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Climate Transition Spillovers and Sovereign Risk

EVIDENCE FROM INDONESIA

RÉGIS GOURDEL, IRENE MONASTEROLO AND KEVIN P. GALLAGHER

ABSTRACT

Recent research studied the economic and financial implications of climate transition risk, emerging from a disorderly low-carbon transition, within countries' borders. However, little is known about the impact of the introduction of low-carbon transition policies and regulations of a country on the economic and financial stability of its trading partners. In this paper, we analyze the impact of climate transition spillover risk, resulting from the introduction of carbon pricing in China, on the macroeconomic competitiveness and public financial stability of Indonesia, a major coal producer and exporter to China. By tailoring the EIRIN Stock-Flow Consistent behavioral model, we quantify the impact of a shock on Chinese demand for Indonesian coal, consistently with the scenarios developed by the Network for Greening the Financial System, on the Indonesian balance of payment economic performance and sovereign risk. We find that transition spillover risk directly and negatively affects the balance of payment

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of Indonesia, leading to indirect and cascading effects on public finance. In addition, a trade-off emerges between economic decarbonization and sovereign financial stability in Indonesia, resulting in carbon stranded assets. Our results highlight the importance for supervisory institutions, such as the International Monetary Fund, to integrate climate spillover transition risks in their financial stability assessment programs in order to better assess the impact of climate risks on sovereign financial stability, and avoid the negative implications of an uncoordinated transition in the region.

JEL: B59, Q50

Keywords: climate transition spillover risks; carbon stranded assets; balance of payment; public debt sustainability; sovereign risk; Stock-Flow Consistent model; Indonesia.

INTRODUCTION

Climate change represents a main threat for sustainable and inclusive development in several low-income and emerging countries (IPCC, 2014; Hallegatte et al., 2016), threatening the development progress already achieved (UNDP, 2020).

In South East Asia, several countries are already exposed to socio-economic and financial losses induced by climate physical risk. This is defined as the impact of hazards (e.g. floods, droughts, etc.) which are worsened by climate change, on economic competitiveness and financial stability (Batten et al., 2016; Hilaire and Bertram, 2019; Ranger et al., 2022).

The 6th Intergovernmental Panel on Climate Change (IPCC) report highlights that climate physical risks are on the rise, leading to massive and potentially irreversible impacts, in absence of timely mitigation and adaptation actions (IPCC, 2021). In this regard, the UNEP (2021) emissions gap report showed that governments' Nationally Determined Contributions (NDC) and recent climate pledges, would only allow a mild mitigation, leading to 2.7°C temperature increase with regards to pre-industrial levels.

Some of the South-East Asian countries that are exposed to physical risk, such as Indonesia, are also leading producers and exporters of fossil fuels, e.g. coal, which in turn are key contributors to CO_2 emissions and to climate change (IEA, 2021). This makes the country also highly exposed to climate transition risk, i.e. a situation in which climate policies and regulations designed to achieve the Paris Agreement temperature targets (UNFCCC, 2015) are introduced in a late and sudden way (Hilaire and Bertram, 2019). Indeed, all low-carbon transition scenarios, including those developed by the Network for Greening the Financial System (NGFS), imply a drastic reduction of CO_2 emissions. For this to happen, extraction and production of fossil fuels should eventually come to an end, leading to realization of carbon stranded assets (Mercure et al., 2018; Cahen-Fourot et al., 2021; McGlade and Ekins, 2015; Caldecott, 2018; Dietz et al., 2021).

In this context, carbon-intensive firms using or producing fossil fuels will experience economic losses (e.g. lower profitability). This will negatively affect, on the one hand, their

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contribution to fiscal revenues and gross domestic product (GDP), and on the other hand, the value of their financial contracts (e.g. stocks, bonds), giving rise to a process of devaluation that can lead to large asset prices volatility, as in the 2008 global financial crisis (Bolton and Kacperczyk, 2020)

Recent literature has analyzed the potential macroeconomic and financial relevance of climate transition risk occurring within the country or region's borders (Lamperti et al., 2018; Lamperti et al., 2021; Dafermos et al., 2018; Monasterolo and Raberto, 2018; Jackson and Jackson, 2021; Carattini et al., 2021). However, a country with high production and export of fossil fuels and high carbon goods can be exposed to climate transition risk as a result of the introduction of climate policies and regulations in its trading partner countries. This can be defined as "climate transition spillover risks" (Ramos et al., 2021) (below shortened as "spillover risk").

China is the main importer of Indonesian coal and has an ambitious low-carbon transition agenda. China is introducing carbon pricing schemes in its regions as well as supporting the development of renewable energy sources with subsidies and regulations (IEA, 2021). In order to achieve its decarbonization targets, China may need to decrease its coal imports from Indonesia, because less fossil fuels will be needed in low-carbon transition scenarios.

In this paper, we analyze the macro-financial relevance of transition spillover risk in Indonesia, providing a quantitative assessment of its impact on the country's fiscal and financial stability. We focus on the implications of NGFS scenarios of change in Chinese demand for coal on Indonesian macroeconomic performance (e.g. GDP, unemployment, balance of payment) and sovereign financial stability (e.g. debt to GDP ratio). Studying the impact of spillover risk on the adjustments in balance of payments and debt to GDP ratios is important to inform financial supervisory work. In particular, those variables play a main role in the International Monetary Fund (IMF)'s Financial Stability Assessment Programs (FSAP), aimed to assess the financial stability of sovereigns. Thus, our analysis aims to inform the integration spillover risks into the IMF's FSAP.

Recently, the IMF, the only global institution charged with monitoring global and cross-border financial stability, has started to focus on climate risk. The IMF has recently devised a climate change strategy that will include transition spillover risk analysis in its surveillance and advice functions (IMF, 2021). Nevertheless, the IMF has yet to conceptualize the potential pathways of spillover risks and to develop the modeling tools to analyse their potential impacts. This paper provides both a conceptual framework and a macroeconomic approach to analyse spillover risks in the economy and public finance, with an application to Indonesia. We analyse the direct impact of China's drop in coal demand on the economic and financial performance of Indonesia's fossil fuel sector. Then, we assess the indirect effects on GDP, employment, balance of payment, and debt to GDP ratio of the country. To this aim, we further develop the EIRIN Stock-Flow Consistent behavioral model (Monasterolo and Raberto, 2018; Monasterolo and Raberto, 2019; Gourdel et al., 2021), and we calibrate it on Indonesia. EIRIN is composed of heterogeneous agents and sectors of the economy, endowed with behavioral rules and heuristics, and interconnected through their balance

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sheet items. To consider the uncertainty of climate change and impacts, EIRIN's agents can depart from perfect foresight and embed bounded rationality and adaptive expectations about the future. In addition, they are subject to asymmetric access to information, depending on their endowments. These characteristics allow us to consider the role of expectations on mispricing in the context of deep uncertainty of climate change, and of how the transition will take place (Schnabel, 2020; OECD, 2021).

The remainder of the paper is organized as follows. Section 2 discusses the low-carbon transition challenges and opportunities for Indonesia and presents the research questions of the analysis. Section 3 presents the main characteristics of the EIRIN macroeconomic model, and its application to Indonesia Section 4 presents the macro-financial risk transmission channels of spillover risk, and how they are modelled in EIRIN, using climate mitigation scenarios for China and Indonesia. Section 5 discusses the results of the macro-financial analysis with a focus on sovereign risk, while section 6 concludes with recommendation to the IMF and financial supervisors.

REVIEW OF MACRO-FINANCIAL RELEVANT CLIMATE RISKS FOR INDONESIA

Climate change has been recognized as a new source of financial risk by academics and financial authorities (Carney, 2015; Dietz et al., 2016; Battiston et al., 2017; BIS, 2021). An international network of 87 central banks, financial regulators and 13 observer institutions organized as the NGFS. It has identified two main channels through which climate change can affect macroeconomic and financial stability, giving rise to climate-related financial risks: climate physical risk and climate transition risk (NGFS, 2019).

Recent climate stress tests assessed the potential impact of climate transition risk on financial actors and stability (Battiston et al., 2017; Roncoroni et al., 2021; Alogoskoufis et al., 2021; Allen et al., 2020; Vermeulen et al., 2021). Research results showed that climate transition risks could negatively affect firms' economic competitiveness, leading to adjustments in their risk profile and metrics (e.g. probability of default) and asset prices, and on the revaluation of the portfolios of financial actors who own their financial contracts.

These studies focused on different jurisdictions and types of financial constracts. However, research about the implications of climate transition risk on sovereigns has been more limited so far. Battiston and Monasterolo (2020) introduced the "climate spread" to assess the implications of the misalignment of the G20 countries to the Paris Agreement climate targets, based on the carbon intensity of their economies. They found that in countries where fossil fuels play either a direct or indirect role on GDP (e.g. Australia, Canada, Norway), the cost of climate misalignment can be reflected in a higher Climate Spread and affect sovereign risk and portfolio performance, if markets were pricing climate transition risk. In addition, Volz and Ahmed (2020) provide a review of the several risks that climate change poses to vulnerable countries, considering the implications for the sovereigns. Indonesia could be exposed to such risk as well, due to the importance that fossil fuels play in its economy.

The role of coal in the Indonesian energy system and economy

Indonesia is the world's fourth largest producer of coal and Southeast Asia's biggest gas supplier (IEA, 2021). The record high coal production of over 10,000 TWh in 2018, following a three-year growth, was followed by decrease in 2020 as a result of the COVID-19 crisis. Domestically, electricity production from coal reaches 53 percent, which is the highest share in the Southeast Asia region (ADB, 2021), while electricity production from renewable energy accounted for 26 percent (Grafakos et al., 2020). Out of the total energy mix, renewable energy made up only 16 percent in 2016, a share that reduces to 6 percent when hydropower sources are excluded (Island, 2016). Indonesia aims to reach 23 percent of renewable energy by 2025, and 31 percent by 2030 (Rimaud et al., 2020).

Indonesia's economic dependency on fossil fuels is explained by the large reserves of coal in the country, but also of natural gas, lignite and crude oil. Coal, being a relatively cheap source of energy, has played a key role in the reduction of Indonesia's energy poverty, as the electrification covers only 91 percent of the population (IRENA, 2018). In addition, the national energy demand has been growing steadily, in part due to a continued demographic increase (IRENA, 2018). The future of energy production of Indonesia will still be coal-based in the mid-term, according to the declarations of Indonesia's president at the COP26 conference in Glasgow.[1] Despite efforts to phase out its coal-fired power plants by the 2040s, as part of a pledge signed at the COP26 climate summit, Indonesia will add more coal capacity by 2030 than it plans to retire. In particular, Indonesia plans to decommission 9.2 gigawatts of coal but then build 13.8 gigawatts of new coal, according to the government's most recent 10-year electricity procurement plan RUPTL.[2]

This is aligned with results by Ray et al. (2021) who found that Indonesia, as well as other nations part of the Association of Southeast Asian Nations (ASEAN), account for a large part of current projected coal plants in the world. New investments in coal power plants are not aligned with the Paris Agreement's climate targets, and the report finds 64 percent of the new coal projects to have a negative Net Present Value (NPV). Importantly, they could trump the Net Zero pledges and efforts of a growing number of investors, negatively affecting investors' expectations about the credibility of the low-carbon transition, and thus the scaling up of climate finance (UNEP-FI, 2021).

Carbon stranded assets and sovereign financial stability in Indonesia

Given the role of coal in energy production and in the economy, the phasing out of coal would have macroeconomic implications on Indonesia, in absence of policies and investments aimed to smooth the low-carbon transition. Phasing out coal would also have implications as its interest rate on debt is higher than its neighboring Asian countries. One central argument in the discussion about phasing out fossil fuels in producing and exporting

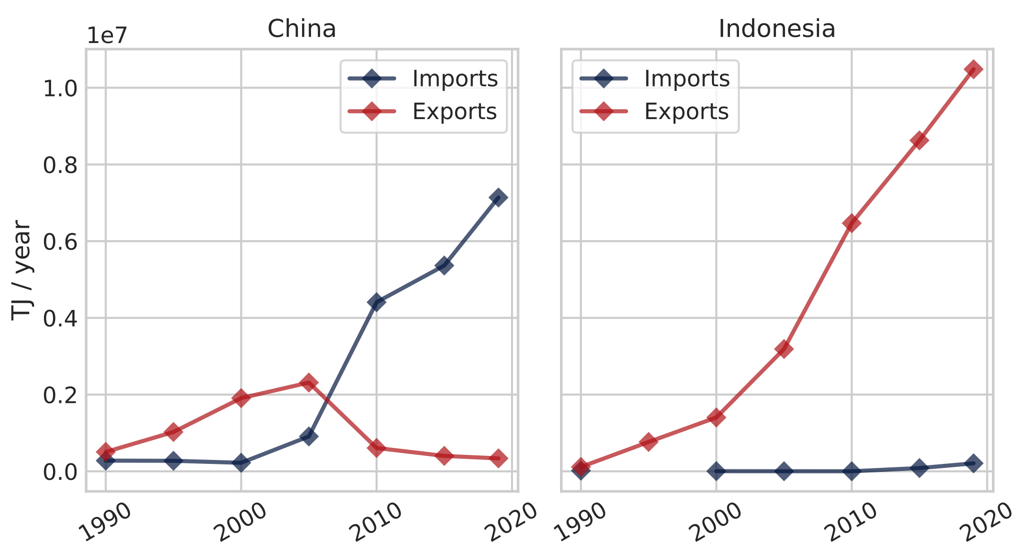
[1] https://news.mongabay.com/2021/11/cop26-cop-out-indonesias-clean-energy-pledge-keeps-coalfront-and-center/

[2] https://gatrik.esdm.go.id/assets/uploads/download_index/files/38622-ruptl-pln-2021-2030.pdf

countries, is the role of such activities on GDP and fiscal revenues, and on poverty reduction in low-income countries. This is particularly true as Sovacool (2010) finds that Indonesia, as well as its neighbors, were not affected by the “resource curse,” whereby countries endowed with more natural resources would exhibit paradoxically high instability and relatively lower economic growth. Bevan et al. (1999) explains the relatively successful development of Indonesia by a governance in the mid-20th century that created a supportive political environment. That means, if the country was successful in growing given these resources, the stop of their use could bring a challenge of its own.

Nevertheless, in Indonesia, the fossil fuel industry benefits from large subsidies but it also accounts for an important share of the Indonesian government’s revenues (Braithwaite and Gerasimchuk, 2019). The country relies on the company Perusahaan Listrik Negara (PLN), which is owned by the state, has a monopoly on the distribution of electricity and produces the majority of it. Braithwaite and Gerasimchuk (2019) find that the fossil fuel industry accounted for 13.6 percent of the Indonesian government’s revenue over the 2014-2016 period, while the sector accounts for 5.8 percent of the GDP only (less than sectors such as manufacturing or agriculture). For other countries with large fossil fuel sectors, here in Latin America, Welsby et al. (2021) finds that large decreases in public revenues can be expected from the slowdown of production. In addition, fossil fuel subsidies are unequally distributed and show a pro-cyclical pattern, yielding little social benefits and contributing to inequality. Furthermore, government’s revenues from the fossil fuel industry have been declining over the last two decades, and this trend is expected to continue.

FIGURE 1 Exports and imports of coal by China and Indonesia
The *x*-axis shows years of reporting, and the *y*-axis shows values imported or exported in tera Joul.



Source: IEA.

Budget deficits have remained broadly unchanged, hinting on the fact that the public finances of the country could absorb the transition with the adequate policies. The G20 (2019) finds that progress has been slow in winding down most harmful subsidies and turning them into distributive mechanisms, in spite of sound plans initially put forth by the Indonesian government. In this context, high financing costs represent a barrier for private investment in clean energy (Wijaya et al., 2021).

Adjustments in sovereign risk affect, from the financial point of view, banks and nonfinancial firms. According to Gross and Pancaro (2021), credit risk transmission channels have contributed to the building-up of risk in the midst of the COVID-19 crisis, in particular with a transmission from corporate to sovereign.

