A Introduction

Tackling climate change requires a transformation of the global economy. While limiting consumption and changing lifestyles would help, reducing greenhouse gas emissions to net zero will be impossible without technological and structural change on a global scale. This transformation will involve costs, but also opportunities – not just to head off an environmental catastrophe, but to reinvent the way the world generates energy, manufactures products and grows food. Just as trade helped to drive economic progress in the past – by incentivizing innovation, leveraging comparative advantages and expanding access to resources and technologies – trade can play a central role in driving progress towards a low-carbon global economy. But harnessing the potential of trade will demand new policies and more cooperation.

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1. The next great transformation

Paradoxically, economic progress is both the cause of and the solution to the climate crisis. To head off dangerous climate change, the Paris Agreement aims to limit the global warming to 1.5°C this century. This means that greenhouse gas (GHG) emissions need to be cut by roughly 50 per cent by 2030 and reach net zero by 2050.[1] The most realistic way modern economies can achieve this goal – without cutting back living standards in richer countries and cutting short development in poorer ones – is by modernizing even more, harnessing human innovation, ingenuity and entrepreneurship to advance low-carbon technologies and to use the planet's resources more sustainably.

Dramatic advances in automation, transportation and industrialization – all powered by fossil fuels – have driven the exponential growth of the global economy over the past two and half centuries, resulting in rising living standards, increased mobility, and improved material well-being for a fast-growing global population. In important ways, the industrial revolution was also an energy revolution (Wrigley, 2010). By discovering how to convert fossil fuels into mechanical energy, starting with the steam engine, humanity unlocked seemingly limitless supplies of energy to power seemingly limitless economic growth and development.

But ever-expanding growth has also released ever-greater amounts of heat-trapping GHG emissions into the atmosphere – from electricity generation, transportation, industry, agriculture and deforestation – which in turn has contributed to the warming of the planet and its negative climactic and environmental knock-on effects. Almost three-quarters of global GHG emissions come from energy consumption; another 18.4 per cent from agriculture, forestry and land use; 5.2 per cent from industrial processes; and 3.2 per cent from waste (Ritchie, Roser and Rosado, 2020). As long as the world remains dependent on high-carbon technologies, increasing economic production will almost inevitably lead to increasing GHG emissions.

Yet, while technological and economic progress has "fuelled" the climate crisis, it is also indispensable to mitigating and overcoming it. Replacing fossil fuels with renewable energies – solar, wind and geothermal power, and others – is essential to avoid and reduce GHG emissions, as are steps to decarbonize transportation, steel production, cement manufacturing and agriculture, and to make economic ecosystems less wasteful and more resource-efficient overall.

Adapting to the adverse effects of climate change will also require technological solutions – from developing drought-resistant crops and resilient water supplies, to building flood defences, improving weather forecasting and setting up early warning systems (UNFCCC, 2016a).

Given that many lower carbon technologies – from solar panels and electric cars to vertical farms and electric arc furnaces – already exist, the challenge is to scale up their production and deployment. One influential study argues that two-thirds of economies, including major emitters like the United States, the European Union and China, could reduce their GHG emissions by 80 per cent by 2030, and achieve carbon neutrality by 2050, through the mass adoption of electrification based on existing wind, hydro and solar technologies (Jacobson et al., 2017).

Even more cutting-edge technologies, such as green hydrogen or direct air carbon capture and storage, are also advancing rapidly. Then there are the myriad "soft" climate technologies – data-crunching, information-sharing, training and education – which are easier to adopt, and which will be just as critical to shift economies towards low-carbon alternatives.

It is also important to focus not just on what technologies are needed, but on how they are used. It has long been recognized that it is only by using new technologies that we learn how to optimize and exploit their full potential (Arrow, 1962). This "learning-by-doing" dynamic can take time (David, 2002). In the same way that it took decades for the invention of the dynamo to translate into mass electrification, it could take years to realize the full potential of solar power or carbon farming. Thus, it makes sense to scale up new, clean, low-carbon technologies now, even if the initial investment costs are high, as expanding capacity early on can encourage usage, improve performance, drive down prices, and ultimately make renewable technologies more attractive and competitive.

