Organisation for Economic Co-operation and Development

Innovation and Business/Market Opportunities associated with Energy Transitions and a Cleaner Global Environment

Issue Paper

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Executive summary

The world faces increasing environmental pressures, including rising air and water pollution, climate change, biodiversity loss and waste generation. Numerous policies and initiatives have emerged at the international level to respond to these challenges, but more must be done to ensure a rapid green transition and a cleaner global environment. These changes will need to happen in a context of other major structural transformations, including economic convergence between developed and developing countries, rising urbanisation, and the diffusion of automation and digitalisation.

Innovation – the creation and diffusion of new ideas – is at the heart of the transition to a cleaner global environment. This includes not only technological innovation, but also innovation in economic and social systems and in lifestyles. Innovation is the main source of modern economic growth, which implies that the green transition is not only compatible with long-term economic growth; it also opens up a vast range of economic opportunities for businesses.

The green transition depends on the development and diffusion of new technological, economic, social, behavioural and business model innovations. These include electricity production, distribution and storage; agriculture and forestry; natural resource exploitation; buildings; transportation; water supply and treatment; waste management; and environmental remediation. Many of the necessary innovations in each of these sectors already exist and now need to be diffused and scaled up. This process can be eased thanks to the development of enabling innovations such as artificial intelligence, the internet of things and blockchain technologies. At least in the technological domain, the pace of innovation for the green transition has accelerated markedly since the mid-2000s. However, it is still insufficient to address the environmental challenges facing the planet today, and there is evidence to suggest that the pace of green innovation has slowed again in recent years. This suggests that major barriers remain and need to be lifted in order to accelerate the transition.

The green transition spans multiple sectors of the economy. It is therefore difficult to quantify the size of the business opportunity associated with the transition. However, recent estimates indicate that the green economy is growing fast, and could represent 10% of global market capitalisation by 2030, approximately the same size as the health or the banking sectors. Transitioning to a green economy has also been shown to deliver additional benefits, from high knowledge spillovers from green innovation to enhanced health and workers' productivity from lower air and water pollution.

Similarly, it is difficult to predict which countries and sectors are best positioned to seize the opportunity stemming from the green transition over the coming decades. Recent trade, patent and output data suggests a highly nuanced picture, without unequivocal winners and losers. Every country has strengths and opportunities in the green economy, but many countries also face weaknesses and threats. Across the vast majority of G20 countries, the analysis reveals that sectors that currently hold a comparative advantage are also leading

green innovators, suggesting that countries will be able to maintain their strong competitive positions in the green economy.

While the transition to a greener economy is a clear business opportunity given the scale of the transformation needed, it will also lead to reallocations both between and within economic sectors. However, evidence suggests that this reallocation is small compared to other trends in the economy, such as automation. Public policies can effectively mitigate these consequences.

There are a number of barriers limiting the development and diffusion of cleaner technologies, and thus preventing the business opportunities associated with the green transition to materialize. These include skills shortages, innovation capacities, lack of business competition, lack of public acceptance of new technologies, infrastructure shortages, policy misalignments such as inefficient fossil fuel subsidies that encourage wasteful consumption, policy uncertainty, and financial barriers.

National governments and the G20 as a group therefore have a clear role to play in fostering innovation for the green transition. A first set of policies to overcome the above-mentioned barriers are domestic in nature. They include setting ambitious, stable and predictable environmental policies, promoting voluntary initiatives by the private sector, introducing public procurement standards, leveraging private finance, promoting collaborative innovation networks and aligning fiscal, labour, education, competition, R&D and environmental policies towards a common goal.

The transition to a greener economy will require not only domestic policies, but also enhanced co-operation and co-ordination among G20 governments. This includes policy convergence on environmental issues, harmonisation of standards, support for international technology diffusion, trade provisions for environmental goods and services and capacity building. The G20 has the scale and scope to create a policy and regulatory framework that fosters innovation and enables fair competition between industrial companies on a global playing field, which in turn would enable the green innovation industry to flourish. The G20 also has the capacity to lower global financial asymmetries and de-risk investment in green innovation-based companies, for example through reporting systems, data collection and voluntary country-owned peer review.

1. Introduction

1. Environmental challenges have become increasingly acute over the last decades. Greenhouse gas emissions continue to rise, despite the projected consequences of unabated climate change: regions of the world could become uninhabitable due to rising sea levels or desertification, the likelihood and intensity of extreme weather events will increase, and changing precipitation patterns and temperatures will affect crops and livestock (IPCC, 2018[1]). The economic costs of climate change impacts have been estimated to lie in the range of 1% to 3.3% of global GDP by 2060 (OECD, 2015[2]). Climate change is intertwined with other environmental problems: continuing loss of biodiversity and

associated ecosystem services (3 million hectares of forest lost per year); rising air pollution (5 million deaths a year); waste generation (2 billion tons of waste dumped per year); and increasing risks of too much, too little or too polluted water (the estimated cost to the economy is in the order of USD 500 billion annually (Sadoff et al., 2015[3])).

2. These environmental challenges have led to international initiatives to scale up policy action, such as the United Nations 2030 Sustainable Development Goals, the Paris Agreement on climate change, the Convention on Biological Diversity's Strategic Plan for Biodiversity 2011-2020 and Aichi Biodiversity Targets; regional efforts to combat air pollution, such as the Convention on Long Range Transport of Air Pollutants; and regional resource efficiency and circular economy policies and roadmaps. These efforts reflect the urgency of a structural transformation of the global economy. For example, countries need to decrease greenhouse gas emissions by 25% by 2030 compared to 1990 levels to keep the chance of reaching the 2°C target of the Paris Agreement and 55% to reach the 1.5°C target, compared to a "business as usual" scenario (IPCC, 2018[4]).

3. The next decades are critical to ensure a transition to a cleaner environment, but these changes will need to happen in a context of other major structural transformations. Global GDP is projected to double over the next 20 years, while urban population is projected to double in the next 40 years, putting further pressures on the environment. Automation and digitalisation are set to change production systems and labour markets profoundly.

4. Innovation – the creation and diffusion of new ideas, products, processes and methods – is fundamental to the transition to a cleaner global environment. Innovation means not only technological innovation but also innovation in economic and social systems and changes in lifestyles. The mix of technologies used for production and consumption needs to radically change across multiple sectors, and technological breakthrough may be necessary in some sectors. Institutional and organisational changes, new services and business models, new ways of consuming, living and moving are also needed to drive systemic changes in production and consumption patterns, habits and behaviours.

5. Innovation is the main source of modern economic growth. This implies that the green transition is not only compatible with long-term economic growth; it also opens up a vast range of economic opportunities for businesses. Other pathways to a cleaner environment, such as through a reduction in economic output, would undoubtedly be incompatible with other development objectives such as social inclusivity and poverty reduction. On the contrary, the structural transformation of the economy made necessary by the green transition – like all previous industrial revolutions that the world has undergone – presents market and business opportunities across all sectors. There is evidence that the green economy is already growing at a fast rate across numerous sectors and this trend will likely only become stronger in the years ahead.

6. What is the scale of this business opportunity? What kinds of innovations are needed across sectors? Who will likely benefit from this transition, in terms of being at the centre of research and development (R&D) efforts, developing the technologies of the future, and generating new economic activities? What are the barriers and challenges that

could prevent such opportunities from materialising? What role is there for G20 government policies and for international co-operation?

7. The objective of this paper is to address these questions based on a review of the literature and new empirical evidence.

- Section 2 presents an overview of the necessary technological innovation across sectors and of the emerging business models compatible with the green transition.
- Section 3 reviews available evidence and presents new data on the direct and indirect benefits from a green transition, and discusses the specific challenges associated with pollution-intensive sectors.
- Section 4 presents the barriers that could prevent this transformation, and discusses policies to address them.
- Section 5 focuses specifically on the role that the G20 could play to facilitate the transition.

2. What does the green transition imply in terms of technological and business model innovation?

8. The green transition depends on the development and diffusion of new technological, economic, social, behavioural and business model innovations in many, if not all, sectors of the economy. This section presents an overview of many of the required innovations, distinguishing between new technologies and new business models induced by new ways of production and consumption. It discusses both green technologies per se and "enabling" technologies, which are not "green" but could contribute to the transition, such as artificial intelligence as a catalyser for smart grid management and intelligent transport systems, among others. The green transition will not only require incremental innovation through small, gradual improvements, but also disruptive or breakthrough innovation for which less is known about the policy settings and enabling framework.

2.1 Green technological innovation

Climate change is one of the most urgent environmental problems and it exacerbates the impact of several other environmental and social problems. Keeping the global average temperature rise well below 2°C requires large-scale transformations of the global energy–agriculture–land-economy system, affecting the way in which energy is produced, agricultural systems are organised, and food, energy and materials are consumed (IPCC, 2018[1])**.**

9. A low-carbon energy transition relies on three broad types of technologies: renewable energy, energy efficiency and energy storage (for the possible role of carbon capture, storage and utilization, see Box 1). Renewable energy needs to be applied both in power generation (e.g. solar PVs, hydrogen) and in the transport sector (e.g. fuel cells, electric vehicles, second-generation biofuels). The share of renewable technologies in electricity production grew twice as fast as energy demand since 2000. While mature technologies (e.g. onshore wind, solar PV) could be further improved, there is room for

breakthrough innovations in, for example, geothermal or concentrated solar power[1] (IEA, 2017[5]; IRENA, 2018[6]). Energy efficiency improvements have a large potential for reducing energy demand, especially in the building and transportation sectors. In the transportation sector, carbon emissions reductions have so far occurred through improved fuel efficiency rather than through the deployment of electric vehicles (EVs), but technical limits to increasing combustion engine efficiency implies that a switch to EVs is needed. However it's important to take a life cycle perspective when evaluating the CO_2 emissions of EVs. In the building sector 320 million tons of oil equivalent (Mtoe) of electricity could be saved by 2040 with increased energy efficiency (IEA, 2017[5]).

10. Improved energy storage technologies are critical for the green transition. It is a necessary condition for electromobility and, in the electricity production sector, it eases the demand of peak loads and increases the flexibility of renewable energy sources. Electrification of end-use sectors will themselves provide new sources of storage (e.g. batteries in EVs). Energy storage technologies are either low efficiency, but can store energy for a long term (e.g. pumped hydropower), or high efficiency, but only allow short-term storage (e.g. flywheels). Despite the lack of scalable, efficient technologies now, even partial energy storage makes the green transition more manageable and viable in the longer term. High-energy-density storage (i.e. where a lot of energy can be stored in small spaces) has the most potential for the future, especially pumped hydropower and thermochemical storages (IEA, 2014[7]).