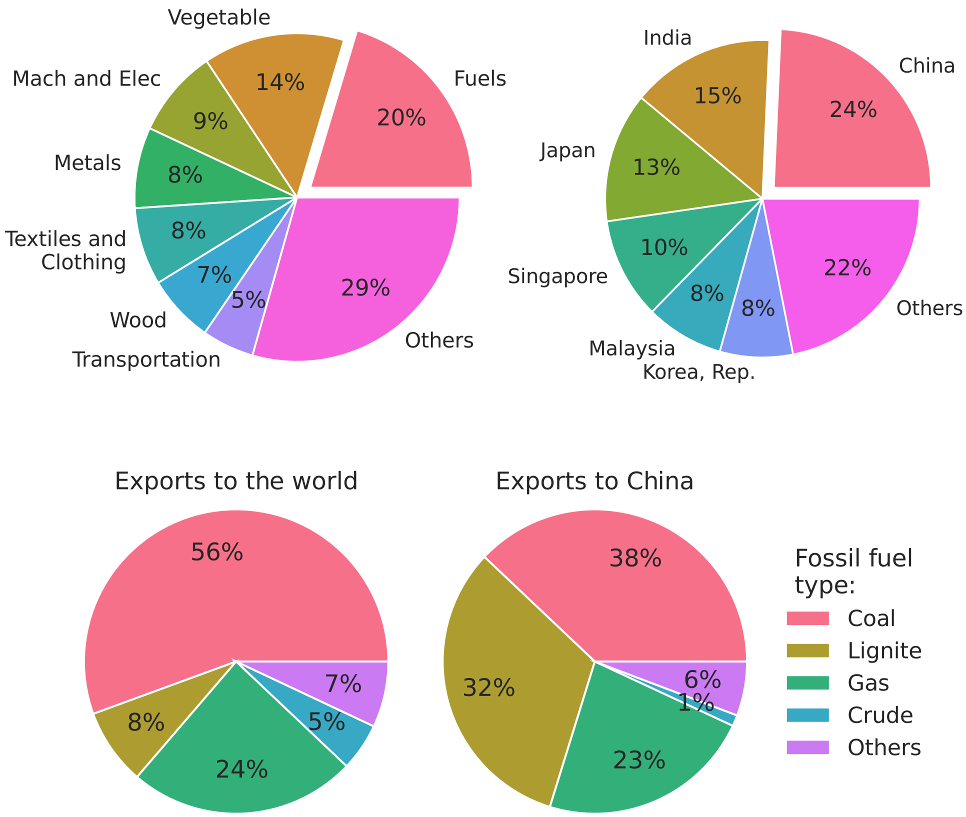
Climate transition spillover risk

Countries such as Indonesia that are large producers and exporters of fossil fuels could also be exposed to an additional type of transition risk, i.e. what Ramos et al. (2021) defined as *climate transition spillover risk*. This consists in the cross-border macro-critical impacts on financial and fiscal systems of the low-carbon transition occurring in one country or region. As known from Shapiro (2021), trade is generally not neutral with regard to carbon emissions and climate change, with so far large subsidies to carbon-intensive commodities implied by the current terms of trade. Moreover, in the case of Indonesia, the volume of coal exported has been significantly growing, as shown in Figure 1, driven to a large extent by imports of neighboring China.

However, that needs not stay so, and imports of coal and other pollutants could decrease in volume as a result of low-carbon transition policies. For instance, in the attempt to foster the decarbonization of its economy, China introduced in 2021 a carbon-pricing mechanism in the form of the largest national emissions-trading scheme (Nogrady et al., 2021). This initiative could make the use and production of coal costlier for China, leading the country to decrease its import of coal. China is the first importer of coal from Indonesia, increasing after tensions with Australia and episodes of power shortages. Figure 2 shows how this importance as a partner appears for trade in general and for fossil fuels in particular.

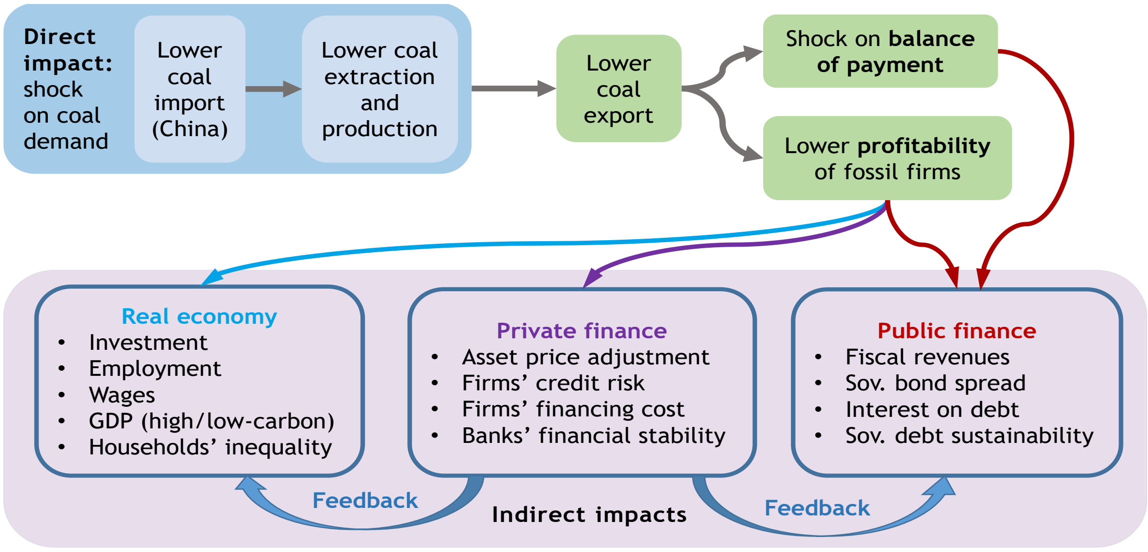
Figure 3 shows the risk transmission channels of the introduction of carbon pricing in China on the economic, private and public finance of Indonesia. We consider a shock on coal demand from China, that leads to lower import of coal from Indonesia, negatively affecting coal production and export in Indonesia. Lower exports affect the country's balance of payments, with negative implications on public finance, through lower fiscal revenues, which in turn affect governments' fiscal budget and debt service, with implications on bond spread and debt sustainability. Lower firms' profitability affects further the real economy in the form of lower investments, higher unemployment and lower GDP. One additional channel is the feedback on financial actors exposed to Indonesian coal producers and their supply chain, via asset price adjustment and adjustment in firm's credit risk. This, in turn, contributes to increasing firms' financing costs (i.e. cost of capital), with potential implications on Non Performing Loans (NPL), and financial instability for exposed banks. Note that implications

FIGURE 2 Details of Indonesia's exports, looking at the breakdown of merchandises exported and the top trading partners for fuel.



Source: WITS - UNSD Comtrade.

FIGURE 3 Transmission channels of from a shock on coal exports. We distinguish the direct impact (on the mining sector that is hit by export reduction), from the indirect impacts that stem from it (reduced workforce, lower profitability, etc).



on sovereign financial stability unfold also via the lower profitability of coal firms, which negatively affect government's fiscal revenues. Feedback between private and public financial actors, via financial exposures, can amplify the original economic shock, with potential implications for individual and systemic risk.

Thus, climate transition spillover risk can be of macro-financial relevance for Indonesia. North-South models analyzed shock transmissions across countries. Recent examples are stock-flow consistent models such as Carnevali et al. (2021), where exports of high-carbon products affect the country where the carbon intensity of pollution is higher. They find that the green economy and the environment benefit from this shift, while the high-carbon sector suffers but recovers eventually. However, no application so far has analyzed the effects of forward-looking shocks in demand for fossil fuel energy, driven by low-carbon transition policy, and the sovereign risk implications.

In this article, we contribute to fill this knowledge gap, addressing the following policy-relevant research questions:

- To what extent and through which channels does the introduction of carbon pricing in China affect Indonesia's balance of payment and sovereign debt sustainability?
- Under which conditions can initial shocks be amplified and create spillover effects?

MODEL DESCRIPTION

We tailor and apply the EIRIN macroeconomic model to identify and quantitatively assess the shock transmission channels to agents and sectors of the economy and finance in Indonesia, and the drivers of shocks amplification and spillovers effects. Then, we study conditions for climate risk amplification, considering the interplay between carbon pricing and the country macro-financial characteristics. In the next section, we provide a description of the key structural and behavioral characteristics of the EIRIN model, before introducing the innovations specific to this application.

Model Overview

EIRIN is a Stock-Flow Consistent (SFC) model[3] of an open economy composed by a limited number of heterogeneous and interacting agents of the real economy and financial system. Agents are heterogeneous in terms of source of income and wealth, and of preferences.

Agents are represented by their balance sheet entries, which calibrated on real data (when possible), and are connected as in a network. The SFC model's characteristics make it possible to trace a direct correspondence between stocks and flows, thus increasing the transparency of shocks' transmission channels.

[3] See for instance Caverzasi and Godin (2015), Dafermos et al. (2017), Dunz et al. (2021b), Naqvi and Stockhammer (2018), Ponta et al. (2018), Caiani et al. (2016), and Carnevali et al. (2021).

EIRIN is a SFC behavioral model, meaning that agents' decisions are informed by with behavioral rules, expectations and heuristics. In addition, EIRIN's agents are endowed with adaptive expectations about the future. The departure from traditional forward-looking expectations allows us to consider the impact of expectations on lack of market coordination and mispricing on the economic outcome of climate change and of the transition. In addition, they contribute to understanding the drivers and implications of out-of-equilibrium states of the economy as well as potential shocks' amplification effects.

The capital and current account flows that structure the model are represented in figure 4. The model is composed of five sectors: the non-financial sector, the financial sector, households, the government and the foreign sector. The non-financial sector is composed of

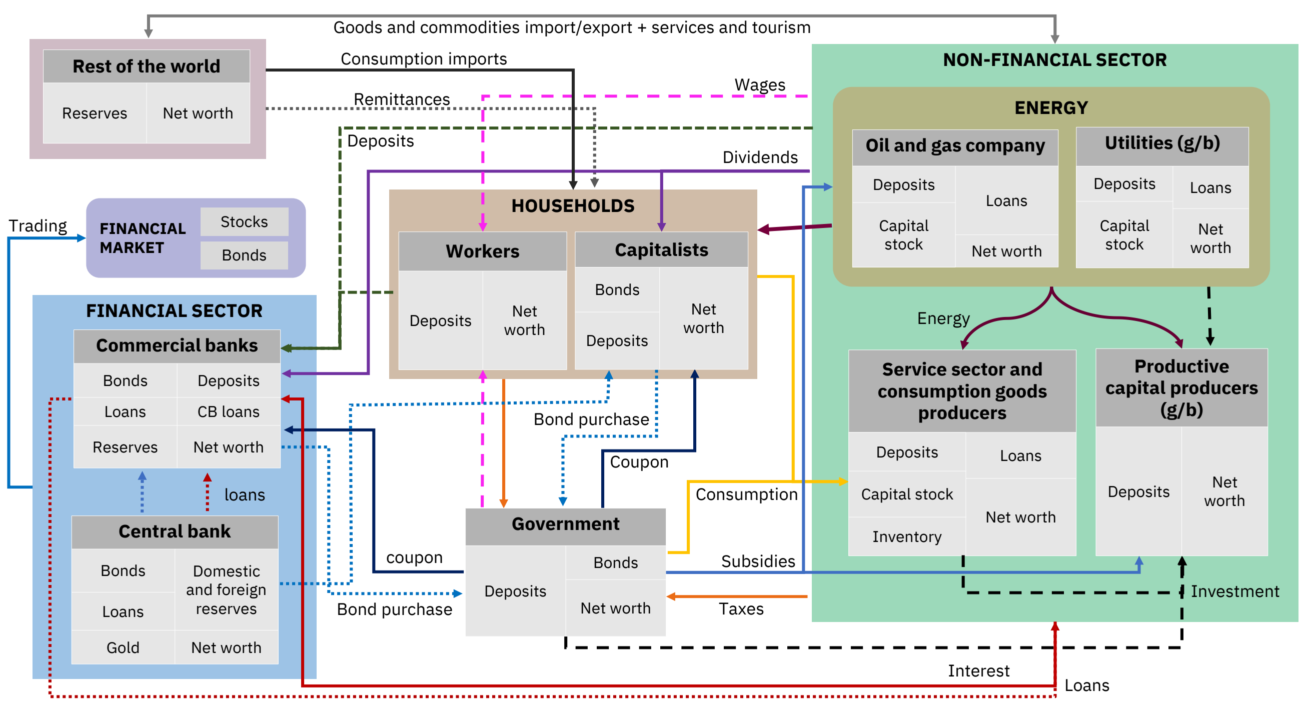
(i) two energy firms (EnB and EnG, brown and green respectively) that supply energy to households and to firms as an input factor for production (red solid line);

(ii) an oil and mining firm that supplies EnB in fossil fuel;

(iii) a capital intensive (for consumption goods) and a labor intensive (for service, tourism, agriculture) producers that provide households heterogeneous consumption products (yellow solid line);

(iv) two productive capital producers (KpB and KpG, brown and green respectively), which supply all of the above.

FIGURE 4 The EIRIN model framework: capital and current account flows of the EIRIN economy. For each sector and agent, a representation in terms of assets and liabilities is provided. The dotted lines represent the capital account flows, while the solid lines represent the current account flows.



The energy firms and the consumption good producers require capital as an input factor for production. To build-up their capital stock, they invest in capital goods (black dashed line), which are produced by the capital good producer. To finance investment expenditures, firms can borrow from the commercial bank (red dotted line), which apply an interest rate to their loans (red solid line). Households, firms and the government have deposits in the commercial bank (green dashed line). The commercial bank also holds reserves at the central bank (blue dotted line), that could provide refinancing lines (red dotted line). The government pays public employees (pink dashed line) and provides emergency relief or subsidies firms of the real economy (blue solid line). The government collects tax revenues from households and firms (orange solid line) and finances its current spending by issuing sovereign bonds (blue dotted line). Sovereign bonds are bought by capitalist households, by the commercial bank, and by the central bank. The government pays coupons interests on sovereign bonds (dark blue line). Households are divided into workers and capitalists, based on their functional source of income: workers receive wage income (pink dashed line); capitalists own domestic firms for which they receive dividend income (purple solid line) and coupon payments for their sovereign bond holdings (dark blue line). The foreign sector provides remittances (grey dotted line) and consumption goods to households (dark grey solid line). The foreign sector generates tourism flows and spending in the country, purchases services and industry goods, and sells resources to firms as inputs for the production (grey solid line).

Markets and sequence of events

EIRIN's agents and sectors interact with each other through a set of markets. Their operations are defined by the sequence of events occurring in each simulation step, which is the following:

1. Policy makers take their policy decisions. The central bank sets the policy rate according to a Taylor-like rule. The government adjusts the tax rates on labor and capital income, on corporate earnings, and on Value Added to meet its budget deficit target.
2. The *credit market* opens. The bank sets its maximum credit supply according to its equity base. If supply is lower than demand, proportional rationing is applied and prospective borrowers revise down their investment and production plans accordingly.
3. *Real markets* open in parallel, they include the market for *consumption goods and services*, the *energy* market, the *labor* market and the *raw materials* market. Prices of the exchanged goods or services are determined, then the nominal or real demand and supply are provided by the relevant agent in each market. Finally, transactions occur generally at disequilibrium, i.e. at the minimum between demand and supply.
4. The financial market opens. The capitalist household and the bank determine their desired portfolio allocation of financial wealth on securities. The government offers newly issued bonds to finance a budget deficit, which includes green investments. The central bank may perform quantitative easing policies and enter the bond market as a buyer of sovereign bonds (green or regular). Then, new asset prices are determined.
5. All transactions and monetary flows are recorded, taxes paid are determined, and the balance sheets of the agents and sectors of the EIRIN economy are updated accordingly.

Agents and sectors' behaviors

We detail below the key mechanisms and behaviors that guide the model, starting by introducing the most common notations used. Let *i* and *j* be two agents. Then, p_i is the price of the output produced by *i*, while p_i^* is the price of the security issued by *i*. $D_{i,j}$ is the demand by *j* of what *i* produces, and $\mathbf{D}_i = \sum_j D_{i,j}$. Moreover, $\mathbf{q}_i$ is the total production of *i* and $q_{i,j}$ is the part of it that is given to *j*. We also denote by M_i the liquidity of *i*, akin to holdings of cash, and by K_i its stock of productive capital where applicable.