Realizing the potential of one innovation also often hinges on marrying it to another innovation (Harford, 2017). Just as the explosion of the internet after the mid-1980s depended on parallel innovations in satellite and fibre optic telecommunications, electric vehicles are now poised to revolutionize clean-energy transportation because they are benefitting from other technological breakthroughs, including the mass production of affordable lithium-ion batteries, the roll-out of electric vehicle charging networks and more readily available renewable energy.

Conversely, the absence of synergistic technologies can significantly slow or block economic progress.

For example, the lack of affordable and efficient technological solutions to the challenge of long-term, large-scale energy storage – a challenge arising from the intermittent nature of some lower carbon energy technologies such as solar and wind power – is a key missing piece of the renewable puzzle which urgently needs to be "discovered" if renewables are to become a reliable replacement for fossil fuels worldwide.

This positive process of technological interaction, cross-fertilization and mutually reinforcing innovation takes place at the global, not just the firm, level. The fact that photovoltaic (PV) cells, which convert solar energy into electricity, are increasingly affordable and available is the result of mutually supportive back-and-forth innovations across several continents, including US investments in PV cell research and development (R&D) in the 1960s and 70s; European policies to accelerate domestic solar panel installation in the 1990s and 2000s; and Chinese efforts to improve and scale production after 2011 (IEA, 2022a).

Technological cooperation, competition and cross-fertilization do not just spur innovation; they also encourages needed technological diffusion. Many developing countries have abundant renewable energy potential that access to low-carbon technologies and infrastructure could unleash (IRENA, 2022). This is starting to happen. Kenya is already a world leader in the number of solar panel systems installed per person, while 90 per cent of Nepal's electricity comes from hydro-electric power. Locally generated renewable energy allows developing and least-developed countries to bypass many of the logistical difficulties and high costs involved in the transmission and distribution of fossil-fuel energy, improving their energy access and self-sufficiency. Bringing clean energy to the 759 million people in the developing world who still lack access to electricity would not only stimulate economic growth and job creation and reduce poverty, but would significantly improve essential services, such as healthcare, education and the internet.

The shift to low-carbon farming – especially climate-smart agriculture techniques that focus on intercropping, crop rotation, agroforestry, and improved water management – can bring similar benefits to developing-country farmers in terms of improved productivity, greater resilience, less deforestation, and reduced reliance on fertilizers and fuels (Brakarz, 2020). In short, the diffusion of low-carbon technologies can provide poorer countries with the essential tools they need both to limit GHG emissions and to accelerate their development.

Achieving a shared and "just" transition to a low-carbon global economy is not just the right thing to do; it is also in everyone's interests. Climate change will not be stopped if only wealthy economies have access to low-carbon technologies while poor economies continue to have to rely on fossil fuel-fired power plants and internal combustion engines. Since everyone is impacted by climate change, everyone has an interest in ensuring that the technological tools and resources to reduce emissions are as widely available as possible.

Wealthy economies can also benefit in more direct ways from technological development in poorer countries. A striking example of North-South technological collaboration is the ambitious plan to deliver Moroccan solar and wind farm electricity to UK consumers via an underwater cable stretching 3,800 km – the world's longest cable of this kind. When completed in 2030, it is hoped that the Xlinks Morocco-UK Power Project will deliver low-cost, clean power to over 7 million UK homes, representing 8 per cent of current UK electricity needs (Hook, 2021).

Indeed, the transition to a low-carbon global economy will create enormous investment, employment and growth opportunities – not just adjustment costs – for developed and developing countries alike. For example, global investment in the low-carbon energy transition – across sectors ranging from power generation, energy storage and electric vehicles, to sustainable materials, electrical efficiency and carbon capture – already totalled US$ 1.3 trillion in 2021, doubling the investment of US$ 655 billion in 2017 (IEA, 2022b). In order to reduce GHG emissions to net zero by 2050, cumulative investment in renewable energy would need to reach US$ 131 trillion over the next 30 years (McKinsey & Company, 2022).