Box 1. Carbon capture, storage and utilization

Carbon capture features prominently in most simulations that halt climate change and deliver on the Paris Agreement's temperature goal (IPCC, 2018). It is one of the most cost-effective ways to reduce carbon emissions in the power sector, with successful examples (e.g. the Sleipner plant in Norway) showing the viability of the technology. Among capture technologies, post-combustion capture is the most developed and widespread option, though other technologies are emerging (e.g. oxy-combustion capture, pre-combustion capture, supercritical CO_2 cycles). Transportation is done through pipelines, but shipping is also improving for long distance (longer than around 2400 km). With respect to storage, deep saline solutions possess the largest potential, as they are able to store potentially 10 times more CO_2 than depleted oil and gas fields.

CO_2 utilization could make carbon capture and storage more attractive. A few industries use CO_2, notably the enhanced oil recovery industry, the beverage industry and the pharmaceutical sector. However, enhanced oil recovery uses mostly natural sources of CO_2, and the demand coming from the beverage and the pharmaceutical industries is low. Though enhanced oil recovery had used mostly natural sources of CO2, economic incentives such as the 45Q tax credits in the US are expected to provide a boost for the enhanced oil recovery industry by CO2 captured from anthropogenic sources (IEA, 2018[8]). New CO_2-based products such as mineral carbonization and CO_2 concretes have potential, but current demand is too low for technology to be scalable. Another product is CO_2 fuel, but the conversion requires energy and CO_2 is ultimately re-released in the atmosphere. Currently, CO_2 utilization is not an alternative to storage (IEA, 2016[9]). It is important to build evaluation criteria or rules to distinguish effective CCU systems from those which cannot reduce life cycle CO_2 emissions.

The loss of biodiversity and ecosystem services is another major global environmental challenge. It negatively affects human health and well-being, disrupts multiple sectors, contributes to climate change and undermines the resilience of socio-economic and environmental systems. Key pressures on biodiversity and ecosystems include agriculture, land use change, pollution, over-exploitation of natural resources and climate change.

11. Most innovation targeting biodiversity loss addresses monitoring and reporting problems. New satellite technologies can provide near-real time updates on deforestation and, with the help of artificial intelligence (AI), quickly recognise illegal logging even in smaller areas (Finer et al., 2018[10]). These technologies also allow for citizen engagement in monitoring (e.g. Ebird), enforcement efforts and new business models (e.g. Global Forest Watch Pro) (Agrawala et al., 2019[11]). The emerging eDNA (environmental DNA) technology also relates to monitoring: researchers take all the DNA found in small water or soil sample, which includes all the DNA of all plants, animals but also bacteria (Stat et al., 2017[12]). This enables more accurate measurement of past and present biodiversity loss. Another promising monitoring approach is the use of acoustic monitoring systems, which identify species and estimate population size near the monitor. The acoustic monitors are also applied to combat poaching or logging, by recognizing its sounds and alerting the authorities (Deichmann and Hernández-Serna, 2017[13]).

12. Synthetic biology offers new solutions to conservation problems: it could modify the genome of invasive species or disease transmitting mosquitoes to make them sterile, or reintroduce already extinct species to balance the environment. Since ecosystems are complex, these interventions could have unintended consequences, which makes synthetic biology controversial in the conservation community (Piaggio et al., 2017[14]).

Outdoor and indoor air pollution poses a considerable threat to human health, particularly in big cities and highly populated areas. The OECD estimates the welfare cost from premature deaths due to exposure to fine particles and ozone in 2017 at USD 5.3 trillion globally.

13. Technological change in air pollution removal technologies (e.g. scrubbers, mechanical collectors) is largely incremental; most benefit comes from energy efficiency and transitioning to renewable resources, which decrease not only carbon emissions, but also air pollution. There are also some new air pollution monitoring technologies enabled by digitalisation, which help citizen engagement and policy design (see section 2.2) (Agrawala et al., 2019[11]). Most human exposure to air pollution comes from transportation, thus switching to EVs or improving energy efficiency helps alleviate air pollution from tailpipe emissions, in addition to reducing carbon emissions.

14. Electric vehicles are mature products, but pose two inter-related challenges (or opportunities). First, batteries are developing quickly but further acceleration is needed both in established li-ion technologies and in emerging technologies, such as ultra-super-capacitors or hydrogen fuel cells. This will help to increase the range and competitiveness of EVs – in 2015 only 4% of transportation (including maritime and aviation) was based on renewable energy, though the demand is increasing rapidly (IRENA, 2018[6]; IEA, 2018[15]). Second, infrastructural innovations are needed: not only a wider and strategic placement of charging stations, but also smart grids and smart charging. Otherwise, distribution systems will be at risk due to the majority of consumers charging their cars at the same time in the evening.

15. There are also emerging experimental approaches to alleviate air pollution, such as building with chemical tiles that convert air pollution to less harmful substances (Ramirez et al., 2010[16]) and buildings that integrate natural infrastructure ('vertical forests', e.g. Bosco Verticale in Milan). Though the solutions are promising, at the moment they are not cost-effective, and may entail environmental costs: chemical tiles emit carbon dioxide and vertical forests require additional water consumption.

Access to clean water presents a challenge on its own: the massive use of water in agriculture and power plants and water pollution from industrial sources makes it increasingly difficult to access clean water – 2.3 billion people are projected to live in water-stressed river basins by 2050 (OECD, 2012[17])**. Pollution is also affecting the oceans, which are already under pressure from over-fishing and climate change.**

16. A key innovation in water quality in the last decade has been the improvement and establishment of membrane treatment, which allows selective water filtering for different pollutants, based on various membrane sizes. This treatment is energy intensive, thus to balance these competing environmental imperatives, its energy demand has to be reduced. Its current market share is 1.9% of the water treatment market, but the membrane treatment has a large growth potential (Royan, 2012[18]). The focus on sanitation also produced a number of new business models (e.g. Millennium Green's rainwater harvesting). Creating artificial wetlands as a purification technique is also improving, providing nature-based solutions for pollutant filtration and disinfection of water. There are promising advances in resource (e.g. phosphorous, hydrogen, ethanol) recovery from water using microbial cells or aquatic plants. Another possible utilization is using microbial cells to generate power from wastewater. Enabling the recovery of resources from wastewater could provide an additional profit motive for water purification, but generally the infrastructures are not ready for a wide-scale application – though there are initiatives for scaling up these technologies (e.g. EU's MEET-ME4WATER) (Science for Environment Policy, 2015[19]).

17. Several incremental advances improve the environmental quality of oceans. Material engineering continues to reduce over-engineering and thus waste. Related to this, nanotechnology develops better self-cleaning, self-healing and self-diagnostic materials. As an indication of the growth of the field, the patents filed in nanotechnology have increased from 300 in the 1990s to 1800 in the 2000s. Biotechnology allows for more efficient aquacultures, thus improving competitiveness against wild fishing, albeit with other negative environmental implications. Advanced satellite technologies enable

governments to form a comprehensive picture of the ships and activities in the oceans. Combining these technologies could lead to disruptive innovations. For example, biotechnology (DNA sequencing and microchemistry) helps trace fish back to specific areas, and newer satellites are able to track unregistered vessels regardless of the weather conditions, making illegal fishing easier to detect. Another example is cleaning oil spills, where satellite imagery (together with AI) could identify oil spills quickly and the advances of biotechnology could improve the environmentally friendly remediation. The market for 'bioremediation' is estimated to be worth around USD 24 million, with quick projected growth (Transparency Market Research, 2015[20]; OECD, 2016[21]).

Managing liquid and solid waste is a challenge not only in water, but also on land. Improving solid waste management and material resource productivity more generally is now widely accepted to require the reduction, reuse and recycling of materials (the 3Rs) where this is possible, and the recovery of energy from non-recyclable material.

18. Processing of organic and inorganic waste improved significantly in the last decade. Increasingly reliable sensors and sophisticated decision and recognition software increased the accuracy and productivity of automatic sorting of waste and the quantity and quality of recovered material fractions as a consequence. These advances, for instance, increasingly allow replacing virgin polymer with recycled polymers, sometimes forming closed loop supply chains (Hopewell, Dvorak and Kosior, 2009[22]; Schneiderman and Hillmyer, 2017[23]). Techniques such as vermin-composting and rapid composting have led to conversion of organic waste into useful agricultural manure at a pace faster than natural decomposition, principally to the developing countries' advantage (UNEP, 2011[24]).

19. The various technologies in biological, thermochemical, chemical and physical conversion of waste-to-energy are all advancing but there's no one-size-fits-all; several studies showed that different waste-to-energy technologies could provide cheap electricity for developing countries (Scarlat et al., 2015[25]). In parallel to technological innovation, organisational innovation, such as through new, circular business models, is creating new opportunities to reduce material consumption or reuse products and materials once they have been refurbished or remanufactured. For instance, Renault is selling remanufactured engines that are as good as new ones, but that are made from parts of engines that had reached the end of their life (OECD, 2019[26]).