By building on Goodwin (1967), **households** are divided into two classes. Income class heterogeneity is functional to assess the distributive effects of the policies introduced in the low-carbon transition and on the channels of inequality. First, the working class (Hw) lives on wages, with gross revenues

$$Y_{\mathrm{Hw}}^{\mathrm{gross}} = \sum_i N_i \cdot w_i \tag{1}$$

where w_i the wage paid by *i* and N_i the size of the workforce it employs (we omit the time dimension for simplicity as all variables are contemporaneous). The labor market mechanism determines the final workforce N_i of each agent based on the total N_{tot} of workers available and the demand for labor of firms (see Gourdel et al., 2021, for details). It also determines the salary level $w_i(t)$ paid by *i*, based on required skills of employing firms. Second, the capitalist class (Hk) earns its income out of financial markets through government bonds' coupons and firms dividends:

$$Y_{\mathrm{Hk}}^{\mathrm{gross}} = c_{\mathrm{G}} n_{\mathrm{Hk,G}} + \sum_i d_i \cdot n_{\mathrm{Hk},i}, \tag{2}$$

where d_i are the dividends of *i* and c_{G} is the coupon's rate. Both households are then taxed, with τ_{Hw} the rate of the income tax, and τ_{Hk} the rate of the tax on profits from capital. Furthermore, both household classes receive net remittances RM_i from abroad.[4]

All households pay their energy bill. This leaves them with Y_i^{disp} as net disposable income:

$$\forall i \in \{\mathrm{Hw}, \mathrm{Hk}\}, \quad Y_i^{\mathrm{disp}} = \underbrace{(1-\tau_i)\cdot Y_i}_{\text{net income}} - p_{\mathrm{En}} D_i^{\mathrm{En}} + \mathrm{RM}_i \tag{3}$$

Households' consumption plans (Eq. (4)) are based on the Buffer-Stock Theory of savings (Deaton, 1991; Carroll, 2001), which balances the *impatience* of households of consuming all their income and wealth right away with their *prudence* about the future preventing them to draw down their assets too far. This results in a quasi target wealth level that households pursue. Then, households split their consumption budget C_i between consumption goods and services, also importing a share β_0 from the rest of the world.

$$C_i = Y_i^{\mathrm{disp}} + \rho\left(M_i - \phi\, Y_i^{\mathrm{disp}}\right) \tag{4}$$

[4] These are negative in the case of the euro area that we analyse.

$$D_i^{\mathrm{Fl}} = (1-\beta_0) \times \beta_1 \times C_i \tag{5}$$

$$D_i^{\mathrm{Fk}} = (1-\beta_0) \times (1-\beta_1) \times C_i \ . \tag{6}$$

The **service firm** Fl (also called labor intensive) and **consumption goods producer** Fk (also referred to as capital intensive) produce an amount q_j of their respective outputs by relying on a Leontief technology. This implies no substitution of input factors, meaning that if an input factor is constrained (e.g. limited access to credit to finance investments), the overall production is proportionately reduced:

$$\forall j \in \{\mathrm{Fl}, \mathrm{Fk}\}, \quad \mathbf{q}_j = \min\left\{\gamma_j^N N_j,\ \gamma_j^K K_j\right\} \ . \tag{7}$$

In contrast, several macroeconomic models allow for substitution of input factors (elasticity of substitution equals 1) by using a Cobb-Douglas production technology. In our case, this would imply a substitution of constrained input factors such as capital stock with labor, while still generating the same level of output.

The two firms set their consumption goods price as a mark-up μ_j on their labor costs w_j/γ_j^N, capital costs $\kappa_j L_j$, energy $p_{\mathrm{En}} q_{\mathrm{En},j}$ and resource costs $p_R q_{R,j}$, such that

$$\forall j \in \{\mathrm{Fl}, \mathrm{Fk}\}, \quad p_j = (1+\mu_j)(1+\tau_{\mathrm{VAT}}) \left[\frac{w_j}{\gamma_j^N} + \frac{\kappa_j L_j + p_{\mathrm{En}} q_{\mathrm{En},j} + p_R q_{R,j}}{q_j} \right] . \tag{8}$$

Higher prices of consumption goods and services driven by higher firms' interest payments on loans, more expensive imports, more expensive energy and/or labor costs, constrain households' consumption budgets, which in turn lower aggregate demand. This represents a counterbalancing mechanism on aggregate demand.

The minimum between real demand of the two consumption goods and the real supply (Eqs. (9) and (10)) determines the transaction amount $\tilde{q}_j$ that is traded in the goods market. The supply of capital intensive consumption goods also takes firm's inventories ($\mathrm{IN}_{\mathrm{Fk}}$) into account. In case that demand exceeds supply, both capitalist and worker households are rationed proportionally to their demand. The share of newly produced but unsold products add up to the inventory stock of Fk's inventories ($\mathrm{IN}_{\mathrm{Fk}}$). Finally, both consumption goods producers make a production plan $\hat{q}_j$ for the next simulation step based on recent sales and inventory levels.

$$\tilde{q}_{\mathrm{Fk}} = \min\left(\mathrm{IN}_{\mathrm{Fk}} + q_{\mathrm{Fk}},\ \frac{1}{p_{\mathrm{Fk}}}\left(D_{\mathrm{Hw}}^{\mathrm{Fk}} + C_{\mathrm{Hk}}^{\mathrm{Fk}} + D_{\mathrm{G}}^{\mathrm{Fk}} + D_{\mathrm{RoW}}^{\mathrm{Fk}}\right)\right) \tag{9}$$

$$\tilde{q}_{\mathrm{Fl}} = \min\left(q_{\mathrm{Fl}},\ \frac{1}{p_{\mathrm{Fl}}}\left(D_{\mathrm{Hw}}^{\mathrm{Fl}} + D_{\mathrm{Hk}}^{\mathrm{Fl}} + D_{\mathrm{G}}^{\mathrm{Fl}} + D_{\mathrm{RoW}}^{\mathrm{Fl}}\right)\right) \tag{10}$$

The **energy sector** (En), divided into renewable and fossil fuel energy producers (EnG and EnB respectively), produces energy that is demanded by households and firms, respectively for consumption and for production. We assume that all demand is met, even if EnB might

have to buy energy from the foreign sector, such that $\mathbf{q}_{\mathrm{En}} = \mathbf{D}_{\mathrm{En}}$. Households' energy demand is inelastic (i.e. the daily uses for heat and transportation), while firms' energy requirements are proportional to their output. The fossil fuel energy company requires capital stock and oil as input factors for production, and only productive capital for its green counterpart but in higher quantity. The energy price is endogenously set from the unit cost of both firms (see Gourdel et al., 2021, for details).

Hw and Hk subtract the energy bill from their wage bill as shown by their disposable income, while firms transfer the costs of energy via mark-ups on their unit costs to their customers (equation (8)). To be able to deliver the demanded energy, the energy producer require capital stock and conducts investment to compensate capital depreciation and expand its capital stock to be able to satisfy energy demand (see Gourdel et al., 2021, for details). The **oil and mining** company MO supplies EnB in oil and exports to the rest of the world as well. It does not control the price of oil, which is assumed to be determined in international markets and thus is modeled as an exogenous variable characterized by a constant growth rate. It faces no restriction on extraction but seeks to maintain its initial level of productive capital to operate.

Both Fl and Fk make **endogenous investment decisions** based on the expected production plans $\hat{q}_i$ that determine a target capital stock level $\hat{K}_i$. The target investment amount $I_i^{\dagger}$ is set by the target capital level $\hat{K}_i$, considering the previous capital endowment $K_i(t-1)$ subject to depreciation $\delta_i \cdot K_i(t-1)$ and potential[5] capital destruction as a consequence of natural disaster shocks $\hat{\xi}(t) \times K_i(t-1)$, hence

$$I_i^{\dagger}(t) = \max\left\{\hat{K}_i(t) - K_i(t-1) + \delta_i \cdot K_i(t-1) + \hat{\xi}(t) \cdot K_i(t-1), 0\right\} \tag{11}$$

Differently from supply-led models (e.g. Solow, 1956), in EIRIN investment decisions are fully endogenous and they are based on firms' Net Present Value (NPV). This in turn is influenced by six factors, i.e (i) investment costs, (ii) expected future discounted revenue streams (e.g. endogenously generated demand), (iii) expected future discounted variable costs, (iv) the agent's specific interest rate set by the commercial bank, (v) the government's fiscal policy and (vi) governments' subsidies.

More precisely, the planned investment is given by $I_i^{\star}(t) = (\varphi_i \cdot M_i(t-1) + \Delta^{+}L_i(t))/p_{\mathrm{Kp},i}(t)$, where ϕ_i is the share of liquidity that i uses to finance investment, $\Delta^{+}L_i$ is the part that comes from new credit, and $p_{\mathrm{Kp},i}$ is the average price of capital, which depends on the ratio of green and brown, at unit prices p_{KpG} and p_{KpB} respectively. The NPV calculations allow us to compare the present cost of real investments in new capital goods to the present value of future expected (positive or negative) cash flows, and it constrains what can be financed through credit. We differentiate in that regard between low-carbon and high-carbon capital, that is, for a level ι of investment, the related NPVs are

$$\mathrm{NPV}_i^{\mathfrak{g}}(\iota, t) = -p_{\mathrm{KpG}}(t) \cdot \iota + \sum_{s=t+1}^{+\infty} \frac{\mathrm{CF}_i^{\mathfrak{g}}(\iota, t, s)}{(1+\kappa_i)^{s-t}} \tag{12}$$

[5] Note that $\hat{\xi}(t)$ denotes the expectation of the physical shock, as the realised value $\xi(t)$ is observed at the end of the period only.

$$\mathrm{NPV}_i^{\mathfrak{b}}(\iota,t) = -p_{\mathrm{KpB}}(t)\cdot\iota + \sum_{s=t+1}^{+\infty}\frac{\mathrm{CF}_i^{\mathfrak{b}}(\iota,t,s)}{(1+\kappa_i)^{s-t}} \tag{13}$$

where $\mathrm{CF}_i^{\cdot}(\iota, t, s)$ describes total expected cash flows expected at s from the new investment. Details of the cash flows calculations are used as in Gourdel et al. (2021). Cash flows are discounted using the sector's interest rate κ_j set by the commercial bank. This computation imposes a limit on investment such that:

$$\Delta^+ L_i(t) \leq \max\left\{\iota \in [0, I_i^{\dagger}(t)]:\ \mathrm{NPV}_i^{\mathfrak{g}}(\iota,t) \geq 0 \text{ or } \mathrm{NPV}_i^{\mathfrak{b}}(\iota,t) \geq 0\right\}. \tag{14}$$

The final realised investment $I_i(t)$ is divided into green and brown capital such that $I_i = I_i^{g} + I_i^{b}$. Then, it is potentially constrained by the supply capacity of the producers.

The **capital goods producers** (Kp, divided into green and brown capital producers, KpG and KpB respectively) supply capital goods to fulfill the production capacity of Fl, Fk and En:

$$\mathbf{q}_{\mathrm{KpB}} = I_{\mathrm{Fl}}^{\mathfrak{b}} + I_{\mathrm{Fk}}^{\mathfrak{b}} + I_{\mathrm{EnB}} \leq \mathbf{D}_{\mathrm{KpB}}, \quad \mathbf{q}_{\mathrm{KpG}} = I_{\mathrm{Fl}}^{\mathfrak{g}} + I_{\mathrm{Fk}}^{\mathfrak{g}} + I_{\mathrm{EnG}} \leq \mathbf{D}_{\mathrm{KpG}}. \tag{15}$$

Newly produced capital goods will be delivered to the consumption good producers and the energy firm at the next simulation step. The capital good producers rely on energy and high-skilled labor as input factors that represent its unit costs. Capital good price p_{Kp} is set as a fixed mark-up μ_{Kp} on unit costs:

$$\forall i \in \{\mathrm{KpG}, \mathrm{KpB}\}, \quad p_i = (1+\mu_{\mathrm{Kp}}) \times \frac{w_{\mathrm{Kp}} N_i + D_i^{\mathrm{En}} p_{\mathrm{En}}}{\mathbf{q}_i} \tag{16}$$

In the financial sector the **commercial bank** (BA) provides loans and keeps deposits. The commercial bank endogenously creates money (Jakab and Kumhof, 2015), meaning that it increases its balance sheet at every lending (i.e. the bank creates new deposits as it grants a new credit). This is consistent with most recent literature on endogenous money creation by banks (McLeay et al., 2014). The EIRIN economy money supply is displayed by the level of demand deposits, including for all other agents in the domestic economy (i.e. excluding the foreign sector). Furthermore, BA gives out loans to finance firms' investment plans. The bank sets sector specific interest rates that affect firms' capital costs and NPV calculations. Thus, credit demanded by firms may be rationed due to insufficient equity capital on the bank's side, in which case credit is allocated proportionally to the amount demanded. When confronted with credit rationing, firms have to scale down their investment plans, while the bank stops paying dividends, thus retaining all net earnings in order to increase its equity capital. Details on the interest rate settings and granted loans are provided in 3.4.

The **central bank** (CB) sets the risk free interest rate ν according to a Taylor like rule (Taylor, 1993). The EIRIN's implementation of the Taylor rule differs from the traditional one because we do not define the potential output based on the Non-Accelerating Inflation Rate of Unemployment (NAIRU) (Blanchard, 2017). Indeed, NAIRU's theoretical underpinnings are rooted in general equilibrium theory, while EIRIN is not constrained to equilibrium solutions and focuses on the analysis of out of equilibrium dynamics. Thus, it would not be logically consistent to adopt a standard Taylor rule and NAIRU.

The interest rate in EIRIN indirectly affects households consumption via price increase stemming from firms that adjust their prices based on higher costs for credit. Households have a target level of wealth stemming from the buffer-stock theory of saving but do not intertemporally maximize their consumption behavior. This prevents monetary policy to have a crowding-out effect on household consumption. The policy interest rate depends on the inflation $\pi - \bar{\pi}$ and output gaps (measured as employment gap $u - \bar{u}$, i.e. the distance to a target level of employment $\bar{u}$):

$$\nu(t) = \omega_{\pi}(\pi(t) - \bar{\pi}) - \omega_{u}(u(t) - \bar{u}) \tag{17}$$

particular, π is the one-period inflation of the weighted basket of consumption goods and services (with a computation smoothed over a year, i.e. m periods):

$$\pi(t) = \frac{\mathbf{q}_{\mathrm{Fl}}(t)}{\mathbf{q}_{\mathrm{Fk}}(t) + \mathbf{q}_{\mathrm{Fl}}(t)} \cdot \left(\frac{p_{\mathrm{Fl}}(t)}{p_{\mathrm{Fl}}(t-m)}\right)^{1/m} + \frac{\mathbf{q}_{\mathrm{Fk}}(t)}{\mathbf{q}_{\mathrm{Fk}}(t) + \mathbf{q}_{\mathrm{Fl}}(t)} \cdot \left(\frac{p_{\mathrm{Fk}}(t)}{p_{\mathrm{Fk}}(t-m)}\right)^{1/m} - 1 \tag{18}$$

The inflation gap is computed as the distance of the actual inflation ϖ to the pre-defined target inflation rate $\bar{\pi}$. Moreover, the CB can provide liquidity to BA in case of shortage of liquid assets.