Similarly, massive investment opportunities are opening up in the steel, cement, farming, forestry and waste management industries as they shift to low-carbon technologies and processes. Building low-carbon industries and infrastructure will not only require new investment and equipment; it will also require new workers and skills. Shifting to clean energy, for instance, could generate 14 million new jobs in clean energy sectors and 16 million additional jobs in energy-related sectors globally by 2030 (IEA, 2021). In short, the transition to a low-carbon economy will entail the construction of a new economy.

The good news is that low-carbon technologies are expanding – and at a faster pace than many predicted (Naam, 2020).[2] For example, renewables accounted for roughly 11 per cent of global primary energy and 30 per cent of electricity generation in 2021 (IEA, 2022b). Despite supply chain bottlenecks, rising raw material prices and growing geopolitical tensions, the International Energy Agency (IEA) projects that renewables are on track to account for almost 95 per cent of the increase in global power capacity through 2026, with solar power alone providing more than half of that increase. The IEA expects the amount of renewable capacity added between 2021 and 2026 to be 50 per cent higher than between 2015 and 2020 – and even these optimistic forecasts may underestimate the speed and scale of the transition.

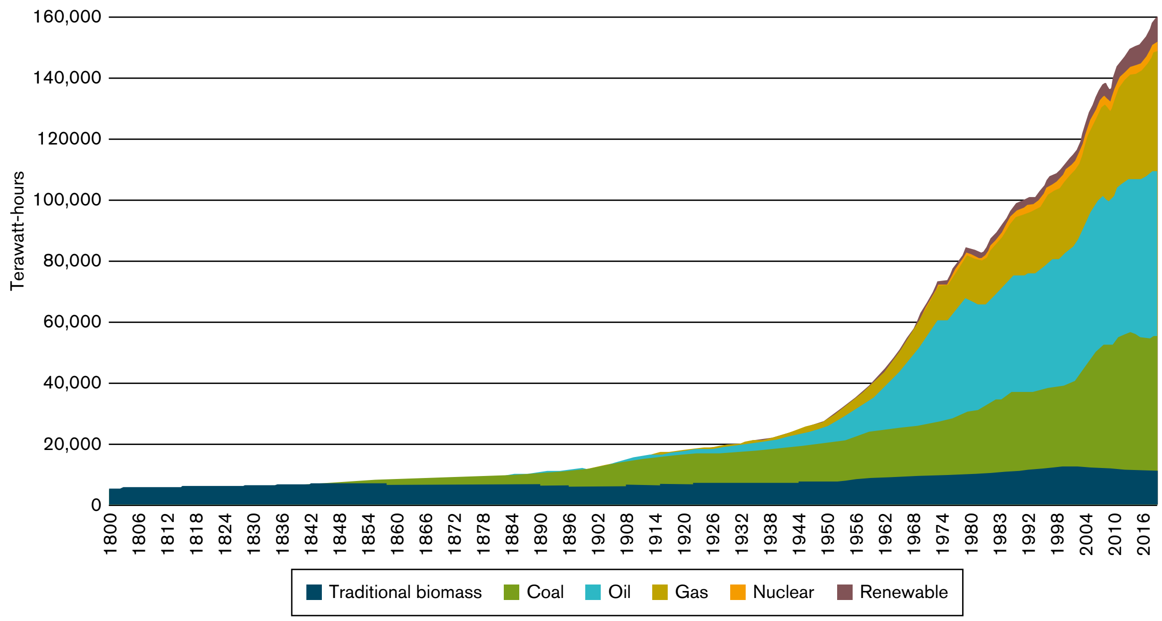
The bad news is that although global renewable energy capacity is growing rapidly, overall global energy demand is growing almost as fast, so fossil fuel consumption continues to rise (see Figure A.1). Nearly 80 per cent of the world's energy is still generated by burning fossil fuels, notably oil, coal and gas, partly because supplies of renewable energy need to be scaled up, and partly because fossil fuel consumption is still subject to strong path dependence due to technological, infastructural, institutional and behavioural lock-ins. Global energy-related carbon emissions rose by 6 per cent in 2021 to 36.3 billion tonnes – their highest level ever, and 65 per cent higher than they were in 1990 (IEA, 2022c). The IEA estimates that the current pace of renewable power capacity growth will need to double over the next decade if the global economy is to stay on a pathway to net zero emissions by mid-century.

