Transboundary Climate-related Risks: Analysing the Impacts of a Decarbonisation of the Global Economy on International Trade, Finance, and Money

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Abstract

This paper analyses the transboundary climate-related economic and financial risks that could result from a decarbonisation of the world economy. The paper first provides a typology of such risks, as those remain under-assessed in the literature despite a growing acknowledgment of their relevance. Using a global macro-econometric model, it subsequently analyses potential impacts of a decarbonisation of the world economy on trade, output, investment and employment, and scrutinises international macroeconomic and financial spillovers. Our analysis suggests that a phasing out of fossil fuel consumption and a concomitant rise of renewable energy usage and trade in low-carbon technology/capital goods and critical minerals will have profound implications for global trade and financial flows, and the international financial and monetary system at large. Changing patterns of trade in energy commodities will impact the balance of payments of both exporting and importing countries and the size and direction of international financial flows. Moreover, the stranding of fossil-fuel related assets will have transboundary wealth and financial stability effects. All these may have potentially meaningful ramifications for the international financial and monetary order.

JEL Codes: F3, F4, Q5.

Keywords: Climate change, transition risks, transboundary risks, trade, international money and finance.

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1. Introduction

To limit global warming to 1.5°C above pre-industrial levels, the world economy needs to decarbonise rapidly. Climate policies to reduce fossil fuel use by major importers can be expected to have important impacts on all exporters. Even if the climate goals were not met, the technological change that is already underway – with a switch to renewable energy and electrical vehicles – can be expected to alter global patterns of trade. In this context, countries face very different challenges as their economies have different structural compositions, natural resource endowments, energy systems and technological characteristics. The trade in fossil fuels has been a driving component of global trade and geopolitics for decades (van de Graaf, 2018; IRENA, 2019; Mercure et al., 2021). In 2019, fuel exports accounted for 11.7 per cent of total merchandise exports globally (Figure 1). However, for some countries, the fuel share of exports or imports can be much higher. For 18 countries, fuel exports account for more than 50 per cent of total merchandise exports, with 7 countries generating 90 per cent or more of their export earnings from fossil fuel exports. On the import side, 14 countries spend a quarter or more of their total merchandise import bill on fuel.

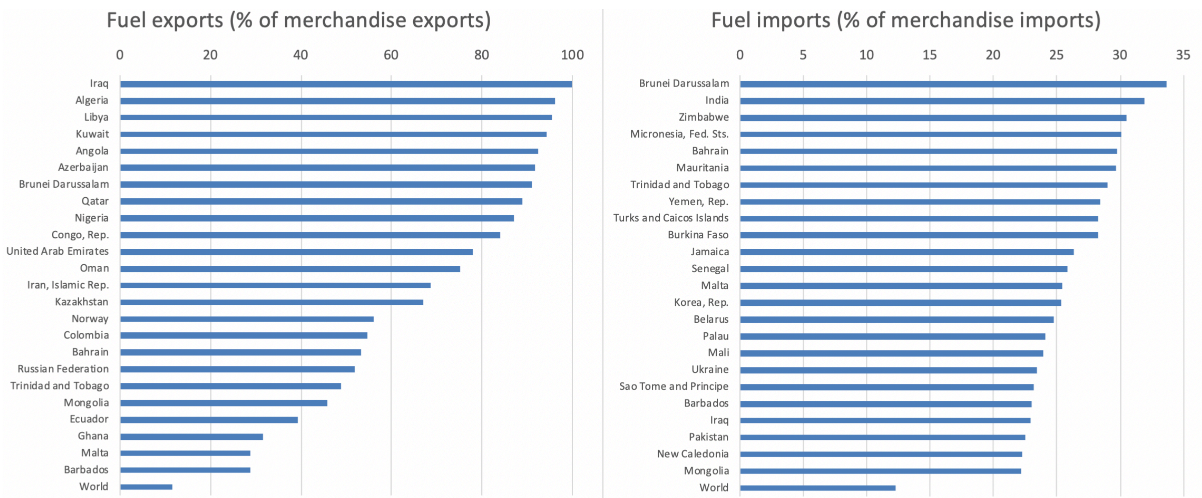

Figure 1: The 25 countries with the largest share in fuel exports/imports as share of total merchandise exports/imports.
Note: Compiled with the World Bank's World Development Indicators, October 2021. Values are for the last available year.

Countries have different characteristics in terms of fossil production/consumption, technological status and ambitions, financial and trade position, but changing patterns of trade in energy commodities may have significant impacts on the balance of payments of both exporting and importing countries and on international financial flows. Moreover, the stranding of fossil fuel related assets can have trans-boundary effects on wealth and financial stability. A phasing out of fossil fuel consumption and a concomitant rise of renewable energy usage could therefore have profound implications on the global economy, with potentially material spillover effects across borders. But the latter, as this paper explores, depend on several factors for each country. Moreover, all these changes may in the end have potentially meaningful ramifications for the international financial and monetary system. International dynamics, which are already highly volatile, are likely to be impacted by something so structural as a technological shift to net-zero.

In order to start assessing these impacts and risks, it is possible to draw upon central banks and financial supervisors' acknowledgment that the transition to a low-carbon economy could generate so-called transition risks (Bank of England, 2015; NGFS, 2018, 2019), i.e. sudden shifts in our economic system that trigger potential significant macrofinancial risks. Central banks and financial supervisors have started to develop scenarios to capture these risks (e.g. NGFS, 2021). Financial regulators and supervisors have recently acknowledged that "shocks to the financial system from climate change can also be transmitted across borders" (FSB, 2020: 25). However, climate-related impacts and risks have barely started to be assessed through transboundary channels, as reflected by the Financial Stability Board's (FSB, 2020) assessment of the implications of climate change for financial stability. For the time being, climate stress tests also tend to largely ignore such transboundary risks (e.g. Alogoskoufis et al., 2021).

The incipient literature suggests that "borderless climate risks" that cascade through the international system (Benzie and Persson, 2019) may become ever more important. Mandel et al. (2021), for instance, present a transborder scenario from increased flood risk. Yet, while a growing body of literature has started to examine the cross-border impacts and risks associated with the physical impacts of climate change, often with a focus on the impact on global value chains or food prices,[1] there has been no systematic analysis of the cross-border transmission of economic and financial risks caused by the transition to a low-carbon economy.

What is missing to date, therefore, is a comprehensive and consistent analytical framework for the transboundary impacts of a low-carbon transition of the world economy (i.e. of transboundary transition risks). This paper seeks to fill this gap by examining and conceptualising the potential impacts of a decarbonisation of the world economy on international trade and financial flows and the international financial and monetary system at large. Taking a quantitative approach using a highly data-driven global macro-econometric model, it analyses potential impacts of a decarbonisation of the world economy on trade, and scrutinises international macroeconomic and financial spillovers.

In doing so, this paper brings two critical contributions to the ability of central banks and financial supervisors to assess climate-related financial risks. First, it shows that several transboundary risk channels that have not (or barely) been assessed could mean that the risks are more significant than those envisioned so far. Second, while the time horizon of our model is 30 years (similar to that used in most climate stress tests), it shows that significant risks could materialise over shorter time horizons. In this sense, the approach and methodology presented

[1] See the recent study by Carter et al. (2021) for a conceptual framework for cross-border impacts of the physical effects of climate change. On cross-border impacts of physical climate change see also Benzie et al. (2019), Bailey and Wellesley (2017), Challinor et al. (2017, 2018), Hedlund et al. (2018), Otto et al. (2017), Schenker (2012), Smith et al. (2018), Peter et al. (2021), Volz et al. (2020), and Adams et al. (2021).

enables to partially overcome the "tragedy of the horizon" (Carney 2015) that has often tended to miss the tail risks related to climate change (Bolton et al. 2020).

The paper is structured as follows. Section 2 first proposes a typology of transboundary risks related to a low-carbon transition. Section 3 analyses potential impacts on trade. Section 4 scrutinises international macroeconomic and financial spillovers. Section 5 provides a summary of the findings and concludes with reflections on the scope for future research in this area and a discussion of data needed to facilitate this.

2. A typology of transboundary effects of a decarbonisation of the world economy

2.1 Major trends and characteristics of the low-carbon transition

Without aiming to be exhaustive, we suggest that establishing a typology of the transboundary effects of a decarbonisation of the world economy should start from assessing these major trends: capital intensity of low-carbon technologies versus fossil fuels, role of different energy sources, production cost trends, location of different sources of energy and specialisation of different countries, second round effects due to reorganisation of the trade surpluses related to the low-carbon transition. We briefly describe these in turn below.

A key aspect of the low-carbon transition is that it is capital intensive: whereas fossil fuel systems tend to entail comparatively lower upfront investments and higher operational costs (fossil fuels need to be physically extracted, transformed and transported to its end-use location), low-carbon technology tends to entail more upfront investment and relatively low operational costs (IEA 2010, 2015, 2020a, 2020b.). To understand the impact at the macroeconomic and global trade level, a key question therefore is whether the loss of cross border expenditures on fuels are balanced by expenditures on low-carbon capital, and whether declines in fuel-related trade flows are compensated by additional trade in technology.

It is first important to understand the structure of the energy system. Oil is the highest value fuel traded internationally, followed by gas and coal. 65% of primary crude oil is ultimately used for mobility of various forms (48% goes into road transport specifically), while most of the rest is used as non-energy feedstock for the petrochemical industry (16%), and comparatively small amounts are used for heating (5%), electricity (3%) and other energy-related applications (IEA, 2021a). Gas/coal are used for both heat and electricity generation (40%/60%) and industry (20%/30%) but negligible amounts are used for mobility. This indicates that, broadly speaking, the diffusion of electric vehicles directly affects global trade of oil, while the diffusion of solar panels and wind turbines directly affects global trade of coal and gas.