2.2 Recent trends in green technology development

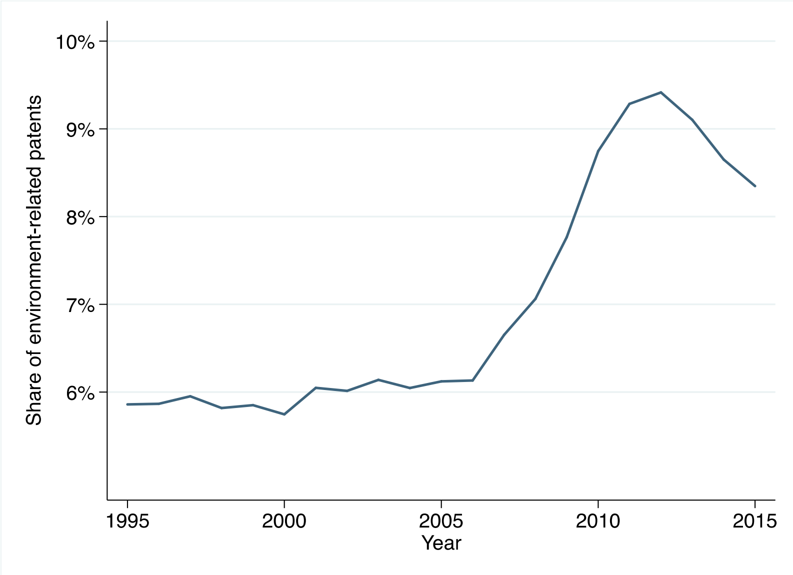
20. The pace and progress of environmental innovation can be measured by looking at global patenting activity in related technologies. Figure 1 shows this activity between 1995 and 2015 for a range of environment-friendly technologies. The combined data cover most of the technologies available today to mitigate greenhouse gas emissions, but also technologies related to air pollution control, waste management, water management, adaptation to climate change, soil remediation and environmental monitoring. Specifically, technologies included are:

- Low-carbon electricity production, for example renewables, nuclear, biofuels, smart grids, energy storage and carbon capture and storage.
- Low-carbon transportation, for example fuel efficiency technologies, electric, hybrid and fuel cells vehicles, and lighter materials.
- Energy efficiency in the buildings sector, for example energy-efficient lighting and heating, and insulation.
- Energy efficiency in the manufacturing sector, for example energy-efficient industrial processes, and material recycling.
- Air pollution control technologies, for example purification of waste gases (e.g. engine exhaust gases), smoke purifiers, dust collectors, and catalytic converters.
- Adaptation to climate change, for example sea walls, tidal barriers, flood forecasting, reforestation, storm shelters, and medical treatment of waterborne diseases.
- Water pollution abatement, for example wastewater or sewage treatment, fertilizers from wastewater, and oil spill clean-up technologies.
- Waste management, for example solid waste collection, material recovery, recycling and re-use, fertilizers from waste, and energy recovery from waste incineration.
- Water saving technologies, for example indoor water conservation (aeration of water, dry toilets), greywater reuse, drip irrigation, drought-resistant crops, leakage monitoring in pipes, rainwater collection and replacing steam power generation by photovoltaics and wind turbines.
- Other environmental technologies, such as remediation of contaminated soil and environmental monitoring.

21. Because growth could reflect the general growth of patenting in all technologies (not just environment-related technologies), Figure 1 indicates environment-friendly inventions as a share of environment-related inventions in all technology areas. Following a period of strong growth between 2006 and 2012, innovation efforts in environmental technologies have declined recently. Between 2006 and 2012, the number of new environment-related inventions patented as a share of total patents globally grew at an annual rate of almost 10 per cent: more than double the rate of innovation of all technologies. However, environmental innovation efforts started to decline in 2013. This recent downward trend in environment-friendly innovation suggests that public policies are needed to lift the barriers to clean technological development. These are discussed in Section 4.

Figure 1. Environmental innovation efforts have declined recently

Share of worldwide patent filings in environment-related technologies.

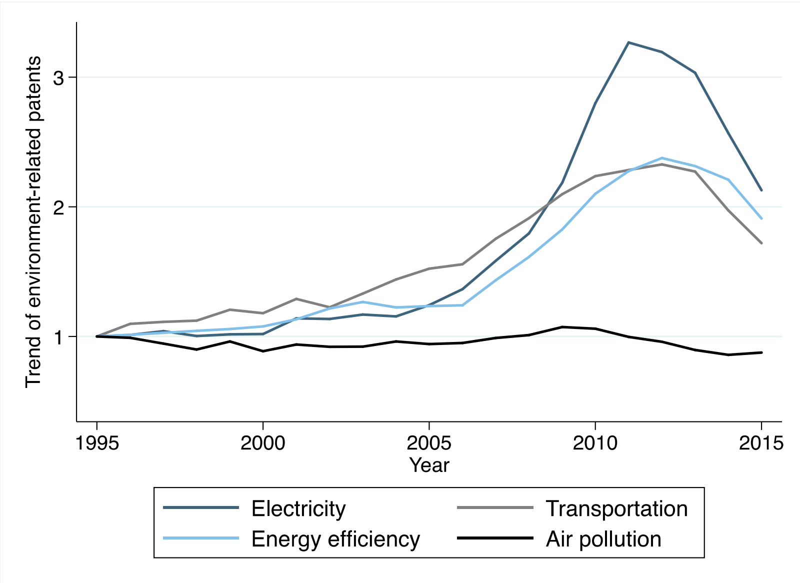


Source: OECD Green Growth Indicators database (OECD, 2017[27]).

22. However, this downward trend in environment-friendly innovation efforts is concentrated in low-carbon technologies. This is shown in Figure 2 and Figure 3, which display the trends for eight technology groups. Figure 2 shows low-emissions technologies (low-carbon electricity production, low-carbon transportation, energy efficiency in the buildings and manufacturing sector, and air-pollution-control technologies) and Figure 3 shows technologies related to water treatment and saving, waste management and climate change adaptation. While low-emissions technologies have clearly declined over the last few years up to 2015 (the last reliable year of data), this is not the case for other environment-related technologies. Technologies related to water use, water treatment, adaptation to climate change and (to a lesser extent) waste management have experienced sustained growth over the last ten years. For example, the level of patenting of water conservation technologies has been higher than the overall rate of patenting for all technologies since 2008, suggesting an increasing focus on the need for better management of water resources. Amongst demand-side (conservation) technology patenting, inventions to conserve water during thermoelectric power production and water storage technologies have grown at an especially high rate (OECD, 2019[28]).

Figure 2. Low-carbon innovation efforts are declining

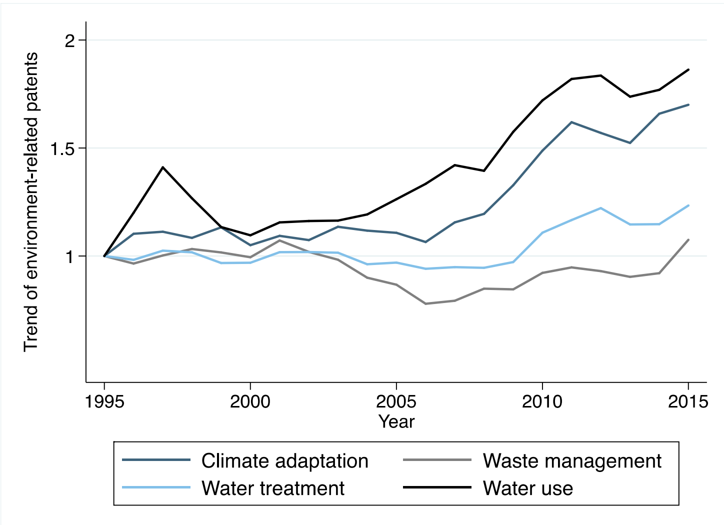
Share of worldwide patent filings in environment-related technologies (1995=1).



Source: OECD Green Growth Indicators database (OECD, 2017[27]).

Figure 3. Environmental innovation efforts have declined recently

Share of worldwide patent filings in environment-related technologies (1995=1).



Source: OECD Green Growth Indicators database (OECD, 2017[27]).

2.3 Enabling technologies

23. Alongside green technologies, a number of technologies that are not strictly speaking green will be necessary to achieve the green transition. This includes in particular digital technologies such as artificial intelligence, the internet of things and blockchain[2].

24. Artificial intelligence (AI) has potential in fields where there is a need for pattern recognition and forecasting; it can contribute to a low-carbon economy through multiple channels. AI can forecast weather and electricity prices, thus mitigating intermittency problems in the system and increasing energy efficiency. Transmission and distribution system operators could use AI for real-time decision support. In general, energy systems are becoming more complex (with more variable renewables in the systems and increasing consumer empowerment), which increases the need for AI solutions. As mentioned above, AI could also help identify oil spills in the oceans from satellite images and could improve emergency decision support systems (OECD, 2016[21]). Biodiversity could also benefit from AI: satellites are complemented by AI to recognise land use change. The waste sector already uses AI algorithms to help with sorting.

25. Though the Internet of Things (IoT) is often viewed as environmentally damaging, because the devices and servers require large amounts of energy, it also presents new opportunities to solve environmental problems. Buildings could adapt in real time to weather conditions and prices, thus increasing energy efficiency (OECD, 2016[29]). There are other applications, such as monitoring the nutrients (and pollutants) in the oceans; and auditory monitoring against poachers, which can only work with widely distributed sensors (OECD, 2016[29]). Cheaper sensors could also give a more accurate picture of air pollution and initiate citizen engagement. The technology has the potential to transform urban environments as well, by using the huge masses of data (CCTV, parking sensors etc.) sent to local governments to create 'smart' cities. A few cities have started to use smart streetlights, which adapt to weather, traffic flows, time of day or requests made to emergency services, all of which contribute to saving electricity. Similarly, 'smart' traffic lights can adapt to traffic flow, reducing air pollution and increasing energy efficiency of transport.

26. Blockchain's main strength could be managing the distributed grid as it facilitates decentralized consumer-to-consumer selling of electricity and balancing supply with demand without needing a third party. It enables trust where there is none and helps facilitate operability between private and public systems, thus lowering transaction costs. It also enables "smart contracts" that automatically facilitate a contract between participants when certain conditions are met. There are several ongoing business pilots applying blockchain to the energy market, e.g. Enerchain in Amsterdam, Electron in the UK, LO3 Energy in Brooklyn (OECD, 2018[30]). Another possible application could be to help combat deforestation and illegal fishing, because blockchain makes it easier to uphold supply chain transparencies, as all participants have a copy of all transactions. While blockchain holds great promises, one should note that it is not always scalable and it is occasionally energy consuming. Good regulation might be essential for efficient utilization of blockchain. It is also important to keep in mind that these new technologies are not ends in themselves, but can be tools to achieve environmental goals (OECD, 2018[31]; IRENA, 2018[6]).

3. What are the business/market opportunities stemming from the transition to a greener economy?

27. The shift of the global economy towards a green growth model prevents environmental damages, such as climate change, biodiversity loss, over-exploitation of natural resources, and air pollution, and thus should lead to welfare improvement. While these welfare benefits are unquestionable, the economic benefits – as measured by employment, productivity or GDP growth – are less easy to predict. While an estimation of the aggregate effects of a green transition is lacking, a previous OECD report showed that, in the case of a low-carbon transition, economic growth and positive environmental outcomes can be reconciled (OECD, 2017[32]). This is especially true in the short-run. In the long run, a greener economy could simply induce substitution of polluting for non-polluting activities, with no quantitative effect on total economic output. However, the transition phase will definitely present opportunities for some sectors and threats for others; some activities will expand based on new technological knowledge while others contract. This section summarizes how and where short-term and long-term economic benefits could occur.