Other sectors also face the challenge of accelerating the shift to low-carbon technologies and practices. The challenge is especially daunting in agriculture – compared to power generation or transportation, for example – because the emissions-reduction technologies are more amorphous and the sector is more diffuse, requiring changes to how over two billion people farm and how billions more eat (McKinsey & Company, 2020). At the same time, the challenge is intensified because of agriculture's unique vulnerability to climate change – including extreme weather events, frequent droughts, and invasive species and pests – and because of an expanding global population's growing need for food.

2. Harnessing the transformative power of trade

What role will trade play in the transition to a low-carbon global economy? In the past, trade has been part of the problem, contributing to climate change both directly, by generating increasing transport emissions (shipping, air freight, trucking and rail), and indirectly, by helping to drive carbon-intensive global growth. But in the future, with the right policies in place, trade can be a major part of the solution.

Figure A.1: Fossil fuels remain the dominant energy source despite increasing use of renewables



Source: Authors' calculations, based on Smil (2017) and BP Statistical Review of World Energy (2017).

Trade can increase counties' access to lower-emissions goods, services and capital equipment, and can help to diffuse critical technologies and know-how. It can drive down the costs of environmental products by encouraging efficiency, economies of scale and learning-by-doing. Perhaps most importantly, it can spur innovation by opening up new market opportunities for low-carbon exports and investments and by incentivizing entrepreneurs and industries to compete to fill them.

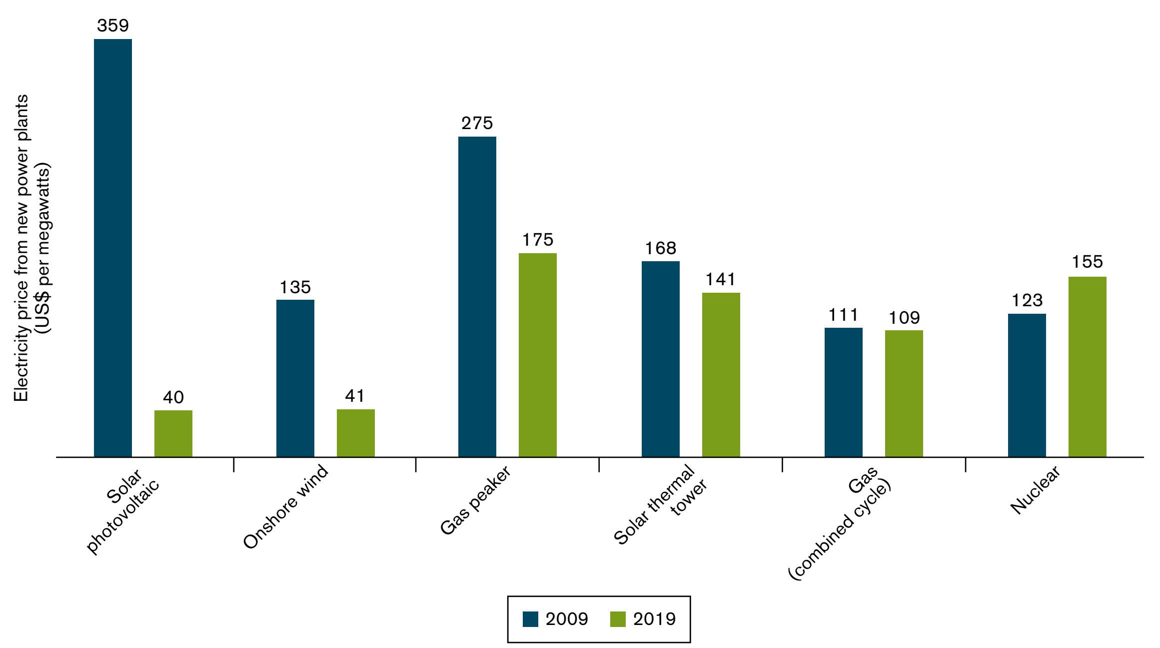
If low-carbon production reaches the point where it beats high-carbon production on price and performance – because environmental costs are internalized in high-carbon production through taxes and other policies or because technological advances alone make low-carbon alternatives cheaper and better – then market forces will increasingly drive the transition and progress will accelerate.