An important aspect of this process is that the costs of most new low-carbon technologies have been declining very rapidly, following the standard Moore's/Wright's law (learning-by-doing), with learning rates of 20-30% or more (see Farmer and Lafond, 2016). It is straightforward to extrapolate current cost trajectories using learning curves. Doing so, one finds that solar photovoltaics are expected to achieve parity with coal and gas-based electricity within the next five years (where this is not already achieved), while electric vehicles could achieve cost parity with conventional vehicles some time between 2025 and 2035 (IEA, 2020a; Lazard, 2020).

Figure 2 shows that the balance in expenditure on technology and fuels between high and low-carbon applications (vehicles and electricity generation are shown, but this is generally true) is clearly negative and declining through the transition towards a low-carbon world. For an imaginary country exporting both oil (or coal/gas) and vehicles (or solar panels/wind turbines), losses in fuel exports may not be fully compensated by gains in low-carbon technology exports once the cost parity threshold has been crossed. By design, if the world achieves the Paris Agreement, by 2050 the majority of the existing trade of fossil fuels should have been eliminated. Therefore, at the global level, energy-related trade flows, which make a large fraction of existing global trade flows, are likely to decline to a new, lower normal.

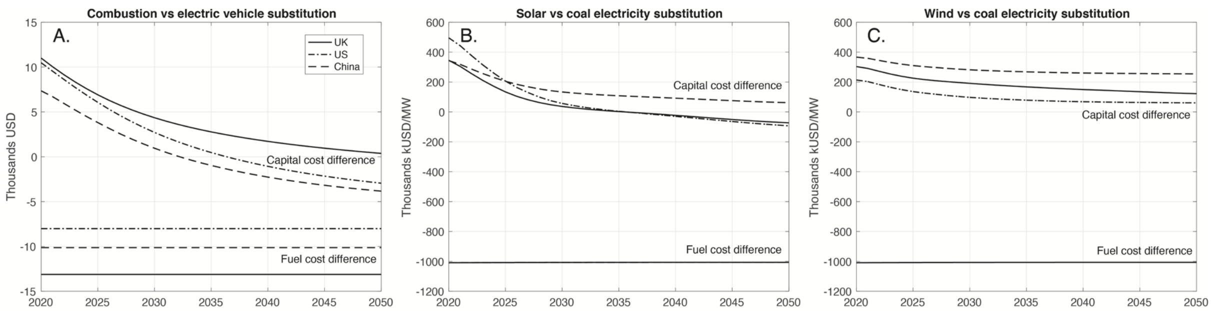

Figure 2: Difference between capital and fuel costs between (A) petrol/diesel and electric mid-range cars, (B) solar and coal electricity and (C) onshore wind and coal electricity.
Note: Declining capital costs are due to learning-by-doing, estimated on a trajectory of technology diffusion simulated using the E3ME-FTT model (Mercure et al., 2021). The data for vehicles are derived from Marklines and manufacturer websites, while the data for renewables are based on IEA and IRENA databases.

2.2 Domestic and international effects of a decarbonisation of the world economy

With the notable exception of the United States (US), fuel and low-carbon technologies tend to be produced in different countries, where for instance large oil producers often have under-developed technology manufacturing sectors (e.g. Organization of the Petroleum Exporting Countries, OPEC), while technology producers tend to be fuel importers (e.g. European Union (EU) countries, China, Japan). Hence, fuel importing countries that also export technology (e.g. China, Japan, the EU) are likely to benefit from a double dividend on their GDP and balance of payments as they reduce energy imports, and spend leftover income domestically (Mercure et al., 2021). Meanwhile, fuel exporters that do not produce technology are likely to suffer a double hit on their trade balance as they lose their fuel exports and begin to import technology (e.g. OPEC countries or Russia).

Such a deep re-organisation of trade due to a low-carbon transition has far-reaching macroeconomic implications. It could affect the volume and direction of foreign investment, as it reverses investment flows that originate from fuel export revenues, which are often re-invested in foreign countries (for example, Saudi investments in the US). It could affect the demand for various currencies and therefore exchange rates. Changes in foreign investment flows could affect the value of assets domestically in various countries. Lastly, it could exacerbate existing imbalances in global trade, where countries with existing surpluses increase those (e.g. China) while countries with negative trade balances exacerbate their import dependence (e.g. the US).

Figure 3 provides an overview of domestic and international effects of a decarbonisation of the world economy. Such decarbonisation will have a multitude of effects at both the national and international level. The three main transition drivers – climate policies, including carbon pricing and industrial policies; technological change; and a change in consumer preferences – will have an initial impact on the domestic economy. These include, inter alia, changes in fossil fuel production/consumption; changes in renewable energy production/consumption; impacts on consumption spending, savings, investment, interest rates, aggregate demand and supply, employment and output; and financial impacts on domestic equity and portfolio investors, banks and insurers through non-performing loans and wealth effects from the stranding of domestic fossil-fuel-related assets and asset gains in the "new economy".

As discussed, the decline in global demand for fossil fuels will lead to changing patterns of international trade. While export and import volumes of fossil fuel will diminish, it remains to be seen to what extent it will be substituted by other forms of trade. Trade in renewable energy may grow but whether this will be substantial is not clear since all countries have some renewable resources. International commerce in green hydrogen may emerge, but this will unlikely match today's volumes of the trade in oil. Perhaps more importantly than trade in renewables, the world economy will see a growth in trade in low-carbon technology/capital goods and critical minerals and intermediate goods required to produce them.

Furthermore, a decline in fossil fuel extraction and consumption and the resulting changing patterns of trade may have significant international macroeconomic and financial effects. These comprise wealth effects and financial stability implications from overseas stranded assets; impacts on sovereign debt markets; and impacts on capital flows, exchange rates, global macroeconomic imbalances, international investment positions and even the international monetary system.

Importantly, the domestic effects, the international trade effects, and the international macroeconomic and financial effects are not only affected by the transition drivers but interlinked and can reinforce each other.

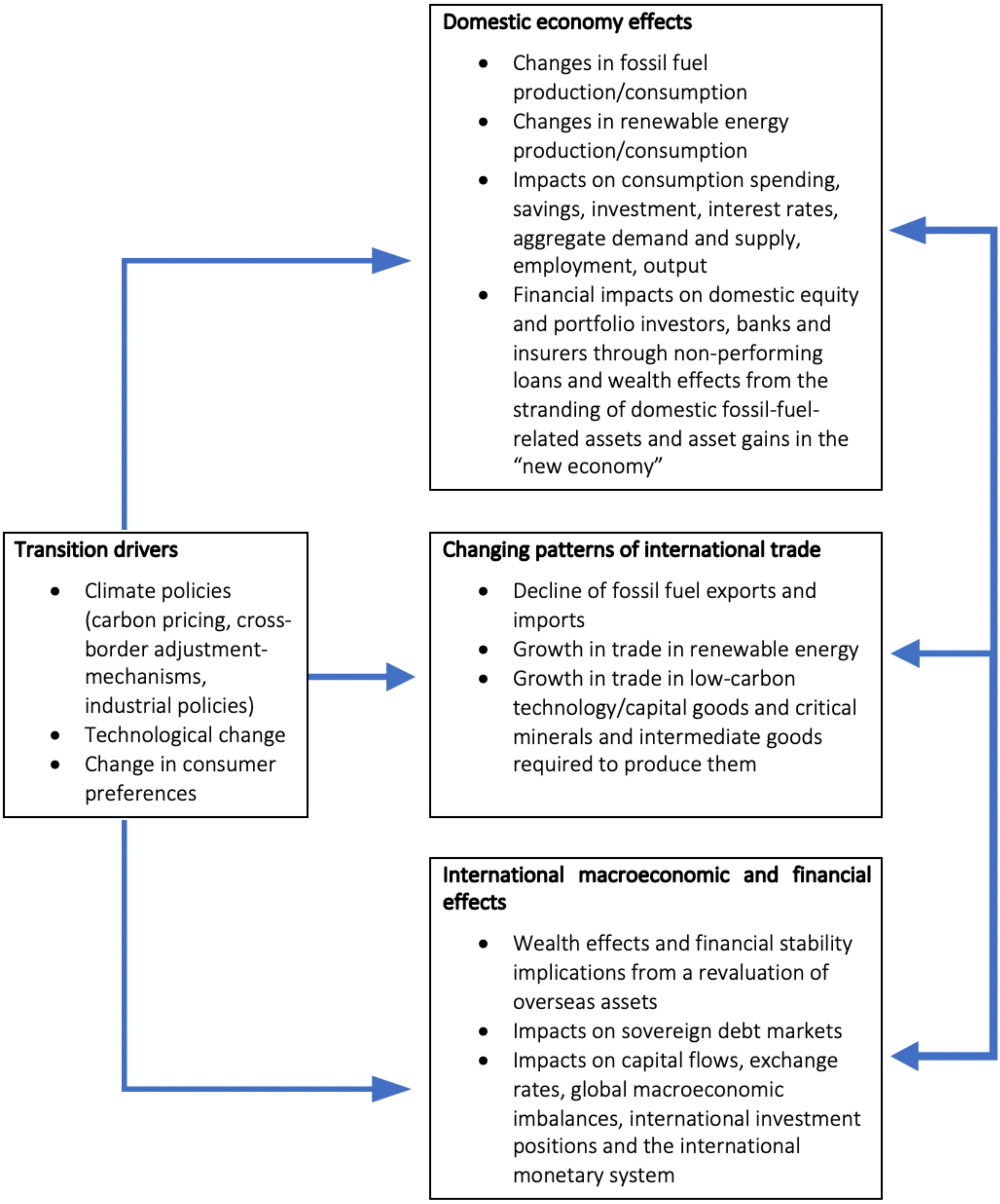

Figure 3: Overview of domestic and international effects of a decarbonisation of the world economy

2.3 Conceptualising transboundary effects

Countries will be affected differently depending on their endowment in fossil fuels, their fossil fuel production and consumption patterns, their technological capabilities to develop and produce low-carbon technologies that will substitute fossil fuel-based technology, their endowment with critical minerals and other commodities needed to manufacture the capital goods required for the low-carbon economy, and their ability to produce renewable energy, among others. It is important to highlight that transition outcomes do not only depend on domestic policies and developments, but are also affected by spillovers and transboundary impacts. Notably, climate policies that reduce fossil fuel use by major importers (e.g. China, Japan, India, the EU) as well as carbon border adjustment mechanisms (CBAMs) will have imminent transboundary impacts on all exporters (e.g. OPEC countries, Canada, Russia, the US). Likewise, technological advances and changes in consumer preferences will in many cases have global repercussions (Mercure et al., 2021).