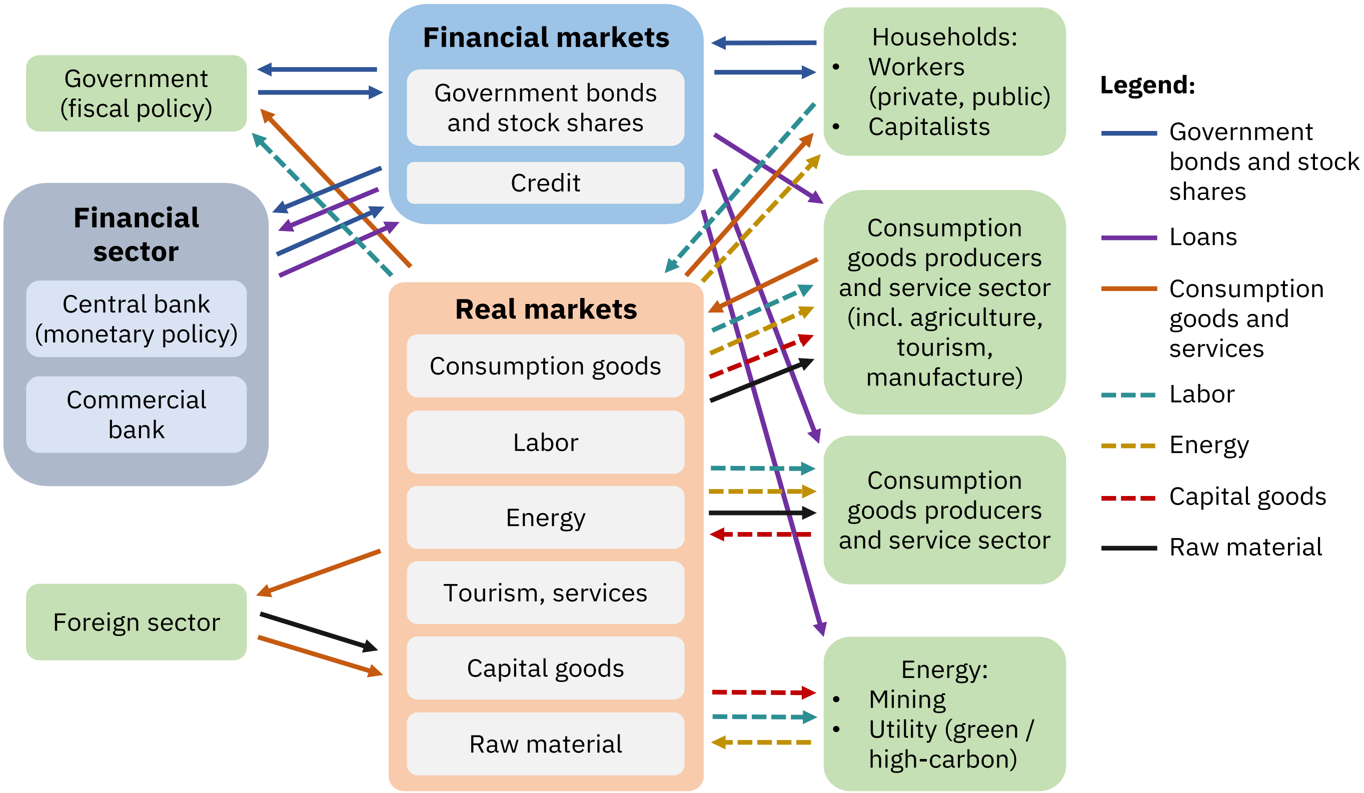
A foreign sector (RoW) interacting through tourism import, consumption good exports, intermediate good exports, consumption good imports, oil, raw materials supply, and potential energy export to the domestic economy. These latter are provided in infinite supply and at a given price to meet the internal production needs. Tourists inflows consist in the consumption of labor-intensive consumption goods. Raw material, consumption good and intermediate good exports are a calibrated share of the country's GDP and are sold at world prices.

A government (G) is in charge of implementing the fiscal policy, via tax collection and public spending, including welfare expenditures, subsidies (e.g. for households' consumption of basic commodities), public sectors' workers and consumption. To cover its regular expenses the government raises taxes and issues sovereign bonds, which are bought by the capitalist households, by the commercial bank and by the central bank. The government pays a coupon rate c_G on its outstanding bonds n_G. Taxes are applied to labor income (wage), to capital income (dividends and coupons), and profits of firms. To meet its budget balance target level, the government adjusts its tax rate. In case of a budget deficit, the tax rate is increased by a fixed amount $\Delta\tau$. In case of a budget surplus exceeding a given threshold, the tax rate is decreased by the same fixed amount $\Delta\tau$. Otherwise, the tax rate τ is kept constant. Furthermore, if the government's deposits are lower than a given positive threshold $\bar{M}$, i.e., $M_G < \bar{M}_G$, the government issues a new amount $\Delta \mathbf{n}_{\mathrm{G}} = \frac{\bar{M}_{\mathrm{G}} - M_{\mathrm{G}}}{p_{\mathrm{G}}^{\dagger}}$ of bonds to cover the gap, where $p_G^{\dagger}$ is the endogenously determined government bond price. All newly-issued bonds are bought by the capitalist households, by the commercial and the central bank. The Government can issue green sovereign bonds to fund new low-carbon investments.

Government spending $C_G = \kappa R_G$ is a fixed percentage κ of revenues from taxes R_G. Government's spending during crises contributes to avoid credit crunch, and compensates households' and firms' liquidity constraints (Brunnermeier et al., 2020).

The interactions among agents, sectors and markets of the EIRIN economy are presented in figure 5. For a detailed description of all sectors, market interactions and behavioral equations, refer to Monasterolo and Raberto (2018), Monasterolo and Raberto (2019), Dunz et al. (2021a), and Gourdel et al. (2021).

FIGURE 5 Interaction of EIRIN's agents, sectors and markets: Black boxes include agents and sectors, while the light blue box contains financial markets and light orange box includes the real markets. The agents and sectors interact through real and financial markets and the outgoing arrows represent the supply, while incoming arrows represent the demand. Authors' own elaboration.



Bank's credit channel

A key determinant of the credit market is the interest rate applied to the different sectors, which is based on sector-specific and macroeconomic indicators. In addition, the credit can be constrained depending on the profitability of investment and on the bank's lending capacity.

Let $\nu(t)$ the risk free interest rate, which is the sum of the policy rate and the bank's net interest margin (NIM). Given the annualised probability of default $\mathrm{PD}_i(t)$ of sector i, we seek to determine its objective loan interest rate $\hat{\kappa}_i(t)$ granted by the bank. We set it to verify

$$\underbrace{\hat{\kappa}_i(t) - \nu(t)}_{\text{credit spread}} = \mathrm{PD}_i(t) \times (1 - \mathcal{R}_i), \tag{19}$$

where R_i is the (constant) expected recovery rate[6] of i. The PDs themselves are computed based on Alogoskoufis et al. (2021), that is, using returns on assets, leverage and sector-specific terms. Then, to determine the actual rate applied, we let the possibility of bridging only part of the distance between the previous interest rate and the objective one. That means, denoting as $\kappa_i(t)$ the realised interest rate at t we have $\kappa_i(t) = \kappa_i(t-1) + \lambda \times (\hat{\kappa}_i(t) - \kappa_i(t-1))$, where $\lambda \in]0, 1]$ is the interest adjustment speed.

Another key aspect is how much the bank is ready to lend at a time t. The maximum credit supply of the bank is set by its equity level E_{BA} divided by the Capital Adequacy Ratio parameter $\widetilde{\mathrm{CAR}}$, in order to comply to banking regulator provisions. The other important information is the the demand for new credit $\mathbf{D}_{BA}(t)$ and the previous credit level $\mathbf{L}(t-1)$. The additional credit that the bank can provide at each time step is given by its maximum supply, minus the amount of loans already outstanding, so that the total of loans makes it realised capital adequacy ratio remain over $\widetilde{\mathrm{CAR}}$:

$$\Delta^{+}\mathbf{L} = \min\left\{\mathbf{D}_{\mathrm{BA}}(t), \frac{E_{\mathrm{BA}}(t-1)}{\widetilde{\mathrm{CAR}}} - \mathbf{L}(t-1)\right\}. \tag{20}$$

Non-Performing Loans (NPL)

Based on the literature on the determinants[7] of non-performing loans (NPL), we compute the NPL ratio such that

$$\Delta^{\%}\mathrm{NPL}(t) = \eta + \sum_{j=1}^{2} \alpha_j \Delta^{\%}\mathrm{NPL}(t-j) + \sum_{j=1}^{p} \beta_j \cdot \mathbf{X}(t-j) + \varepsilon(t) \tag{21}$$

where $\Delta^{\%}$ is the quarter-on-quarter growth operator, while η, α and β represent parameters. The vector $\mathbf{X}$ of predictor variables includes the growth rate of real GDP, and the change in the policy rate. Therefore, the computation of the NPL ratio is completely *endogenous* in the model, as no predictor variable is part of the scenario.

[6] See Hamilton and Cantor (2006) on the model itself, and Bruche and González-Aguado (2010) on the macroeconomic determinants of recovery rates.

[7] Following in particular Beck et al. (2015) and Tente et al. (2019).

A sector i pays interests with rate $\kappa_i(t)$ at t on its total loans $L_i(t-1)$ of the previous period. Taking into account the NPL ratio, the total interests paid is:[8]

$$\mathrm{ID}_i(t) = \kappa_i(t) \times L_i(t-1) \times (1 - \mathrm{NPL}(t)) \tag{22}$$

The interests paid on debt are subtracted from the operating earnings of i and added to that of the banking sector. Similarly, the repayment of the debt is reduced:

$$\Delta^- L_i(t) = \chi_i \times L_i(t-1) \times (1 - \mathrm{NPL}(t)) \tag{23}$$

where χ_i is the (constant) repayment rate of i, inversely proportional to the typical loan length of the sector.

Government's financing strategy

We consider a government that repays bonds at maturity[9] to better capture the development of sovereign risk in the longer run. The government issues sovereign bonds with different maturities can be issued. We assume that, at a period t, the government will repay the mean of bonds issued in a time window from $t - s_1$ to $t - s_2$, where $s_1 \geq s_2 > 0$. Thus, the amount of debt repaid by the state at t is

$$\mathrm{DR}(t) = \frac{1}{s_1 - s_2 + 1} \sum_{\tau = t - s_1}^{t - s_2} \Delta^+ \mathbf{n}_{\mathrm{G}}(\tau) \cdot p^*_{\mathrm{G}}(\tau) \tag{25}$$

where $\Delta^+\mathbf{n}_{\mathrm{G}}$ denotes the number of bonds newly issued, and p^*_{G} is the series of bond prices. Thus, it is immediate to verify that no bonds older than s_2 periods will be kept on the government's balance sheet, and the number of bond securities removed from the market at t is

$$\Delta^- \mathbf{n}_{\mathrm{G}}(t) = \frac{1}{s_1 - s_2 + 1} \sum_{\tau = t - s_1}^{t - s_2} \Delta^+ \mathbf{n}_{\mathrm{G}}(\tau) \,. \tag{26}$$

Then, the amount repaid is redistributed between the three bonds' holders in the EIRIN model (i.e. central bank, capitalist households and banks) in proportion of their current bond holdings.[10] In this model setting, we are also able to analyse under which conditions the sudden emission of sovereign bonds to compensate for climate change impacts can be amortized through a gradual repayment (and not repaying the entirety at a single time in the future).

[8] Note that, the unpaid interest should normally start in the previous period, because of the 90 days limit used to define the NPL. This can be neglected provided that variations in the NPL ratio are small.

[9] Thus, we revise previous EIRIN model's applications of Monasterolo and Raberto (2018).

[10] This is a proxy, because there is no information about securities by issuance dates in the portfolios of both. However, this is generally reasonable to the extent that the portfolio allocation of both sector changes little across time. Moreover, this can also be achieved by assuming that all bonds traded between the two are representative of a perfect slice of all bonds issued.

The second key novelty of this version of the EIRIN model regards the way in which the government issues bonds. Previously, the issuance of bonds was a response to budget deficits or negative liquidity. Now, the government also uses debt when its inflation-adjusted cost is lower than the contemporaneous use of liquidity. More precisely, let us denote by h the expenses of the government at a time t. Thus, the cost of financing it through liquidity alone would be h itself. By assumption from our repayment model, if the expense is financed through debt the associated principal would be repaid between times $t + s_1$ and $t + s_2$. In between, the government pays interest with a coupon rate c_G.

We compute the cost of debt with the conservative assumption that it is reimbursed after s_1 periods, where α is a lower-end estimate of inflation, taken as second decile of inflation values observed over the past five years. We obtain an estimated repaid price of $\sum_{k=0}^{s_1-1} \frac{c_G h/p_{\mathbf{b}}^{\dagger}}{(1+\alpha)^k} + \frac{h}{(1+\alpha)^{s_1}}$, which after dividing by h gives us the relative cost of debt

$$\zeta(\alpha, s_1) = \frac{c_G}{p_{\mathbf{b}}^{\dagger}} \cdot \frac{1+\alpha}{\alpha}\left[1-(1+\alpha)^{-s_1}\right]+(1+\alpha)^{-s_1} \tag{27}$$

Thus, debt is the cheapest option when $\zeta(\alpha, s_1) < 1$. We consider that the cheaper debt is, the larger is the share of expenses covered by it, such that

$$\Delta^+ L = \max\{0, 1-\zeta(\alpha, s_1)\} \times h\,. \tag{28}$$

This means that, if the inflation-adjusted cost of debt is, for example, 90 percent that of a direct payment, 10 percent of the cost will be covered by debt. In addition, we also let the possibility to define a maximum debt level allowed, so that no additional debt will be contracted, even if profitable, when the pre-existing amount already exceeds the threshold.

MODEL CALIBRATION AND CLIMATE TRANSITION SCENARIOS

In this section, we describe (i) the calibration of the EIRIN model, performed to reproduce the main Indonesian real and financial indicators, and (ii) the scenarios designed to address the transition risk and the spillover effects. In particular, in section 4.2 we discuss the considered NGFS scenarios and how they are embedded into EIRIN model, focusing on the Indonesian carbon price and on the demand of coal by China. The latter is channeled into EIRIN as a shock on Indonesian export of coal (see below).

Model calibration

To ensure that the shocks' dimensions are quantitatively meaningful, we initialize, calibrate and empirically validate the EIRIN model to selected characteristics and real data from Indonesia. The model depends on more than 100 parameters, and the calibration is split in two groups, which rely on two separate set of parameters and benchmark values:

- Parameters that can be calibrated on real data, e.g. taxes or markups;
- "Free" parameters that cannot be observed directly, but are set such that other endogenously produced values match observed data: GDP growth, inflation, relative value added of the sectors, imports and exports to GDP, with breakdown by sector/products, unemployment rate and sector employment share, shares of energy use and carbon emissions of the sectors, etc.

Parameters are calibrated based on data from the World Bank, the IMF (WEO), Bank Indonesia and the World Integrated Trade Solution (WITS).[11] In Table 1, we present the outcomes of this second-step calibration by comparing model's indicator means with observed data means during a time span of 10 years. Beyond these macro-economic indicators, the calibration process also considers the sectors' value added, the energy consumption of the different sectors as well as their contribution to carbon emissions, and the relation with the rest of the world through imports and exports.

Note that there can be some tensions between the different parameters and data series that we use. In particular, although tax rates for personal income, corporate profits and VAT are known, with use lower values so as to take into account the share of informal work.[12] This is because informal work is otherwise not explicitly integrated in the model. Through these changes, we reach a size of the government that is more in line with the data. More precisely, as the full panel of revenues and expenses, some tension may persist. Thus, as shown in table 1, the revenues of the government as a share of GDP are slightly higher than the average of real values, while the expenditures are slightly lower.

Similarly, the combination of inflation and deposit rate observed in Indonesia cannot be observed from the Taylor rule that is used within EIRIN for rate setting, hence there is a value lower in our simulations. On the inflation in particular, a strong downward trend has been observed in recent years, with an inflation of 3.03 percent in 2019. Thus, although the value we reach is lower than the average of the period, it is actually higher than the most recent observations. Moreover, Bank Indonesia has a target of 3 ± 1 percent of inflation yearly, and the country seems to stabilize around this target now. This justifies a more ad hoc calibration, which departs somewhat from the simple average of observations.

[11] Accessible at https://data.worldbank.org, https://www.imf.org/en/Publications/WEO, https://www.bi.go.id and https://wits.worldbank.org/ respectively.

[12] https://www.bps.go.id/

TABLE 1 Calibration table.
"Real values" come from real data time series, with observations from 2014 to 2019 where available.