This is already happening. Scientific advances, more efficient production processes, and rising global demand – all supported by open world trade – have driven an astonishing reduction in price and improvement in performance of low-carbon technologies (see Figure A.2). The price of solar power, for example, has fallen by almost 90 per cent since 2010, while the efficiency of solar panels has doubled since 1980. Last year alone, the cost of electricity from onshore wind fell by 15 per cent, and from offshore wind by 13 per cent. The price of lithium-ion batteries has plunged by 97 per cent since 1990, while their energy density has nearly tripled in just 10 years.

Even more challenging sectors, such as steel production, managed to cut energy use in half between 1975 and 2015 – with reductions continuing – because of technological advances and a shift from traditional blast furnaces toward electric arc furnaces (IEA, 2020). As a result of these dramatic price and performance improvements, low-carbon technologies are becoming more economically competitive, not just more environmentally sustainable, alternatives. For example, almost two-thirds of the world's new wind and solar power plants are able to generate electricity more cheaply than the world's cheapest new coal plants (IEA, 2022a; WTO and IRENA, 2021).

The fundamental driver of this change is improvements in technology and production, which are in turn being driven by strong learning-by-doing effects. As the world gets better at building, installing and using solar panels, for example, the price falls and the technology improves. It has been estimated that every time the number of solar panels installed doubles, their price drops another 30 to 40 per cent (Naam, 2020). By helping to create a competitive, dynamic and integrated a global marketplace for solar and other clean technologies, trade plays a central

Figure A.2: The price of renewables has plunged in the last 10 years



Source: Authors' calculations, based on Lazard's Levelized Cost of Energy Analysis (2019).

role in underpinning and accelerating this process. It is significant that between 2010 and 2020, exports of solar panels increased and their prices fell sharply (see Figure A.3).