Figure 4 presents a stylised conceptualisation of main transboundary effects. For simplicity, we distinguish four types of countries: a fossil-rich country that exports fossil fuel; a tech-providing country, which produces and exports capital goods needed for the net-zero transition; a commodity-rich country that is endowed with the critical minerals (e.g. rare earths) needed as input to manufacture the capital goods required for the low-carbon economy; and a country that is currently importing fossil fuels but aiming to decarbonise its economy and will have to import low-carbon technology to be able to do so.

A decline in international demand for fossil fuels and an associated fall in fossil fuel prices has adverse economic effects for the fossil fuel exporting country. The prospect of a further decline in demand reduces investment in fossil fuel extraction, and leads to lower investment, employment and depressed output. It also prompts a revaluation of fossil-fuel related assets. A stranding of fossil fuel assets causes negative wealth effects. In case these assets are owned by international investors, these negative wealth effects will hurt overseas investors. Everything else assumed constant, falling exports cause a deterioration of the current account and put devaluation pressure on the exchange rate. A deterioration of the country's international investment position implies less investment of petrodollars in international financial centres. This could also have implications for the international currency reserve system (Svartzman and Althouse, 2020). Likewise, energy, trade and finance agreements, as well as currency swaps, such as the recent agreements denominated in yuan between China and Russia, could also have implications for the international monetary system.

The effects in the clean tech-exporting country are exactly the converse. International demand for clean tech capital goods increases and boosts investment and production of clean tech, with positive effects on output and employment. The boom in clean tech leads to positive wealth effects, which benefit both domestic and international investors. An improvement of the current account causes appreciation pressure on the exchange rate. An improvement of the country's international investment position triggers more investment in international financial centres, which may or may not be the same as in the past. The effects are the same for the critical minerals-exporting country.

In reality, countries may be fossil fuel importers and exporters at the same time (as in the case of the US or Nigeria). They may also be producers of clean-tech or have the potential to be one. The position of countries may be expected to evolve dynamically, depending on both domestic and international developments. In the following, we will discuss in greater depth the potential impacts of a decarbonisation of the world economy on international trade and financial flows and the international financial and monetary system at large.

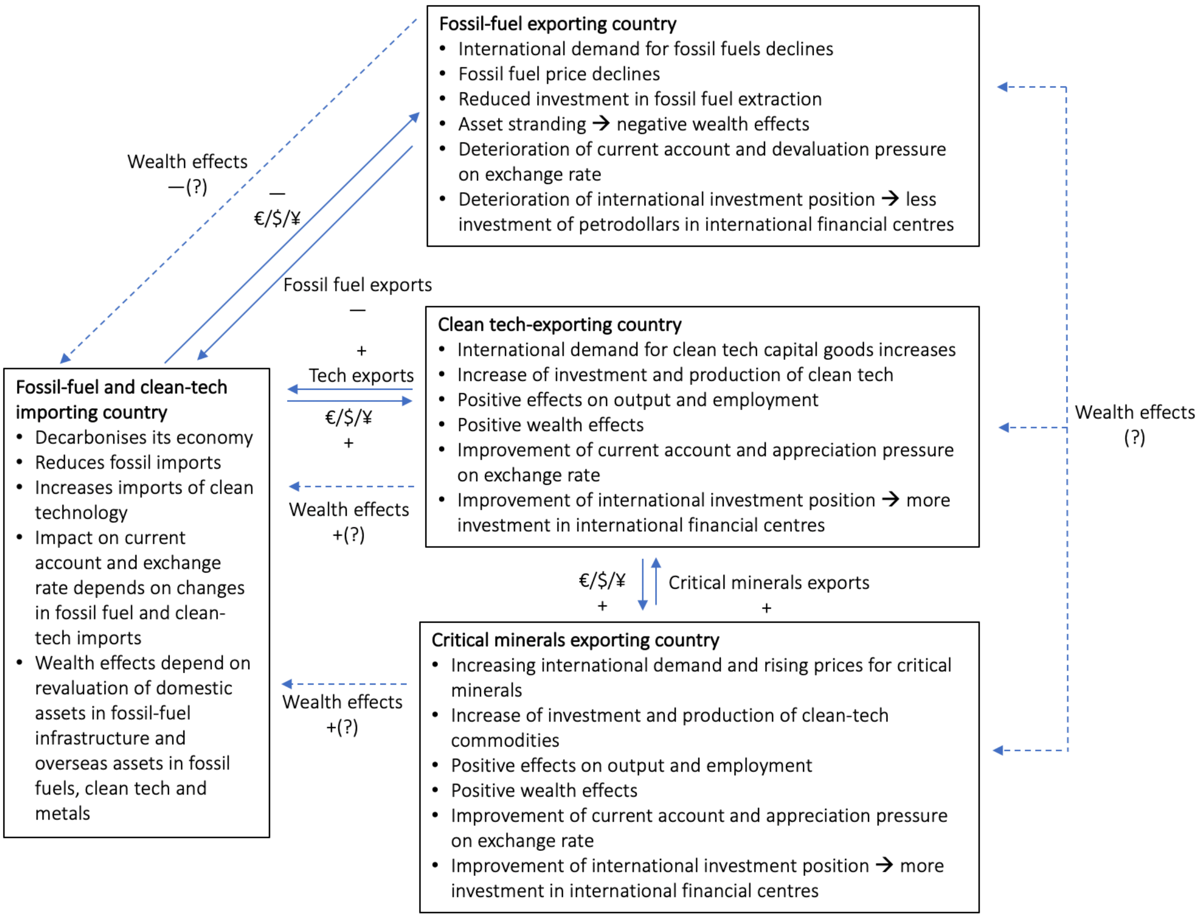

Figure 4: Transboundary effects affecting different types of countries

3. International trade effects

International trade effects of a global net zero transition may be substantial. To start with, there is currently an implicit subsidy to CO_2 emissions in internationally traded goods (Shapiro, 2021). Indeed, in most countries, import tariffs and non-tariff barriers are substantially lower on dirty than for clean industries. This global implicit subsidy in trade policy is estimated at between \$85 and \$120 per ton of CO_2. This thus amounts to the equivalent of a negative carbon pricing on international trade flows. So how will global trade flows be affected if a global net zero strategy is put in place, if trade in fossil fuels dries up and gets replaced by trade in renewable energy and low-carbon technologies (and commodities needed to produce them)? Not only is the current structure of trade barriers essentially biased in favour of dirty industries, but it also does not seem to allow the full incorporation of net zero constraints. The trade system recognises governments' authority in these areas, for example through exceptions to Article XX of the General Agreement on Tariffs and Trade, but progress on incorporating sustainability norms into the international trade regime has been very limited so far. Trade tensions due the mainstreaming of environmental and social concerns might sharply rise. Establishing a level playing field through an international agreement on the transition to near-zero emissions for globally traded products by the mid-2020s would be essential to mitigate these trade-related trans-boundary effects (IEA, 2021b).

Such an agreement would however require a degree of coordination that is highly doubtful to obtain. There is a strong case that countries aiming at deploying a net zero strategy may resort to measures to shield domestic near-zero emissions production from competition from products that create emissions (IEA, 2021b). This is already the case of the current carbon border adjustment mechanism in preparation at the EU level, or tariffs on solar panel imports into the US. More generally, export controls, subsidies to state-owned enterprises in the mining and processing sectors, or carbon border taxes could develop and restrict trade practices. In the low international cooperation case developed by the IEA (2021b) in its net zero prospective assessment, many technologies and mitigation options are deployed with a 5 to 15 years delay compared to the cooperation scenario, jeopardising the Paris Agreement's objectives.

3.1 Fossil fuel exports and imports

To estimate potential impacts of a decarbonisation of the world economy on trade, we employ E3ME-FTT, a global macro-econometric model that integrates a range of social and environmental processes (Mercure et al., 2018a, 2018b, 2019). E3ME is a widely used global macroeconometric model disaggregated over 70 regions and 43 industrial sectors. Its behavioural relationships are estimated over data starting in 1970. It projects the evolution of the economy until 2070 under a demand-led economic framework, and estimates the demand for goods and services on the basis of disposable income of economic agents, investment by sector on the basis of recent economic activity, sectoral employment, intermediate and final production using input-output relationships, bilateral trade and crucially, technological progress. The model also estimates energy use for and emissions from 12 widely traded fuels in physical units. The FTT model, for its part, simulates on the basis of recent trends the diffusion of key technologies with a high level of granularity (power generation, transport, heating, steelmaking), covering over 80% of fossil fuel use across the economy. Lastly, the framework incorporates a detailed representation of natural resources extraction, use and depletion, in renewables and fossil fuels, including data over 120,000 oil and gas assets worldwide, covering most existing resources and reserves.