3.1 The growing green economy

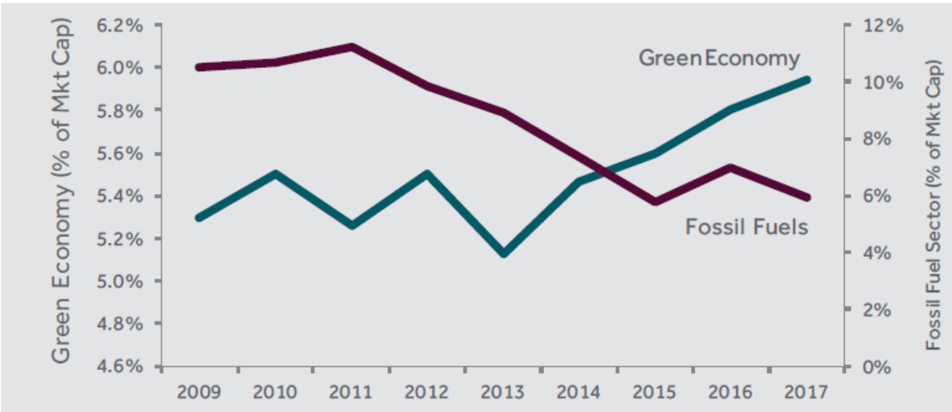
28. A well-managed transition to a greener economy will create opportunities for businesses and workers. The companies that supply cutting-edge clean technologies listed in the previous section (and further clean technologies that do not yet exist) are expected to grow, as these technologies will massively diffuse over the next decades. For example, low-carbon intensity sectors – including renewable energy manufacturers, electric cars producers, and so on – will see the demand for their products increase as consumers look for substitutes to high-carbon goods. Opportunities will arise all along the supply chain, from technology providers to users of more energy-efficient technologies. Some sectors will grow more than others, but within each sector, companies using resources more efficiently will have a competitive advantage. There will also be significant opportunities for financial institutions, which will direct investment towards sustainable projects.

29. Evidence shows that the green economy is already growing. Recent analysis by FTSE Russell (2018[33]) shows that there are approximately 3,000 listed global companies (as of 2017) with exposure to the green economy (defined as products and services in renewable and alternative energy, energy efficiency, water, and waste and pollution).[3] This number has risen by approximately 20% since 2009, based on the 30% of global listed market capitalization. According to this study, the green economy now represents 6% of the market capitalisation of listed global companies, amounting to approximately USD 4 trillion. This shows a significant investment opportunity, approximately the same size as the fossil fuel sector.

30. Moreover, the green economy proportion of the global market capitalization is growing, while the fossil fuel sector is shrinking (see Figure 4). Figure 6 shows the longer-term prospects of the green economy: continuing on the current trajectory would lead to a 7% of market capitalisation by 2030 (higher than the fossil fuel industry). With accelerated green investment, market capitalisation would increase to 10% by 2030, approximately the

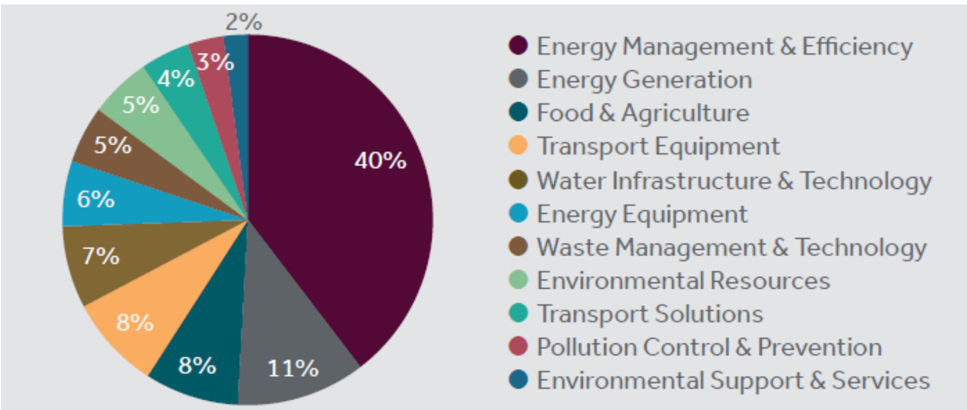
same size as the health sector, just below the banking sector. Interestingly, the FTSE Russell data indicates that the green economy spans multiple sectors of the economy (Figure 5) and not only in sectors whose primary activity is to contribute to environmental protection, such as the waste management sector. A recent paper estimates that 20% of the US workforce could be employed in the green economy (Bowen, Kuralbayeva and Tipoe, 2018[34]).

Figure 4: Growth of the green economy vs fossil fuel sector



Source: FTSE Russell (2018[33])

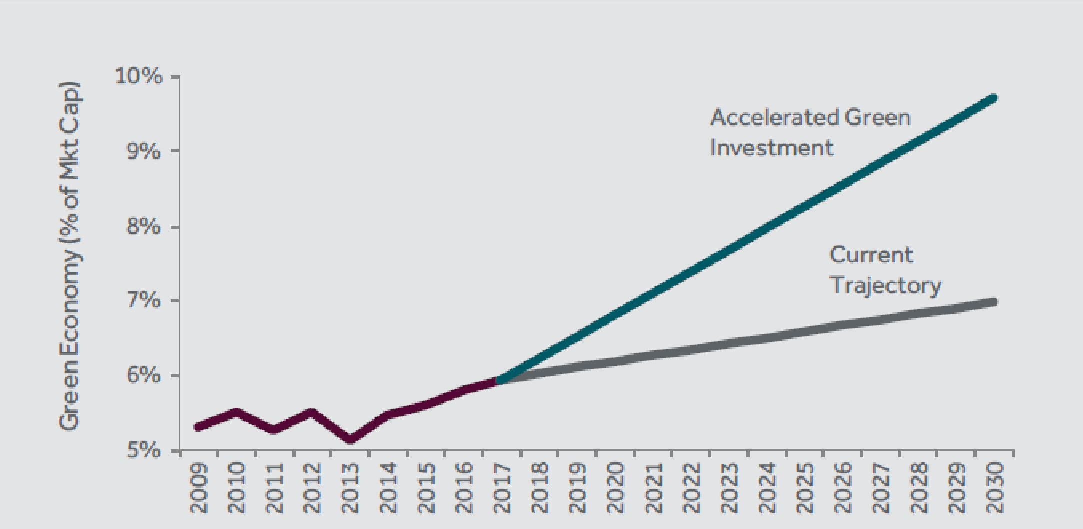
Figure 5: Green economy by green sector



Source: FTSE Russell (2018[33])

31. The recent period offers many examples of regions and sectors that have benefitted from efforts to improve the quality of the environment, e.g. Denmark's wind industry (which today represent 10% of all Danish exports) or China's PV industry.

Figure 6. Potential future growth of the green economy



Source: FTSE Russell (2018[33])

3.2 Indirect benefits from the green transition at the macro level

32. Alongside these "direct" benefits to green and greening sectors, there will be indirect benefits spanning the economy, such as from technological and non-technological knowledge spillovers and productivity improvement from better health due to low air pollution.

33. It is well established in the economic literature that R&D activities provide not only private returns to inventors, but also returns to the society which are not captured by inventors (Geroski, 1995[35]). In most cases, new technologies must be made available to the public for the inventor to reap the rewards of invention. However, by making new inventions public, some (if not all) of the knowledge embodied in the invention becomes public knowledge. This public knowledge may lead to additional innovations.[4] These knowledge spillovers provide benefits to the public as a whole, but not to the innovator. An obvious example of such a spillover is Android-based smart phones. Apple first launched the now dominant design of smart phones. However, other companies such as Google were also able to benefit from Apple's original R&D investments by building upon or improving the original design.[5] Economists studying the returns to research consistently find that knowledge spillovers result in a large wedge between private and social rates of return to R&D. Typical results include marginal social rates of return between 30 and 50 percent. In comparison, estimates of private marginal rates of return on investments range from 7 to 15 percent (Popp, 2010[36]).

34. Since firms make investment decisions based on their private returns, the wedge between private and social rates of return suggests that socially beneficial research opportunities are ignored by firms because they are unable to fully capture the rewards of such innovations. Climate change policies that address this market failure and induce

innovation in low-carbon technologies can therefore increase welfare (depending on the extent to which increased R&D investment in low-carbon technologies comes at the expense of investments in other welfare-enhancing technologies).

35. Recent research has demonstrated that knowledge spillovers are 60% larger for low-carbon than for high-carbon technologies (Dechezleprêtre, Martin and Mohnen, 2014[37]). Where does the low-carbon advantage come from? One potential explanation is that clean technologies are mostly new technology fields. New technology fields offer potentially high marginal private returns to first movers and might thus generate large knowledge spillovers. Dechezleprêtre, Martin and Mohnen (2014) compare the spillovers from low-carbon and high-carbon technologies to a range of other emerging technologies, such as IT and biotechnologies. They find that the intensity of spillovers from low-carbon technologies is comparable to other emerging technologies. Knowledge spillovers from high-carbon technologies are lagging behind. [6]

Figure 7: **Low-carbon and high-carbon spillovers versus other emerging fields**

Note: The figure compares the intensity of knowledge spillovers (as measured by patent citations) in a number of technologies, compared to the average patented technology. The y-axis represents the percentage difference in the intensity of knowledge spillovers. For example, a value of 0.2 means that the technology induces 20% more knowledge spillovers than the average patented technology. Black dots are point estimates; the black lines show 95% confidence intervals. Source: (Dechezleprêtre, Martin and Mohnen, 2014[37])

36. Thus, there is evidence for policies that encourage the development of new low-carbon technologies can have economy-wide benefits through increased innovation spillovers. An important implication of this finding is that seeking only 'win-win' solutions with no losers would risk leaving many socially beneficial policies off the table.

37. Another indirect benefit of low-carbon technologies is improved air quality. The potential economic consequences of both the market and non-market impacts of air pollution are significant and underscore the need for strong policy action. Spikes in air pollution and long-term exposure to high concentrations of air pollutants affect human health, causing increase in both mortality (i.e. the number of premature deaths attributable to air pollution) and morbidity (i.e. the increase in the incidences of illnesses due to air pollution). Pollution-related illnesses include lung cancer, cardiovascular diseases (ischemic heart disease and stroke), respiratory diseases (chronic bronchitis and asthma) and chronic obstructive pulmonary diseases (Hunt et al., 2016[38]). The additional cases of illness result in more hospital admissions, medical expenses and absences from work. In turn, the absences from work can lead to a reduced productivity of labour. However, air pollution can also have a direct impact on labour productivity, without resulting in absences from work (OECD, 2016[39]).