	Simulation Values		Real Values	
	Mean observation	Standard deviation	Mean observation	Standard deviation
Real GDP growth (in percentage points)	4.43	0.01	5.03	0.10
Total exports (% of GDP)	20.44	0.11	20.59	1.84
Revenues from tourism (% of GDP)	1.73	0.00	1.55	0.16
Share of goods in exports (% of total exports)	62.18	0.31	61.61	2.24
Share of services in exports (% of total exports)	13.08	0.07	13.71	1.46
Share of mining commodities in exports (% of total exports)	24.74	0.38	24.68	2.97
Total imports (% of GDP)	19.34	0.02	20.63	2.30
Inflation (in percentage points)	3.05	0.01	4.39	1.57
Lending rate from the commercial bank (in percentage points)	6.41	0.01	11.52	1.01
Deposit rate of the central bank (in percentage points)	0.41	0.01	7.27	1.05
Total government expenditures (% of GDP)	24.95	0.27	17.08	0.84
Total government revenues (% of GDP)	25.03	0.04	14.79	0.89
Government revenues from taxes (% of GDP)	23.73	0.05	10.30	0.44
Level of the public debt (% of GDP)	24.09	0.27	30.53	1.58
Net remittances received (% of GDP)	0.49	0.00	0.51	0.10
Value added of the consumption goods sector (% of GDP)	31.01	0.01	20.89	0.57
Value added of the service sector (% of GDP)	43.74	0.02	43.41	0.65
Value added of all the upstream (non consumption goods/services) sectors (% of GDP)	26.69	0.07	32.17	0.85
Share of employees in the consumption goods sector (% of total employees)	20.66	0.14	35.60	2.14
Share of employees in the service sector (% of total employees)	51.80	0.02	46.68	1.84
Share of employees in upstream sectors (% of total employees)	23.87	0.17	17.72	0.34
Share of unemployment (% of total workforce)	7.02	0.07	4.12	0.34
Firms' total credit (% of GDP)	20.85	0.76	38.37	1.11
Share of investment financed through credits (% of total investments)	19.02	0.85	12.80	0.00
Share of investment financed own liquidity (% of total investments)	80.98	0.85	66.00	0.00
Share of renewable energy (% of total energy consumption)	26.09	0.05	25.04	3.38
Share of GHG emissions of the energy sector (% of total emissions)	0.46	0.01	0.43	0.01
Share of GHG emissions of the industry (all except service firms) (% of total emissions)	0.26	0.00	0.24	0.02

NGFS scenarios selection and implementation in the EIRIN model

We use 3 scenarios (out of six available[13]), produced in 2021 by the NGFS:

- *Current policies*: assumes that only currently implemented policies are preserved. Emissions grow until 2080 leading to about 3°C of warming and severe physical risks. It is the "hot house world" or "business-as-usual" scenario.
- *Below 2°C*: gradually increases the stringency of climate policies, with an immediate start, giving a 67 percent chance of limiting global warming to below 2°C.
- *Net zero 2050*: ambitious scenario that limits global warming to 1.5°C by the end of the century (with a 50 percent chance) through stringent climate policies introduced immediately and innovation.

Several models are employed to project these scenarios. We use the output of the REMIND-MAgPIE 2.1-4.2 (Hilaire and Bertram, 2020), which has the advantage of a better geographical downscaling. In particular, results are available for a region corresponding roughly to the ASEAN, where Indonesia is the largest by population. Moreover, it singles out China, which is important in our simulation as the country is the first trading partner of Indonesia.

We do not take into account the impact of physical climate damages in our base simulations because our analysis focuses on transition risk. The latter is implemented through an increasing carbon price, represented in Figure 6a. Model-wise, it comes as a rate $\tau^{GHG}(t)$ such that the revenues generated by a sector *i* at *t* are given by $Em_i(t) \times \tau^{GHG}(t)$ where Em_i denotes the total carbon emissions of *i* and covers roughly scope 1 and 2 emissions.

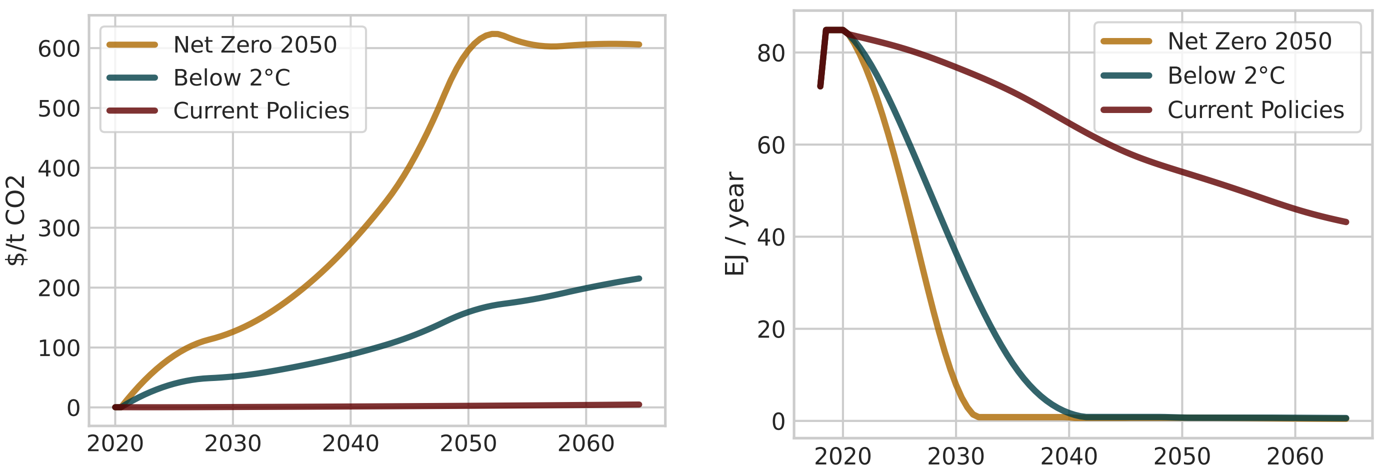
The paths for the carbon price are very different under the different scenario. First, "Net Zero 2050" exhibits a very sharp increase until the beginning of the 2050s (also the end of our simulation horizon), and a plateau at a high value after. The increase is more moderate for the "Below 2°C" scenario, with a value in 2050 less than a third of that of "Net Zero 2050." Finally, under current policies some level of carbon pricing exists, but it remain very close to zero over the whole simulation period. Due to the relative absence of an initial carbon price in Indonesia, the carbon tax cannot be calibrated in a standard fashion within our model. Therefore, this is based on an ex post assessment of the size of the tax revenues. As a comparison point, consider that the CO2 emissions of real economy sectors in 2019 in Indonesia was 559 million tons (from the International Energy Agency). Meanwhile the GDP in current US dollars was of 1.119 trillion in the same year (from World Bank data). Considering these two values, it comes that a carbon price of USD 200 per tonne of CO2 would yield an additional revenue corresponding to 10 percent of GDP. This is in fact superior to the total tax revenues reported for that year (9.75 percent of GDP, from IMF data).

[13] The other three sceanarios are "Divergent net zero", "Delayed transition" and "Nationally determined contributions." We do not consider them as they have not been used with the REMIND-MAgPIE 2.1-4.2 and therefore do not have the same richness with regards to available series.

Shock on Chinese coal demand and implications for Indonesia's coal export

Given its economic and energy composition, Indonesia is highly exposed to climate transition risk directly, and indirectly via transition spillover risk. On the one hand, in order to align with the NGFS's below 2°C or Net Zero scenarios, Indonesia should largely decrease in the volume of coal it produces and sells to other countries. This, in turn, represents a potential threat to its current accounts and budget. On the other hand, Indonesia's export of coal will suffer from shock in Chinese coal demand, due to the Chinese low-carbon transition, as represented in figure 6b.

FIGURE 6 Key variables from NGFS scenarios used to define the transition shock.
Left panel: evolution of the Indonesian carbon price in USD 2010 per ton of CO2-eq under the different scenarios of the model REMIND-MAgPIE 2.1-4.2 IntegratedPhysicalDamages (median), region "other Asia."
Right panel: use of coal by China, as a reference series to shock the quantity exported by Indonesia, from the model REMIND-MAgPIE 2.1-4.2.



Source: NGFS scenarios 2021.

In line with dynamics observed for carbon pricing, "Net Zero 2050" features very abrupt changes, with a demand for coal close to zero around 2032, and a ten-year delay in the case of "Below 2°C." On the other hand, current policies come with a much slower reduction in coal demand, with a value in 2050 still equal to around two thirds of the initial one.

In our baseline simulations, i.e. the business as usual case, we assume that the sheer quantity of fossil fuel exported from Indonesia to the rest of the world increases at a constant rate ϵ_O. Then, the shocked export value is given as a reduction ϕ on the baseline value. That is, we have

$$q_{\mathrm{MO,RoW}}(t+1) = (1+\epsilon_O) \times q_{\mathrm{MO,RoW}}(t),$$
$$\tilde{q}_{\mathrm{MO,RoW}}(t) = (1-\varphi(t)) \cdot q_{\mathrm{MO,RoW}}(t)\,.$$

RESULTS

In this section we present the results of the simulations run with EIRIN on macroeconomic and public finance indicators. Then, we analyze *(i)* the direct and indirect impacts of transition shocks and the related transmission channels, and *(ii)* the impact of spillover risk on macroeconomic indicators and public finance.

Direct and indirect impacts

The direct impacts considered in this study involve two main dimensions:

(a) A domestic dimension, i.e. the evolution of the carbon price in Indonesia (see Figure 6a).

(b) An external dimension, i.e. the evolution of primary energy (coal) demand by China (see Figure 6b).

Both dimensions have been investigated in the context of three NGFS scenarios, including "Below 2°C," "Net Zero 2050" and "Current Policies" (see below). Each is characterized by different transmission channels through which the shocks propagate into the Indonesian economy, with cascading effects on GHG emissions, macroeconomic indicators and public finance (indirect impacts). In particular, the increase in carbon price *(a)* impacts on the production costs of high-carbon firms while adding to the government's budget, and the reduction in demand of coal by China *(b)* affects the Indonesian exports.

Transmission channels *(b)* are analyzed in the context of the NGFS scenarios. In particular, the decrease in the demand of coal by China is largely emphasized in the scenarios "Below 2° C" and "Net Zero 2050" (Figure 6b), mainly driven by the phasing out of fossil fuel needed to reach climate targets. Lower demand for coal by China translates also into lower imports, thus affecting its trading partners.

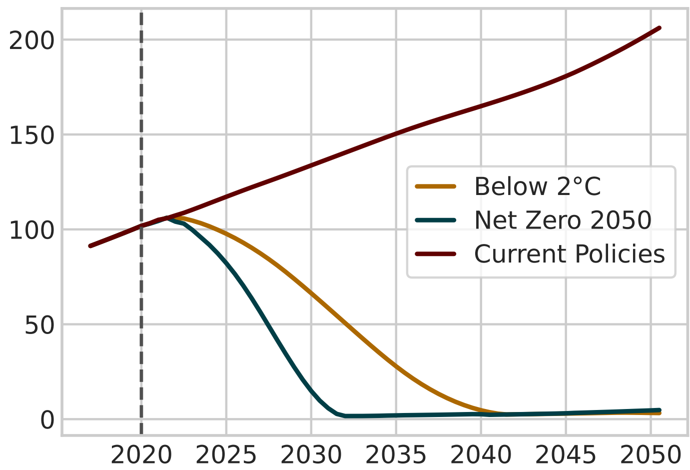
As China is the first importer of coal from Indonesia (see Section 2), the latter suffers a reduction on its coal exports. Results shown in figure 7 are in line with the scenario design. In the scenarios "Below 2°C" and "Net Zero 2050," the quantity exported converges to zero. The trajectory of "Below 2°C" is smoother than what would be predicted from figure 6b. This is due in part to a positive export trend from the calibration, and the price increase of fossil fuel (see Section 4). Furthermore, in the scenario "Current Policies," the exports of coal and other fossil fuels still slightly increase in value.

Then, we compare the baseline simulations to a counterfactual with no shock on fossil fuel exports.

On one hand we have the *(a + b)* scenario where both channels operate, i.e. assuming that the quantity of fossil fuel exported from Indonesia is shocked due to changes in China's demand for coal. It is represented by a solid line "With spillover" in charts.

On the other hand, the counterfactual is a scenario *(a)* only, with no shock on fossil fuel exports. It is represented by a dashed line "No spillover" in the figures presented. Thus, we can identify the scope of changes attributable to spillover risk.

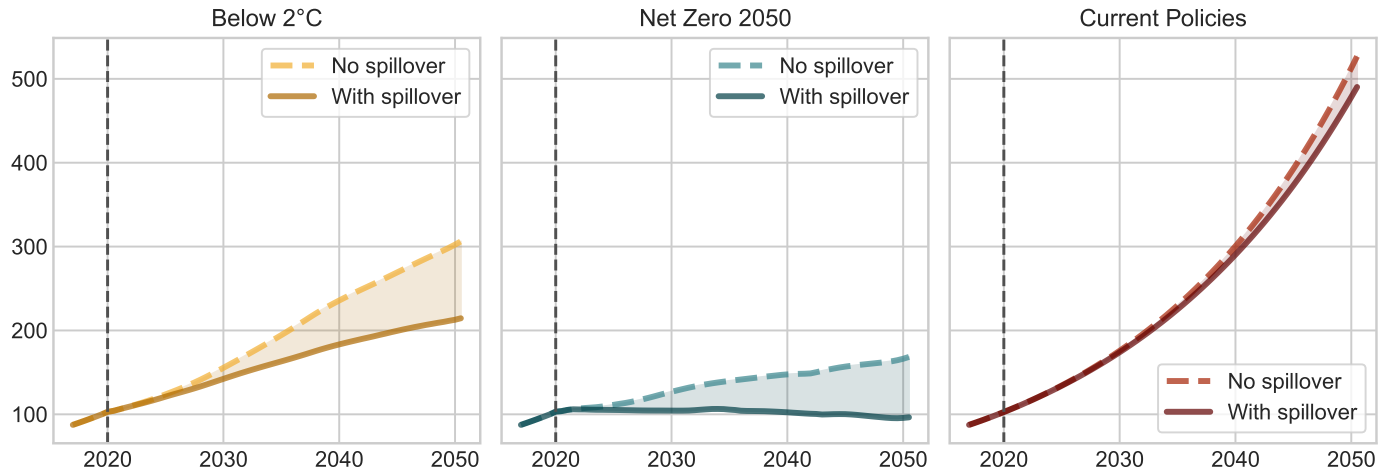
FIGURE 7 Total value of coal and other fossil fuel exported by Indonesia, indexed at 100 at the start of the scenarios and adjusted for inflation.



Regarding the green house gases (GHG) emissions, figure 8 shows their evolution in response to the impacts of carbon price *(a)* and coal demand in China *(b)* over the three NGFS scenarios considered. Two main results can be highlighted here:

1. The GHG emissions are smaller for "Net Zero 2050" and "Below 2°C" with respect to the "Current Policies" scenario, mainly driven by the transition to renewable in the energy sector;
2. Transition spillover effects tend to decrease the overall levels of emissions, due to the lower pollution from the operations of the mining sector, which is significant given its carbon intensity.

FIGURE 8 Total GHG emissions from the domestic economy, indexed at 100 at the starting time of the scenarios.



More details are provided in the appendix (Figure 14), which shows the breakdown by sector of emissions. These results do not consider lower emissions on the side of coal importers, which would add to the total saved on carbon emissions.

However, it is worth noting that in the scenarios "Net Zero 2050" and "Below 2°C" the emissions are smaller compared to "Current Policies," but not to the extent planned by the scenario. This is because we operate in the absence of CDR inclusion, and is also explained by the model calibration, whereby the economy is expected to sustain a high level of growth over the calibration period, making a reduction in total emissions difficult to achieve.