The macroeconomic core of E3ME is a demand-led input-output and econometric-driven accounting system. The demand for final goods and services is first estimated, on the basis of prices (domestic and import prices) and disposable household income. This drives the demand for intermediate products and investment goods (production capital) through the input-output framework and with investment equations. Disposable income is determined from econometrically determined employment and wages, while investment is determined on the basis of the needs of industry to expand and the prices of capital goods. The allocation of finance is demand-driven, which implies that loans are created on the basis of the credit-worthiness of projects, where new investment ventures do not necessarily crowd out other investment elsewhere in the economy (see Pollitt and Mercure, 2017; Mercure et al., 2019). Behavioural relationships for consumption, investment, employment, imports and exports are estimated through multivariate linear cointegration methods by sector and region on data since 1970, which therefore involves tens of thousands of equations.

Crucially, trade relationships are established on a bilateral basis between each region. The demand for all energy vectors is estimated in physical units, according to 22 energy using sectors. For fossil fuels, three global pools of fuels is assumed to exist (coal, oil, gas), and a database covering more than 40,000 oil and gas wells (from Rystad) is used to determine which assets are economically viable to produce at each time step, the marginal cost of which determine an endogenous oil price in the model.

The evolution of technology follows a different, evolutionary methodology grounded into the theory of the diffusion of innovations (Rogers, 2010). Technology diffusion follows S-shaped diffusion curves, where the initial evolution is slow, followed by a rapid deployment, and a slow process of market saturation. Meanwhile, technology costs follow endogenous learning-by-doing relationships function of cumulative deployment, where cost reductions attract more deployment, which cause more cost reductions, in self-reinforcing patterns typically observed with innovations. The 'Future Technology Transformations' family of models apply this methodology to a total of 88 technologies in power generation, road transport, household heating and steelmaking, covering over 60% of global CO2 emissions.

Scenarios of global energy demand and low-carbon transition until 2070 were developed in order to better understand future energy-related geopolitics and the financial ownership of transition risks (Mercure et al., 2021). 12 scenario variations were explored. This includes a baseline for energy use from the IEA, the model's own baseline on the basis of its own projections over low- and high-carbon technology diffusion and decline, a scenario based on the current emission reduction pledges of major economies, and a hypothetical scenario that achieves net-zero emissions worldwide. To complement those, an analysis of geopolitical strategic behaviour by oil and gas producers was done using three scenarios of output, where OPEC either respects strict quotas of production to maintain prices high, carries on with current trends, or acquires an increasing share of declining markets by flooding oil and gas markets with low-cost fuels, pushing out other producers (denoted SO here for 'sell-off').

Figures 5-8 show the estimated difference in, respectively, exports, imports, output, and employment by sector between the IEA and Net-Zero SO scenarios for selected countries (Canada, China, India, Russia, the US) and country groups (EU, OPEC, rest of the world (ROW)). Three time points are shown in each sector, 2030 (blue), 2040 (red) and 2050 (yellow). Figure 9 shows the estimates for the fossil export balance relative to total baseline exports; Figure 10 shows the estimated change in the trade balance relative to GDP; and Figure 11 displays the change in real GDP relative to the baseline.

The data shows a complex story of decline in fossil fuel exports and related manufacturing for the large fuel producing countries, linked to reductions in imports by the large energy importers. Importantly, since renewable resources are widely distributed across the globe, solar energy costs are breaking parity with the lowest cost fossil fuel-based electricity generation, and since the transport of electricity requires substantial and expensive transmission infrastructure, electricity is not expected to be traded widely across borders in a low-carbon world. Therefore, while the global use of energy services continues to grow through the low-carbon transition, the loss of exports and imports of fossil fuels is not compensated for by the trade of electricity or any other low-carbon energy carriers.

Furthermore, in a low-carbon world, volumes of fossil fuels demanded until 2070 become limited, and compare relatively closely with available reserves in OPEC countries, where they are on average most competitive to extract (Rystad, 2021). Geopolitical analysis suggests it is likely that OPEC producers, in order to maximise the value of their existing fossil fuel assets, maintain or increase current oil and gas output between now and 2050 as global demand peaks and declines, thereby increasing their market share at the expense of that of non-OPEC producers (Van de Graaf and Bradshaw, 2018; IRENA, 2019). This pushes products originating from less competitive extraction sites such as deep offshore, arctic, shale oil/gas and tar sands out of global oil and gas markets.

Most economies globally will likely evolve to some small or large degree away from primary and secondary industries towards services going towards 2070 (Van de Graaf and Bradshaw, 2018). However, in fossil fuel-producing countries, substantial levies on fossil fuel production typically finance sizeable fractions of government expenditure, in areas covering most sectors of these economies. The loss of these royalties implies potential severe reductions in public spending, affecting disposable income spent on final goods and services (assuming no compensatory deficit spending by governments, which could not be maintained indefinitely). Hence the transition and related trade effects affect not only industry but also services.

Our estimates suggest Canada, Russia and the US will see their fossil fuel exports decline very rapidly, while OPEC countries (and Saudi Arabia in particular) will be able to expand fossil fuel exports due to lower production cost. However, already in 2040, OPEC countries will see a deterioration of its trade balance. Canada, Russia and the US will see their trade balance deteriorate within a decade from now. China, the EU and India, in contrast, are going to see their trade balances improve. India is going to benefit the most, relative to GDP. These three economies are also going to benefit from the low-carbon transition in terms of output growth.

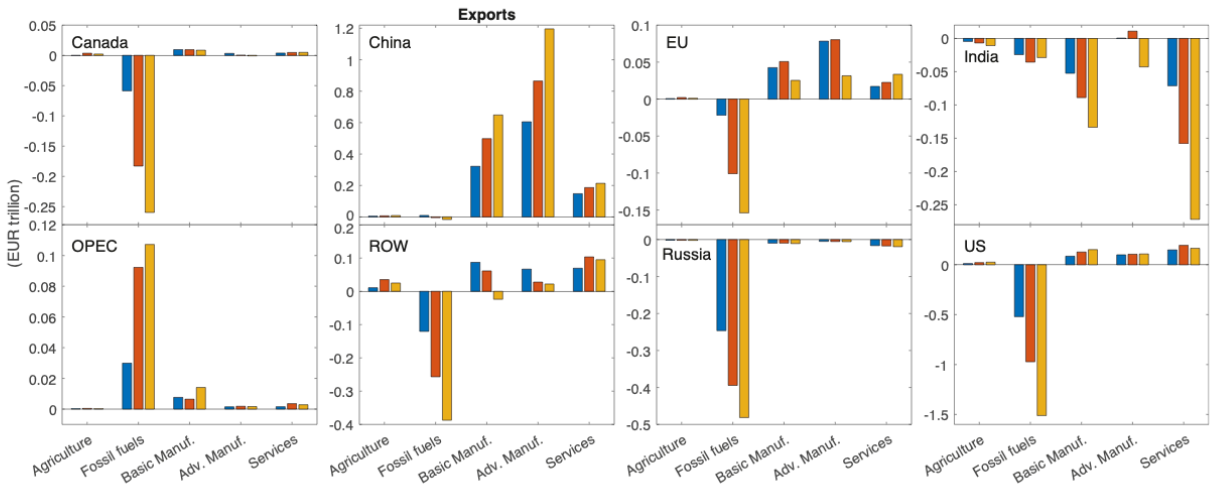

Figure 5: Difference in exports by sector between the IEA and Net-Zero SO scenarios, estimated using E3ME-FTT.

Note: Three time points are shown in each sector, 2030 (blue), 2040 (red) and 2050 (yellow).

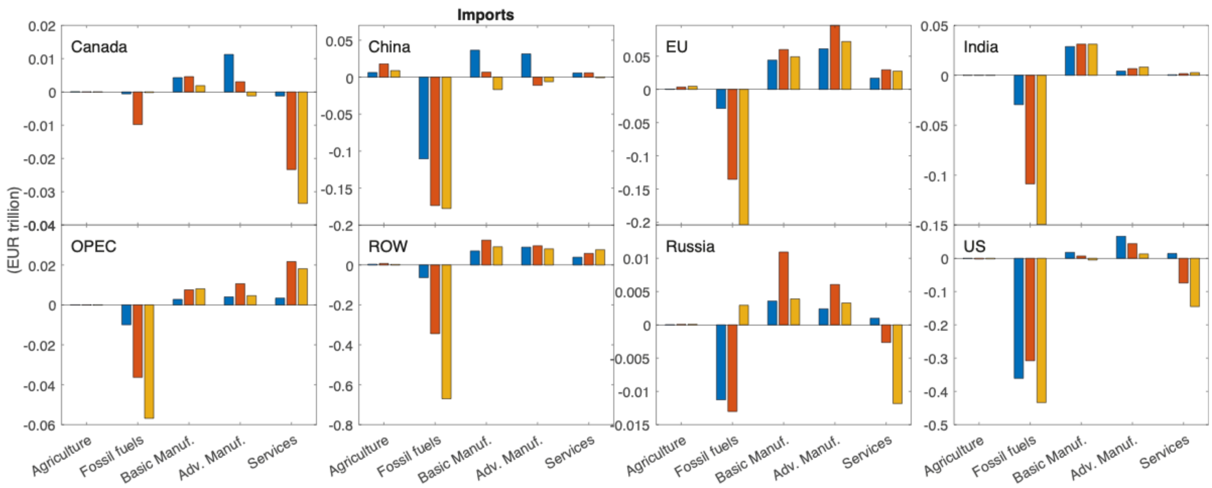

Figure 6: Difference in imports by sector between the IEA and Net-Zero SO scenarios, estimated using E3ME-FTT.