3.3 Looking forward: Competitiveness in a greener world at the country-sector level

38. Which countries and sectors are best positioned to seize the opportunities stemming from the green transition? Fankhauser et al., (2013) identify three success factors for green competitiveness at the sector level: the speed at which sectors convert to green products and processes (measured by the rate of green innovation), their ability to gain and maintain market share (measured by existing comparative advantages as revealed by international trade data) and a favourable starting point (measured by current output). This section applies the methodology proposed by Fankhauser et al., (2013) and uses up-to-date data to provide an indication as to which sectors in which countries are well positioned to benefit from a low carbon transition (for more details on the indices, see Box 3).

Box 3. Green index and competitiveness index

For each economic sector in each G20 country[1], an index of green innovation activity is calculated, which measures the ratio of green patents to total patenting activity. It is combined with an index of revealed comparative advantage on the world market, which measures each country-sector's relative export share (Balassa, 1965[40]). This indicator offers an indication of a particular country-sector's ability to gain and maintain market share in the future. Total sector output indicates the potential size of green output, assuming the green economy implies that each sector will in effect have to "green" itself. The units of analysis are all manufacturing sectors at the three-digit industry level (ISIC Rev. 3 codes 151-369) in the G20 countries. In particular, the analysis uses the recently developed Y02 class from the European Classification System (ECLA), which covers patents related to 'technologies or applications for mitigation or adaptation against climate change'.

39. The 50 sectors in the analysis play different roles in today's economy with respect to the environment and its protection. The sample includes sectors that cause most environmental damage during production, such as pulp, paper and paperboard. It includes sectors whose output causes most environmental damage at the consumption stage, such as motor vehicles, and sectors whose output may cause most damage in the final disposal stage, like processing of nuclear fuel. The sample also includes sectors that may or may not be relatively benign in their own environmental footprint, but that have the potential to contribute to the greening of other sectors. One such sector is electricity distribution and control apparatus, which holds the key to smarter electricity grids.

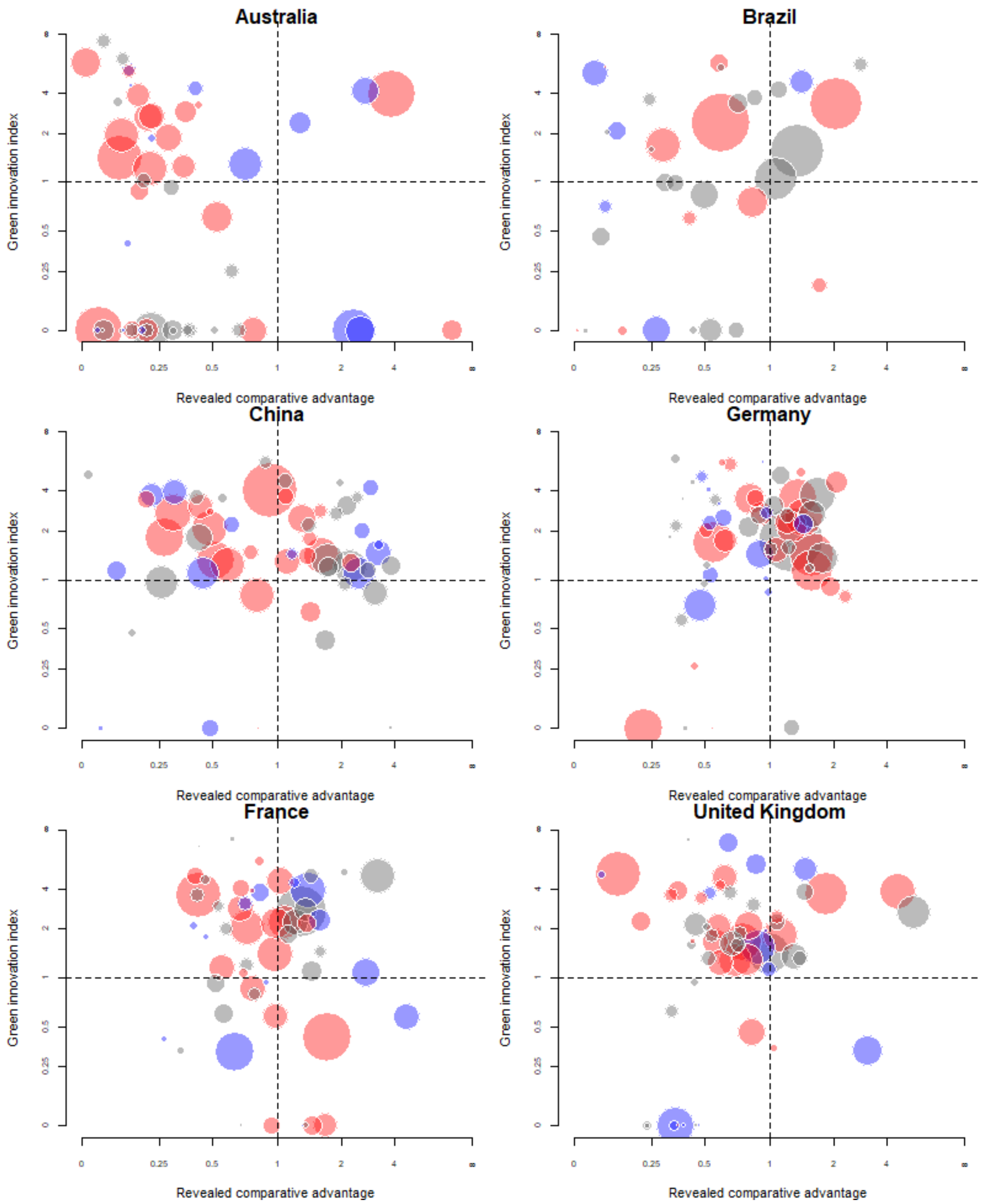
40. Figure 8 shows the potential competitiveness of all sectors in the G20 countries. The size of the circles indicates the relative importance of the sector in the economy. Red circles indicate a heavy manufacturing industry, blue indicates light manufacturing, and grey indicates other manufacturing. The horizontal axis shows the revealed competitiveness index, with the world average normalised to one. The vertical axis measures the green innovation index, with the world average again normalised to one. Individual country charts in Figure 8 can be interpreted as follows:

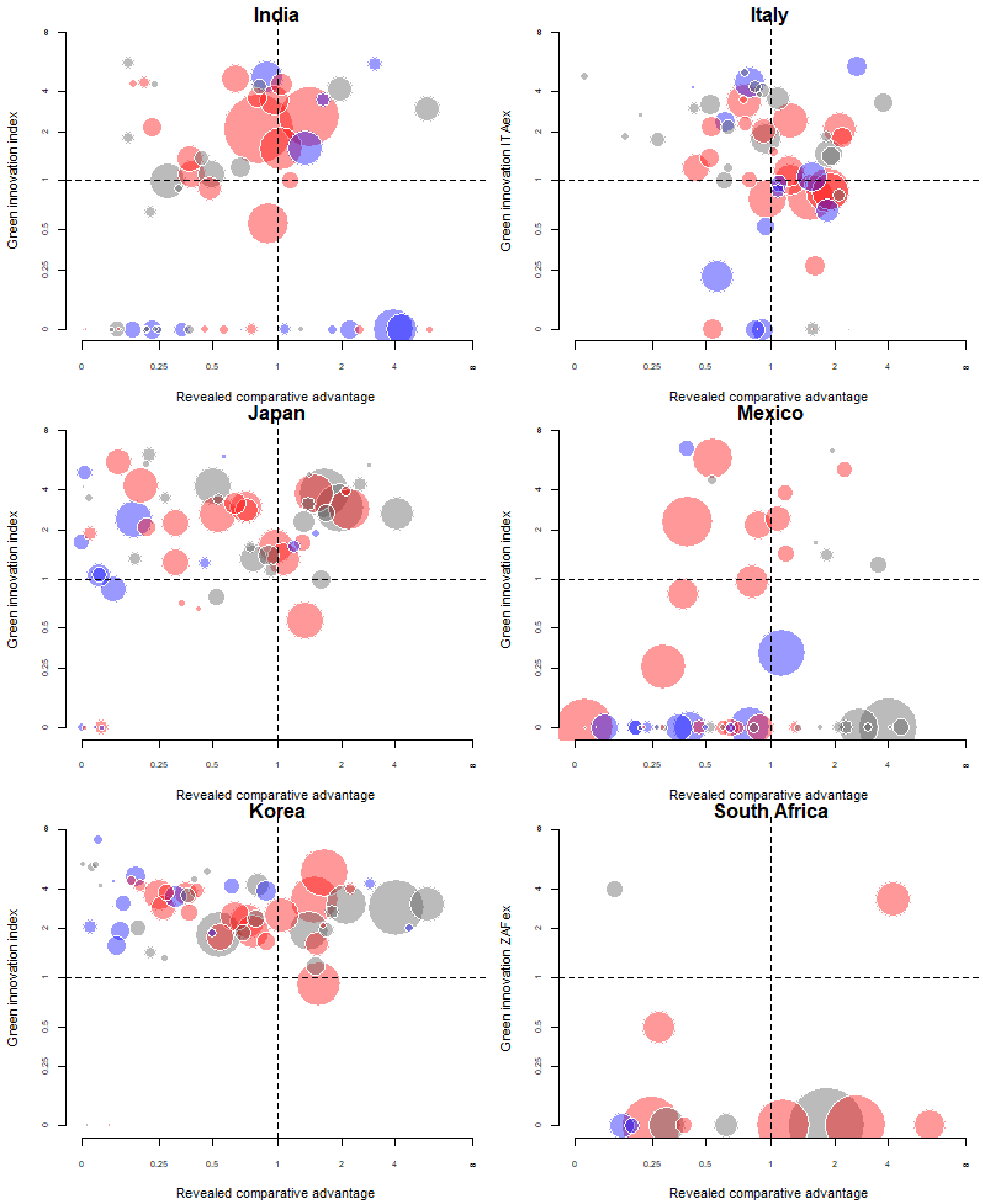
- Sectors in the top-right quadrant signify strengths: these sectors are areas of current comparative advantage (high score on the x-axis) and there is substantial green innovation (high score on the y-axis), which should ease the conversion to low-carbon products and processes. The sectors are thus well positioned to remain areas of competitive strength in the green economy.
- Sectors in the top-left quadrant signify opportunities: these sectors are currently not areas of comparative advantage; they export less than the world average. However, there is significant low-carbon innovation, which could facilitate the conversion to low-carbon products and processes. The sectors could therefore become areas of future strength, displacing less innovative incumbents.
- Sectors in the bottom-right quadrant signify threats: these sectors are areas of current comparative advantage, but where there is insufficient low-carbon

