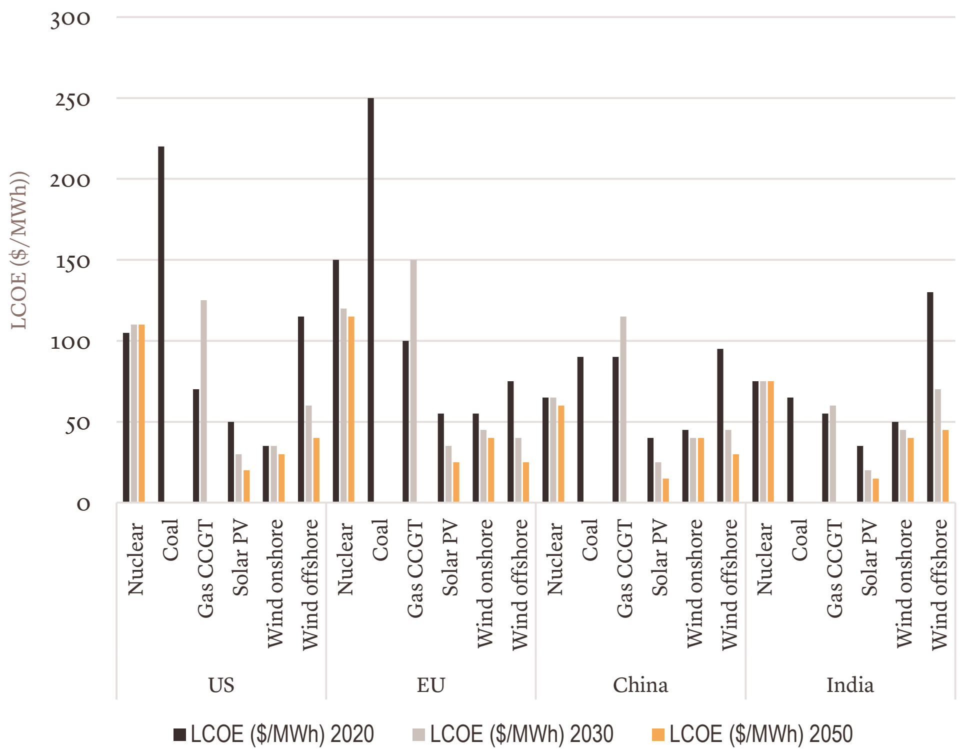
Source: Ives et al. 2021[14]. Primary oil, coal and gas paths are based on price data; all other technology paths are based on cost data. Costs and prices are scaled by technology-specific useful energy conversion factors. The dashed yellow line and shaded area show the cost forecast for the LCOE of solar PV in the Fast (Decisive) Transition scenario (median and 95% confidence interval).

[15] Ives et al. 2021, www.energychallenge.info/report

system based on renewables plus storage could save the world trillions and result in much lower energy costs for all – creating a positive dynamic that could drive rapid change[16].

The International Energy Agency's (IEA) latest research on the topic sends a similar message. Under its Net Zero scenario, the IEA estimates that in the next 10 to 30 years, the cost of electricity from gas would likely rise across geographies, while a further drop in costs for solar and offshore wind is also likely (Figure 71). There is no doubt that wind and solar capacity must be scaled up to reach Net Zero by 2050. According to BNEF, 505 gigawatts of new wind power globally need to be provided each year to 2030 (5.2 times the 2020 total) as well as 455 gigawatts of solar PV (3.2 times the 2020 total). Such an electrification process could lower household energy and fuel bills by up to 50% over business as usual[17].

Fig 71: Levelized cost of electricity (LCOE)[18] by technology (varies by geography)



Source: IEA. Note: there is no data for coal in 2030 and 2050 or gas CCGT in 2050 as these energy sources are assumed to have been phased out under a Net Zero scenario.

[16] Rupert Way, Matthew C. Ives, and others, Empirically Grounded Technology Forecasts and the Energy Transition, 2021 <https://www.inet.ox.ac.uk/publications/no-2021-01-estimating-the-costs-of-energy-transition-scenarios-using-probabilistic-forecasting-methods/>.

[17] Alberto Gandolfi and others, 'Energy costs and affordability: who pays for Net Zero?' Goldman Sachs Research, 5.9 (2021), 56.

[18] LCOE calculations are based on a levelized average lifetime cost approach, using the discounted cash flow (DCF) method. Costs are calculated at the plant level, and therefore do not include transmission and distribution costs but include costs induced into the system by the variability of wind and solar PV at higher penetration rates.

The energy transition requires a long-term perspective. In accordance with the Paris agreement, governments could enable more clean energy by redesigning energy markets, for example by scaling up storage technologies which have shown consistent cost declines similar to those of wind and solar[19], or by investing in greater transmission capacity, rather than investing further in fossil assets. Recent negotiations as part of COP26 in Glasgow identified how some developing countries (India and China) may rely on fossil fuel assets longer than others. In developed regions as well, legacy fossil fuel assets may also need need support to act as a backstop in periods of crisis. Nonetheless, if we are to successfully mitigate climate change, new fossil fuel investment without some clear carbon takeback obligation[20] needs to be stopped and redirected towards renewables.

Overall, renewables are poised to provide an increasing share of global energy consumption in a way that is cleaner and more cost competitive, compared to fossil-based sources of energy. As per the IEA's Net Zero scenario, by 2030 we need to see a significant slow-down (or contraction in a net zero scenario) in the demand for oil and gas energy (requiring around US$3trn in annual investments in industry, buildings, and transport) and a rapid increase in the production of wind and solar based energy.

This pathway will create winners and losers across the global economy. Countries which are well-positioned to supply high value-added products necessary to the production and supply of wind and solar energy are likely to benefit enormously with up to 10-fold increases in the deployment of solar and wind possible over the next decade,[21], while those relying on fossil fuel exports are faced with declining markets and the spectre of stranded assets[22]. Equally, the corporate landscape of the energy sector, from the supply of basic materials through energy production to energy supply, will shift radically.

In the next two sections, we propose to analyse the position of countries and corporates in this energy transition and discuss investment implications at the corporate level.

19 Way et al. 2021

20 Stuart Jenkins and others, 'Upstream Decarbonization through a Carbon Takeback Obligation: An Affordable Backstop Climate Policy', Joule, 5.11 (2021), 2777–96 <https://doi.org/10.1016/J.JOULE.2021.10.012>.

21 Way et al. 2021

22 J. F. Mercure and others, 'Macroeconomic Impact of Stranded Fossil Fuel Assets', Nature Climate Change, 2018 <https://doi.org/10.1038/s41558-018-0182-1>.

The macro-picture: wind and solar complexity index and complexity potential

As set out in Section 1, this report seeks to ask a central question in a world of evolving comparative advantages: as the transition to a green economy unfolds, which countries, regions and economic assets are poised to appreciate, and which are set to decline?

Investors hoping to gain exposure in rapidly growing clean technology industries can draw upon GCI and GCP scores to better understand which countries are currently nurturing competitive industries, and which are likely to do so in the future. However, it should be noted that these scores are only one kind of indicator and are by no means exhaustive or prescriptive when making investment or policy decisions. We explore here the relationship between countries' green competitiveness and their corporate structure to better understand this connection, with a focus on solar and wind.

GCI and GCP are country level indicators (current and potential) of global green competitiveness, which may not easily translate into an assessment of the performance of individual companies. To examine the relationship between green competitiveness at the country and corporate level, Complexity Index (CI) and Complexity Potential (CP) scores are re-calculated on a subset of green products that are specific to wind and solar industries[23]. Countries are ranked by the subset of complexity scores to identify current and potential leaders in each renewable energy sector. Major corporations and markets in wind and solar are subsequently compared at the country level. Comparative analysis based on Complexity Index / Complexity Potential (CI/CP) scores for solar and wind explores the relationship between green competitiveness at the country and corporate level, and how this can help investors and policymakers to understand and develop strategies and policies in the renewable energy sector and in the transition to a green economy.

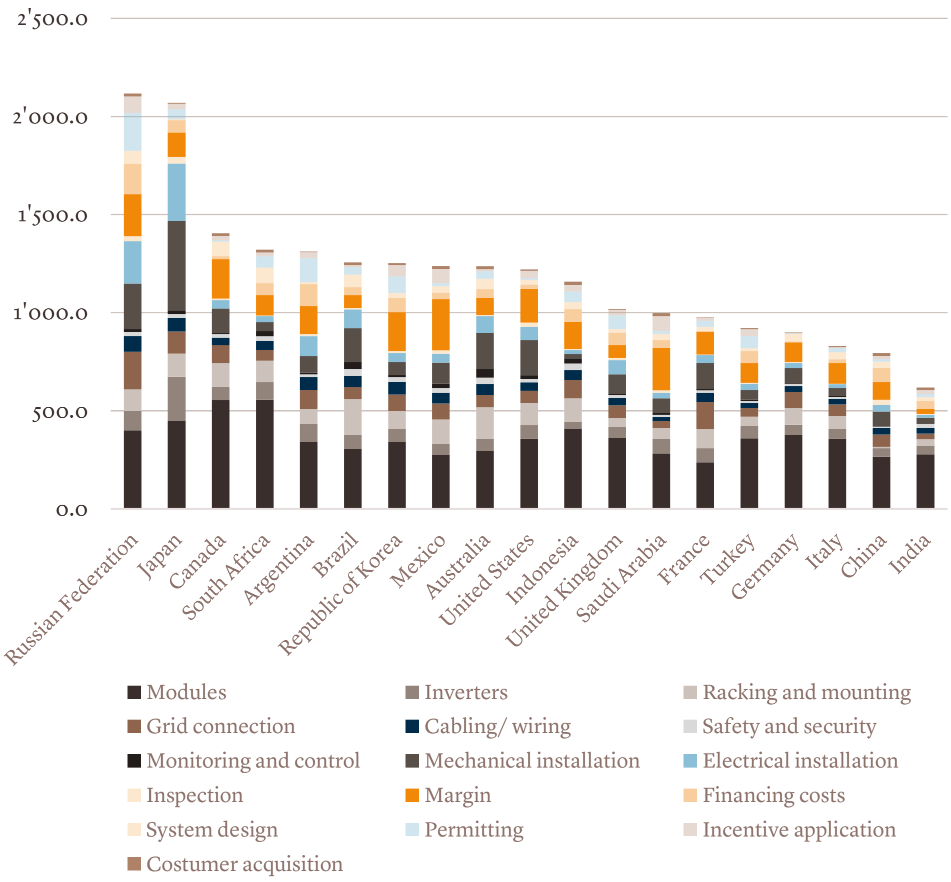
The costs of wind and solar have been above fossil fuel alternatives for most countries for much of the last two decades. During this time, deployment was primarily driven by government support in the form of feed-in tariffs, subsidies, quotas, and other such measures. However, countries that have had the greatest deployment of renewables in terms of installed capacity, including China, Germany, and India, now have some of the lowest levelised costs for renewables, (Figure 72)[24] despite not having the best sun or wind available resources[25] – suggesting the benefits to be gained from learning-by-doing.

[23] These scores include multiple products beyond wind turbines and solar panels, as well as accounting for the complexity of these products.

[24] IRENA, Renewable Power Generation Costs in 2018, International Renewable Energy Agency, 2019 <https://doi.org/10.1007/SpringerReference_7300>.

[25] By the best sunlight and wind resources we are referring to the technical potential for renewable energy generation in these countries, which is measured as the geographical potential energy generation (irradiance or wind) after the losses of the conversion from the extractable primary energy flux to secondary energy carriers or forms (electricity, fuel) are taken into account - de Vries et al. 2007.

Fig 72: Breakdown of utility scale solar PV installed costs by country (2019).