Note: Three time points are shown in each sector, 2030 (blue), 2040 (red) and 2050 (yellow).

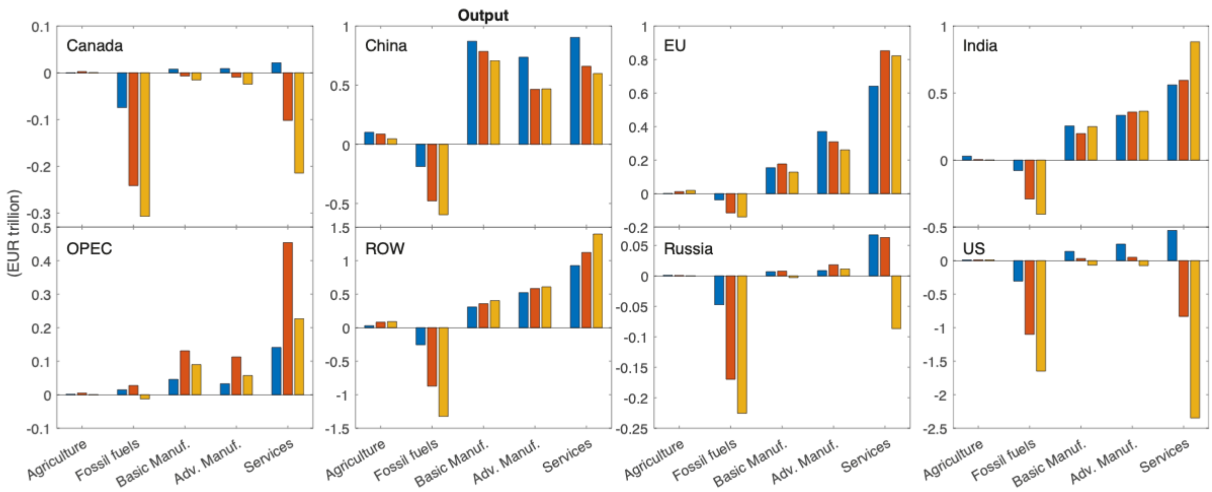

Figure 7: Difference in output by sector between the IEA and Net-Zero SO scenarios, estimated using E3ME-FTT.

Note: Three time points are shown in each sector, 2030 (blue), 2040 (red) and 2050 (yellow).

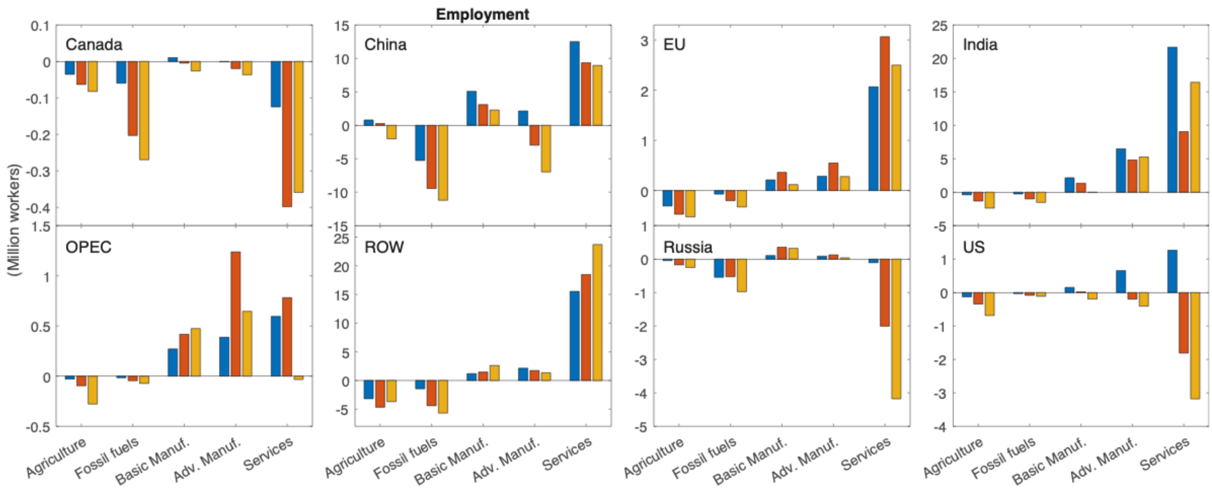

Figure 8: Difference in employment by sector between the IEA and Net-Zero SO scenarios, estimated using E3ME-FTT.
Note: Three time points are shown in each sector, 2030 (blue), 2040 (red) and 2050 (yellow).

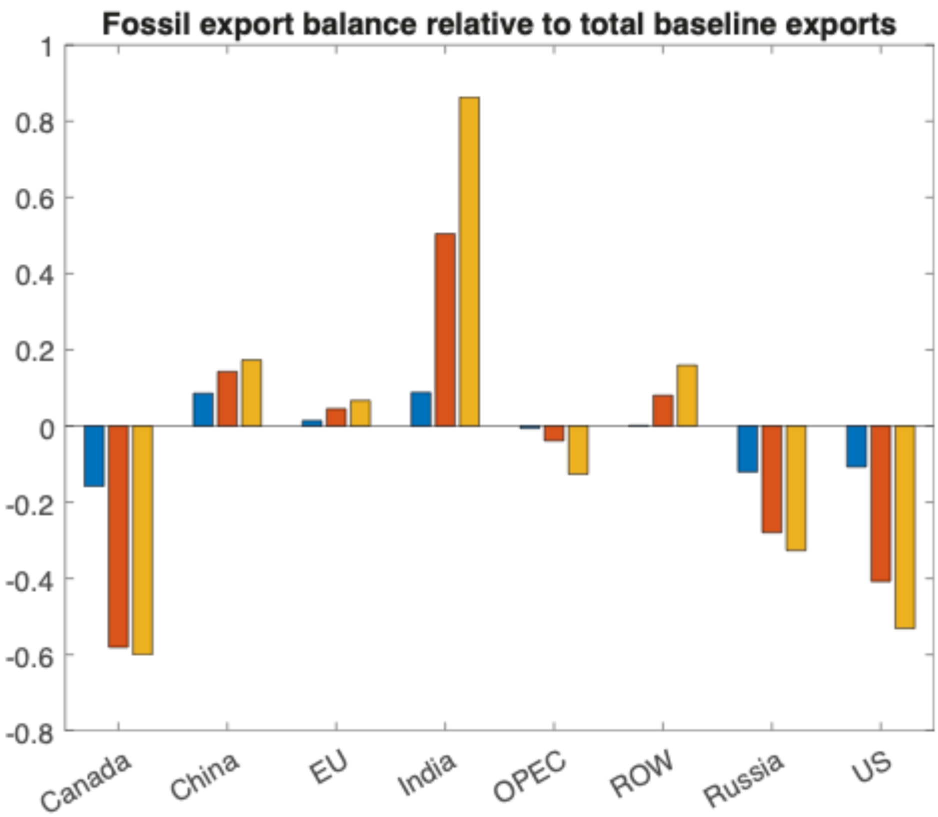

Figure 9: Fossil export balance relative to total baseline exports, estimated using E3ME-FTT.
Note: Three time points are shown in each sector, 2030 (blue), 2040 (red) and 2050 (yellow).

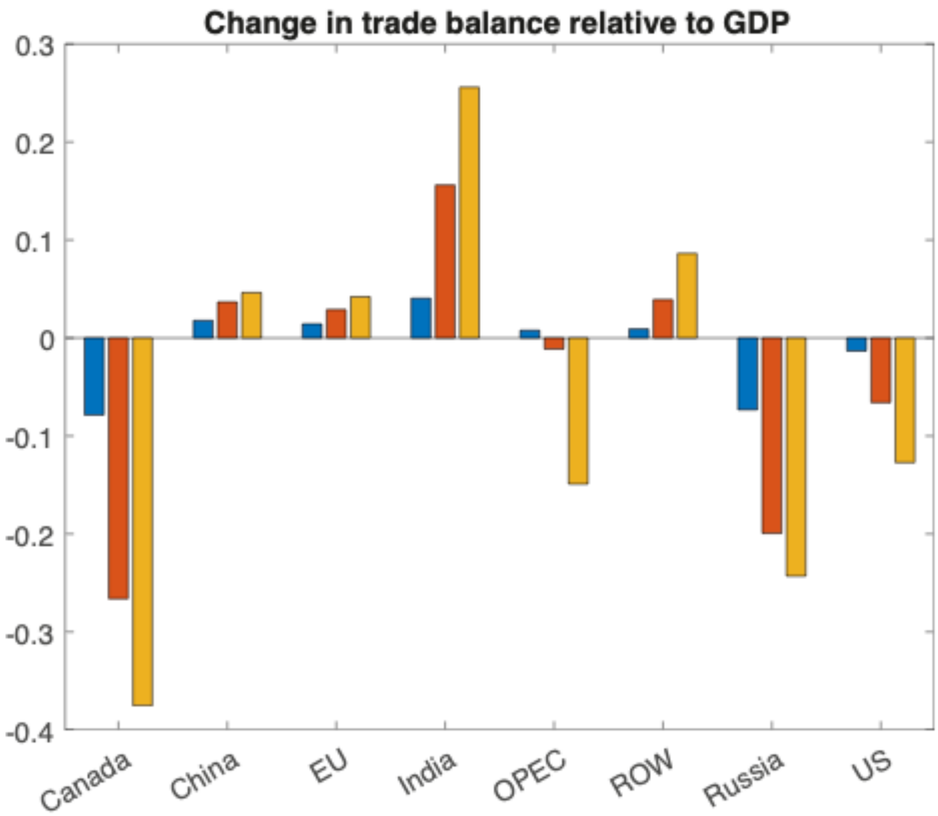

Figure 10: Change in the trade balance relative to GDP, estimated using E3ME-FTT.
Note: Three time points are shown in each sector, 2030 (blue), 2040 (red) and 2050 (yellow).