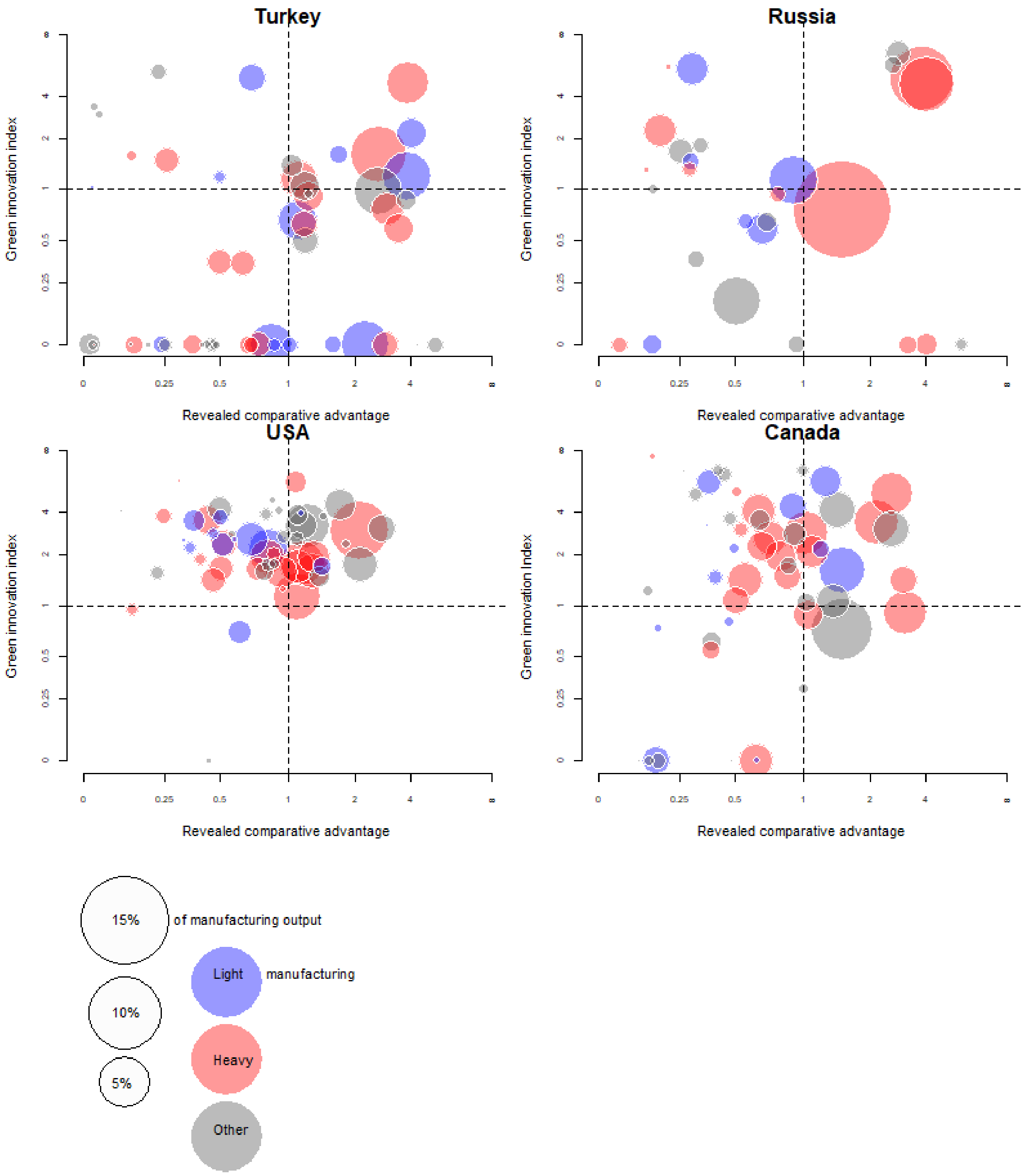
innovation. The conversion to clean products and processes may stall and market share may be lost as the green economy grows.

- Sectors in the bottom-left quadrant signify weakness: these sectors are neither areas of current comparative advantage, nor is there sufficient low-carbon innovation to build up a new area of comparative advantage.

Figure 8: Potential areas of green competitiveness by sector-country




India
Green innovation index
Revealed comparative advantage
Italy
Green innovation ITAex
Revealed comparative advantage
Japan
Green innovation index
Revealed comparative advantage
Mexico
Green innovation index
Revealed comparative advantage
Korea
Green innovation index
Revealed comparative advantage
South Africa
Green innovation ZAFex
Revealed comparative advantage


Turkey
Russia
USA
Canada
Green innovation index
Revealed comparative advantage
0
0.25
0.5
1
2
4
8
15%
of manufacturing output
10%
5%
Light
manufacturing
Heavy
Other

41. Without going into sectoral detail, Figure 8 suggests a highly nuanced picture without unequivocal winners and losers. Every country has strengths and opportunities in the green economy, but most countries also face weaknesses and threats. Some countries – including Canada, China, Germany, Japan, Korea, the UK and the US – seem to be the best positioned to take advantage of the green economy based on their current profile, with a heavy concentration of strengths and opportunities. Itis interesting to see that across many countries – including Russia, Turkey and Brazil – the sectors that currently hold a comparative advantage are also leading green innovators, suggesting that countries may be able to maintain their strong competitive positions in the green economy.

42. Concentrating on sectors with positive green innovation scores, an even distribution of sectors in Brazil, France, Italy, Russia and Turkey can be observed, suggesting a fairly equal balance between strengths, weaknesses, opportunities and threat. In China, Korea and Japan, the visual picture suggests promising new opportunities. Sectors that do not currently enjoy a comparative advantage are innovating strongly, potentially opening new areas of comparative advantage. India and Turkey exhibit noticeable strengths, but also a sizeable fringe of low green innovation sectors.

43. One important observation is the significant number of sectors, across countries, with hardly any green innovation at all: in some countries, there is a noticeable concentration of sectors with a green innovation score of zero at the bottom of the chart. Few of them are areas of current comparative advantage for their country, but there are exceptions, for example in Mexico, South Africa, and to a lesser extent Australia and Turkey.

44. The focus of this analysis on countries is motivated by data availability, but it is important to recognize that, within each country, regions also have a large role to play as some of the new technologies necessary for the green transition are dependent upon local conditions, including resource availability, technical capabilities and demand. As such, it is necessary not only for countries but also for regions to encourage green innovation, collect data, track progress and share experiences with each other.

3.4 Managing a just and inclusive transition

45. While the transition to a greener economy is a clear business opportunity given the scale of the transformation needed, it will also lead to reallocations both between and within economic sectors. There is limited analysis of the potential sectoral adjustments. An important contribution in this regard is provided by a recent OECD paper (Chateau, Bibas and Lanzi, 2018[41]). The authors analyse structural changes to the labour market induced by decarbonisation policies in line with a 450ppm CO_2 concentration target in 2035, and estimate variations in output and employment at the sector level.

46. In general, the aggregate impact of the changes on employment is expected to be limited. Simulations suggest that the overall reallocation of jobs (sum of created and destructed jobs) would be around 0.3% for OECD countries and 0.8% for Non-OECD countries (Chateau, Bibas and Lanzi, 2018[41]). These rates are relatively small compared to reallocation movements observed during the past decades: job reallocation rates averaged at 20% over period 1995-2005 in OECD Member countries. One of the main

explanations for the limited consequences in terms of job reallocations is that the heavily impacted sectors (mostly energy sectors) represent only a small share of total employment (82% of the largest CO_2 emitting non-agricultural sectors comprise only 8% of the total jobs in 27 OECD countries).

47. These reallocations also appear small when compared with other major macroeconomic trends such as globalisation and the diffusion of new information and communication technologies. Ever-increasing computing power, Big Data, the penetration of the Internet, Artificial Intelligence (AI), the Internet-of-Things and online platforms are among the developments radically changing prospects for the type of jobs that will be needed in the future, and how, where and by whom they will be done. One study commissioned by the OECD and using workers' reports of the tasks involved in their job from the OECD's Survey of Adult Skills (PIAAC), Arntz, Gregory and Zierahn (2016[42]) estimates that 9% of jobs are at a high risk of being automated. In addition, 25% of jobs will be changed fundamentally. In comparison, therefore, the green transition appears very manageable.

48. Job losses from the green transition are expected to be concentrated in "brown" sectors, broadly defined as carbon-intensive industries and sectors related to extraction and processing of fossil fuels. For example, employment in 'Mining and fossil fuel supply' and "Fossil-fuel electricity generation" is predicted to decrease by around 8% in OECD countries compared to baseline estimations (Chateau, Bibas and Lanzi, 2018[41]). In a recent report, the ILO estimates the impact of measures taken to maintain temperature rise below 2°C (ILO, 2018[43]). "Brown sectors" are found to decrease their workforce between 11% (extraction of gas and petroleum) and 19% (coal-powered electricity generation) by 2030, compared to a business-as-usual scenario.

49. It is important to note that these numbers refer to narrowly defined subsectors. At a larger level, the simulations show that jobs are not lost, but shifted across sub-sectors. For example, within the electricity generation industry as a whole, the simulation results indicate that fossil fuels generators experience job losses while renewable energy generators experience job gains. Since renewable energy is more labour-intensive than fossil-based energy, the transition creates jobs in the electricity sector in net terms. Similarly, the ILO report estimates that carbon emissions reduction measures in the production and use of energy will lead to the creation of some 24 million jobs, but also to job losses of around 6 million. The net increase of approximately 18 million jobs across the world results from the adoption of sustainable practices, including changes in the energy mix, projected growth in the use of electric vehicles, and increases in energy efficiency in existing and future buildings (ILO, 2018[43]).

50. The transition to circular economy also entails job reallocation. A literature survey by the OECD reviews more than 20 modelling studies about macroeconomic consequences of the circular economy (McCarthy, Dellink and Bibas, 2018[44]). According to the survey, most papers find that the circular economy transition would create jobs on the net. However, the authors argue that the relatively narrow scope in terms of regions and sectors of the modelling exercises limits the generalisation. They argue that the net effect on employment of a circular economy transition is uncertain.