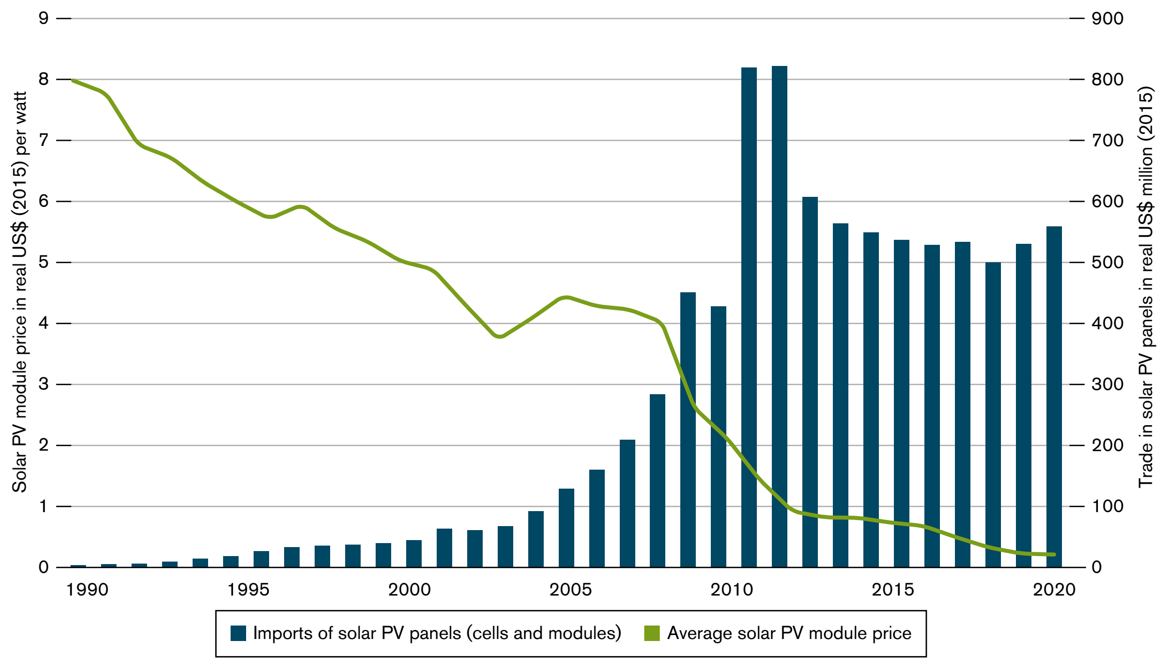
But the contribution of trade and trade policy to a just low-carbon transition could be strengthened and improved. One positive step would be to reduce trade-distorting measures on climate-friendly goods, services and technologies and to strengthen supply chains. Opening up trade across a range of low-carbon products and services would expand global access, increase competition and lower prices, making it easier and cheaper for economies to transition to low-carbon energy, mobility and production alternatives, and thus reducing overall emissions. Conversely, by making it more difficult to import key environmental technologies, e.g., by raising tariffs or imposing restrictions, the shift from a high- to a low-carbon economy will only be slowed and impeded.

Another key issue is the interface between trade and environmental subsidies and other support measures. A growing number of countries use subsidies either to encourage producers to invent, adopt and deploy low-carbon technologies, or to encourage consumers to purchase environmentally sustainable products and services. If they are well-targeted and non-discriminatory, environmental subsidies can play a positive role in scaling up new technologies and making climate-friendly products more affordable. Government incentives to insulate homes, install solar panels or buy electric vehicles are increasingly common examples.

But subsidies can also be used to support carbon-intensive production and consumption, making the climate crisis even worse. In the case of fossil fuel subsidies – which amounted to US$ 440 billion in 2021 (IEA, 2022d) – many governments find themselves in the contradictory position of encouraging oil, gas and coal industries even as they are discouraging them with carbon taxes and regulations. Moreover, subsidies can negatively impact other trade partners by distorting markets or unfairly boosting exports. The challenge is to find an optimal balance between maximizing positive spillovers from environmental support measures – both nationally and globally – and minimizing negative ones.

One of the most challenging issues is the relationship between trade and carbon pricing. Environmental

Figure A.3: As the use of solar panel exports increases, their price falls



Source: Authors' calculations, based on data on solar PV module costs from Kavlak, McNerney and Trancik (2018) and Bloomberg Terminal and trade figures from the UN Comtrade database.

Note: The trade data covers the Harmonized System (HS) code 85414.03, which does not distinguish between solar PV cells and modules and other products such as light-emitting diodes.

subsidies and carbon prices are essentially the opposite sides of the same coin. The former makes environmentally friendly purchases cheaper, while the latter makes environmentally damaging ones more expensive, all with the aim of persuading firms and consumers to switch to less carbon-intensive alternatives.

Ideally there would be a global agreement on carbon prices. Instead, close to 70 separate carbon pricing initiatives have been adopted in 46 national jurisdictions worldwide – which risks creating a patchwork of different systems, tax rates, covered products and certification procedures. As a result, countries with high carbon taxes worry that their industries will shift to low- or no-carbon tax countries – i.e., "carbon leakage" concerns. Conversely, countries with no carbon taxes worry that their exports will be unfairly shut out of carbon-taxing countries – i.e., "hidden protectionism" concerns. Although WTO rules – especially those concerning national treatment – allow tax adjustments at the border, adjusting taxes for carbon could prove far more complex than adjusting them for alcohol, for example. The challenge is to find a policy mix that balances the need to discourage carbon emissions with the need to encourage trade to support a low-carbon transition.