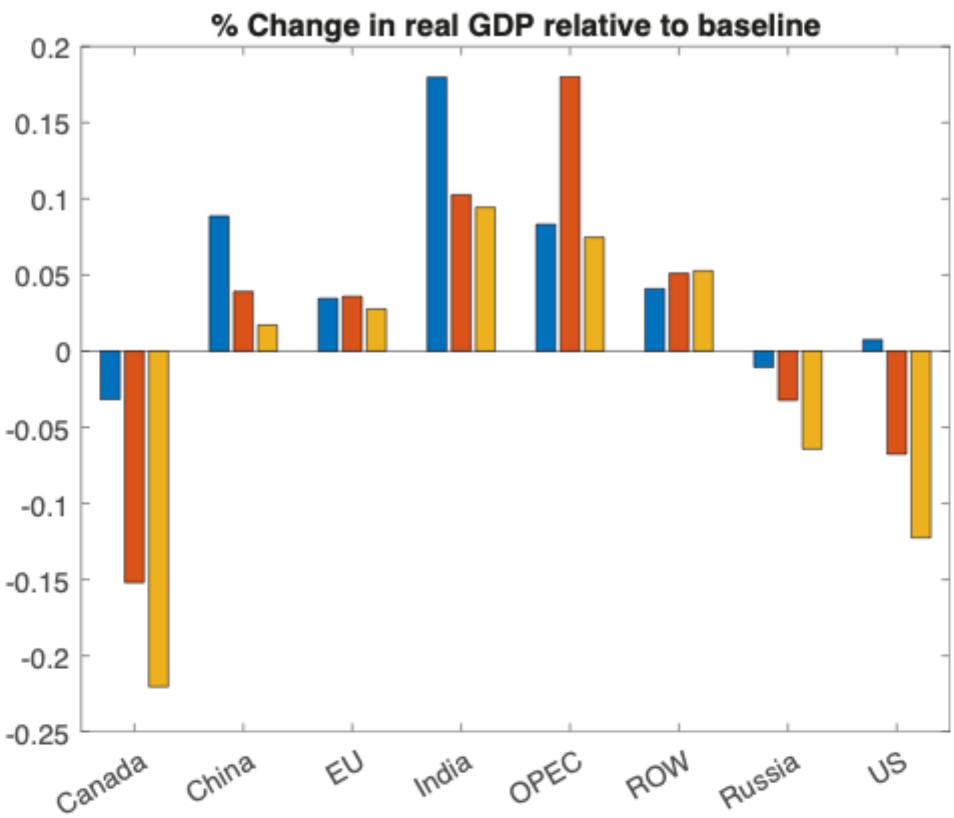

Figure 11: Change in real GDP relative to baseline, estimated using E3ME-FTT.
Note: Three time points are shown in each sector, 2030 (blue), 2040 (red) and 2050 (yellow).

3.2 Trade in renewable energy

If we consider the energy mix in the net zero scenario of IEA (2021b), the share of fossil fuels in total energy use declines from around 70% today to 30% in 2050, with the vast majority of fossil fuels still being used in the heavy industries sectors, mainly as chemical feedstock (50%) or in plants equipped with carbon capture, utilisation and storage (CCUS, around 30%). Electricity becomes the dominant fuel in industrial energy demand growth, with its share of total industrial energy consumption rising from 20% in 2020 to 45% in 2050. Some 15% of this electricity is used to produce hydrogen, which can play an important role in shaping trade patterns. Bioenergy plays an important role, contributing 15% of total energy use in 2050, but sustainable supplies are limited, and it is also in high demand in the power and transport sectors. Renewable solar and geothermal technologies provide heat to make a small but fast-growing contribution in that scenario.

Increasing global demand for low-carbon hydrogen in the IEA (2021) net zero scenario provides a means for countries to export renewable electricity resources that could not otherwise be exploited. For example, Chile and Australia announced ambitions to become major exporters in their national hydrogen strategies. With a declining demand for natural gas, gas producing countries could join this market by exporting hydrogen produced from natural gas with CCUS. Long-distance transport of hydrogen, however, is difficult and costly because of its low energy density, and can add around USD 1-3/kg of hydrogen to its price, so that producing hydrogen sometimes may be cheaper than importing it. But globally, trade in hydrogen develops over time with large volumes exported from gas and renewables-rich areas in the Middle East, Central and South America and Australia to demand centres in Asia and Europe (IEA, 2021c).

Solar and wind energy, as well as batteries for electric cars are all using important amounts of (imported) mineral resources, which become the essential dimension of a specific trade related risk, as their supply chains can quickly be affected by regulatory changes, trade restrictions or political instability in a small number of countries.

3.3 Trade in low-carbon technology and critical minerals

The IEA (2021d) recently highlighted the key role of critical minerals in clean energy transitions. The net zero scenario sees a major increase in demand for critical minerals such as copper, lithium, nickel, cobalt and rare earth elements that are essential for many clean energy technologies. There are several potential vulnerabilities that could hinder the adequate supply of these minerals and lead to price volatility at the international level (IEA, 2021d). Today's production and processing operations for many minerals are highly concentrated in a small number of countries, making supplies vulnerable to political instability, geopolitical risks and possible export restrictions. New critical mineral projects can have long lead times, so the rapid increase in demand in the net zero scenario could lead to a mismatch in timing between supply and demand which could reduce the pace of national net zero strategies.

For lithium, cobalt and rare earth elements, the world's top three producing nations control well over three quarters of global output. In some cases, a single country is responsible for around half of worldwide production. The Democratic Republic of the Congo (DRC) and China were responsible for some 70% and 60% of global production of cobalt and rare earth elements respectively in 2019. The level of concentration is even higher for processing operations, where China has a strong presence across the board. China's share of refining is around 35% for nickel, 50-70% for lithium and cobalt, and nearly 90% for rare earth elements. Chinese companies have also made substantial investment in overseas assets in Australia, Chile, the DRC and Indonesia. High levels of concentration, compounded by complex supply chains, increase the risks that could arise from physical disruption, trade restrictions or other developments in major producing countries. As security of supply comes into sharper focus, potential distortions to the free trade of critical minerals become increasingly sensitive, even if quantitative restrictions are largely prohibited under GATT article XI. Export restrictions introduced by China, Indonesia and the DRC reflect the varying objectives being pursued, but may be justified under certain limited exceptions such as environmental conservation or national security.

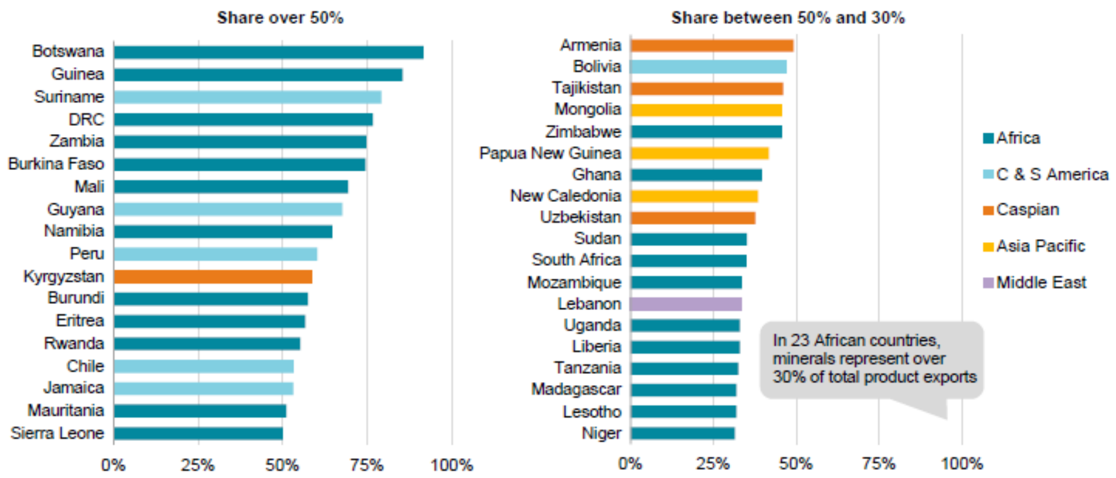

Figure 12: Share of minerals and metals in total product exports for mineral producing countries, 2019.
Note: The chart shows countries whose shares (based on monetary value) is above 30%. Standard international trade classification codes 27, 28, 68, 667 and 971 were included in the minerals and metals category. C & S America = Central and South America.
Source: IEA (2021d).

Beyond the geographical concentration of mining and processing capabilities, the international pricing mechanisms of many metals bear specific risks. Many base metals such as copper are widely traded in the market with reliable pricing mechanisms. However, this is not the case for some energy transition minerals with smaller markets, such as lithium and cobalt. These minerals have been historically regarded as "minor minerals" and traded on a bilateral basis, resulting in low pricing transparency and liquidity. Buyers need to rely on information provided by suppliers, making it difficult to manage price risks and affecting investment decisions down the value chain. However, as demand grows, end users will increasingly call for more transparency around pricing to hedge risks. Establishing reliable price benchmarks will be an important step towards enhancing market transparency and supporting market development. But this process takes time and creates a short to medium run transboundary trade risk.