Source: IEA. IRENA Renewable Cost Database. © IRENA 2019

Table 11: Ranking of countries by GCI and Wind and Solar CI

Country	GCI	Country	Wind and Solar CI
Germany	4.74	Germany	4.53
Italy	3.57	China	3.72
Austria	3.36	USA	3.65
USA	3.36	Denmark	3.44
China	3.23	Japan	3.38
Japan	3.12	Austria	2.76
Denmark	3.04	Romania	2.71
Czechia	2.78	South Korea	2.67
United Kingdom	2.65	Hungary	2.64
France	2.48	Finland	2.63

High deployment does not automatically imply that a country has the capacity to competitively produce the equipment necessary to generate energy from renewable sources. However, research in the field of economic geography suggests that agglomeration economies, including knowledge spillovers, economies of scale and better access to supply chains and skilled labour, may lead to a positive reinforcement cycle for cultivating technologically sophisticated production capabilities, which can provide a supportive environment for companies to flourish[26]. Moreover, Mealy and Teytelboym (2020)[27] have shown that a high GCI is correlated with high indicators of environmental policy stringency. A high CP score in wind and solar industries implies that a country is likely to increase its competitiveness in those technologies in the future, which may be interpreted as indicating a comparatively attractive investment environment.

Among renewable energy technology, the development of wind and solar products provides one of the largest contributions to a country’s green competitiveness, as they involve the greatest number of specific green products as inputs in the construction of facilities. From 295 products analysed in this report, 75 products have been identified as technologies and related goods used in the renewable energy sector[28]. Of the 75 unique products, 22 products are specific to the construction of wind facilities, and 15 specific to solar facilities[29]. There are an additional 9 products that have overlapping usage for both wind and solar facilities.

[26] Stuart S. Rosenthal and others, ‘Evidence on the Nature and Sources of Agglomeration Economies’, 4 (2004), 2119–71 <https://econpapers.repec.org/RePEc:eee:regchp:4-49> [accessed 20 November 2021]; Glenn Ellison, Edward L. Glaeser, and William R. Kerr, ‘What Causes Industry Agglomeration? Evidence from Coagglomeration Patterns’, American Economic Review, 100.3 (2010), 1195–1213 <https://doi.org/10.1257/AER.100.3.1195>.

[27] Mealy and Teytelboym, 2020, "Economic Complexity and the Green Economy", Research Policy.

Table 12: Ranking of Countries by Wind CI and Solar CI

Country	Wind CI	Country	Solar CI
Germany	5.16	Japan	4.93
Denmark	3.8	South Korea	4.2
USA	3.63	Other Asia	4.11
Romania	3.34	Germany	3.85
Finland	3.12	China	3.82
Japan	2.83	Austria	3.37
Hungary	2.78	Denmark	3.31
Austria	2.66	Finland	3.25
Italy	2.58	USA	2.54
Sweden	2.54	Switzerland	2.53

Taking the subset of green products relevant to wind and solar industries, complexity index and complexity potential scores are re-estimated, and countries are ranked in order to illustrate how complexity scores can be used to understand countries' comparative and potential strengths in the renewable energy sector. Table 11 shows the ranking of the top 10 countries by their CI within wind and solar, as well as their relative overall GCI. It is important to note that, to the authors' knowledge, this is the first time a technology-specific aggregate complexity score has been constructed in this manner. While the Green Complexity Index and the Green Complexity Potential are measures introduced in Mealy and Teytelboym (2020) and have undergone a number of validation exercises, as well as academic peer review, the wind and solar specific indices discussed in this section are not based on peer-reviewed research and should be interpreted with greater caution. Future research may investigate the construction and implications of technology-specific complexity scores.

There are some notable changes in countries that have a higher complexity rating in wind and solar production compared to their overall GCI rank (Table 11) China, Denmark, and South Korea show higher rankings in CI for wind and solar relative to their GCI rank overall. In contrast, although Italy, Austria, Czechia, and the United Kingdom rank highly in their overall level of green complexity, they do not rank as highly in wind and solar complexity.

[28] The list of products in renewable energy is taken from the International Centre for Trade and Sustainable Development 2008 mapping study: Wind, Izaak. HS Codes and the Renewable Energy Sector. ICTSD programme on Trade and Environment, 2008.

[29] Of the remaining 29 green products, 15 are for biomass, 7 are for hydropower, 5 are for geothermal. There are an additional 2 products that are not specific to any particular type of renewable energy industry.

Table 13: Ranking of countries by GCP and Wind and Solar CP

Country	Total GCP	Country	Wind and Solar CP
China	3.92	Italy	4.43
Italy	3.89	China	3.99
Spain	3.33	Spain	3.69
France	2.85	Turkey	2.93
Germany	2.75	France	2.88
Turkey	2.55	India	2.86
Poland	2.5	Poland	2.61
India	2.4	Portugal	2.48
Austria	2.38	Czechia	2.25
Netherlands	2.3	USA	2.23

Despite differences in the ranking of countries by CI for wind and solar manufacturing relative to their overall ranking in green complexity, countries still face very different comparative positions within these technologies. As noted earlier, there are more green products that are specific to solar or wind than products with overlapping usage between the two or with other types of renewable energy. Therefore, while a country might have a similar CI for wind and solar relative to their overall GCI, countries may be more specialised in one renewable technology. Table 12 shows a ranking of countries by CI for wind and solar separately.

Comparing the country rankings in Table 12, countries demonstrate some specialization between their green complexity in wind or solar, but not equally for both. Germany, Denmark, the United States, and Romania are more specialised in wind relative to solar. In contrast, Japan, South Korea, and China are more specialised in solar compared to wind. This indicates a significant difference in a country's specialisation in renewable energy that may otherwise be overlooked by the ranking of countries in Table 11. This is evident in the case of the US, which is ranked 3rd in wind and solar complexity combined, but has higher specialisation in solar product complexity. South Korea ranks 8th for combined wind and solar complexity, while in Table 12 South Korea is ranked second in solar but is not ranked in the top 10 for wind.

Table 14: Ranking of countries by Wind CP and Solar CP

Country	Wind CP	Country	Solar CP
China	4.56	China	4.92
Italy	4.2	Italy	3.67
Spain	3.95	Poland	3.58
Turkey	3.13	Spain	3.48
France	2.83	Germany	3
India	2.66	France	2.97
Portugal	2.65	India	2.81
Croatia	2.62	USA	2.72
Poland	2.54	Turkey	2.63
Netherlands	2.39	Czechia	2.46

To get a sense of future wind and solar trajectories, re-calculations of CP for a subset of wind and solar products have been similarly compiled and included in Table 13. From the rankings, the same countries that rank highly in green complexity under CI do not rank as highly under CP, suggesting that the countries that already have a high degree of complexity have less potential. The ranking of countries by CP overall and for the subset of wind and solar technology are similar, with the top 2 positions occupied by the same two countries. Aside from countries that are consistently ranked highly overall and for a subset of wind and solar potential CP, those that demonstrate a better position in wind and solar products relative to their overall GCP are Turkey, India, Portugal, and Czechia. This suggests that these countries are well positioned with a high potential complexity in wind and solar manufacturing, relative to other forms of green product development.

Similarly, Table 14 illustrates the CP ranking of countries by wind and solar separately. The disaggregated rankings for wind and solar illustrate different specializations for a country's potential in either wind or solar production. Although Spain does not appear in the top 10 for any measure of CI, it consistently appears in the top 10 for CP scores under wind and solar. While Turkey appears as the fourth ranked country by CP for the combined wind and solar products, it has greater potential in wind manufacturing compared to solar. In contrast, while Poland is ranked seventh for the combined wind and solar products, it has greater potential in solar, where it is ranked third.

To compare the relative position of countries according to their CI and CP in wind and solar for the seven countries studied in this report, along with Italy, Figure 73 and Figure 74 illustrate the relationship between countries' current complexity and their potential. They illustrate which countries have higher potential compared to their current levels of complexity in wind and solar, and in relation to other countries. From the figures, the correlation between a country's CI and a country's CP in wind or solar is clearly positive, but not perfect. This is particularly true for countries that score highly according to either measure[30], broadly indicating that countries that have a high level of complexity in wind or solar currently are not the same countries that have the highest potential.

The comparative rankings and position of countries according to their green complexity in wind and solar suggests potential future leaders in the production of these renewable energy products. Knowing which countries are specialised in the production and manufacture of wind and solar products compared to other types of green products adds to the information available to investors as they strategically develop their portfolios in the renewable energy sector.

[30]Wind correlation coefficient: 0.642, solar correlation coefficient: 0.535.

Fig 73: A scatterplot of wind CP and wind CI (2015-2019) for all countries with the seven case study countries and Italy highlighted

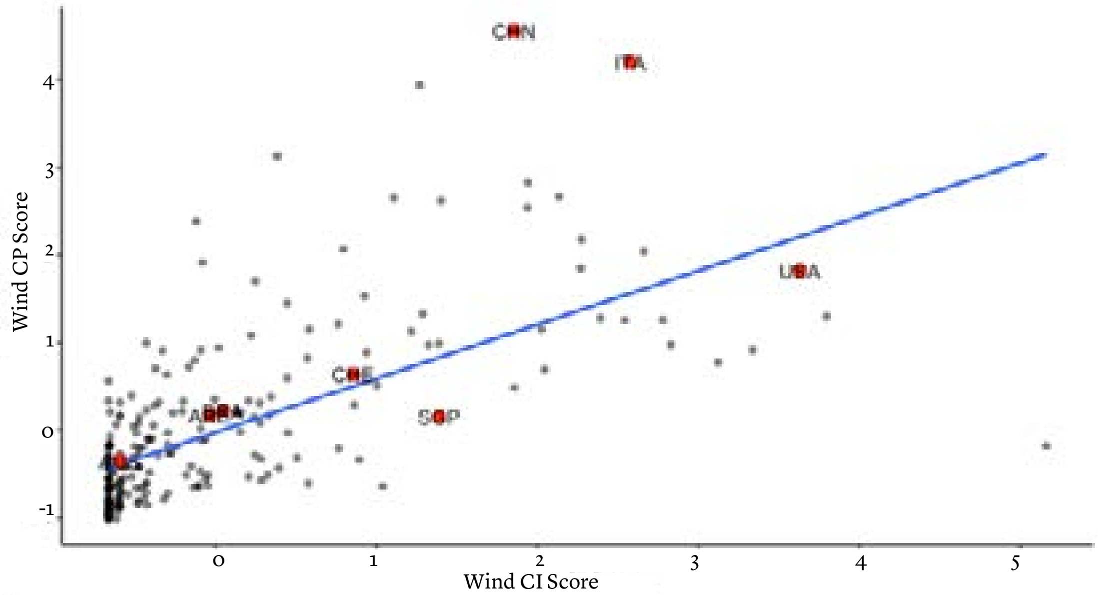
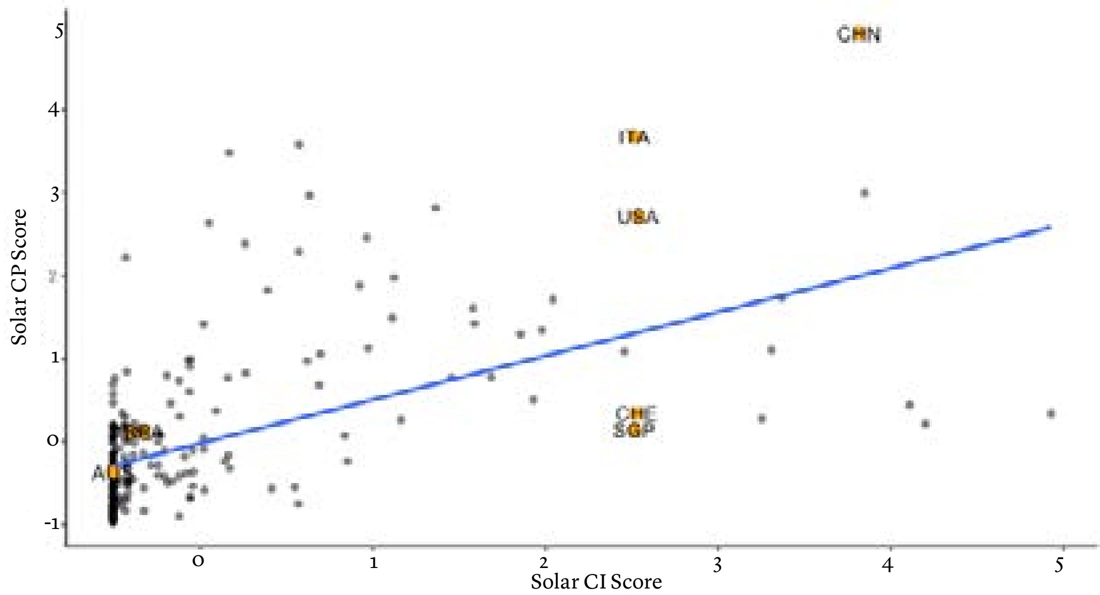


Fig 74: A scatterplot of solar CP and solar CI (2015-2019) for all countries with the seven case study countries and Italy highlighted



Source: Authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version).