Arguably the most important way trade can contribute to a "just" transition to a low-carbon global economy is by helping to expand, diffuse and share technological progress. Today's world economy is an increasingly interdependent system, and climate change is the most challenging collective action problem it has ever faced. It is unrealistic, not to mention unfair, to expect poorer countries to take the same steps to curb carbon emissions as advanced ones if they lack the technological and financial resources to do so. Indeed, this is explicitly recognized in the core concept of "common but differentiated responsibilities" set out in the Paris Agreement. The developed world has a direct stake in helping the developing world to manufacture, deploy and maintain low-carbon technologies, if only because no one country can solve the climate crisis on its own. Trade cooperation is key to driving this global transformation; trade fragmentation would invariably set it back.

3. Overview of the report

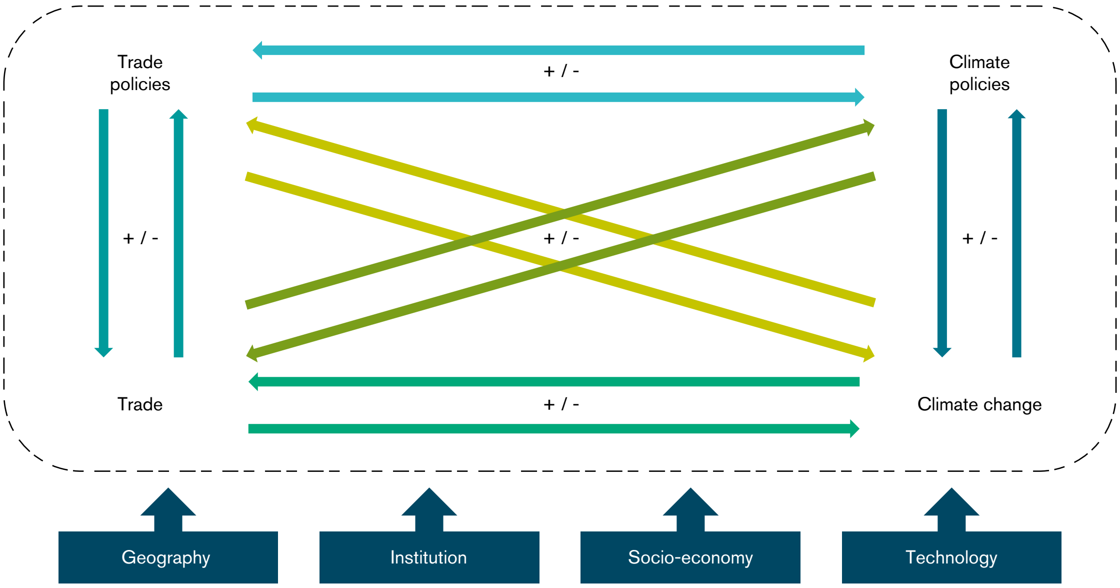
This year's *World Trade Report* looks at the relationship between climate change and trade, examines why trade is an indispensable part of the solution to tackling climate change, and discusses areas where policies need to improve. A core message of the report is that solving the climate crisis depends on a far-reaching transformation of the global economy, and that trade will be critical to driving the needed technological and economic shift to a low-carbon future.

The other core message is that this unprecedented global shift will require unprecedented international cooperation – and that there is no alternative to achieving a just transition where the costs and benefits are more evenly and equitably shared. Thirty years after the adoption of the United Nations Framework Convention on Climate Change (UNFCCC), this report underscores how the goals of environmental sustainability and economic development are not only compatible, but inextricably and mutually dependent.

Although the issue of trade and climate change is by no means new, the relationship is complex, multifaceted and fast-evolving. This is partly due to the fact that the relationship not only involves the interplay between international trade and climate change, but also covers linkages with trade policies and climate policies (see Figure A.4). Their interactions occur in several directions, with both direct and indirect mechanisms which are in part determined by geographical, institutional, socio-economic and technological conditions. The global nature of climate change further amplifies this complexity (WTO and UNEP, 2009).