3.4 Trade in intermediate goods

Besides the direct emissions during the production process, it is also possible to estimate the indirect emissions both upstream (emissions embodied in intermediate inputs) and downstream (emissions after production until final consumption), using hybrid Multi-Regional Input Output (MRIO) modelling, and thus move beyond the transboundary risks from trade in final products or raw materials (Magacho et al., 2021). Once the potential sunset industries are defined, one can calculate the external exposure of each country considering its dependency on these industries to raise foreign currency. This net raise of foreign currency, as export industries use directly and indirectly imported inputs to produce, means that despite raising foreign currency by exporting, some countries might consume foreign currency in order to import intermediate inputs.

The higher the dependence of these industries, the higher is the country exposure. However, countries with high productive and technological capabilities can easily migrate from one product to another, which means that despite being exposed to the low-carbon transition, they are less vulnerable. Based on the Economic Complexity Approach (Hidalgo et al., 2007), Mealy and Teytelboyn (2020) developed a method to estimate countries' capabilities in green products. Based on the complexity of products that countries' are competitive, the authors estimate the Green Complexity Potential (GCP). The GCP indicates what are the countries with the higher technological and productive capabilities to migrate to green products based on the products the country already is competitive.

4. International macroeconomic and financial spillovers

Changing patterns of global trade due to a decarbonisation of the word economy can be expected to have implications also for global financial flows, investments, financial stability and the international monetary system. In the following, we will first discuss the transboundary wealth effects and financial stability implications of a stranding of fossil fuel related assets before considering possible impacts on sovereign debt markets and the broader impacts on global macroeconomic imbalances and the international monetary system. Data limitations constrain for the time being our ability to model these effects, as we do for trade in Section 3.

4.1 Stranded assets, wealth effects, and financial stability implications

Asset stranding is one of the most intensely studied aspects of the impacts of climate change policy. Estimations of remaining carbon budgets (Allen et al., 2009; Rogelj et al., 2019) unambiguously show that vast proven fossil fuel reserves would need to remain underground under any ambitious mitigation scenario (Meinshausen et al., 2009; Heede and Oreskes, 2016).[2] Studies of committed emissions from invested capital have shown that increasing shares of the global fossil fuel infrastructure is subject to premature decommissioning (Davis et al., 2010; Tong et al., 2019; Pfeiffer et al., 2018; Guivarch and Hallegatte, 2011; Rozenberg et al., 2015). Potentially trillions of dollars of investments have already gone into such assets at risk of stranding, and might still flow if investors' expectations do not align to a low-carbon world soon (Pfeiffer et al., 2018; Caldecott, 2018; Mercure et al., 2018, 2021), not to mention sectors that have invested in physical capital operable only with fossil fuels (e.g. certain steel and concrete manufacturing methods, airplanes) or are focused on fossil fuel-dependent final products (e.g. internal combustion engine supply chains, gas turbine manufacturing).[3] Industries that depend heavily on carbon-intensive technologies, notably long-distance mass tourism, could experience a sudden increase in asset stranding (e.g. of hotels and restaurants that depend on local airport traffic) if carbon pricing, regulations, social norms or consumer behaviour in foreign export markets were to shift rapidly and make the business models on which these industries are based non-viable.

Yet, while considerable effort has gone into understanding the geographical distribution of stranded assets (McGlade and Ekins, 2015; Welsby et al., 2021; Edwards et al., 2021) and regional macroeconomic consequences (Mercure et al., 2018; Stolbova et al., 2018), much less is understood about transboundary effects. Many assets – both equity and debt – are sold to international customers and on-sold on secondary markets that are highly internationalised. Driven in particular by nonbank financial institutions, market-based finance and foreign participation have grown considerably since the Global Financial Crisis, owing to the liberalisation of domestic financial markets in developing and emerging economies, accommodative policies in developed economies, and so-called search for yield (Garcia Pascal et al., 2021). Moreover, the immediate owners of financial assets (e.g. a local subsidiary of an international bank) may have a parent organisation abroad, which may in turn be owned by other firms. Behind these corporate ownership networks lies a potentially global distribution of ultimate owners.

Funds illustrate the international linkage well. Large asset managers invest in virtually every traded company in the world as well as a range of alternative assets, but are headquartered in a particular country. Their clients in turn come from all over the world. For instance, the US

[2] Unruh problematised the conceptual idea of carbon lock-in prior to quantitative carbon budget estimates (Unruh, 2000; Unruh and Carrillo-Hermosilla, 2006).

[3] Meantime, physical risks from changed weather patterns, temperature changes and flooding threaten vast swaths of invested productive capital, and land and real estate assets (IPCC, 2018; Mandel et al., 2021; Dafermos et al., 2018).

investment manager BlackRock reported one third of its assets under management were owned by clients outside the Americas in its 2020 annual report (BlackRock, 2021). Fixed income funds have undergone tremendous growth since the Global Financial Crisis, with the capital allocated to them rising from about $1 trillion to $3.5 trillion in developing and emerging economies, and from about $5 trillion to $30 trillion in advanced economies, between 2008 and 2020 (Garcia Pascual et al., 2021), raising questions about financial markets' resilience to shocks, including related to transition risks. As noted by the IMF (2021), investment funds have large exposures to sectors that are most sensitive to the low-carbon transition (ECB 2021; ESMA 2021), implying the existence of global financial stability risks. Debt networks are equally internationalised (Dungey et al., 2019; Nardo et al., 2017) and interlinked with equity networks, as acutely highlighted by the debt securitisation that fueled the 2007-08 subprime housing crisis.

Clearly, any widespread asset stranding will have a strong transboundary effects on financial assets valuation and wealth, second and further round effects within the financial system and the potential to affect global financial stability (Stolbova et al., 2018; Bolton et al., 2020; Vermeulen et al., 2021; Semieniuk et al., 2021a; Stiglitz, 2010). As illustrated by the COVID-19 shock, one channel through which asset stranding could lead to cross-border spillovers is large-scale asset sell-off in financial markets. This could result from the emergence of a "focal point" around selling and liquidity pressures for funds in a context of lower market liquidity and downward pressures on asset prices, which could potentially generate adverse feedback loops (see also Garcia Pascual et al., 2021).

Furthermore, if stranded assets are used as collateral for cross-border loans, their sell-off could offset part of the risk mitigation stemming from the collateral (BIS, 2021). Financial institutions that have cross-border exposures to firms that have not abated their carbon emissions could also suffer credit-related losses, as carbon pricing, regulations, or changes to consumer behavior or market sentiment toward carbon-intensive products or investments could dent these firms' competitiveness and hit their profitability (BIS, 2021).

To get a better sense of the potential risks, we review the small but growing number of studies that explicitly trace cross border effects of asset stranding.[4] Cahen-Fourot et al. (2021) look at how supply-side constraints on fossil fuel production can create under-utilisation of capital stocks in downstream sectors via multi-regional production networks. Their results suggest that global value chains can act as a stranding propagation mechanism to other regions, with the US, China and Japan being particularly exposed to this type of transition risk. Manych et al. (2021) find that since 2015, most coal power plants have been constructed in Asia, but that many financing sources are located abroad, raising the finance-based (as opposed to

[4] Regarding transboundary capital stranding effects stemming from the physical impacts of climate change, Mandel et al. (2021) examine scenarios of cross-border effects from capital stranding in 109 countries representing 95% of global GDP due to intensified flooding from climate change. They find that most countries' financial exposure to asset loss risk is dominated by financial exposure to flood risks in other countries, and that Northwestern European countries are most exposed (risk on the same order of magnitude as their capital buffer) due to their network centrality as well as an increase in flood-risk relative to historical averages.

territorial) emissions of many advanced economies, by up to 10% (17%) in the US (Japan). Given that many of these coal plants face stranding, the transboundary effects will likely be palpable.

Semieniuk et al. (2021b) show for scenarios of asset stranding in the global oil and gas sector that the loss of advanced economy companies and ultimate owners is much larger than the physical asset loss in these countries. This is due to transborder equity ownership. In their medium scenario, OECD country corporate shareholders are exposed to 55% of losses even though only 36% of physical assets are likely to strand in OECD countries. The share falls by 2 percentage points to 53% for ultimate owners as funds managed in OECD countries distribute losses to clients around the world.

As renewable energy is not expected to become internationally traded, it is unlikely to be predominantly traded in one of the main international currencies, unlike oil. This exposes international investors to currency risk, in addition possibly to more regulatory risks given the dependence of their revenues on domestic policy frameworks (Ameli et al., 2021).

The Financial Stability Board has identified several real and financial channels through which transition risks could cross borders (FSB, 2020). First, climate-related shocks could propagate across borders through the co-movement in risk premia on assets exposed to climate-related risks in different countries. For instance, policy measures taken in one jurisdiction – either in response to the crystallisation of physical risks or as part of a disorderly low-carbon transition – could be seen as foreshadowing the future path of policies in other jurisdictions. Conceivably, a broader sell-off could occur, for example if financial markets anticipate selling and liquidity pressures on fixed income funds, including those that have lower climate risk exposures, as occurred with the COVID-19 shock. Such a response of the global financial system to shocks could amplify credit, liquidity and counterparty risks in unpredictable ways.

Second, current approaches to risk diversification and management may not take climate risk into account, such that they may be inadequate to the task in the event of a shock induced by transition risk. This could generate an adverse feedback loop between contracting bank lending and insurance provision (FSB, 2020). As climate risk – including transition risk – materializes, insurers may increase prices and/or reduce coverage, potentially hampering economic activity in countries with firms that depend significantly on such insurance.