The micro and meso picture: wind and solar companies

Wind and solar capacity could increase ten-fold in just 20 years as part of global efforts to achieve the Paris goals and reach net zero by mid-century, according to Way et al. 2021[31]. This research also suggests that future global solar capacity is set to be at least triple future global wind capacity. Using both export competitiveness data and corporate level data at both the country and corporate level can help investors navigate the rapidly changing global wind and solar landscape.

Institutional investors will play a key role in facilitating growth in wind and solar capacity – pension funds, insurance companies and other long-term asset owners and managers form a substantial pool of private capital that is increasingly being directed at the renewables sector. Pureplay wind and solar companies, making up a complex value chain that operates across globally integrated supply chains, are an increasingly central focus for investors who want to gain exposure to the clean energy transition. This section analyses some of the implications of such increases in wind and solar investments at the corporate level, to complement to the previous wind and solar investment implications at the national level.

To combine both a country-level and company-level perspective, a global sample of major wind and solar companies was constructed. The selection sought to capture specialized, pureplay companies with the greatest exposure to wind and solar industries. The wind and solar product value chain was examined (Figure 75), unpacking the various activities associated with each technology, ranging from upstream materials production to downstream electricity generation. This value chain acted as a starting point in constructing a dataset of publicly listed companies with a high level of purity to wind and solar industries. The methodology used to derive our sample of wind and solar corporates follows industry best practices - however, it is not based on peer-reviewed research and should be interpreted with caution.

Firstly, the value chain activities in Figure 2 were mapped onto the S&P Global Trucost Climate Impact Sectors Classification (CISC). The CISC defines corporate revenue streams based on 447 underlying high climate impact sub-industries. High climate impact in this context refers to sub-industries that are key to a low-carbon transition, as defined in the EU Low Carbon Benchmarks Regulation (2019/2089). Relevant CISC sub-industries were selected and mapped to the most relevant activity in the wind and solar value chains. In total, 32 CISC sub-industries were selected (16 Upstream, 12 Midstream, and 4 Downstream).

Secondly, each of the 32 CISC sub-industries was assigned an Exposure Score (ranging from 0 to 1), using expert judgement and engagement with industry professionals (Figure 76). The Exposure Score was calculated using two considerations – specialisation and relevance.

[31] Way, Rupert, Matthew C. Ives, Penny Mealy, and J.Doyne Farmer, Empirically Grounded Technology Forecasts and the Energy Transition, 2021 https://www.inet.ox.ac.uk/publications/no-2021-01-estimating-the-costs-of-energy-transition-scenarios-using-probabilistic-forecasting-methods/

Fig 75: Wind and solar value chain

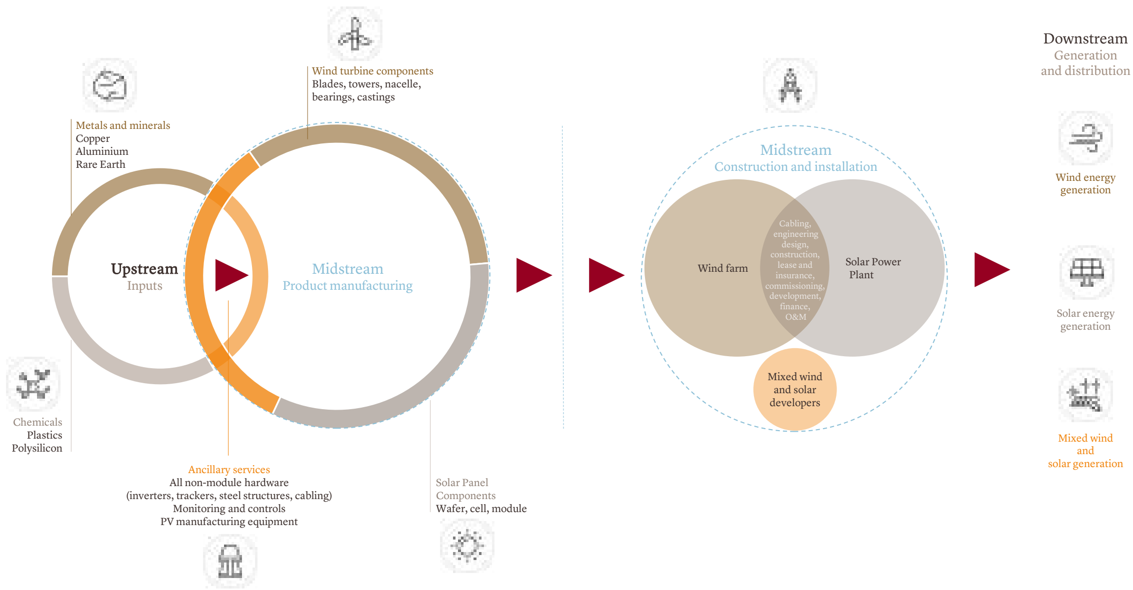


Fig 76: Exemplifying the scoring process employed to score companies

Company	Revenue breakdown Sectors	Revenue breakdown Exposure scores for sub	Final Purity Score
SIEMENS GAMESA Wind turbine manufacturer	100% Turbine and turbine generator set units manufacturing	1	1
CANADIA SOLAR Solar panel components manufacturer	20% Semiconductor and related device manufacturing 1% Solar Power Generation 29% Other non residential structures	1 0.8 0.6	0.88

The first was the specialisation of the sub-industry, capturing how much the sub-industry exclusively contributes to the wind and solar value chain; pureplay activities were assigned higher scores than generic, diversified sub-industries whose activities play less of a direct role in driving wind and solar growth. Secondly, the relevance of the sub-industry to wind and solar products specifically was analysed; this assigned higher scores to midstream (core manufacturing) activities that involved component manufacturing and installation, whilst reducing the emphasis on upstream and downstream activities. Overall, for example, the sub-industry "Turbine and turbine generator set units manufacturing" was given a high score (specialisation = high, relevance = high), as it sits in the relevant midstream product component manufacturing section of the value chain, whilst also being quite exclusive in its link to wind turbine manufacturing. "Custom computer programming services", on the other hand, whilst being a relevant sub-industry to product manufacturing, scored low on specialisation as wind and solar activities likely only comprise a small segment of the sub-industry.

On average, upstream and downstream sub-industry exposure scores were low (0.33 and 0.5 respectively), whilst midstream sub-industry scores were higher (0.8). This focus on midstream manufacturing activities also attempts to encapsulate the range of products, as opposed to services and inputs.

A further keyword analysis was performed using company descriptions, filtering out companies with little relevance to wind or solar value chains. Furthermore, all companies with purity scores below 0.3 were excluded from the sample, to maintain high average purity to wind and solar industries.

The framework produced a sample of 93 companies, providing an indication of the corporate landscape for the wind and solar industries. Table 15 shows summary statistics; the sample contained companies from nineteen countries, with a strong presence in China and the US in terms of headquarter location, primarily in midstream activities.

Table 15: Summary statistics on solar and wind companies in 19 major economies

	Upstream	Midstream		Downstream	
Company Location (Headquarters)	Inputs	Product Manufacturing	Construction and Installation	Generation and Distribution	Total Companies
China	4	16	11	1	32
USA		5	5		10
Germany	1	4	2	1	8
Canada		1	3	1	5
India		2	2	1	5
Japan		2	2		4
South Korea	1	3			4
Spain		1	2	1	4
Thailand			3	1	4
Taiwan		3			3
France		1		1	2
Italy			1	1	2
Norway	1		1		2
Sweden			1	1	2
Switzerland		1	1		2
Denmark			1		1
Greece			1		1
Israel				1	1
United Kingdom		1			1
Total Companies	7	40	36	10	93

Table 16: Top 10 countries for each category of sample revenue (W+S = wind and solar)[32]

Country	Portion of sample revenue – Wind and Solar (%)	Country	Portion of sample revenue – Solar (%)	Country	Portion of sample revenue – Wind (%)
China	33	China	23.6	China	13.7
USA	14.1	USA	11.5	USA	6.8
Japan	6.7	Japan	5.9	India	4.4
India	6.3	Thailand	3.6	Germany	3.1
Germany	4.5	India	3.0	Japan	2.2
Thailand	3.6	Canada	2.5	Canada	2.2
South Korea	3.2	South Korea	2.5	Italy	1.9
Canada	2.7	Germany	2.2	Sweden	1.5
Spain	2.6	Spain	2.2	United Kingdom	1.2
Italy	2.4	Taiwan	2.0	France	1.1
Other	20.9	Other	34.0	Other	54.9

For each company, data was retrieved on revenue breakdown by country. Table 16 shows the top 10 countries in terms of revenue generated from wind and solar companies in the sample. For example, when all revenues generated for each company in the sample were aggregated, 33% were drawn from wind and solar products sold in China. The dominance of China and the US markets in this regard mirrored the number of companies from each country present in the sample, with 32 and 10 companies based in China and the US respectively. The top 10 countries in each category of Table 16 differ somewhat from Table 12, which shows the top 10 ranked countries by wind and solar CI. China features lower on CI compared to the size of its corporate level influence. Thailand, Spain, and Canada, have lower CI ranks, yet all feature more prominently in the corporate level data. Germany, which has the highest wind CI rank, fails to come close to China in terms of the number of leading wind and solar companies in the sample. The corporate data does not have any company representation from Denmark, Finland, Romania, or Austria in the top ten rankings, which all feature prominently in the rankings of countries based on CI (both combined wind and solar and individually).

[32] Some revenue classifications apply to both wind and solar which explains the discrepancies between the total wind and solar revenue share, and the sum of the solar and wind revenue shares.

Table 17: Revenues (%) generated by country. Seller country are shown in rows and buyer country in columns.

Revenues (%) generated by country

Headquater location

	Canada	China	Germany	India	Italy	Japan	Spain	Thailand	USA
Canada	36%	3%	6%	0%	0%	23%	1%	0%	5%
China	0%	85%	1%	1%	0%	1%	0%	0%	4%
Germany	1%	10%	33%	1%	4%	2%	1%	0%	16%
India	0%	0%	0%	97%	0%	0%	0%	0%	2%
Italy	0%	0%	7%	0%	67%	1%	1%	0%	2%
Japan	1%	4%	1%	2%	0%	69%	0%	2%	5%
Spain	2%	1%	2%	2%	7%	0%	40%	0%	20%
Thailand	0%	0%	0%	0%	0%	13%	0%	79%	0%
USA	4%	7%	1%	1%	0%	4%	0%	0%	67%
Other	1%	6%	4%	2%	1%	3%	3%	0%	19%

It thus appears that the countries that are most competitive and complex in wind and solar exports do not necessarily dominate the wind and solar industry in the corporate sample. What drives the apparent discrepancies between CI rank and corporate level representation? First, the sample of companies used in this analysis is relatively small and may not be representative of country's corporate landscapes relating to wind and solar. Secondly, the Green Complexity Index (GCI) measures the number and complexity of green products that a country has exported competitively. It is thus aimed at measuring exports, and in the context of Wind and Solar CI, specifically in products related to these areas. Moreover, competitiveness measures based on trade data are based on the relative importance of each product in a country's exports, whereas the corporate level analysis in this section may well be coloured by the size of each country's economy. This highlights the importance of considering multiple factors and indicators when navigating the landscape of green competitiveness. It is also important to note that the location of a company's headquarters can often be different from the location of its manufacturing activities. Table 17 provides evidence of this disconnect. In general, a reasonable proportion of a company's revenues in the sample are generated from the country in which the company is headquartered. For example, companies that are headquartered in Canada on average generate 36% of their revenues within Canada. Interestingly, this pattern is far more pronounced for Asian companies.