Macroeconomic indicators

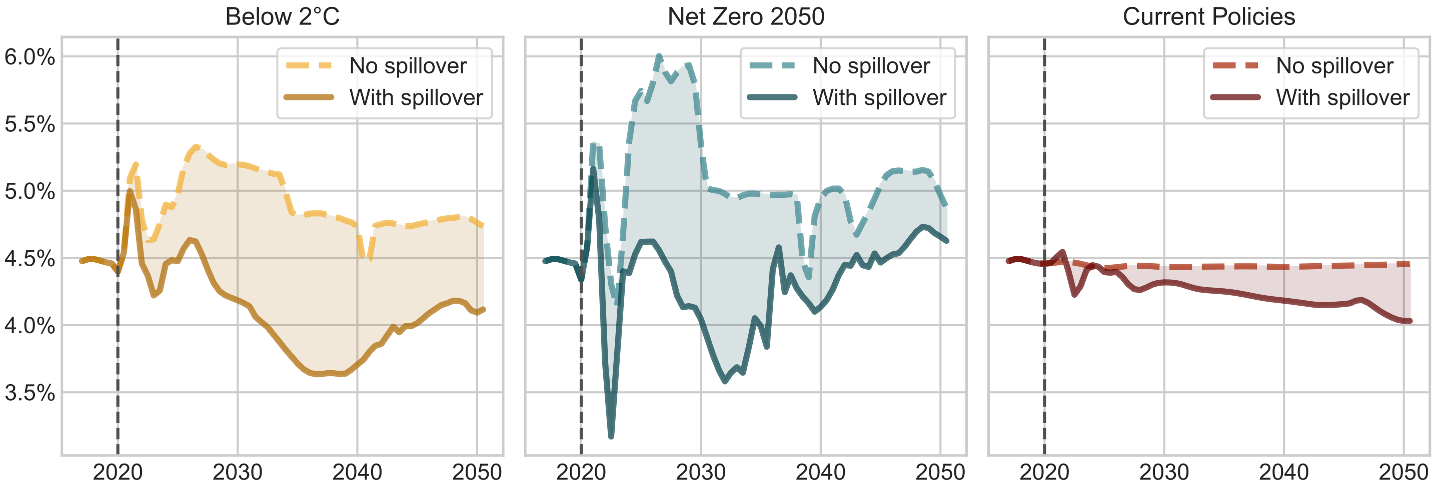
We discuss here the results of the simulated scenarios on key macroeconomic indicators. Figure 9 shows the real GDP growth rate. The main dynamics are driven by the NGFS scenarios and by the spillover effect. In particular, "Net Zero 2050" and "Below 2°C" show higher real GDP growth rate with respect to "Current Policies." The result is driven by larger investments in green capital both by the consumption good producers and by the green energy producer sector, in order to foster the transition to a low-carbon economy. Green investments lead to an increase in employment (discussed in appendix A) and, thus, in wages and households' consumption.

Crucially, when the carbon price is very high – especially in the case of the scenario "Net Zero 2050" – the government's budget increases significantly, following the introduction of the policy.[14] The only exception is represented by government's expenses linked to subsidies for green energy and green capital, which are increasing (by design) in the "Net Zero 2050" and "Below 2°C" scenarios. However, as shown in the appendix, Figure 20, sustainability expenses are dwarfed by the carbon tax income in the two scenarios, such that most of the additional budget can be considered as being re-injected in the general expenses. Thus, the differences observed in Figure 9 are also influenced by government's budget allocation, which contributes to foster economic growth in the short and medium term, compared to the "natural" money flow circulation.

With regard to spillover risk, Figure 9 shows that the reduction in export driven by lower coal demand from China (Figure 6b) negatively affects Indonesian real GDP in all the NGFS scenarios considered. Lower Chinese demand for Indonesian coal has both a direct and indirect impact on the Indonesian economy, i.e. a direct (and negative) impact on Indonesian export, and an indirect (and negative) impact on Indonesian mining sector. Indeed, the lower export of coal reduces the activity of the mining company, in turn decreasing its demand for labor as well as the profits reversed to the government. In turn, higher unemployment and lower government's revenues negatively affect the Indonesian economy, as highlighted by the growth in sectors' value added presented in Figure 16.

14 We do not make any assumption about how the added tax income is recycled. It is affected to the general budget of expenditures and redistribution in the same proportions as before.

FIGURE 9 Growth rate of the real GDP in the NGFS scenarios.
The *x*-axis displays years of simulation. The *y*-axis displays the year-on-year growth rate of real GDP.

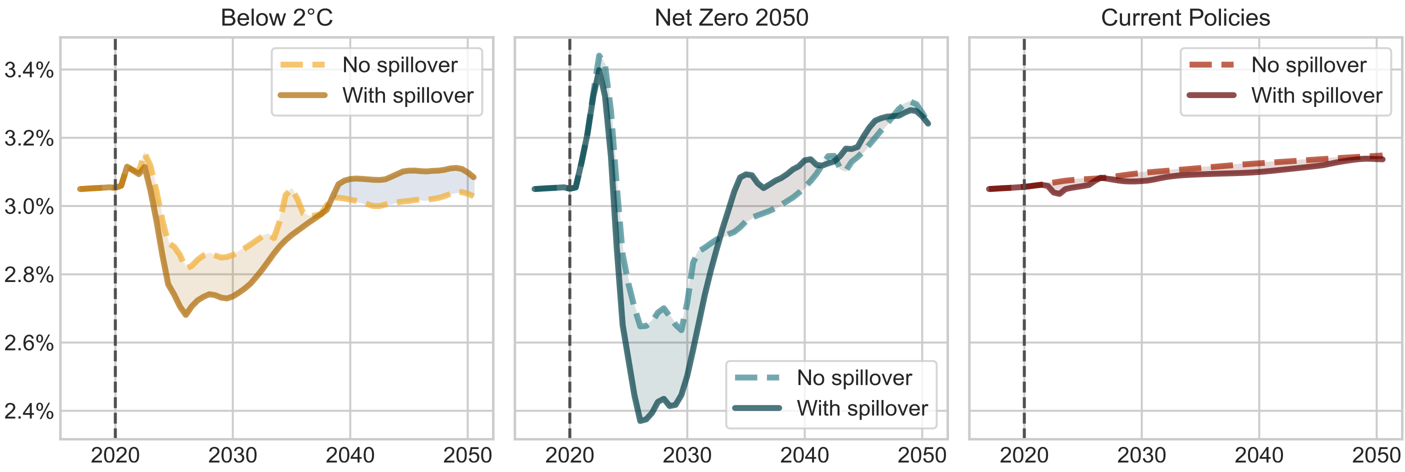


Furthermore, as observed in Figure 10, low-carbon transition scenarios are characterized by lower inflation compared to scenarios of current policies. In contrast, lower effects emerge by spillovers. We provide in the appendix, Figure 17, a breakdown of inflation by sub-categories of products. The series represented in Figure 10 corresponds to a CPI-like indicator, including the downstream sectors of consumer goods and services. The sector breakdown shows lower inflation for categories of product, with a relevant role of services. In this second sector, which is less carbon intensive, the increase in carbon tax is relatively small compared to other sectors. Lower inflation can be explained at the light of the higher demand that these sectors face due to the government's reinvestment of the carbon tax proceeds in less carbon intensive activities.

As a result, interest payments on debt and capital depletion in total expenses decrease.[15] This also explains the catch up effect that is observed after a few years as both debt and lost capital realign to production levels. Moreover, the spillover effect is small relative to the scenario, and thus, less relevant from a monetary policy point of view, in comparison to country-level climate transition risks.

[15] We should also consider the natural time delay of stock variables, as a result of adjustment in economic conditions, investment decisions and fiscal policy.

FIGURE 10 Inflation rate in the NGFS scenarios.
The *x*-axis displays years of simulation. The *y*-axis displays the yearly inflation rate based on a representative and adaptive basket of services and consumption good.



Public finance indicators

In this section we show the effect of climate transition scenarios and spillover risk on public finances, focusing on the balance of payment, the budget balance to GDP ratio, and the government debt to GDP ratio.[16]

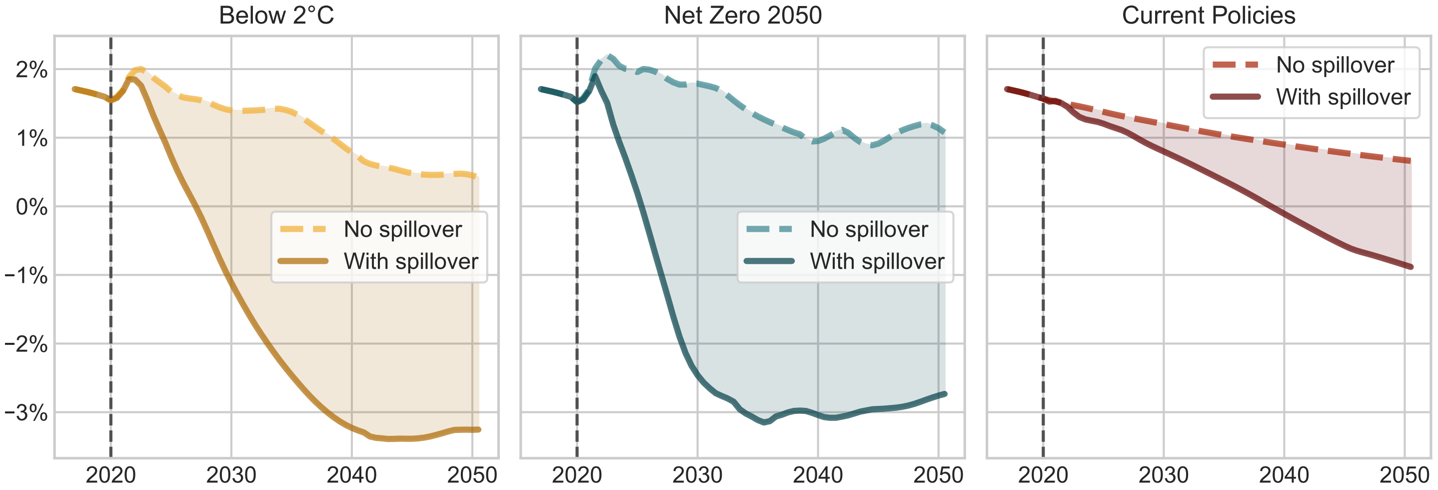
The balance of payments, represented in Figure 11, is most affected, and negatively, by the spillover risk, which directly affects the reduction of coal export, as a result of the decreasing demand by China (Figure 6b). Thus, while values are stable in the "No spillover" counterfactual, we observe a 6 percent drop (in GDP points) when including the export shock. This magnitude is in line with known data about the importance of fossil fuel export in the Indonesian economy (see Figure 2 and calibration Table 1). Export shows the worst performance in the transition scenarios, i.e. "Net Zero 2050" and "Below 2°C," which are characterized by abrupt drops in coal and fossil fuel exports. The relative slopes conditioned to these transition scenar-ios are comparable in trend to those of exports in Figure 7. Overall, given the importance of fossil fuels in the initial volume of exports, the impact of the shock is very significant for the country's trade.

In relation to this, Figure 12 shows larger government's deficits in spillover risk scenarios. In the "Below 2°C" and "Net Zero 2050" scenarios, the budget balance to GDP sets almost to 2 percent lower when including spillover risk, for a relevant part of the simulation period. Meanwhile, the gap with the counterfactual also increases in the "Current policies" scenario, measures alone (in the "No spillover" counterfactual) do not induce a significant difference

Nonetheless, note that our simulations assume no changes in fiscal policies (e.g. welfare measures) that could smooth the economic shock.

[16] The balance of payment is measured as the difference of exports and imports for the regions of interest. Remittances are not included in it (and are supposed stable as a share of domestic GDP by calibration).

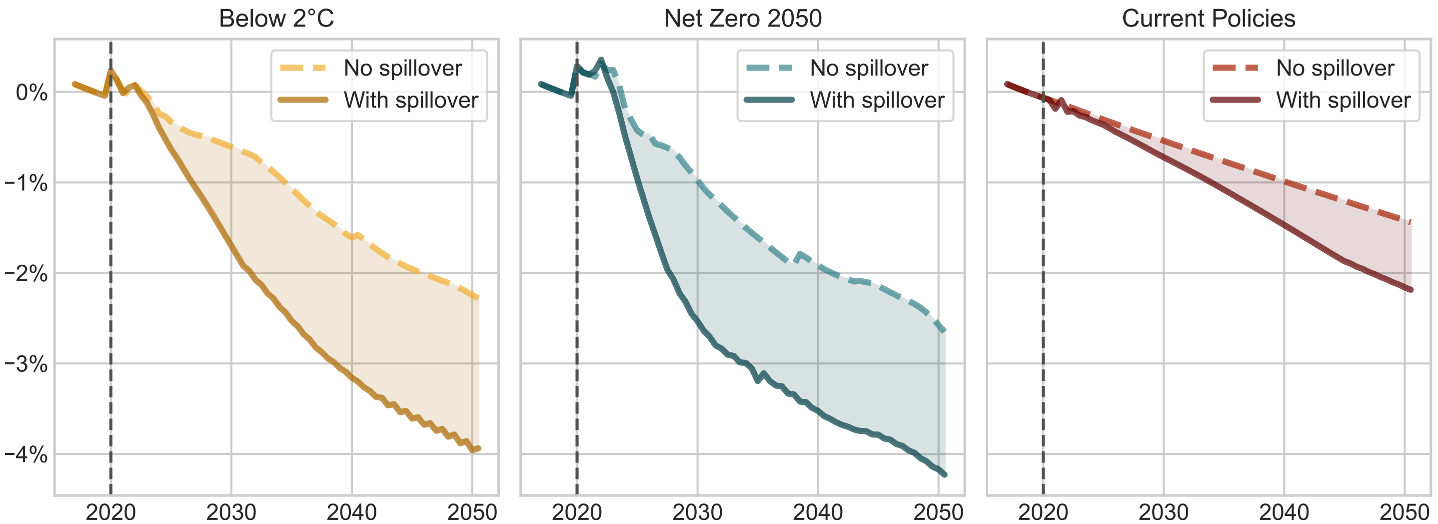
FIGURE 11 Balance of payment in the three scenarios, as percentage of GDP, differentiating versions with and without the spillover effects from the shock on fossil fuel exports.



but remains lower, in the range of 1 percent at the end of the period. Note that the transition measures alone (in the "No spillover" counterfactual) do not induce a significant difference in budget balance when compared to "Current policies." This is because the NGFS scenarios are designed with a carbon tax as a primary variable, thus generating additional income for the government (see Figure 20 in the appendix for the comparison to expenses). Low-carbon transition measures are also characterized by indirect effects to the economy. However, the difference between scenarios "Below 2°C" and "Net Zero 2050" is relatively small, suggesting that enforcing more stringent low-carbon transition measures does not necessarily lead to a higher fiscal cost for Indonesia. The same remarks apply when we consider spillover risk.

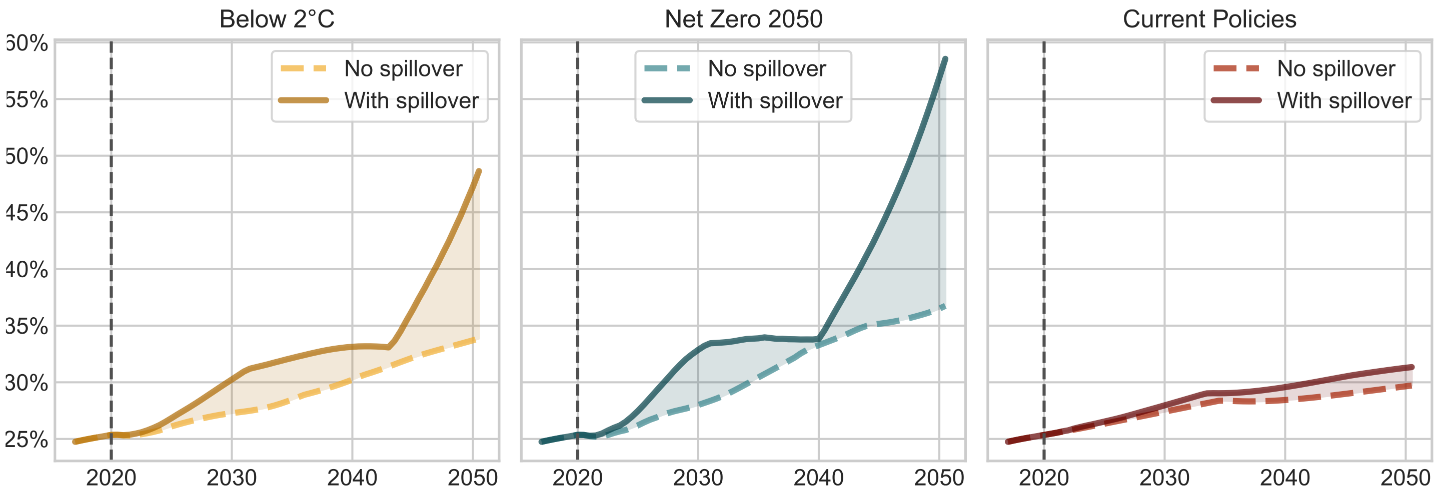
The worsening of budget balance is primarily due to the loss of revenues generated by the mining sector, which is largely owned by the State and also pays taxes on its profits.