Third, the exposure of financial institutions constitutes another risk channel. The dependence of many developing economies on cross-border lending by banks, insurance companies and other asset owners could transmit transition risks across borders (FSB 2020), for instance via a "sudden stop" in capital inflows that could adversely impact domestic equity and bond issuers. Divestment from fossil fuel producers could reduce financial risks for individual financial institutions while increasing global systemic financial risk through the stranded assets channel. Cross-border climate risk contagion could occur through financial institutions. Indeed, cross-border financial flows could result in a concentration of transition risks in some jurisdictions, creating financial stability risks. Preliminary analysis by the FSB suggests that cross-border lending could amplify climate risks in countries that are recipients of cross-border lending (FSB, 2020). As noted by the FSB, in developing and emerging economies macroeconomic vulnerabilities could amplify such effects via exchange rate depreciation and broader capital outflows.

Another channel is the interaction of physical and transition risks. For example, Latin American and Caribbean countries, many of which depend significantly on hydropower, could be forced to increase fossil fuel investments – and therefore stranded assets – to compensate for lower hydropower due to droughts and low river water levels, as occurred in Argentina, Bolivia, Brazil and Chile in 2021.

This research is only in its infancy, although the existing evidence could in principle be increased by some existing studies with implicit results. For example, in their analysis of the effects of high-carbon asset devaluation on the European interbank market, Battiston et al. (2017) do not explicitly trace cross-border transactions, but their finding that some banks suffer most losses from second-round (interbank) effects implies that large-scale asset stranding anywhere in Europe would have strong cross-border effects on banks listed in the EU. This analysis could be re-run with an explicit measure of gross and net cross-border risks. Work could also be done on modelling transmission channels and how to deal with timing of realisation of stranding, which is true for all transition and physical risk studies, hence progress is expected.

One major obstacle to progress is availability of data: most existing data is too costly for academics except when equipped with major grants, limiting the number of studies. Additionally, data on debt and fund holders is difficult to access for academics without collaboration with regulators or fund managers, which in turn tend to have access only to a geographically limited or their own clients' set of data respectively. Yet, even the small sample of existing studies already holds one powerful message: transboundary exposures redistribute losses towards the global centres of finance and the most wealthy countries and could contribute to a destabilisation of global financial markets. Analysis of wealth loss and risks from stranded assets that ignores cross-border flows is liable to underestimating risks and the potential for instability.

4.2 Impacts on sovereign debt markets

Credit rating agencies and debt markets have started to recognise climate-related sovereign risks (Volz et al., 2020). Empirical evidence suggests that markets are already pricing, at least partially, the physical risks of climate change, increasing the cost of debt in climate vulnerable countries (Kling et al., 2018; Beirne et al., 2021a, 2021b). Volz et al. (2020) identify transition risks as a potential source of sovereign risk, with potential implications on the investability of sovereign bonds and the cost of debt. Transition impacts can cause fundamental and enduring structural changes to the economy (Semieniuk et al. 2021a) that erode sources of fiscal revenue and require large-scale government spending to smoothen adverse transition impacts and create new opportunities for workers that lost their jobs and communities that have lost their livelihood. The fiscal impact of transition risk materialisation could be extremely large, with oil exporters in Latin American and the Caribbean standing to lose up to $3 trillion in royalties by 2035 (Solano-Rodríguez et al., 2019). Our estimations of the impact of a decarbonisation of global trade on output, investment and employment in Section 3 highlight the potential magnitude of these effects. Changes to output, investment and employment, as well as financial instability caused through a stranding of fossil fuel assets, would almost certainly have ripple effects on public finances.

Potential downgrades by credit rating agencies would make it costlier for sovereigns to refinance themselves in international debt markets. As recently pointed out by the Institute of International Finance, a "[f]ailure to reduce reliance on carbon-intensive activities could add to upward pressure on EM government borrowing costs by reducing investor appetite for EM assets" (Tiftik and Mahmood, 2021). Worryingly, the willingness of international investors to provide funding to governments facing high transition risks, and hence also international financing conditions, could worsen exactly at a time when declining exports and deteriorating current account balances increase a country's need for and dependency on external finance. At the worst, countries with a heavy dependency on the fossil fuel economy may experience a sovereign debt crisis, which itself could have contagious effects internationally.

4.3 International macroeconomic and financial impacts

A decline in fossil fuel extraction and consumption and the associated changes to imports and exports may have significant international macroeconomic and financial impacts. To start with, changes in imports and exports related to a decarbonisation of global trade as discussed in Section 3 can have substantial effects on the balance of payments. Fossil-fuel exporting countries may experience a deterioration of the current account and a worsening of their international investment position. Historically, fossil fuel exporting countries have been among the biggest contributors to global macroeconomic imbalances (Arezki and Hasanov, 2013; Obstfeld, 2018). With oil revenues drying up, some may turn from current account surplus to current account deficit countries. Some may be subsequently forced to liquidate their international assets to finance their deficits. The extent to which this may prove disruptive to international financial markets depends on the speed and scale of this unravelling. Fossil fuel dependent economies diversifying away from oil, coal and gas (e.g., Hendrix, 2019; Peszko et al., 2020) may mitigate transition risks. However, there are very few countries that have started such a process in earnest.

While fossil fuel exporters are likely to see their external position deteriorate, countries exporting low-carbon capital goods and critical minerals may experience the opposite effects:

a rise in exports, an improvement of their current account, and a strengthening of their international investment position, as discussed above.

Furthermore, fossil fuel exporters may not only lose export revenues, they may also see a decline in foreign direct investment in the fossil fuel sector. Conversely, countries with a technological edge in low-carbon capital goods or large endowment of critical minerals may see a surge in foreign investment. Overall, we may see significant changes to international patterns of capital flows that could also affect global interest rates. The net impact of a decarbonisation of the world economy on growth and trade remains uncertain, however, a lack of decoupling of GDP and emissions could lead to a contraction in output and trade in order to remain within remaining carbon budgets.

Regardless of the evolution in the level of international trade, changes in international trade patterns could have wider ramifications for international macroeconomic interdependencies and the international monetary system. A deterioration of the international investment position of fossil fuel exporting countries would also put an end to large flows of investment of petrodollars into international financial centres, especially the US (Higgins et al., 2006). At the same time, we may see new international investment flows from clean-tech and critical mineral exporters. Whether these will go to the same destinations and use the same currencies as before is an open question and may also depend on geopolitical factors. All this could also have wider implications for the international reserve system and the status of the dollar as the global lead currency.

It is important to highlight that these changes may play out in parallel in a larger group of countries. The decarbonisation of the world economy could therefore result in systemic changes to the global monetary and financial system that could prove highly disruptive.

Additional risk channels could potentially emerge. Energy efficiency measures in key jurisdictions could impact the international monetary system, notably via crypto asset markets, which are highly energy intensive.[5] Sovereigns' backstop role for banks could also amplify transboundary transition risks: climate-vulnerable sovereigns' ability to backstop domestic banks could be compromised due to a sudden loss of access to international debt markets or central bank swap lines. This could lead to multifaceted crises that are directly or indirectly related to transboundary transition risks, including financial, fiscal and balance of payments crises. The extent to which such multifaceted crises could occur simultaneously across countries, and the implications of such dynamics for global economic and financial stability, remains an open question.

[5] As of August 2021, Bitcoin was estimated to consume around 0.8% of global electricity production.

5. Conclusion

In this paper, we made a first attempt at analysing the transboundary impacts of a decarbonisation of the world economy. Using the E3ME-FTT global macro-econometric model, we were able to gauge the impacts of a decarbonisation of the world economy on trade, output, investment and employment. The results show a substantial decline in fossil fuel exports and related manufacturing for the large fuel producing countries (with a time lag for OPEC countries), linked to reductions in imports by the large energy importers, with sizable effects on different sectors of the respective economies. While a lack of data does not allow us to include trade in renewable energy, low-carbon technology/capital goods and critical minerals in our model, the rise in trade in these areas may cause further, profound changes to international commerce. The changing patterns of trade are expected to have significant impacts on the balance of payments of both exporting and importing countries and on international financial flows. Moreover, the stranding of fossil fuel related assets can have trans-boundary effects on wealth and financial stability. All these may have potentially meaningful ramifications for the international financial and monetary order.

For the time being, we are not yet able to model several of these effects due to data limitations. For instance, we currently lack data on foreign investment in the fossil fuel sector, and data on international lending into the carbon economy. Going forward, our ambition is to compile data on international financial stocks and flows related to the carbon economy that will enable us to model at least partial effects of a low-carbon transition on international macroeconomic interdependencies and international financial flows.

Several dimensions of the transboundary impacts of a decarbonisation of the world economy on international trade, finance and money were not analysed in this paper and warrant attention in future research. The first is the nature of transboundary risks by country or region, depending on whether the transition to net-zero emissions is (i) orderly or disorderly, and (ii) coordinated or divergent across countries or regions. The second is the interaction of physical and transition risks, as many countries and regions are bound to experience the crystallisation of both types of climate-related financial risks in a combined way as climate change accelerates. The third is the macroeconomic implications of the role of central banks (or lack thereof) in the decarbonisation of the economy. Fourth, and related to the latter, is the impact of the low-carbon transition on inequality, both within and across economies, and the international political economy and geopolitical implications of such impacts. Indeed, the emergence of trade restrictions or quantity constraints in international trade may determine which economies ultimately benefit or suffer most from a decarbonisation of the world economy. Finally, research is needed on the impact of decarbonisation on inflation, as a large-scale transformation of the productive structure of the economy – and in particular of the energy sector – is bound to impact both inflation and the volatility of some key prices, such as that of oil, which in turn could have profound political economy and, ultimately, macroeconomic implications.

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