Companies from China, India, Japan, and Thailand all generate well over half of their revenues domestically, whilst for Western companies the values are considerably lower.

Overall, these results seem to explain the differences between CI and corporate level rankings. Germany, with the highest Wind and Solar CI ranking, seems to be the most competitive in exporting wind and solar products; unsurprisingly, companies headquartered in the country only generate 33% of revenue domestically. The fact that Chinese companies generate 85% of revenue at home suggests that China has a very strong domestic wind and solar market. Overall, countries with lower Wind and Solar CI rankings may still be interesting for investors; corporate expertise may just be directed inwards, to the domestic market. Further analysis could draw upon national production data to complement export data, in order to better understand this dynamic.

As China is poised to become the largest market for wind and solar energy, comparing the financial characteristics of its companies with other countries reveals interesting results. Table 18 provides more detail on the company profiles, in both midstream and downstream segments of the value chain (upstream activities were left out due to their limited presence in the sample). Chinese wind and solar component manufacturers seem to be, on average, larger than similar companies from other countries, whilst also trading at higher premia based on price-to-earnings (P/E) ratios. However, Chinese wind and solar companies involved in downstream operations operate with higher capitalisation ratios than in other regions.

Table 18: Summary information on the profiles of Chinese solar and wind companies vs Rest of World.

	Solar		Wind	
Wind and Solar	China	Rest of World	China	Rest of World
Average Market Cap. (US$bn)	13.2	9.6	2	3.5
Average price/earnings (PE) ratio	108	16.2	17	58.4
Average capitalisation ratio (debt/equity)	0.38	0.42	0.72	0.58
Number of companies	16	25	12	32

Discussion

Several more specific investment implications can be drawn out from the CI/CP scores and corporate level analysis. Firstly, opportunities across the wind and solar value chain vary across both the relevance and the specialization of activities. Midstream activities that manufacture solar panel and wind turbine components, and the construction of wind and solar farms that are connected to the grid via specialized cabling and equipment, operate as the engine of growth for both industries. Materials inputs and downstream electricity generation offer less pure play exposure to the wind and solar products theme. China, Germany, Japan, South Korea, Taiwan, and the United States have the highest number of product manufacturing companies in the sample; many of these are concentrated in the solar panel components sector. China, the US, and Japan (already with the highest solar CI ranking) are simultaneously set to consolidate country-level complexity in solar products, all with high CP rankings.

China is clearly playing an increasingly central role in the wind and solar landscape. Our corporate level analysis revealed than Chinese companies on average generate 85% of their revenue from within China, and so whilst its wind and solar capabilities are clearly substantial at the corporate level, they may yet be able to further capitalise on export opportunities. China has the highest solar CP rank of any country, suggesting that product complexity will likely increase; this could lead to technological innovation in other areas and push corporate performance towards increased profitability in the future. In conclusion, the Chinese market seems to offer the highest growth market for both wind and solar products – both at the export level and the corporate level. As its strong domestic wind and solar market is well placed to expand internationally, both areas can benefit substantially.

The US is likely to continue playing a key role in terms of trade as well as at the corporate level, based on wind and solar CI and CP scores, and because American wind and solar companies have the largest average market capitalization out of any country in the sample. This is especially true in its solar capabilities; its companies are more profitable than Chinese rivals, and it ranks highly under both solar CI and solar CP. However, its dependence on Chinese raw materials for wind and solar products, combined with ongoing trade tensions, imply supply chain risks that could hamper both export and corporate competitiveness into the future. The United States is 100% reliant on foreign sources of arsenic, gallium, and indium, all of which are crucial components in solar cells. China dominates the global supply of many of these metals, as well as other rare-earth metals[32], aluminium, and refined copper that are used in wind turbine manufacturing and other renewable energy products. In recent months, Chinese

[31] "Zhang, L., Wang, J., Wen, H., Fu, Z. and Li, X., 2016. Operating performance, industry agglomeration and its spatial characteristics of Chinese photovoltaic industry. Renewable and Sustainable Energy Reviews, 65, pp.373-386.

magnesium production, which is responsible for 87% of global supply, has slowed significantly due to power cuts and reduced energy consumption in China, forcing plants to close or halt production. Magnesium is critical in aluminium production, which in turn is a key material in both solar panels and wind turbines. China's dominance in supplying such materials presents significant supply chain risks for companies in the US and Europe, who rely on Chinese imports to drive production. The recent US-China climate agreement at COP26 to jointly accelerate the low-carbon transition and climate technology innovation has been received with cautious optimism[33].

Finally, perhaps the most interesting investment trend is the increasing role European countries will play in the energy transition. Italy, Spain, France, Turkey, and Poland all have very high CP ranks across both wind and solar products and could present attractive markets for private sector investment if this is followed by the development of trailblazing domestic wind and solar companies. Policy must also identify where opportunities for growth lie in the context of their countries' capabilities. For example, Switzerland's wind and solar product manufacturing capabilities are relatively weak, and thus return low CI and CP scores. This was recognised by State Secretary for International Finance Daniela Stoffel during a panel at COP26 in Glasgow; she argued that Switzerland's strong financial services industry and expertise in sustainable finance could play a key role in providing the necessary capital to accelerate the energy transition, thus contributing via a different route.

[32] The EU's Critical Raw Materials framework sets out a comprehensive review of many of the materials used in wind and solar products. Available at: https://ec.europa.eu/growth/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en

[33] https://www.state.gov/u-s-china-joint-glasgow-declaration-on-enhancing-climate-action-in-the-2020s/

Conclusion

“

The world is in the midst
of a new industrial revolution,
and industries, investors and governments
that actively invest in and foster high-growth climate
compatible industries have much to gain.

6. Conclusion

Megatrends are shifting the global competitiveness landscape. Even if the politics of climate change mitigation can, at times, appear intractable, it is unlikely to stop the processes that have already been set in motion with consistent declines in the cost of renewable energy, batteries, electrolysers, and other clean technologies. Technological change is supporting automation, mechanisation, electrification, and dynamic optimisation, all of which are helping to drive the clean energy transition. While the long-term picture is clear, the path to this new green economy will be littered with tales of winners and losers: those who are able to seize the opportunities arising from the transition, and those who are left behind holding stranded assets. The aim of this report is to help investors navigate this changing landscape, by not only illuminating the megatrends, but also analysing which countries and industries are well-placed in terms of their current and future green competitiveness.

At the national level one can already see that some countries have captured value from fast growing green sectors. China is a case in point, having emerged as a global solar PV manufacturing powerhouse. The US has similarly captured value within its own large domestic market. The laggards are also visible: Australia and, to a lesser extent, the UAE, have only most recently shown signs of providing a favourable environment for green investment.

Clean energy financing is not without its challenges: renewable energy projects generally have high capital costs and carry significant risk in many developing countries. Yet, these technologies have also exhibited remarkable learning rates which have led to cost declines and remarkable growth. It is likely that products that are complementary to renewable energy, such as batteries and electrolysers for green hydrogen, will also grow substantially in the years to come. The fate of the hydrocarbon sector is also clear. Most hydrocarbon power generators, if not already uneconomic, are set to become more expensive than low-carbon alternatives in the next 5-10 years.

Given this, investors aiming to curate portfolios that will maximise value would do well to disentangle short-term noise from long-term trends. As this report shows, a global green race is underway; a race in which early movers will be rewarded and laggards will risk losing global competitiveness.

7. Appendix

7. Appendix

A. Measuring green competitiveness

Empirical evidence has shown that industrial development is often path-dependent: countries and regions are significantly more likely to develop competitiveness in products and services which require similar capabilities to those they already produce[1,2]. There is further evidence to suggest that countries which specialise in more technologically sophisticated products tend to enjoy greater income and growth[3,4,5].

We employ the approaches introduced by Hidalgo and Hausmann (2007a)[6] and Mealy and Teytelboym (2020)[7] to measure competitiveness in exporting green products. Using CEPII's BACI database of bilateral international trade[8] we construct a panel of country-level exports in products at the 6-digit level from 1995-2019. This data provides bilateral trade flows between more than 200 countries for over 5,000 products. To prevent our analysis from being skewed by short-term fluctuations in trade, we use annual average values over rolling 5-year periods (1995-1999, 1996-2000, etc).

$$Revealed\ Comparative\ Advantage_{cp} = \frac{Exports_{cp}}{\sum_p Exports_{cp}} \Big/ \frac{\sum_c Exports_{cp}}{\sum_c \sum_p Exports_{cp}}$$

We first calculate "Revealed Comparative Advantage" (RCA), which is a product p's share in a country c's exports, divided by this product's share in global trade. We then define a binary variable m which takes the value 0 or 1. If RCA > 1, we say that a country exports "more than its fair share" in this product; it exports the product competitively and m=1. If RCA is below 1, the country does not have competitiveness in the product and m=0.

1 Hidalgo, C.A., Klinger, B., Barabási, A.L. and Hausmann, R., 2007. The product space conditions the development of nations. Science, 317(5837), pp.482-487.

2 Frank Neffke, Martin Henning, and Ron Boschma, 'How Do Regions Diversify over Time? Industry Relatedness and the Development of New Growth Paths in Regions', Economic Geography, 87.3 (2011), 237–65 <https://doi.org/10.1111/J.1944-8287.2011.01121.X>.

3 Hidalgo, C.A. and Hausmann, R., 2009. The building blocks of economic complexity. Proceedings of the national academy of sciences, 106(26), pp.10570-10575.

4 Hidalgo and Hausmann 2017

5 Ricardo Hausmann & Jason Hwang & Dani Rodrik, 2007. "What you export matters," Journal of Economic Growth, Springer, vol. 12(1), pages 1-25, March.

6 Hidalgo and Hausmann.

7 Mealy, Penny, and Alexander Teytelboym, 'Economic Complexity and the Green Economy', Research Policy, 2020, 103948 <https://doi.org/10.1016/j.respol.2020.103948>

8 Guillaume Gaulier and Soledad Zignago, 'BACI: International Trade Database at the Product-Level (the 1994-2007 Version)', SSRN Electronic Journal, 2010 <https://doi.org/10.2139/ssrn.1994500>.

$$Proximity_{p,p'} = min\left\{\frac{\sum_c m_{cp} * m_{cp'}}{\sum_c m_{cp}}, \frac{\sum_c m_{cp} * m_{cp'}}{\sum_c m_{cp'}}\right\}$$

Using RCA, we calculate the probability that a country exports product p' if it also exports product p: this is the proximity (or similarity) of product p and product p'. We then define the proximity of product p to country c as the average proximity of product p to other products which the country exports with RCA>1 (cf. Hidalgo and Hausmann, 2007a). We also use the algorithm developed by Hidalgo and Hausmann (2007a) to calculate the Product Complexity Index (PCI), which is a proxy for technological sophistication. For more detail on the mathematical interpretation of PCI, please refer to Mealy et al (2019)[9].

[9] Penny Mealy, J. Doyne Farmer, and Alexander Teytelboym, 'Interpreting Economic Complexity', Science Advances, 14.2 (2019) <https://doi.org/10.1126/SCIADV.AAU1705/SUPPL_FILE/AAU1705_SM.PDF>.

B. Green Goods and the EU taxonomy

To see how our green goods classification compares to other definitions of sustainability, we map our 19 categories to the six environmental goals set out in the "EU taxonomy for sustainable activities". The EU taxonomy is a classification system created for the purpose of identifying which investments are "sustainable" and consistent with the European Green Deal. It was published in June 2020 and entered into force the following month. The following table lists the categories included in the EU taxonomy and maps them against all corresponding categories within our list of traded green products.