FIGURE 12 Government's budget balance in the three scenarios, as percentage of GDP, differentiating versions with and without the spillover effects from the shock on fossil fuel exports.



Consistently, public debt increases the most in all scenarios, characterized by spillover risk (Figure 13), increasing in particular at the end of the period. Nevertheless, given the country's relatively low initial level of debt, its increase is still manageable. The debt level is in part reached through the mechanism described in Section 3, and the rest of it is taken on to compensate the government's deficit. This highlights the importance of considering all risk channels in the analysis of the macroeconomic and financial implications of low-carbon transition scenarios. Indeed, overlooking spillover risks could erroneously lead us to level up public debt across scenarios.

FIGURE 13 Government debt in the three scenarios, as percentage of GDP, differentiating versions with and without the spillover effects from the shock on fossil fuel exports.



CONCLUSION

We analyzed the macro-financial criticality of climate transition spillover risk (shortened in the paper as "spillover risk") on sovereign risk in Indonesia. Spillover risk emerges from a shock in Chinese demand for Indonesian coal as a result of carbon pricing introduction in China.

First, we defined the concept of climate transition spillover risk. Then, we identified the spillover risk transmission channels that can have macro-critical implications, and we quantitatively assessed their impacts on the country's economy. To do so, we tailored and calibrated the EIRIN SFC behavioral model. With EIRIN, we analyzed and compared the impact of climate transition scenarios provided by the NGFS, as well as the impact of spillover risk, on key macroeconomic and public finance indicators. We focused on the direct impacts (shrinking export markets) and indirect impacts (i.e. asset prices, investment and fiscal revenue) of spillover risk in Indonesia, as a result of the introduction of carbon pricing in China.

Finally, we draw lessons regarding how our analysis could support financial institutions with a financial stability mandate, such as the IMF, in the assessment of climate-related financial risk, and on how this analysis could be deployed into the toolkit of climate strategy at the IMF.

TABLE 2 Summary of main macroeconomic and environmental results. The *spillover risk* column refers to the effect of adding effects from a shock on fossil fuel exports to a scenario. The *low carbon transition policies* column refers to the effect of moving from one scenario to the other, in the direction of more stringent climate change mitigation. A *downward arrow* denotes negative impacts, an *upward arrow* denotes positive impacts, and a *tilde* means there is no significant impact, or that it varies depending on other conditions.

Variable	Spillover Risk	Low-Carbon Transition Policies
GDP	↓	↑
Balance of payments	↓	~
Public debt	↑	↑
Unemployment	↑	↓
GHG emissions	↓	↓

Our results, summed up in Table 2, show that spillover risk can induce trade-offs in terms of sovereign economic and financial stability, and decarbonization. On the one hand, spillover risk negatively affects GDP growth and the main macroeconomic indicators in Indonesia. The slowdown in economic growth is driven by the drop in coal production, leading to the realization of carbon stranded assets. This, in turn, negatively affects the Indonesian balance of payments, fiscal budget and public debt. Importantly, the impact on the Indonesian fiscal budget is not negligible and can trigger public debt imbalances if not mitigated by adequate fiscal measures or external financing, from entities such as the IMF. Beyond public financing, our results suggest important real economy effects. In particular, spillover risk negatively affects employment, and social consequences not modeled here (e.g. inequality and poverty) could slowdown the progress toward a low-carbon economy. On the other hand, spillover risk leads to lower GHG emissions in Indonesia. Nevertheless, the decrease is not enough to achieve the country's ambitious climate mitigation targets.

Our findings shed new light on the importance for fossil fuels' exporting countries, such as Indonesia, to diversify their economy (Mercure et al., 2021), and join other countries' decarbonization efforts. This option would be superior, in terms of macroeconomic and sovereign financial stability, to "free-riding" when their trading partners are winding down fossil fuel energy.

Implications for the governance of the low-carbon transition at the regional and global level follow. At the regional level, the coordinated introduction of policies for the low-carbon transition in the South-East Asia region, and of the support from regional institutions, such as the Chang Mai Initiative for Multilateralization, the Asian Infrastructure Investment Bank, the Asian Development Bank, among the others, could help countries to smooth the negative effects of the spillover risk in the economy and public finance. In this regard, the introduction of macroeconomic models that allow to monitor the implications of spillover risks in the region could inform the design of coordinated low-carbon transition measures.

At the global level, the IMF may have a significant role to play. As the only global and membership-based institution charged with maintaining the stability of the financial system, the IMF now recognizes that climate change and climate change policy can pose risks to

financial and fiscal systems. This paper provides an operative framework through which the IMF can trace the channels of spillover risk and quantitatively assess them in its client countries.

Efforts to model macro-critical climate risks should be incorporated in various parts of the IMF toolkit. This, in turn, can help reforming FSAPs and Article IV surveillance activities that will help member states understand the macro-critical implications of climate change and climate change policy on their economies. Results from such modeling efforts can guide the IMF in its advisory functions—to help countries design financial and fiscal policies to support climate resilience, adaptation and green structural transformation that minimizes risks for stability and balance of payments concerns. Second, it can help the IMF pinpoint the new kinds of financial packages it may need to help member states prevent and mitigate the impacts of transition spillovers on member-state economies.

BIBLIOGRAPHY

ADB (2021). *Greening markets. Market-based approaches for environmental management in Asia*. Asian Development Bank. doi: 10.22617/TCS210239-2.

Allen, Thomas et al. (2020). *Climate-related scenarios for financial stability assessment: an application to France*. working paper 774. Banque de France.

Alogoskoufis, Spyros et al. (2021). *ECB economy-wide climate stress-test. Methodology and results*. Occasional Paper Series 281. European Central Bank. doi: 10.2866/460490.

BIS – Bank for International Settlements (2021). *Climate-related risk drivers and their transmission channels*.

Batten, Sandra, Rhiannon Sowerbutts, and Misa Tanaka (2016). "Let's talk about the weather: the impact of climate change on central banks." Working Paper 603. Bank of England.

Battiston, Stefano, Yannis Dafermos, and Irene Monasterolo (2021). "Climate risks and financial stability". In: *Journal of Financial Stability* 54. doi: 10.1016/j.jfs.2021.100867.

Battiston, Stefano, Antoine Mandel, Irene Monasterolo, Franziska Schütze, and Gabriele Visentin (2017). "A climate stress-test of the financial system." In: *Nature Climate Change* 7.4, pp. 283–288. doi: 10.1038/NCLIMATE3255.

Battiston, Stefano and Irene Monasterolo (2020). "On the dependence of investor's probability of default on climate transition scenarios." In: Available at SSRN. doi: 10.2139/ssrn.3743647.

Bevan, David, Paul Collier, and Jan Willem Gunning (1999). *The Political Economy of Poverty, Equity, and Growth. Nigeria and Indonesia*. isbn: 9780195209860.

Blanchard, Olivier (2017). *Macroeconomics*. 7th. Pearson.

Braithwaite, David and Ivetta Gerasimchuk (2019). *Beyond Fossil Fuels: Indonesia's fiscal transition*. GSI report. International Institute for Sustainable Development.

Brunnermeier, Markus, Jean-Pierre Landau, Marco Pagano, and Ricardo Reis (2020). *Throwing a COVID19 liquidity life-line*. url: https://voxeu.org/debates/commentaries/throwing-covid-19-liquiditylife-line.

Cahen-Fourot, Louison, Emanuele Campiglio, Antoine Godin, Eric Kemp-Benedict, and Stefan Trsek (2021). "Capital stranding cascades: The impact of decarbonisation on productive asset utilisation."

Caiani, Alessandro et al. (2016). "Agent based-stock flow consistent macroeconomics: Towards a benchmark model." In: *Journal of Economic Dynamics and Control* 69, pp. 375–408.

Caldecott, Ben (2018). *Stranded assets and the environment: Risk, resilience and opportunity*. Routledge.

Carattini, Stefano, Garth Heutel, and Givi Melkadze (2021). Climate policy, financial frictions, and transition risk. National Bureau of Economic Research. doi: 10.3386/w28525.

Carnevali, Emilio, Matteo Deleidi, Riccardo Pariboni, and Marco Veronese Passarella (2021). "Crossborder financial flows and global warming in a two-area ecological SFC model." In: *Socio-Economic Planning Sciences* 75. Decision-Making for Environmental Sustainability, p. 100819. issn: 0038-0121. doi: 10.1016/j.seps.2020.100819.

Carney, Mark (2015). "Breaking the Tragedy of the Horizon–climate change and financial stability." In: *Speech given at Lloyd's of London* 29, pp. 220–230.

Carroll, Christopher D. (2001). "A Theory of the Consumption Function, with and without Liquidity Constraints." In: *Journal of Economic Perspectives* 15.3, pp. 23–45.

Caverzasi, Eugenio and Antoine Godin (2015). "Post-Keynesian stock-flow-consistent modelling: a survey." In: *Cambridge Journal of Economics* 39.1, pp. 157–187.

Dafermos, Yannis, Maria Nikolaidi, and Giorgos Galanis (2017). "A stock-flow-fund ecological macroeconomic model." In: *Ecological Economics* 131, pp. 191–207.

Deaton, Angus (1991). "Saving and Liquidity Constraints." In: *Econometrica* 59, pp. 1121–1142.

Dietz, Simon, Alex Bowen, Charlie Dixon, and Philip Gradwell (2016). "'Climate value at risk'of global financial assets." In: *Nature Climate Change* 6.7, pp. 676–679.

Dietz, Simon, Dan Gardiner, Valentin Jahn, and Jolien Noels (2021). "How ambitious are oil and gas companies' climate goals?" In: *Science* 374.6566, pp. 405–408.

Dunz, Nepomuk, Arthur Hrast Essenfelder, Andrea Mazzocchetti, Irene Monasterolo, and Marco Raberto (2021a). "Compounding COVID-19 and climate risks: the interplay of banks' lending and government's policy in the shock recovery." In: *Journal of Banking & Finance*, p. 106306.

Dunz, Nepomuk, Asjad Naqvi, and Irene Monasterolo (2021b). "Climate Sentiments, Transition Risk, and Financial Stability in a Stock-Flow Consistent Model." In: *Journal of Financial Stability*, p. 100872.

Goodwin, Richard (1967). "A Growth Cycle." In: *Socialism, Capitalism and Economic Growth*. Cambridge University Press.

Gourdel, Régis, Irene Monasterolo, Nepomuk Dunz, Andrea Mazzocchetti, and Laura Parisi (2021). *Assessing the double materiality of climate risks in the EU economy and banking sector*. accepted for publication.

Grafakos, Stelios, Dereje Senshaw, Andres Toro, Jaya Wahono, and Soim Lee (2020). *Employment Assessment of Renewable Energy: Indonesian Power Sector Pathways*. GGGI country report.

Gros, Daniel et al. (2016). Too late, too sudden: Transition to a low-carbon economy and systemic risk. Reports of the Advisory Scientific Committee 6. European Systemic Risk Board (ESRB). doi: 10.2849/703620.

Gross, Christian and Cosimo Pancaro (May 2021). "Credit risk transmission during the pandemic: the sovereign-bank-corporate nexus." In: *Financial Stability Review*. European Central Bank.

Hallegatte, Stephane et al. (2016). *Shock Waves : Managing the Impacts of Climate Change on Poverty*. World Bank. url: https://openknowledge.worldbank.org/handle/10986/22787.

Hilaire, Jérôme and Christoph Bertram (2019). *A sustainable and responsible investment guide for central banks' portfolio management*. Network for Greening the Financial System.

— (2020). *The REMIND-MAgPIE model and scenarios for transition risk analysis*. Potsdam Institute for Climate Impact Research.

IEA (2021). *Net Zero by 2050*. International Energy Agency.

IMF (2021). *IMF Strategy to Help Members Address Climate Change Related Policy Challenges: Priorities, Modes of Delivery, and Budget Implications*. Policy Paper 2021/057. International Monetary Fund.

IPCC (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change.

— (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Intergovernmental Panel on Climate Change.

IRENA (2018). *Renewable Energy Market Analysis: Southeast Asia*. International Renewable Energy Agency.

Island, Jeju (2016). *Pushing the Envelope on Renewable Energy*. Special report for Asian regional policy dialogue. Global Green Growth Institute.

Jackson, Andrew and Tim Jackson (2021). "Modelling energy transition risk: The impact of declining energy return on investment (EROI)". In: Ecological Economics 185, p. 107023. issn: 0921-8009. doi: 10.1016/j.ecolecon.2021.107023.

Jakab, Zoltan and Michael Kumhof (2015). "Banks are Not Intermediaries of Loanable Funds And Why this Matters." In: *Bank of England Staff Working Paper* 529. issn: 1556-5068. doi: 10 . 2139 / ssrn . 2612050.

Lamperti, Francesco, Valentina Bosetti, Andrea Roventini, Massimo Tavoni, and Tania Treibich (2021)." Three green financial policies to address climate risks". In: *Journal of Financial Stability* 54, p. 100875. doi: 10.1016/j.jfs.2021.100875.

Lamperti, Francesco, Giovanni Dosi, Mauro Napoletano, Andrea Roventini, and Alessandro Sapio (2018). "Faraway, so close: coupled climate and economic dynamics in an agent-based integrated assessment model". In: Ecological Economics 150, pp. 315–339. doi: 10.1016/j.ecolecon.2018.03.023.

McGlade, Christophe and Paul Ekins (2015). "The geographical distribution of fossil fuels unused when limiting global warming to 2 C." In: *Nature* 517.7533, pp. 187–190.

McLeay, Michael, Amar Radia, and Ryland Thomas (2014). *Money Creation in the Modern Economy*. Quarterly Bulletin Q1. Bank of England, pp. 1–14.

G20 – Members of the peer-review team: China, Germany, Italy, Mexico, New Zealand, World Bank, IEA, IISD – GSI, GIZ Indonesia and the OECD (Chair of the peer-review) (2019). *Indonesia's effort to phase out and rationalise its fossil-fuel subsidies. A report on the G20 peer-review of inefficient fossil-fuel subsidies that encourage wasteful consumption in Indonesia*.

Mercure, J-F et al. (2018). "Macroeconomic impact of stranded fossil fuel assets." In: *Nature Climate Change* 8.7, pp. 588–593.

Mercure, J-F et al. (2021). "Reframing incentives for climate policy action". In: *Nature Energy* 6.12, pp. 1133–1143. doi: 10.1038/s41560-021-00934-2.

Monasterolo, Irene (2020). "Climate change and the financial system." In: *Annual Review of Resource Economics* 12, pp. 299–320.

Monasterolo, Irene and Marco Raberto (2018). "The EIRIN flow-of-funds behavioural model of green fiscal policies and green sovereign bonds." In: *Ecological Economics* 144, pp. 228–243.

— (2019). "The impact of phasing out fossil fuel subsidies on the low-carbon transition." In: *Energy Policy* 124, pp. 355–370.

Naqvi, Asjad and Engelbert Stockhammer (2018). "Directed technological change in a post-Keynesian ecological macromodel." In: *Ecological economics* 154, pp. 168–188.