The report opens with a chapter on adapting to the consequences of climate change. While reducing GHG emissions to limit the rise in global temperature to well below 2°C – and preferably to below 1.5°C – is essential to limit the consequences of climate change, past GHG emissions have already caused, and continue to cause, global temperatures and sea levels to rise, and have increased extreme weather events. Many consequences of climate change are already hard to reverse. Adapting to the changing climate and its cascading impacts is therefore a sustainable development imperative. Chapter B explores how the geophysical effects of climate change will affect international trade, and identifies the effects of such changes on trade costs, supply chains and the most vulnerable regions and sectors. It discusses ways in which international trade and trade policy can help with climate change adaptation strategies, and outlines how international cooperation, and the WTO in particular, can contribute to helping countries, and in particular developing and least-developed countries, adapt to some of the disruptive consequences of climate change.

Figure A.4: The relationship between climate change and trade is complex and multifaceted



Source: Authors' elaboration.

Mitigating climate change by reducing GHG emissions is essential but requires a large-scale transition to a low-carbon economy. Chapter C examines the role of ambitious climate change mitigation policies and well-functioning financial markets in supporting and accelerating the transition to a low-carbon economy. It discusses how the transition to a low-carbon economy could change trade patterns and provide new economic opportunities, as well as certain initial disadvantages for some economies. Such changes require enhanced international cooperation, and the WTO can play an important role in supporting climate-change mitigation efforts.

Among the many policies to mitigate climate change, carbon pricing has attracted increasing attention as it puts a price on carbon emissions as a means of reducing emissions and supporting investment into lower-carbon alternatives. Chapter D explores the role of carbon pricing in reducing GHG emissions and the relationship between carbon pricing, trade and trade policies. The necessity of developing a solution to the current patchwork of uncoordinated carbon pricing policies, which could lead to tensions in the global trading system, is discussed, as well as the importance of international cooperation to achieve convergence on global carbon pricing approaches.

While international trade separates production and consumption across space, the emissions generated in one country to produce goods and services are not necessarily the same as the ones required for its consumption. Chapter E analyses how the emissions originating from international trade can be measured, and examines how trade both contributes to GHG emissions and diffuses the technology and know-how needed to make production processes cleaner. The necessity for greater international cooperation to establish adequate carbon measurement and verification, improve carbon efficiency in transportation, and ensure the environmental sustainability of global value chains, is reviewed.

The development and diffusion of climate-friendly technologies, including renewable energy and energy efficient technologies, are key to tackle climate change. Chapter F discusses how trade in environmental goods and services can enable access, deployment and diffusion of environmental technologies, which are instrumental in mitigating carbon emissions and developing ways in which people and trade can adapt to climate change. While the WTO agreements ensure that trade in environmental technologies flows as smoothly and predictably as possible, the WTO could make an even greater contribution to promoting trade in environmental goods and services.

Endnotes

1 "Net Zero" involves reducing greenhouse gases (GHGs) to as close to zero as possible, so that any GHGs that are produced can be absorbed from the atmosphere. GHGs are gases in the atmosphere such as water vapour, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) that can absorb infrared radiation, trapping heat in the atmosphere. This greenhouse effect means that emissions of GHGs due to human activity cause global warming. The species of gases reported under the common reporting format of the United Nations Framework Convention on Climate Change (UNFCCC) are: CO_2 from fossil fuel combustion and industrial processes (CO_2-FFI); net CO_2 emissions from land use, land-use change and forestry (CO_2-LULUCF); methane (CH_4); nitrous oxide (N_2O); and fluorinated gases (F-gases), comprising hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3) (IPCC, 2022a). Although carbon dioxide is the primary GHG emitted through human activities, methane has become an emerging GHG given its more potent heat-trapping ability.

2 It has been pointed out that economic authorities have dramatically underestimated the rapid expansion and declining costs of renewables every year since 2000 (Beinhocker, Farmer and Hepburn, 2021).