EU taxonomy	Corresponding category green trade
Climate change mitigation	Cleaner or More Resource Efficient Technologies and Products Efficient Consumption of Energy Technologies and Carbon Capture and Storage Energy Efficiency Environmental Monitoring, Analysis and Assessment Equipment Gas Flairing Emission Reduction Heat and Energy Management Renewable Energy
Climate change adaptation	Environmental Monitoring, Analysis and Assessment Equipment Natural Risk Management
The Sustainable use and protection of water and marine resources	Clean up or Remediation of Soil and Water Environmental Monitoring, Analysis and Assessment Equipment Natural Resource Protection Resources and Pollution Management Wastewater Management and Potable Water Treatment Water supply
The transition to a circular economy	Environmentally Preferable Products based on End-Use or Disposal Characteristics Management of Solid and Hazardous Waste and Recycling Systems Waste Management, Recycling and Remediation Wastewater Management and Potable Water Treatment
Pollution prevention control	Air Pollution Control Clean up or Remediation of Soil and Water Environmental Monitoring, Analysis and Assessment Equipment Environmental Preferable Products based on End-Use or Disposal Characteristics Gas Flairing Emission Reduction Management of Solid and Hazardous Waste and Recycling Systems Noise and Vibration Abatement Renewable Energy Resources and Pollution Management Waste Water Management and Potable Water Treatment
The protection and restauration of biodiversity and ecosystems	Clean up or Remediation of Soil and Water Cleaner or More Resource Efficient Technologies and Products Environmental Monitoring, Analysis and Assessment Equipment Environmental Preferable Products based on End-Use or Disposal Characteristics Management of Solid and Hazardous Waste and Recycling Systems Noise and Vibration Abatement Resources and Pollution Management

C. Data Sources

- **Green Complexity and Trade**
  All measures based on trade data are the authors' own calculations based on Gaulier, G. and Zignago, S., 2010. Baci: international trade database at the product-level (the 1994-2007 version). Some, though not all, were originally published in Andres, P and Mealy, P (2021) Green Transition Navigator. Retrieved from www.green-transition-navigator.org. Those measures, which include GCI, GCP, country-to-product proximity, and others, can be obtained from the Green Transition Navigator website.

- **Recovery spending**
  Recovery spending information was sourced from the observatory database downloaded on 25 June from https://recovery.smithschool.ox.ac.uk/tracking/

  GDP data was sourced from World bank GDP data 2019 or latest in current US dollars on 25 June 2021 from https://data.worldbank.org/indicator/NY.GDP.MKTP.KD

  The Recovery dataset used in this chapter distinguishes between different categories:

  Covid spending ⊇ Recovery spending ⊇ Green recovery spending ⊇ Renewable recovery spending

  - **Covid spending** is all fiscal spending of the past year or so
  - **Recovery spending** is that part of Covid spending that is intended for the long term (e.g. excluding liquidity support or direct cash transfers, including infrastructure investment)
  - **Green recovery spending** is that part of Recovery spending that is deemed green
  - **Renewable recovery spending** is that part of Recovery spending that is part of fiscal spending archetype 'eta': Clean energy infrastructure investment

  The Recovery Observatory recognises 5 typologies, 40 archetypes and 158 sub-archetypes of fiscal spending. Renewable energy is archetype eta (η): Clean energy infrastructure investment. It is part of typology Recovery: investment measures. Sub-archetypes include the construction of new renewable generation facilities ($\eta 1$), upgrades to the transmission infrastructure ($\eta 4$), and building of CCS installations ($\eta 8$).

  It is important to note that these figures indicate spending plans, not actuals, and may therefore not correspond to how governments have actually allocated funds. In this analysis we have focussed solely on long-term recovery spending which has the potential to impact an economy’s competitiveness, and not on short-term rescue spending.

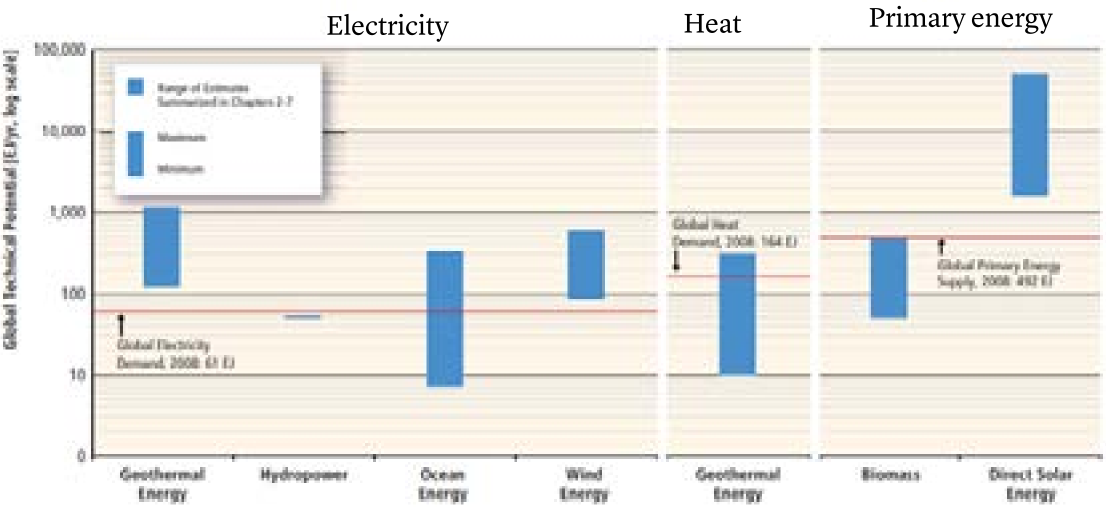
Current green energy resources

The time trends in electricity generation capacity for each country shown in this report were source from IRENA (2021), Renewable Capacity Statistics 2021; & IRENA (2020), Renewable Energy Statistics 2020, The International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/publications/2021/March/Renewable-Capacity-Statistics-2021

Future green energy potential

The availability of green energy sources varies over time and locations. This variation is not only caused by the climatic or resource characteristics, but also by land use, labour costs, access to finance, and political support. Some of these factors cannot or can only be approximately quantified. As shown in Figure 1, estimates for global technical potential from renewable resources vary by orders of magnitude. Therefore, a full and precise assessment of the long-term role of renewable energy sources for each country is not viable.

Figure 1: Ranges of global technical potentials of RE sources derived from studies presented in Chapters 2 through 7. Biomass and solar are shown as primary energy due to their multiple uses[10].



Range of Estimates of Global Technical Potentials

	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Geothermal Energy	Biomass	Direct Solar Energy
Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

[10] IPCC, 2012, Renewable Energy Sources and Climate Change Mitigation, Special Report of the Intergovernmental Panel on Climate Change, https://archive.ipcc.ch/pdf/special-reports/srren/SRREN_Full_Report.pdf, p39

Understanding the potential of harnessing solar energy is particularly important given the geographic potential is 3 to 100 times more than current global energy supply and it is available in virtually every country on earth. Capturing the energy of sunlight is subject to a diversity of constraints related to the solar irradiance in a certain area; geographical constraints such as the slope and the existing use of the land; practical constraints, such as proximity to human settlement; and regulatory constraints, e.g., the protected status of the land, often related to ecosystem and wildlife preservation.

In this study we focus on a country's technical potential for all such renewable resources, which is a subset of a country's geographical potential. The geographical potential is the energy flux theoretically extractable in areas that are considered suitable and available for this production i.e. in areas which are not excluded by other incompatible land cover/use and/or by constraints set on local characteristics such as elevation and minimum average wind speed. The technical potential is the geographical potential after the losses of the conversion from the extractable primary energy flux to secondary energy carriers or forms (electricity, fuel) are taken into account[11].

There is unfortunately little consensus in the global scientific community on how best to measure the technical potential for the various renewable resources available. As noted by the IPCC Working Group III, "a variety of practical, land use, environmental, and/or economic constraints are used in estimating the technical potential of RE, but with little uniformity across studies in the treatment of these factors, including costs.[12]" There is, however, consensus that "technical potentials will not be the limiting factors for the expansion of renewable energy on a global scale.[13]"

Total country renewable resources were calculated by combining onshore and offshore wind and hydro resources with either solar or biomass totals depending on which provided the maximum potential. This simplified methodology ensures a conservative total that assumes biomass and solar resources are mutually exclusive, which will not always be the case.

Every effort was made to source the green energy potential data from reliable, peer-reviewed sources that apply a single methodology to the broadest possible list of countries used in this report. These are listed below by energy resource. In the cases where countries were not covered by the main data source the additional sources are also listed.

---

11 Bert J.M. de Vries, Detlef P. van Vuuren, and Monique M. Hoogwijk, 'Renewable Energy Sources: Their Global Potential for the First-Half of the 21st Century at a Global Level: An Integrated Approach', Energy Policy, 35.4 (2007), 2590–2610 <https://doi.org/10.1016/j.enpol.2006.09.002>.

12 Clarke L. and others, Transformation Pathways. In: Climate Change 2014: Mitigation of Climate Change, 2014 <https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter6.pdf>.

13 IPCC, 2012, Renewable Energy Sources and Climate Change Mitigation, Special Report of the Intergovernmental Panel on Climate Change, https://archive.ipcc.ch/pdf/special-reports/srren/SRREN_Full_Report.pdf , p796

Solar resources

Solar resource potential by country was sourced entirely from the World Bank, 2020, Solar Photovoltaic Power Potential by Country, https://documents.worldbank.org/en/publication/documents-reports/documentdetail/466331592817725242/global-photovoltaic-power-potential-by-country and associated resources found online at https://globalsolaratlas.info/

Extensive information on the methodology used to generate solar potential which included geographic potential (irradiance, terrain effects, cloud cover, temperature, etc) are available at https://globalsolaratlas.info/support/methodology. For our measure of technical potential we used "Practical potential (PVOUT Level 1, kWh/kWp/day), long-term" values. These values were than multiplied by the PV equiv area (m2) for each country to produce a total technical potential. All of these data are available for download at https://globalsolaratlas.info/global-pv-potential-study. Note that Level 1 excludes unsuitable land, using of relevant global datasets, due to physical/technical constraints, such as rugged terrain, presence of urbanized/industrial areas, forests, and areas that are too distant from the centres of human activity.

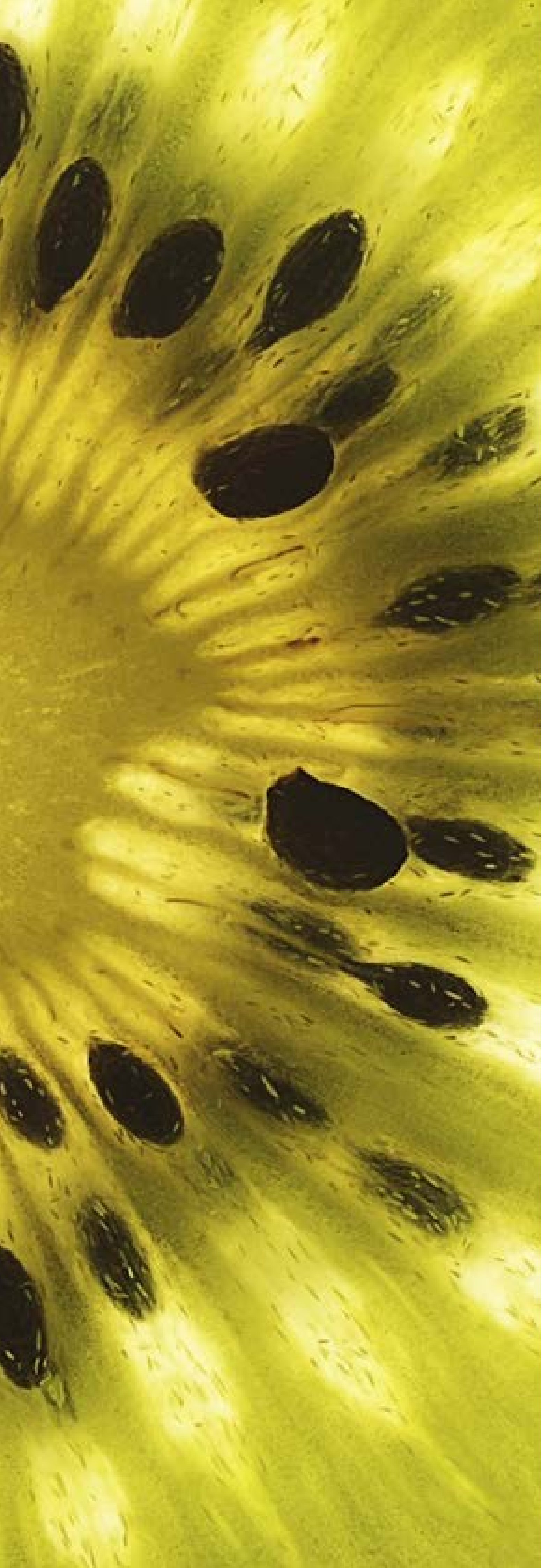
Wind resources

The primary source for wind resources for this report was Eurek, Kelly, Patrick Sullivan, Michael Gleason, Dylan Hettinger, Donna Heimiller, and Anthony Lopez, 'An Improved Global Wind Resource Estimate for Integrated Assessment Models', Energy Economics, 64 (2017), 552–67 https://doi.org/10.1016/j.eneco.2016.11.015 as well as as well as Dujardin, Jérôme, Annelen Kahl, and Michael Lehning, 'Synergistic Optimization of Renewable Energy Installations through Evolution Strategy', Environmental Research Letters, 16 (2021) https://doi.org/10.1088/1748-9326/abfc75 and Swiss Energy Scope, https://www.energyscope.ch/en/questions/what-is-switzerlands-wind-energy-potential/

The methodology employed by Eurek et al. excluded areas primarily based on geographic limitations, such as water, excessive elevation or slope for onshore resources; water depth, sea ice, and distance from shore for offshore resources; as well as land use suitability and regulation limits such as protected areas.