51. Finally, even within narrowly defined sectors, there will be reallocations between firms as energy efficiency becomes a competitive asset. In a global firm-level study, Albrizio, Kozluk and Zipperer (2017) show that while the most technologically-advanced firms benefit from a tightening of environmental policies in terms of productivity gains, a third of less productive firms experience a productivity slowdown. Even if these reallocations are small compared to usual job movements across sectors, it will be important to pay attention to potentially negatively affected firms and sectors in this transition.

4. What are the barriers/challenges for such opportunities to materialise?

52. Many of the technologies needed for a cleaner global environment, and in particular to hold global temperature rise well below 2°C, already exist. Many more, such as AI, promise to advance low-emissions technologies even further, provided there are sufficient incentives for public and private investment in R&D. Despite this, many existing solutions are not yet deployed at scale. Only four out of 38 low-emissions technologies fundamental to achieving the 2°C target are on track to penetrate markets sufficiently: PV, lighting, data centres and networks, and electric vehicles (IEA, 2018[45]).

53. There are a number of barriers limiting the development and diffusion of new cleaner technologies, and thus preventing the business opportunities associated with the green transition to materialize. Some of these barriers would apply to any transformation of the economy, while others are specific to the green transition.

54. Any structural transformation of the economy faces generic barriers that are not specific to the green transition. These include skills shortages, innovation capacities, and lack of competition, among others:

- New technologies require new skills to enable the technologies to be developed and diffused, and new infrastructure to be deployed. Thus, a successful green transition is likely to entail, for example, upgrading skill sets in industries experiencing only minor adjustments; gearing up educational institutions and firms to provide the new skills for new occupations and sectors that will emerge from the green economy[7]; and retraining and realigning skills in sectors that will decline as a result.
- More generally, strong innovation capabilities will be required. This includes not only the training of researchers, but a well-functioning innovation ecosystem. In particular, the financing of R&D and innovative activities is notoriously difficult in a freely competitive market, because the primary output of resources devoted to invention is the knowledge of how to make new goods and services, and this knowledge can be easily appropriated by competitors. Financial barriers emerge because investors lack the knowledge necessary to accurately evaluate the risk-return profile of new technologies. Lack of adequate financing along the entire innovation chain is one of the main obstacles in the commercialisation of science. For example, in the EU there is a structural problem with access to financing for disruptive science and R&D-based companies ("deep-tech"), especially for early-

stage companies whose products are not finalised and therefore cannot obtain seed funding.

- Barriers to a dynamic business environment, such as limitations to competition, can slow down any transition. Encouraging the entry of new, adventurous firms (and the exit of less innovative and less productive firms), is important as new firms are often the vehicle through which radical, game-changing innovations enter the market, as older incumbent firms often focus on incremental changes to established technologies. Lack of business dynamism (i.e. lack of market entry and exit) means that low-emissions innovations may not overtake fossil fuel-based incumbents and secure their place in mainstream markets, even if they are more efficient. Concentration of market power means that long-term investors (e.g. asset-heavy banks, institutional investors) may favour incumbents because of perceived stable returns. Though alternative forms of financing (e.g. business angels and VC) can take greater risks, they do not invest with a sufficiently long time horizon to drive the transition.

- Social barriers result from lack of public acceptance and engagement with new technologies (e.g. due to lack of information or perceived negative health and safety consequences).[8] Communicating, preventing, correcting and mitigating adverse effects has become important for the deployment and diffusion of new technologies. This is increasingly challenging as innovations become more complex.

- Compared to large firms, smaller firms are more dependent on external sources of technology and knowledge. Managers of small firms may have insufficient information about production processes or are unaware of best available low-emissions technologies and practices applied elsewhere. Similarly, potential suppliers may have learning costs, lack expertise or face other structural barriers to promoting the diffusion of low-emissions technologies.

- Political and institutional barriers result from governance and co-ordination failures due to incoherence or inconsistent timing across policy areas. Misalignments can be horizontal (i.e. between innovation policies and sectoral policies), vertical (i.e. between ministries and implementing agencies) or multi-level. Especially in large-scale systems, technologies can be subject to lock-in or dominant design that prevents other technologies from emerging. For example, diffusion of low-emissions vehicles is hindered not only by price or battery storage capacity, but also by the lack of a charging network in cities and along motorways.

55. Alongside these generic barriers to any structural economic transformation, there exist barriers specific to the green transition.

- Recent work by the OECD on system innovation shows that policies aimed at transitioning sociotechnical systems to more environmentally sustainable configurations differ significantly from those aimed at increasing the economic performance of existing systems. There is also concern that traditional incentives to business R&D are not favouring innovations directed at climate change and other systemic challenges (Cervantes, Copeland and Zarnic, 2018[46]).

- Provision of inefficient government subsidies for the wasteful consumption of fossil fuels and failure to take environmental externalities into account (e.g. negative externalities from fossil fuel-based technologies, or positive externalities from low-emissions technologies), means that prices under-incentivise the uptake of low-emissions innovations. Unregulated emissions in some countries/sectors or misaligned fiscal policies favouring fossil fuel based technologies reduce the size of the future market for green technologies, which in turn reduces innovation. In other words, private investment in green technologies will increase, if the demand is large enough, so policies should align the private costs with the public (environmental) costs. Despite efforts to price this information in, there is significant room for improving market pricing.
- An important feature of the green transformation is that - at least in the short term until green technologies become cost-competitive with brown technologies - demand for green goods depends on public policies. Policy uncertainty has been shown to depress investment and economic growth (Bloom et al., 2018[47]).
- Regulatory gaps can act as a barrier to the adoption of low-emissions technologies. For example, upstream power sectors increasingly rely on waste as a fuel (to reduce CO_2 emissions and landfill), but their ability to do so is sometimes hindered by outdated regulations at local, national and even international level (notably as concerns the export and import of waste). Environmental policies that treat entrants and incumbents in a differentiated manner are another threat.
- Other barriers may be sector-specific, such as the high capital intensity of the energy sector or the integrated solutions in-demand from water utilities.

5. What role for policy and for the G20?

56. What can G20 governments do, both individually and as a group, to overcome the barriers presented in the previous section and pave the way for a global green transition? This section explores key opportunities for G20 Member States to better harness innovation for the green transition.

5.1. Domestic policies: supporting innovation and environment-friendly activities

57. A first set of policies to overcome the above mentioned barriers are domestic in nature, but they can be further enhanced by international cooperation. Indeed, a major role for public actors will be to provide direction and co-ordination to different policy areas in order to work towards a common goal.

Environmental policies

58. First, more ambitious environmental policies – such as emissions and natural resource pricing policies, elimination of inefficient fossil fuel subsidies that encourage wasteful consumption or other environmentally-harmful subsidies, or subsidies for the development and dissemination of green technologies – are needed to discourage polluting activities and over-exploitation of natural resources. They will also encourage the

widespread adoption of cleaner technologies. Policies are shown to be cost-effective when underpinned by a clear, long-term commitment by governments, providing innovators with the confidence they need to take long-term decisions (Climate Finance Study Group, 2016[48]). To reduce the political risk for financiers at all stages of the innovation cycle, timing and consistency are important (Veugelers, 2012[49]), as are flexibility, stability, targeting, stringency and predictability (Criscuolo and Menon, 2015[50]). As a result, it is important that G20 governments set long-term comprehensive environmental strategies at the national level covering both climate change and other environmental issues. Such long-term strategies are critical to encourage the private sector to act towards green transitions, including through voluntary initiatives or sandbox approaches (e.g. UK FCA's Regulatory Sandbox).

59. Environment-friendly mission-oriented policies, demand-side policies, regulation and performance standards, and public procurement can support the integration of environmental considerations in the innovation policy. Immature but potentially transformative low-emissions innovations must often compete against hefty incumbent technologies in markets with high barriers to entry and exit, which makes them risky for innovators. Governments can help to break path dependence in these circumstances – as has been the case for renewable electricity (Climate Finance Study Group, 2016[48]). The rise in global investment in renewable power capacity (to USD 266 billion in 2015 – more than double the allocation to new coal and gas generation) was driven in large part by significant support to technology deployment through targeted incentives (e.g. fixed prices and guaranteed purchase for renewable electricity (Climate Finance Study Group, 2016[48]; FS-UNEP and BNEF, 2016[51])).

60. Governments can smooth out the flow of finance by using public funds to invest directly (e.g. the US loan to Tesla) or by using public funds or policies to leverage private finance (e.g. the European Investment Council). For example, in Turkey policy support coupled with investments from multilateral development banks (MDBs) and the Clean Technology Fund (CFT) helped to leverage private sector capital, and transformed Turkey's renewable energy and energy efficiency markets from a virtually non-existent to one that could be financed on commercial terms over 2009 to 2014 (World Bank, 2015[52]).

61. Mainstreaming biodiversity and other environmental considerations across all sectors of the economy is crucial to improve coherence and policy alignment (OECD, 2018[53]). Budgeting processes can also be used to help attain these objectives. The Paris Collaborative on Green Budgeting promotes the use of the policy tools of budgeting (taxes, financial outlays, and co-ordination) to promote the alignment that is essential to meet environmental goals (OECD, 2018[53]).

62. Finally, governments should promote collaborative innovation networks – which may matter more than a traditional menu of fiscal measures for de-risking innovation (Bennett, 2018[54]). Dedicated platforms that foster cooperation between researchers, companies and governments can enhance innovation performance and help funding it. Illustrative examples are the Fraunhofer Institute in Germany, the Environmentally Sound Technology (BEST) Cooperation Platform for Brazil, Russia, India, China and South Africa (10th BRICS Summit, 2018[55]), or the Innovation for Cool Earth Forum (ICEF) hosted by Japanese government.

Aligning policies

63. Policy makers face the need to develop a vision of what future sustainable systems will look like, including what technologies are likely to play important roles in the future system, what infrastructures will be needed, and how business models and patterns of behaviour will need to change. One major implication from this system innovation approach is that innovation policies will need to be aligned with policies in other areas affecting the rate and direction of innovation, notably (OECD, 2015[56]; Ang, Röttgers and Burli, 2017[57]):

- Education and labour market policies, to help people prepare for the change by equipping them with analytical expertise and the skills necessary to contribute to and benefit from innovations (e.g. STEM degrees, entrepreneurship skills, communication skills, digital literacy).
- Investment policies, to support not only physical investment in clean technologies but also complementary investments in process-based innovations and knowledge-based capital (e.g. software, data, organisational capital).
- Competition policies, to promote open markets for the exchange of knowledge and innovations beyond sectors and jurisdictions in order to enable exit of fossil-based business models and allow for experimentation with new ideas, technologies and business models. For example, easing trade barriers and services regulation is relevant in the context of global value chains.
- Fiscal policies, to encourage business R&D (e.g. through contracts, grants, awards, tax credits) with a focus on social returns and international good practices (e.g. the G20 peer review process of inefficient fossil-fuel subsidies that encourage wasteful consumption, the Green Budgeting Initiative and BEPS).
- Framework policies, such as intellectual property rights (IPRs). The infrastructure for collaboration between research institutes and firms needs to be continuously adapted to support the entry and growth of innovative firms – and facilitate the exit of those with climate-unsustainable business models. Existing IPR policies are not always well suited to the fast-changing nature of innovation and firms that tend to privilege trade secrecy and confidentiality agreements for protecting their intellectual assets (Agrawala et al., 2019[11]).