- **Hydro resources**
  Hydro resource potentials were primarily sourced from Rogner, Hans-Holger, Roberto F. Aguilera, Cristina L. Archer, Ruggero Bertani, S.C. Bhattacharya, Maurice B. Dusseault, and others, 'Energy Resources and Potentials', Global Energy Assessment (GEA), 2012, 425–512 https://doi.org/10.1017/cbo9780511793677.013 with additional information sourced from Von Sperling, Eduardo, 'Hydropower in Brazil: Overview of Positive and Negative Environmental Aspects', Energy Procedia, 18 (2012), 110–18 https://doi.org/10.1016/j.egypro.2012.05.023 and https://en.wikipedia.org/wiki/Electricity_sector_in_Norway

- **Biomass resources**
  Biomass resource potentials were primarily sourced from Deng, Yvonne Y., Michèle Koper, Martin Haigh, and Veronika Dornburg, 'Country-Level Assessment of Long-Term Global Bioenergy Potential', Biomass and Bioenergy, 74 (2015), 253–67 https://doi.org/10.1016/j.biombioe.2014.12.003 and Rogner, Hans-Holger, Roberto F. Aguilera, Cristina L. Archer, Ruggero Bertani, S.C. Bhattacharya, Maurice B. Dusseault, and others, 'Energy Resources and Potentials', Global Energy Assessment (GEA), 2012, 425–512 https://doi.org/10.1017/cbo9780511793677.013



8. References

7. References

Alova, Galina, 'A Global Analysis of the Progress and Failure of Electric Utilities to Adapt Their Portfolios of Power-Generation Assets to the Energy Transition', Nature Energy, 5 (2020), 920–27 <https://doi.org/10.1038/s41560-020-00686-5>

Altenburg, Tilman, and Claudia Assmann, eds., Green Industrial Policy: Concept, Policies, Country Experiences (Geneva, Bonn: UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE), 2017) <https://www.die-gdi.de/buchveroeffentlichungen/article/green-industrial-policy-concept-policies-country-experiences/> [accessed 19 August 2021]

Andres, Pia, and Penny Mealy, 'Green Transition Navigator', Retrieved from Www.Green-Transition-Navigator.Org, 2021

Austrade, Why Australia Benchmark Report 2021, 2021 <https://www.austrade.gov.au/benchmark-report/resilient-economy>

Bazilian, Morgan, Victoria Cuming, and Thomas Kenyon, 'Local-Content Rules for Renewables Projects Don't Always Work', Energy Strategy Reviews, 32 (2020), 100569 <https://doi.org/10.1016/J.ESR.2020.100569>

Bernard, Steven, 'Singapore Fails to Keep Pace with Wealthy Peers on Carbon Emissions', The Financial Times, 12 March 2021 <https://www.ft.com/content/a60e9464-a55d-4066-a839-46e334fde094> [accessed 19 August 2021]

Biden Harris Democrats, 'The Biden Plan for a Clean Energy Revolution and Environmental Justice', Battle for the Soul of the Nation, 2021 <https://joebiden.com/climate-plan/> [accessed 19 August 2021]

Brown, Patrick R., and Audun Botterud, 'The Value of Inter-Regional Coordination and Transmission in Decarbonizing the US Electricity System', Joule, 2021, 115–34 <https://doi.org/10.1016/j.joule.2020.11.013>

Burchard, Hans von der, 'EU-Switzerland Relations Head for Trouble as Partnership Deal Unravels', Politico, 26 May 2021 <https://www.politico.eu/article/eu-switzerland-relations-head-for-trouble-as-partnership-deal-unravels/>

Carnell, Robert, and Prakash Sakpal, Singapore Green Plan 2030 – Important Steps towards a Sustainable Future, 2021 <https://think.ing.com/articles/singapore-green-plan-2030-important-steps-towards-a-sustainable-future/#a3>

CAT, 'CAT Climate Target Update Tracker: UAE', Climate Action Tracker, 2020 <https://climateactiontracker.org/climate-target-update-tracker/uae/> [accessed 19 August 2021]

———, 'Country Summary: Brazil', Climate Action Tracker, 2020 <https://climateactiontracker.org/countries/brazil/> [accessed 27 July 2021]

———, 'Country Summary: Singapore', Climate Action Tracker, 2020

———, 'Country Summary: Switzerland', Climate Action Tracker, 2020 <https://climateactiontracker.org/countries/switzerland/> [accessed 14 September 2021]

———, 'Country Summary: UAE', Climate Action Tracker, 2020 <https://climateactiontracker.org/countries/uae/> [accessed 19 August 2021]

———, 'Current Policy Projections: Singapore', Climate Action Tracker, 2020 <https://climateactiontracker.org/countries/singapore/current-policy-projections/> [accessed 19 August 2021]

Charles, Kerwin Kofi, Erik Hurst, and Mariel Schwartz, 'The Transformation of Manufacturing and the Decline in US Employment', NBER Macroeconomics Annual, 33 (2019), 307–72 <https://doi.org/10.1086/700896>

China Power Team, Is China Leading in Global Innovation? China Power. Updated January 28, 2021. Accessed July 19, 2021., 2019 <https://chinapower.csis.org/china-innovation-global-leader/>

Chow, Winston, 'Singapore's Climate Action: It Is Time to Be More Ambitious', Research Collection School of Social Sciences. Paper 3173., 2020, 19–19 <https://ink.library.smu.edu.sg/cgi/viewcontent.cgi?article=4430&context=soss_research> [accessed 19 August 2021]

Chowdhury, Sarwat, 'South Korea's Green New Deal in the Year of Transition', UNDP Blog, 2021 <https://www.undp.org/blogs/south-koreas-green-new-deal-year-transition> [accessed 10 August 2021]

Crowley, Kate, 'Up and down with Climate Politics 2013–2016: The Repeal of Carbon Pricing in Australia', Wiley Interdisciplinary Reviews: Climate Change, 8 (2017), e458 <https://doi.org/10.1002/WCC.458>

David, Andrew S., and Dennis Fravel, U.S. Wind Turbine Export Opportunities in Canada and Latin America, Office of Industries Working Paper, 2012 <https://www.usitc.gov/publications/332/ID-032_final.pdf> [accessed 19 August 2021]

David Kupfer, Felipe Silveira Marques João Carlos Ferraz, 'Industrial Policy as an Effective Development Tool: Lessons from Brazil', in Transforming Economies: Making Industrial Policy Work for Growth, Jobs and Development, ed. by José M. Salazar-Xirinachs, Irmgard Nübler, and Richard Kozul-Wright (Geneva: ILO publishing, 2014), pp. 291–305 <http://www.ilo.org/global/publications/books/WCMS_315675/lang--en/index.htm> [accessed 19 August 2021]

Dupont, Elise, Rembrandt Koppelaar, and Hervé Jeanmart, 'Global Available Solar Energy under Physical and Energy Return on Investment Constraints', Applied Energy, 257 (2020), 113968 <https://doi.org/10.1016/j.apenergy.2019.113968>

———, 'Global Available Wind Energy with Physical and Energy Return on Investment Constraints', Applied Energy, 209 (2018), 322–38 <https://doi.org/10.1016/j.apenergy.2017.09.085>

EIA, 'Country Analysis Executive Summary: United Arab Emirates', Independent Statistics & Analysis, 2020

Ellison, Glenn, Edward L. Glaeser, and William R. Kerr, 'What Causes Industry Agglomeration? Evidence from Coagglomeration Patterns', American Economic Review, 100 (2010), 1195–1213 <https://doi.org/10.1257/AER.100.3.1195>

Energy.gov.au, 'Australian Electricity Generation - Fuel Mix', Department of Industry, Science, Energy and Resources Website. <https://www.energy.gov.au/data/australian-electricity-generation-fuel-mix>

Eurek, Kelly, Patrick Sullivan, Michael Gleason, Dylan Hettinger, Donna Heimiller, and Anthony Lopez, 'An Improved Global Wind Resource Estimate for Integrated Assessment Models', Energy Economics, 64 (2017), 552–67 <https://doi.org/10.1016/j.eneco.2016.11.015>

European Commission, 'Carbon Border Adjustment Mechanism: Questions and Answers', EC Press Release, 2021 <https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3661>

——, European Green Deal (Brussels, 2021) <https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en>

Farmer, J.D., and François Lafond, 'How Predictable Is Technological Progress?', Research Policy, 45 (2016), 647–65 <https://doi.org/10.1016/j.respol.2015.11.001>

Fort, Teresa C., Justin R. Pierce, and Peter K. Schott, 'New Perspectives on the Decline of US Manufacturing Employment', Journal of Economic Perspectives, 32 (2018), 47–72 <https://doi.org/10.1257/jep.32.2.47>

Frey, Carl Benedikt, 'How Culture Gives the US an Innovation Edge over China', MIT Sloan Management Review, 62 (2021), 55–61

Gao, Yanyan, Leizhen Zang, Antoine Roth, and Puqu Wang, 'Does Democracy Cause Innovation? An Empirical Test of the Popper Hypothesis', Research Policy, 46 (2017), 1272–83 <https://doi.org/10.1016/j.respol.2017.05.014>

Garrett-Peltier, Heidi, 'Green versus Brown: Comparing the Employment Impacts of Energy Efficiency, Renewable Energy, and Fossil Fuels Using an Input-Output Model', Economic Modelling, 61 (2017), 439–47 <https://doi.org/10.1016/j.econmod.2016.11.012>

Gorodnichenko, Yuriy, and Gerard Roland, 'Individualism, Innovation, and Long-Run Growth', Proceedings of the National Academy of Sciences of the United States of America, 108 (2011), 21316–19 <https://doi.org/10.1073/pnas.1101933108>

Gramkow, Camila, and Annela Anger-Kraavi, 'Developing Green: A Case for the Brazilian Manufacturing Industry', Sustainability 2019, Vol. 11, Page 6783, 11 (2019), 6783 <https://doi.org/10.3390/SU11236783>

Grubb, M., Paul Drummond, Alexandra Poncia, Will McDowall, David Popp, Sascha Samadi, and others, 'Induced Innovation in Energy Technologies and Systems: A Review of Evidence and Potential Implications for CO 2 Mitigation', Environmental Research Letters, 2021 <https://doi.org/10.1088/1748-9326/abde07>

Grubb, M, Jean Charles Hourcade, and K Neuhoff, Planetary Economics: Energy, Climate Change and the Three Domains of Sustainable Development, Planetary Economics (London, UK, 2014) <https://doi.org/10.4324/9781315857688>

Grüll, Philipp, and Sarah Lawton, 'The Green Compromise in the Austrian Airlines Bailout', Euractiv.Com, 10 June 2020 <https://www.euractiv.com/section/aviation/news/the-green-compromise-in-the-austrian-airines-bailout/>

Gurgel, Angelo C., Sergey Paltsev, and Gustavo Velloso Breviglieri, 'The Impacts of the Brazilian NDC and Their Contribution to the Paris Agreement on Climate Change', Environment and Development Economics, 24 (2019), 395–412 <https://doi.org/10.1017/S1355770X1900007X>

Hansen, U. E., I. Nygaard, M. Morris, and G. Robbins, 'The Effects of Local Content Requirements in Auction Schemes for Renewable Energy in Developing Countries: A Literature Review', Renewable and Sustainable Energy Reviews, 127 (2020), 109843 <https://doi.org/10.1016/J.RSER.2020.109843>

Hausmann, Ricardo, Jason Hwang, and Dani Rodrik, 'What You Export Matters', Journal of Economic Growth, 12 (2007) <https://doi.org/10.1007/s10887-006-9009-4>

Henry, Don, and Sangeetha Chandra-Shekeran, 'State Leadership on Emissions Reduction Is Crucial', University of Melbourne Pursuit, 3 May 2021 <https://pursuit.unimelb.edu.au/articles/state-leadership-on-emissions-reduction-is-crucial>

Hepburn, Cameron, Brian O'Callaghan, Nicholas Stern, Joseph Stiglitz, and Dimitri Zenghelis, 'Will COVID-19 Fiscal Recovery Packages Accelerate or Retard Progress on Climate Change?', Oxford Review of Economic Policy, 36 (2020), S359–81 <https://doi.org/10.1093/oxrep/graa015>

Hickey, Conor, John O'Brien, Ben Caldecott, Celine M. McInerney, and Brian O'Gallachoir, 'Can European Electric Utilities Manage Asset Impairments Arising From Net Zero Carbon Targets?', SSRN Electronic Journal, 2020 <https://doi.org/10.2139/SSRN.3531724>

Hidalgo, C. A., and R. Hausmann, 'The Building Blocks of Economic Complexity', Proceedings of the National Academy of Sciences, 106 (2009) <https://doi.org/10.1073/pnas.0900943106>

Hidalgo, C. A., B. Klinger, A.-L. Barabasi, and R. Hausmann, 'The Product Space Conditions the Development of Nations', Science, 317 (2007) <https://doi.org/10.1126/science.1144581>

Hofbauer Pérez, Maria, and Carla Rhode, 'Carbon Pricing: International Comparison', Ifo DICE Report I, Spring Volume 18 (2020)

Hofstede, Geert, Geert Hofstede, Culture's Consequences: Comparing Values, Behaviours, Institutions, and Organizations Across Nations, Sage Publications, 2001

House Committe on the Budget, 'The Build Back Better Act: Transformative Investments in America's Families & Economy', 2021 <https://budget.house.gov/publications/report/build-back-better-act-transformative-investments-america-s-families-economy> [accessed 8 November 2021]

Houseman, Susan N, Understanding the Decline of U.S. Manufacturing Employment, Upjohn Institute Working Paper, 2018 <https://doi.org/10.17848/wp18-287>

Hughes, Llewelyn, and Jonas Meckling, 'The Politics of Renewable Energy Trade: The US-China Solar Dispute', Energy Policy, 105 (2017), 256–62 <https://doi.org/10.1016/J.ENPOL.2017.02.044>

IEA, 'Reports: Electric Vehicles', IEA, 2020 <https://www.iea.org/reports/electric-vehicles>

——, Sustainable Recovery Tracker (Paris, France, 2021) <//www.iea.org/reports/sustainable-recovery-tracker>

——, 'The 10th Five-Year Plan for Economic and Social Development of the People's Republic of China (2001-2005)', IEA/IRENA Renewables Policies Database, 2021 <https://www.iea.org/policies/1736-the-10th-five-year-plan-for-economic-and-social-development-of-the-peoples-republic-of-china-2001-2005?page=4&q=China> [accessed 19 July 2021]

——, World Energy Outlook 2020, 2020, MML

IISD, Delivering Climate Ambition Through Market Mechanisms: Capitalizing on Article 6 Piloting Activities, 2021 <https://sdg.iisd.org/commentary/policy-briefs/delivering-climate-ambition-through-market-mechanisms-capitalizing-on-article-6-piloting-activities/>

IPCC, 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, ed. by V

Masson-Delmotte, P Zhai, H-o Pörtner, D Roberts, J Skea, PR Shukla, and others, Ipcc - Sr15, 2018, II <www.environmentalgraphiti.org> [accessed 2 March 2021]

IRENA, Future of Solar Photovoltaic: Deployment, Investment, Technology, Grid Integration and Socio-Economic Aspects (A Global Energy Transformation: Paper), International Renewable Energy Agency, 2019, NOVEMBER <https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019.pdf>

———, Renewable Power Generation Costs in 2018, International Renewable Energy Agency, 2019 <https://doi.org/10.1007/SpringerReference_7300>

Ives, M.C., L. Righetti, J. Schiele, K. De Meyer, L. Hubble-Rose, F. Tieng, and others, A New Perspective on Decarbonising the Global Energy System, Oxford University Smith School of Enterprise and the Environment, 2021 <www.energychallenge.info>

Jenkins, Stuart, Eli Mitchell-Larson, Matthew C. Ives, Stuart Haszeldine, and Myles Allen, ‘Upstream Decarbonization through a Carbon Takeback Obligation: An Affordable Backstop Climate Policy’, Joule, 5 (2021), 2777–96 <https://doi.org/10.1016/J.JOULE.2021.10.012>

Jinping, Xi, ‘Statement by H.E. Xi Jinping President of the People’s Republic of China at the General Debate of the 75th Session of The United Nations General Assembly’, Ministry of Foreign Affairs of the People’s Republic of China, 2020 <https://www.fmprc.gov.cn/mfa_eng/zxxx_662805/t1817098.shtml>

Koh, John, ‘Singapore MPs Call for Minimum 15-Fold Carbon Tax Increase by 2040’, IHS Markit Net-Zero Business Daily News Research & Analysis, 2021 <https://ihsmarkit.com/research-analysis/singapore-mps-call-for-minimum-15fold-increase-in-carbon-tax-b.html> [accessed 19 August 2021]

Krukowska, Ewa, and Tara Patel, ‘EU Aims to Have 30 Million Electric Cars on the Road by 2030’, Bloomberg, 3 December 2020

Kumar, Deepak, Stephen P. Long, and Vijay Singh, ‘Jet Fuel from Sugarcane? It’s Not a Flight of Fancy’, The Conversation, 21 November 2017 <https://theconversation.com/jet-fuel-from-sugarcane-its-not-a-flight-of-fancy-84493>

Lamb, William F., Thomas Wiedmann, Julia Pongratz, Robbie Andrew, Monica Crippa, Jos G.J. Olivier, and others, ‘A Review of Trends and Drivers of Greenhouse Gas Emissions by Sector from 1990 to 2018’, Environmental Research Letters, 2021 <https://doi.org/10.1088/1748-9326/abee4e>

Lehmann, Erik E., and Nikolaus Seitz, ‘Freedom and Innovation: A Country and State Level Analysis’, Journal of Technology Transfer, 42 (2017), 1009–29 <https://doi.org/10.1007/s10961-016-9478-3>

Liu, Hongqiao, ‘In-Depth Q&A: Will China’s Emissions Trading Scheme Help Tackle Climate Change?’, Carbon Brief, 2021 <https://www.carbonbrief.org/in-depth-qa-will-chinas-emissions-trading-scheme-help-tackle-climate-change>

Liu, Kerry, ‘Chinese Manufacturing in the Shadow of the China–US Trade War’, Economic Affairs, 38 (2018), 307–24 <https://doi.org/10.1111/ecaf.12308>

Lo, Joe, ‘Peru and Switzerland Sign “World First” Carbon Offset Deal under Paris Agreement’, Climate Home News, 21 October 2020 <https://www.climatechangenews.com/2020/10/21/peru-

switzerland-sign-world-first-carbon-offset-deal-paris-agreement/>

Londoño, Ernesto, 'Bolsonaro's Sudden Pledge to Protect the Amazon Is Met With Skepticism', New York Times (New York, 21 April 2021) <https://www.nytimes.com/2021/04/21/world/americas/bolsonaro-climate-amazon.html>

Ma, Xinyue, Understanding China's Global Power (Boston, MA, 2020) <https://doi.org/10.1038/s41586-019-1368-z>

MacDonald, Connor, and Peter Sloman, 'Resource Extraction, Economic Growth, and the Climate Dilemma in Canada and Australia', The Political Quarterly, 91 (2020), 780–85 <https://doi.org/10.1111/1467-923X.12902>

Mallapaty, Smriti, 'China's Five-Year Plan Focuses on Scientific Self-Reliance', Nature (NLM (Medline), 2021), 353–54 <https://doi.org/10.1038/d41586-021-00638-3>

Massi, Eliza, and Jewellord Nem Singh, 'Industrial Policy and State-Making: Brazil's Attempt at Oil-Based Industrial Development', Third World Quarterly, 39 (2018), 1133–50 <https://doi.org/10.1080/01436597.2018.1455144>

Mattauch, Linus, Felix Creutzig, and Ottmar Edenhofer, 'Avoiding Carbon Lock-in: Policy Options for Advancing Structural Change', Economic Modelling, 50 (2015), 49–63 <https://doi.org/https://doi.org/10.1016/j.econmod.2015.06.002>

Mealy, Penny, J. Doyne Farmer, and Alexander Teytelboym, 'Interpreting Economic Complexity', Science Advances, 5 (2019) <https://doi.org/10.1126/sciadv.aau1705>

Mealy, Penny, and Alexander Teytelboym, 'Economic Complexity and the Green Economy', Research Policy, 2020, 103948 <https://doi.org/10.1016/j.respol.2020.103948>

Mercure, J. F., H. Pollitt, J. E. Viñuales, N. R. Edwards, P. B. Holden, U. Chewpreecha, and others, 'Macroeconomic Impact of Stranded Fossil Fuel Assets', Nature Climate Change, 2018 <https://doi.org/10.1038/s41558-018-0182-1>

Milman, Oliver, 'Biden Returns US to Paris Climate Accord Hours after Becoming President', The Guardian, 20 January 2021 <https://www.theguardian.com/environment/2021/jan/20/paris-climate-accord-joe-biden-returns-us> [accessed 19 August 2021]

Mission of Switzerland to the EU, 'Environment and Climate – Stepping up Cooperation on Shared Challenges', 2021 <https://www.eda.admin.ch/missions/mission-eu-brussels/en/home/key-issues/enviroment-climate.html>

Moriarty, Patrick, and Damon Honnery, 'What Is the Global Potential for Renewable Energy?', Renewable and Sustainable Energy Reviews, 16 (2012), 244–52 <https://doi.org/https://doi.org/10.1016/j.rser.2011.07.151>

Moser, Marisa, Mauri Aparecido de Oliveira, and Ricardo Luiz Pereira Bueno, 'Comparison between Brazil and the 30 Most Innovative Countries in the World', EMAJ: Emerging Markets Journal, 7 (2018), 19–28 <https://doi.org/10.5195/emaj.2017.141>

NDRC, China's Intended Nationally Determined Contribution: Enhanced Actions on Climate Change (Beijing, 2015) <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/China First/

China’s First NDC Submission.pdf>

Neffke, Frank, Martin Henning, and Ron Boschma, ‘How Do Regions Diversify over Time? Industry Relatedness and the Development of New Growth Paths in Regions’, Economic Geography, 87 (2011) <https://doi.org/10.1111/j.1944-8287.2011.01121.x>

O’Callaghan, Brian J., and Em Murdock, Are We Building Back Better? Evidence from 2020 and Pathways to Inclusive Green Recovery Spending - Summary for Policymakers, 1386 <https://wedocs.unep.org/bitstream/handle/20.500.11822/35282/AWBBB_ES.pdf> [accessed 10 August 2021]