Benefits from policy packages

64. Governments have at their disposal a range of policy options to both generate economic growth and to combat climate change. How these policies are combined will influence both economic growth and the extent to which countries move towards low emission and resilient pathways. The policy combinations can be stylised as choices along two dimensions: economic policies and climate policies. If chosen appropriately, a combination of climate policy instruments, and well-aligned fiscal initiatives and structural reforms will allow G20 countries to both achieve climate goals and escape the low-growth trap. In times of crises and low growth, there is a need for structural reforms. While these reforms could take many different forms, it is possible to design them with environmental

goals in mind. This not only creates high growth, but also ensures a smooth transition to an environmentally-friendly, low-emissions economy (OECD, 2017[32]).

5.2. International co-operation between G20 member countries and beyond

65. The transition to a greener economy will require not only domestic policies, but also enhanced co-operation and co-ordination among G20 governments. For example, convergence on environmental policy stringency could help ensure that future markets for environmental goods and services are predictable and that concerns related to competitiveness do not lead to a "race to the bottom". Harmonisation of standards at the international level could also provide innovating businesses with greater opportunities in terms of market size. Support for international technology diffusion – in particular towards developing economies – is also critical and includes, for example, incentivizing South-South transfers of technology; lower tariffs for environmental goods and services; ensuring that trade in recyclable waste and of used products is not unduly restricted; intellectual property rights protection and management; and capacity building through appropriate financial support for developing countries.

Box 5. Catalysing global efforts to cut emissions and boost growth: Mission Innovation

Low-emissions R&D is under-supplied by the private sector, owing to long time horizons and uncertainty surrounding future commercial viability (OECD, 2018). There is a strong case for international co-ordination of efforts – also because knowledge spillovers from R&D can cross borders, which hinders the willingness of individual governments or firms to act alone.

In response, Mission Innovation (MI), an intergovernmental initiative comprising the European Union and 24 countries, representing 58% of the world's population and 80% of public budget for clean-energy research, was launched in 2015 to co-ordinate global efforts to scale up clean energy R&D. MI members have pledged to double related investment over five years (accounting for USD 35 billion by 2020) and promote knowledge-sharing and collaboration among governments, businesses and investors (Mission Innovation, 2018).

So far, an additional USD 4 billion of public sector funding in clean-energy innovation has been invested since 2015; with nearly 40 new international research and innovation partnerships initiated broadly aligned with the MI Innovation Challenges. For example, the new UK-Canada collaboration on smart grid and energy storage is worth GBP 11 million; and the MI Champion Innovation Programme was launched to recognise change-making innovators (Mission Innovation, 2018).

In addition to steering government action, MI helps to catalyse private sector efforts. The partnership with the Breakthrough Energy Coalition is an unprecedented commitment by private investors to provide risk-tolerant investments in the early-stage technologies emerging from MI countries (Mission Innovation, 2017).

MI also helps to form public-private partnerships. In co-operation with the World Economic Forum, MI provides a platform for communication between public and private sector actors with regular webinars and R&D Opportunities Workshops in key technology areas (e.g. on sustainable batteries, data on heating and cooling performance in buildings, and new public-private innovation mechanisms in India and Sweden (Mission Innovation, 2018).

MI is a big step in the right direction, and so far, results have been promising. The question is whether the targets for doubling public funding are set over the right time-frame. Long-term targets (such to 2030 rather than 2020) may reduce public funding spikes and associated adjustment costs, and could ultimately reduce the overall cost of decarbonisation (Dechezleprêtre, Martin and Bassi, 2016).

How are the MI R&D investment estimates standardised? Given that MI is a voluntary initiative, the methodologies behind countries' investment estimates are not formally co-ordinated, which leads to discrepancies in what countries count as "clean" energy. For example, nine MI members include nuclear energy; twelve of them include cleaner fossil energy; and renewables and energy storage are the only technology areas included by all countries (IEA, 2017). Further progress on measuring private R&D is needed.

66. The G20 has the scale and scope to create a policy and regulatory framework that fosters innovation and enables fair competition between industrial companies on a global playing field, which in turn would enable the low-emissions and green innovation industry to flourish. To this end, the Business 20 Energy, Resource Efficiency and Sustainability Task Force (B20 ERES) has called for a G20 energy innovation action plan to enable governments to create incentives to develop and use innovative technologies, including digital technologies. Similar platforms already exists, such as the G20 Resource Efficiency Dialogue (International Chamber of Commerce, 2017[58]).

67. The G20 also has the capacity to lower global financial asymmetries and de-risk investment in low emissions innovation-based companies, for example through a reporting system to monitor the scale-up of green technology SMEs, the use of public funds to signal innovative green technologies to investors and the inclusion of SMEs in the design of green finance platforms (G20 Insights, 2017[59]).

68. The G20 could also help improve data about investment risks linked to climate change and biodiversity, which could ultimately boost investments in low-emissions and green innovations. In 2017, the G20/OECD Task Force on Institutional Investors and Long-term Financing launched the Infrastructure Data Initiative, a joint initiative of the European Investment Bank (EIB), the Global Infrastructure Hub (GIH), the Long-Term Infrastructure Investors Association (LTIIA), the Long-term Investors Club (LTIC) and the OECD.

69. The G20 has already introduced a voluntary country-owned peer review process of "inefficient" fossil-fuel subsidies. This transparency enhancing exercise documents and evaluates how governments deploy public resources to support the production and use of fossil fuels. It is also an opportunity for G20 members to express their commitment to

phasing-out "inefficient fossil fuel subsidies that encourage wasteful consumption, while providing targeted support for the poorest". A peer review could be a building block towards fiscal and structural reforms that enable a low-carbon and *just* energy transition.

Notes

[1] Bosetti *et al* (2016) conduct a meta-analysis of 29 studies of expert elicitations about the future of green technologies, possible pitfalls and the needed areas of government support. They note that government support could increase or decrease uncertainty about technology, as it could expand the possible technologies which increases uncertainty. They also note, that the greatest potential for technological change isn't necessarily the best R&D investment: large cost decrease doesn't equal large societal benefits, but it's important to elicit both, since a technology may help us to act later in the future. According to the experts, solar PV is consistently ranked as one of the largest potential costs reductions in the future. CCSU is also expected to improve, but with greater dispersion. With nuclear technology the experts are divided: some expect large cost decreases, others expect it to change slowly (utility-scale energy storage, wind, vehicles, gas turbines, geothermal and energy efficiency technologies, have been the subject of few (or no) publicly available expert elicitations. As a result, the ability to analyze these technologies and determine how they fit into energy RD&D portfolios is limited).

[2] Artificial Intelligence (AI): AI can be understood as machines performing human-like cognitive functions. Its rapid diffusion is driven by recent strides in machine learning, an AI discipline that automatically identifies patterns in complex data sets.

Blockchain: Blockchain is a decentralised and disintermediated technology that facilitates economic transactions and peer-to-peer interactions. In addition to supporting information exchange, it enables protocols for value exchange, legal contracts and similar applications."

Internet of Things: The Internet of Things (IoT), which comprises devices and objects whose state can be altered via the Internet, with or without the active involvement of individuals. It includes objects and sensors that gather data and exchange these with one another and with humans.

All definitions are from OECD (2017[67]).

[3] The main way of measuring green economic output to date has been to identify the sectors whose activities are deemed to contribute to environmental protection and aggregate their output into a single value for the green economy. The drawback of this approach is that it categorises sectors dichotomously as either 'environmental' or 'non-environmental', rather than assessing the share of green production in all sectors. The FTSE Russell indicator confirms that much of the green revenue does not accrue in explicitly green sectors, but may, for example, concern the wind turbine division of an engineering firm or the biofuel activities of oil companies.

[4] Intellectual property rights, such as patents, are designed to protect inventors from such copies. However, their effectiveness varies depending on the ease in which inventors may 'invent around' the patent by making minor modifications to an invention.

[5] Sticking to energy, an example is the massive social benefits (and smaller emissions benefits) in the near term that are accruing due to the development of lithium ion technology. Note that private returns are harder to capture in sectors such as energy as, for example, a green electron is no more attractive than a dirty one to the end-user. By contrast, innovation can demonstrably improve the quality of a mobile phone and differentiate it from its competitors, allowing greater scope for returns to innovation to be captured.

[6] The measure of knowledge spillovers coming from low-carbon and high-carbon patents using a global dataset of patent citations. Any innovator applying for a patent is required to reference all previous innovations - so called prior art - on which the new innovation is based. A citation indicates that the knowledge contained in the cited document has been useful in the development of the new knowledge laid out in the citing patent and thus represents a knowledge flow. For this reason, patent citations have been used frequently to measure knowledge spillovers. The analysis focuses on two sectors: transport and electricity production, which jointly account for the bulk of carbon emissions. In the electricity generation sector, low-carbon technologies cover renewable energy sources, while high-carbon technologies are those based on fossil fuels (mostly coal and gas). In the automotive sector, low-carbon technologies encompass electric, hybrid and hydrogen vehicles, while high-carbon technologies are associated to internal combustion and gasoline engines.

[7] However, recent evidence suggests that green jobs do not massively differ from non-green counterparts, suggesting that re-training can happen relatively easily (Bowen, Kuralbayeva and Tipoe, 2018[34]). Only around 1% of jobs are unique to the green economy. 19% of the jobs would be 'indirectly' green, meaning that they would take part in the green economy, but not necessarily involved in specifically green tasks. As a comparison, the digital transformation implies a much broader diffusion of new skills, with now almost every skilled job requiring literacy on the personal computer.

[8] Chowdhury et al. 1993 gives the example of cultural restrictions in South Asia, where there is lack of institutional support for women learning how to swim and women feel obliged to wear clothes, which make swimming difficult. These norms increase their flood vulnerability and decreases these regions' potential for adaptation.

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