O’Callaghan, Brian, N. Yau, E. Murdock, D. Tritsch, A. Janz, A. Blackwood, and others, Global Recovery Observatory, Oxford University Economic Recovery Project, 2020 <https://recovery.smithschool.ox.ac.uk/tracking/> [accessed 25 June 2021]

OECD, ‘Overcoming Barriers to International Investment in Clean Energy’, in Green Finance and Investment (Paris, France: OECD Publishing, Paris, 2015) <https://doi.org/10.1787/9789264242661-18-en>

Oxford University Economic Recovery Project, IMF, UNEP, and GIZ, Global Recovery Observatory: Draft Methodology Document, 2021 <https://recovery.smithschool.ox.ac.uk/wp-content/uploads/2021/03/20210201-Global-Recovery-Observatory-Draft-Methodology-Document-.pdf> [accessed 10 August 2021]

Paybarah, Azi, ‘China Says It Won’t Build New Coal Plants Abroad. What Does That Mean?’, The New York Times (New York, 22 September 2021) <https://www.nytimes.com/2021/09/22/world/asia/china-coal.html>

Pfeiffer, Alexander, Cameron Hepburn, Adrien Vogt-Schilb, and Ben Caldecott, ‘Committed Emissions from Existing and Planned Power Plants and Asset Stranding Required to Meet the Paris Agreement’, Environmental Research Letters, 13 (2018) <https://doi.org/10.1088/1748-9326/aabc5f>

Pichler, Anton, Marco Pangallo, R Maria Rio-chanona, and J Doyne Farmer, ‘In and out of the UK Lockdown: Propagation of Supply and Demand Shocks in a Dynamic Input-Output Model’, 2020

Pollin, Robert, Heidi Garrett-Peltier, James Heintz, and Bracken Hendricks, Green Growth A U.S. Program for Controlling Climate Change and Expanding Job Opportunities, 2014

Popovich, Nadja, Livia Albeck-Ripka, and Kendra Pierre-Louis, ‘The Trump Administration Rolled Back More Than 100 Environmental Rules. Here’s the Full List.’, The New York Times, 20 January 2021 <https://www.nytimes.com/interactive/2020/climate/trump-environment-rollbacks-list.html> [accessed 19 August 2021]

Probst, Benedict, Vasilios Anatolitis, Andreas Kontoleon, and Laura Díaz Anadón, ‘The Short-Term Costs of Local Content Requirements in the Indian Solar Auctions’, Nature Energy, 5 (2020), 842–50 <https://doi.org/10.1038/s41560-020-0677-7>

Reuters, Jake Spring, and Lisandra Paraguassu, ‘Brazil’s Bolsonaro, under U.S. Pressure, Vows Climate Neutrality by 2050’, Reuters (Brasilia, 22 April 2021) <https://www.reuters.com/business/environment/bolsonaro-says-brazil-will-reach-climate-neutrality-by-2050-2021-04-22/>

Ritchie, Hannah, and Max Roser, 'China: Energy Country Profile', Our World in Data, 2021 <https://ourworldindata.org/energy/country/china> [accessed 19 July 2021]

———, 'CO_2 and Greenhouse Gas Emissions', Our World in Data, 2020 <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions#citation> [accessed 19 August 2021]

———, 'Energy', Our World in Data, 2020 <https://ourworldindata.org/energy> [accessed 19 August 2021]

RNZ, 'Australia PM Refuses to Set "net Zero by 2050" Climate Target as Global Warning Issued', Radio New Zealand, 10 August 2021 <https://www.rnz.co.nz/news/world/448880/australia-pm-refuses-to-set-net-zero-by-2050-climate-target-as-global-warning-issued>

Rogner, Hans-Holger, Roberto F. Aguilera, Cristina L. Archer, Ruggero Bertani, S.C. Bhattacharya, Maurice B. Dusseault, and others, 'Energy Resources and Potentials', Global Energy Assessment (GEA), 2012, 425–512 <https://doi.org/10.1017/cbo9780511793677.013>

Rosenthal, Stuart S., William C. Strange, Stuart Rosenthal, and William Strange, 'Evidence on the Nature and Sources of Agglomeration Economies', 4 (2004), 2119–71 <https://econpapers.repec.org/RePEc:eee:regchp:4-49> [accessed 20 November 2021]

Searle, Stephanie, and Chris Malins, 'A Reassessment of Global Bioenergy Potential in 2050', GCB Bioenergy, 2015, 328–36 <https://doi.org/10.1111/gcbb.12141>

Shepherd, Christian, 'China Turns Its Back on Bangladesh BRI Coal Projects', Financial Times, 2021 <https://www.ft.com/content/30840645-58d2-4da5-be05-f476623677d2> [accessed 19 August 2021]

Simington, Rory, 'Australian Coal Exports Bounce Back from China's Ban', Wood Mackenzie, 4 March 2021 <https://www.woodmac.com/news/opinion/australian-coal-exports-bounce-back-from-chinas-ban/>

SolarPower Europe, 'Solar Power 2019–2023', Global Market Outlook, 2018, 94

Von Sperling, Eduardo, 'Hydropower in Brazil: Overview of Positive and Negative Environmental Aspects', Energy Procedia, 18 (2012), 110–18 <https://doi.org/10.1016/j.egypro.2012.05.023>

State Council of The People's Republic of China, '"Made in China 2025" Plan Issued', 2015 <http://english.www.gov.cn/policies/latest_releases/2015/05/19/content_281475110703534.htm>

Stubley, Peter, 'Swiss Voters Reject New Climate Law to Help Cut Carbon Emissions', The Independent (London, 14 June 2021) <https://www.independent.co.uk/climate-change/news/switzerland-referendum-climate-change-emissions-b1865193.html>

Suzigan, Wilson, Renato Garcia, and Paulo Henrique Assis Feitosa, 'Institutions and Industrial Policy in Brazil after Two Decades: Have We Built the Needed Institutions?', Economics of Innovation and New Technology, 29 (2020), 799–813 <https://doi.org/10.1080/10438599.2020.1719629>

Tabeta, Shunsuke, 'China Plans to Phase out Conventional Gas-Burning Cars by 2035', Nikkei Asia, 27 October 2020 <https://asia.nikkei.com/Business/Automobiles/China-plans-to-phase-out-conventional-gas-burning-cars-by-2035>

Tan, Su-Lin, 'China-Australia Relations: US Coal Continues to Fill Void Left by Ban on Australian Exports, Canberra Report Says', South China Morning Post (Hong Kong, 30 June 2021)

The Economist, 'How Climate Targets Compare against a Common Baseline', The Economist (London, 7 August 2021)

———, 'How to Assess the Costs and Benefits of Lockdowns', The Economist, July 2021 <https://www.economist.com/finance-and-economics/2021/07/01/how-to-assess-the-costs-and-benefits-of-lockdowns>

———, 'What Is China's Five-Year Plan? The Economist Explains', The Economist, 4 March 2021 <https://www.economist.com/the-economist-explains/2021/03/04/what-is-chinas-five-year-plan>

The White House, 'FACT SHEET: President Biden Sets 2030 Greenhouse Gas Pollution Reduction Target Aimed at Creating Good-Paying Union Jobs and Securing U.S. Leadership on Clean Energy Technologies', White House Statements and Releases, 2021 <https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/> [accessed 19 August 2021]

———, 'FACT SHEET: The American Jobs Plan', White House Statements and Releases, 2021 <https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/> [accessed 19 August 2021]

———, 'FACT SHEET: The American Jobs Plan Supercharges the Future of Transportation and Manufacturing', White House Statements and Releases, 2021 <https://www.whitehouse.gov/briefing-room/statements-releases/2021/05/18/fact-sheet-the-american-jobs-plan-supercharges-the-future-of-transportation-and-manufacturing/> [accessed 19 August 2021]

Thompson, Dakota J., Wester C.H. Schoonenberg, and Amro M. Farid, 'A Hetero-Functional Graph Resilience Analysis of the Future American Electric Power System', IEEE Access, 9 (2021), 68837–48 <https://doi.org/10.1109/ACCESS.2021.3077856>

UAE, 'Operation 300bn, the UAE's Industrial Strategy', The United Arab Emirates' Government Portal, 2021 <https://u.ae/en/about-the-uae/strategies-initiatives-and-awards/federal-governments-strategies-and-plans/the-uae-industrial-strategy> [accessed 19 August 2021]

———, 'The UAE's Response to Climate Change', The United Arab Emirates' Government Portal, 2021 <https://u.ae/en/information-and-services/environment-and-energy/climate-change/theuaesresponsetoclimatechange> [accessed 19 August 2021]

———, 'UAE Energy Strategy 2050', The United Arab Emirates' Government Portal, 2021

UNFCCC, 'Australia's First Nationally Determined Contribution towards Achieving the Objective of the United Nations Framework Convention on Climate Change (Updated Submission)', 2020 <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Australia First/Australia NDC recommunication FINAL.PDF>

———, 'Federative Republic of Brazil First Nationally Determined Contribution towards Achieving the Objective of the United Nations Framework Convention on Climate Change (Updated Submission)', 2020 <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Brazil First/Brazil First NDC (Updated submission).pdf>

——, ‘Singapore’s Update of Its First Nationally Determined Contribution (NDC) and Accompanying Information’, 2020 <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Singapore First/Singapore’s Update of 1st NDC.pdf> [accessed 19 August 2021]

——, ‘Switzerland’s First Nationally Determined Contribution towards Achieving the Objective of the United Nations Framework Convention on Climate Change (Updated Submission)’, 2020 <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Switzerland First/Switzerland_Full NDC Communication 2021-2030 incl ICTU.pdf>

USAID, Greenhouse Gas Emissions in Brazil, USAID, 2018

Volz, Ulrich, Shamshad Akhtar, Kevin P Gallagher, Stephany Griffith-Jones, Jörg Haas, and Moritz Kraemer, Debt Relief for a Green and Inclusive Recovery Debt Relief for a Green and Inclusive Recovery A Proposal (Berlin, 2020)

de Vries, Bert J M, Detlef P van Vuuren, and Monique M Hoogwijk, ‘Renewable Energy Sources: Their Global Potential for the First-Half of the 21st Century at a Global Level: An Integrated Approach’, Energy Policy, 35 (2007), 2590–2610 <https://doi.org/10.1016/J.ENPOL.2006.09.002>

——, ‘Renewable Energy Sources: Their Global Potential for the First-Half of the 21st Century at a Global Level: An Integrated Approach’, Energy Policy, 35 (2007), 2590–2610 <https://doi.org/https://doi.org/10.1016/j.enpol.2006.09.002>

Wangkiat, Paritta, ‘Green Recovery’, Bankok Post (Bankok, 21 June 2021) <https://www.bangkokpost.com/business/2135711/green-recovery>

Watts, Jonathan, ‘Amazon Rainforest “Will Collapse If Bolsonaro Remains President”’, The Guardian (London, 14 July 2021)

Way, Rupert, Matthew. C. Ives, Penny Mealy, and J.D. Doyne Farmer, Empirically Grounded Technology Forecasts and the Energy Transition, 2021 <https://www.inet.ox.ac.uk/publications/no-2021-01-estimating-the-costs-of-energy-transition-scenarios-using-probabilistic-forecasting-methods/>

White House, American Jobs Plan (Washington, DC, 2021) <www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/>

Workman, Daniel, ‘Electric Cars Exports by Country’, World’s Top Exports, 2021 <https://www.worldstopexports.com/electric-cars-exports-by-country/>

World Bank, Solar Photovoltaic Power Potential by Country, 2020 <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/466331592817725242/global-photovoltaic-power-potential-by-country> [accessed 30 November 2020]

——, ‘Total Greenhouse Gas Emissions (Kt of CO_2 Equivalent)’, World Bank Data, 2020 <https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE> [accessed 19 August 2021]

Zhou, Lihuan, Sean Gilbert, Ye Wang, Miquel Muñoz Cabré, and Kevin P. Gallagher, Moving the Green Belt and Road Initiative: From Words to Actions, 11 August 2018 <https://www.wri.org/research/moving-green-belt-and-road-initiative-words-actions> [accessed 19 August 2021]

Important Information