NGFS – Network for Greening the Financial System (2019). *A call for action. Climate change as a source of financial risk.*

Nogrady, Bianca et al. (2021). "China launches world's largest carbon market: but is it ambitious enough?" In: *Nature* 595.7869, pp. 637–637.

OECD (2021). *Financial markets and climate transition: Opportunities, challenges and policy implications*. url: https://www.oecd.org/finance/Financial-Markets-and-Climate-Transition-Opportunitieschallenges-and-policy-implications.htm.

Ponta, Linda, Marco Raberto, Andrea Teglio, and Silvano Cincotti (2018). "An agent-based stock-flow consistent model of the sustainable transition in the energy sector." In: *Ecological Economics* 145, pp. 274–300.

Ramos, Luma, Kevin P. Gallagher, Corinne Stephenson, and Irene Monasterolo (2021). "Climate risk and IMF surveillance policy: a baseline analysis." In: *Climate Policy*, pp. 1–18. doi: 10.1080/14693062. 2021.2016363.

Ranger, Nicola Ann, Olivier Mahul, and Irene Monasterolo (2022). *Assessing Financial Risks from Physical Climate Shocks: A Framework for Scenario Generation*. World Bank Group.

Ray, Lee et al. (2021). *Do Not Revive Coal. Planned Asia coal plants a danger to Paris*. Carbon Tracker.

Rimaud, Cedric, Haran Siva, Miguel Almeida, Andrew Whiley, and Krista Tukiainen (2020). *ASEAN Green Finance. State of the Market 2019*. Climate Bonds Initiative.

Roncoroni, Alan, Stefano Battiston, Luis Onésimo Leonardo Escobar Farfàn, and Serafin Martinez Jaramillo (2021). "Climate risk and financial stability in the network of banks and investment funds." In: *Journal of Financial Stability*.

Schnabel, Isabel (2020). *When markets fail – the need for collective action in tackling climate change. Speech by Isabel Schnabel, Member of the Executive Board of the ECB, at the European Sustainable Finance Summit, Frankfurt am Main, 28 September 2020*. url: https://www.ecb.europa.eu/press/key/date/ 2020/html/ecb.sp200928_1~268b0b672f.en.html.

Semieniuk, Gregor, Emanuele Campiglio, Jean-Francois Mercure, Ulrich Volz, and Neil R Edwards (2021). "Low-carbon transition risks for finance." In: *Wiley Interdisciplinary Reviews: Climate Change* 12.1, e678.

Shapiro, Joseph S (2021). "The environmental bias of trade policy." In: *The Quarterly Journal of Economics* 136.2, pp. 831–886.

Solow, Robert M (1956). "A contribution to the theory of Growth." In: *The Quarterly Journal of Economics* 70.1, pp. 65–94. doi: 10.1080/02724980343000242.

Sovacool, Benjamin K (2010). "The political economy of oil and gas in southeast asia: Heading towards the natural resource curse?" In: *The Pacific Review* 23.2, pp. 225–259.

Taylor, John B. (1993). “Discretion versus policy rules in practice.” In: *Carnegie-Rochester Conference Series on Public Policy* 39, pp. 195–214. issn: 0167-2231. doi: 10.1016/0167-2231(93)90009-L.

UNEP-FI (2021). *High-Level Recommendations for Credible Net-Zero Commitments from Financial Institutions. Input paper to the G20 Sustainable finance Working Group*. UNEP Finance Initiative.

UNDP – United Nations Development Programme (2020). *Covid-19 and Human Development: Assessing the Crisis, Envisioning the Recovery*.

UNEP – United Nations Environment Programme (2021). *The Heat Is On. A world of climate promises not yet delivered*. Emissions Gap Report 2021.

UNFCCC – United Nations Framework Convention on Climate Change (2015). *Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015*.

Vermeulen, Robert et al. (2021). “The heat is on: A framework for measuring financial stress under disruptive energy transition scenarios.” In: *Ecological Economics* 190, p. 107205.

Volz, Ulrich and Sara Jane Ahmed (2020). *Macrofinancial risks in climate vulnerable developing countries and the role of the IMF. Towards a joint V20-IMF Action Agenda*.

Welsby, Dan, Baltazar Solano Rodriguez, Steve Pye, and Adrien Vogt-Schilb (2021). *High and dry: stranded natural gas reserves and fiscal revenues in Latin America and the Caribbean*. IDB working paper series IDB-WP01197.

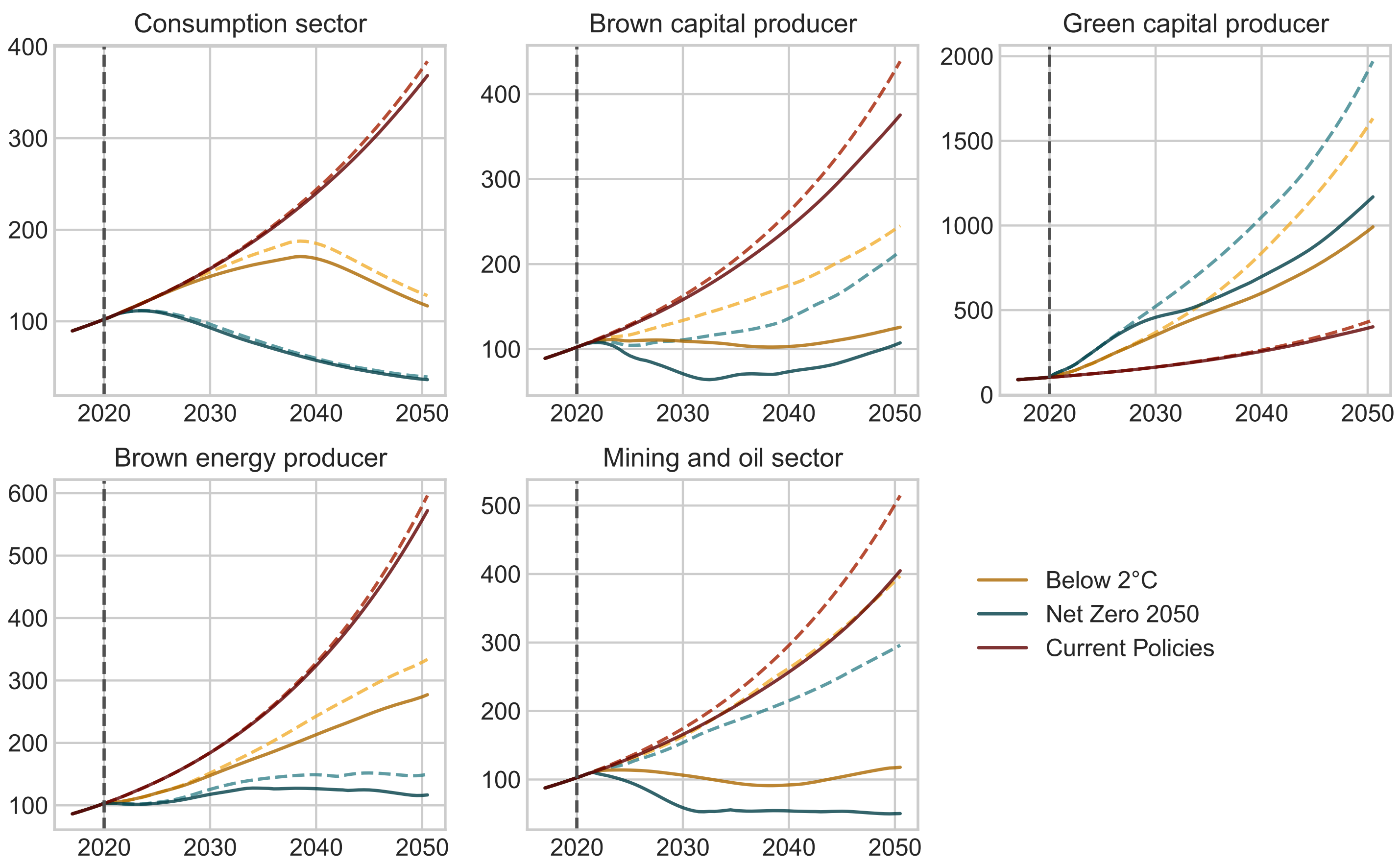
Wijaya, Muhammad Ery et al. (2021). *Leveraging fiscal stimulus to improve energy transition: Case of South Korea and Indonesia*.

APPENDIX: ADDITIONAL RESULTS

In this appendix, are analyze more detailed results that extend on what is presented in Section 5. First, we represent the GHG emissions of the different sectors in Figure 14. This allows us to observe that the transition pathways are successful in bringing down the GHG emissions of all sectors except for that of the green capital producer. This last case is explained by the higher demand for green capital, hence larger emissions from the producer's own operations. Features of green capital relative to brown capital are to reduce the quantity of raw material and energy required in production. Thus, the increase in green capital production is important in reducing the emissions of the consumption sector (aggregating for consumption goods and services in this figure). On the other hand, the difference induced by the coal export shock is relatively small for most sectors, except for the mining and oil sectors where we observe a large decrease in emissions when including spillovers. Here as well, this is driven by a change in the production level of the sector.

Moreover, the other key driver that drives down the GHG emissions of the two transition scenarios relative to the baseline is the increase in renewables in the energy mix. This is represented in Figure 15, where we observe a sharp increase of the renewables share under the

FIGURE 14 Sector breakdown of carbon emissions under different scenarios, with dashed lines representing the counterfactual with no spillover risk. "Consumption sector" aggregates both the consumption goods producers and the service sector.

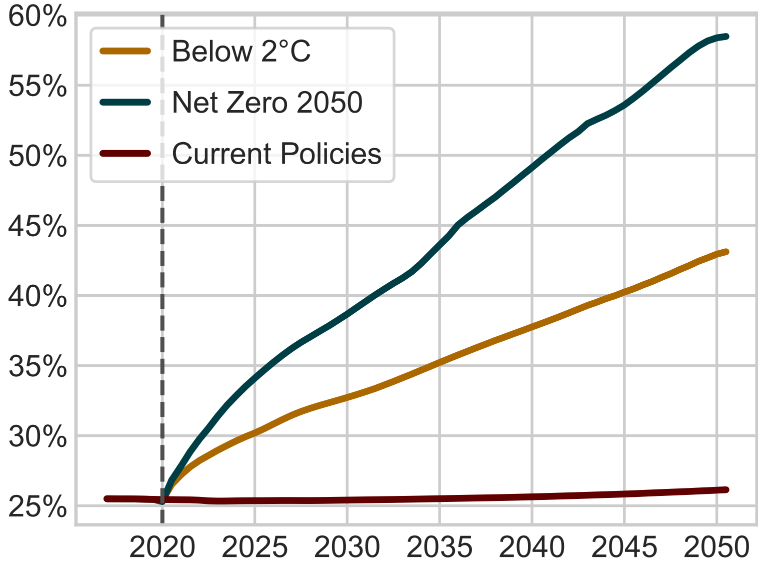


"Net Zero 2050" scenario, reaching close to 50 percent of the total energy mix in 2050, and a slower increase under the "Below 2°C" scenario, reaching close to 40 percent in 2050.

To better explain the differences in growth between the different scenarios discussed in Figure 9, we represent in Figure 16 the yearly changes in value added for sectors in the economy. Thus, we observe that the consumption sector is the one that absorbs the best the shock, with the smallest deviations from its baseline growth. Moreover, in its case the transition policies cause the growth of the output to slow in the short-run before catching up after a few years. For the brown capital producer, transition policies imply a marked halt to its growth, with its value added even decreasing for a prolonged period of time with the "Net Zero 2050" scenario. On the contrary, the green capital producer exhibits a very high growth over the same period of time, reflecting its increased profits and higher share in the capital market production.

Looking now at the energy sector, the pattern is somewhat different, with only a short dip in growth for the brown energy producer under the two transition scenarios, and a relatively unchanged level for "Current Policies." On most of the remaining period, it grows at a rate

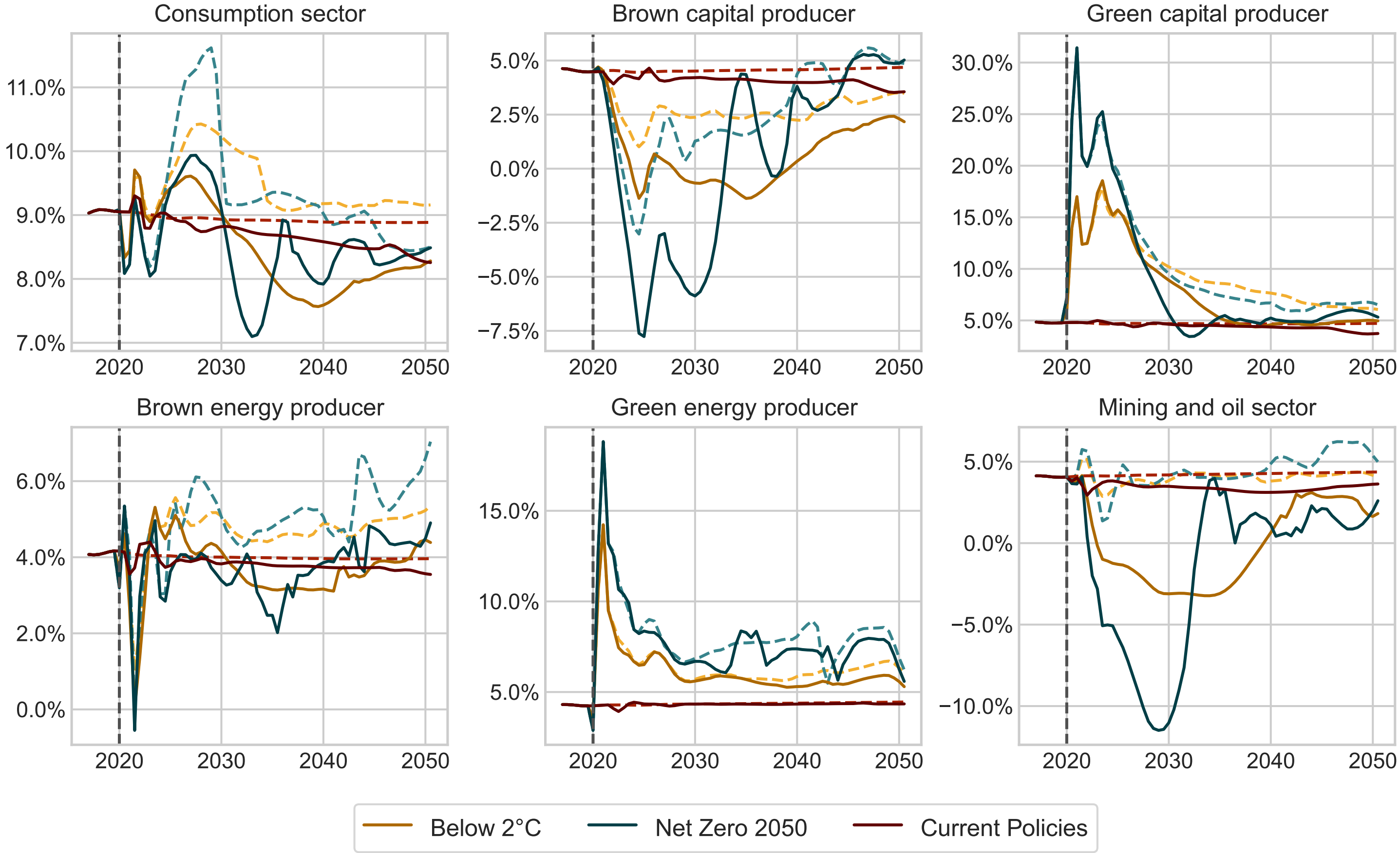
FIGURE 15 Share of renewable energy over the total produced under the different scenarios, with spillover.



above its previous baseline value. For the green energy sector, transition policies cause a high growth in output for a few years, before stabilizing for the rest of the simulation horizon at a growth rate still several points above its baseline value.

Finally, the mining and oil sector is the only one where the spillover cases have a trajectory with very different dynamics compared to the no-spillover alternative. In the absence of spillover, differences observed between scenarios are relatively small, with a growth rate generally slightly above its baseline value. When integrating spillover risk, however, we

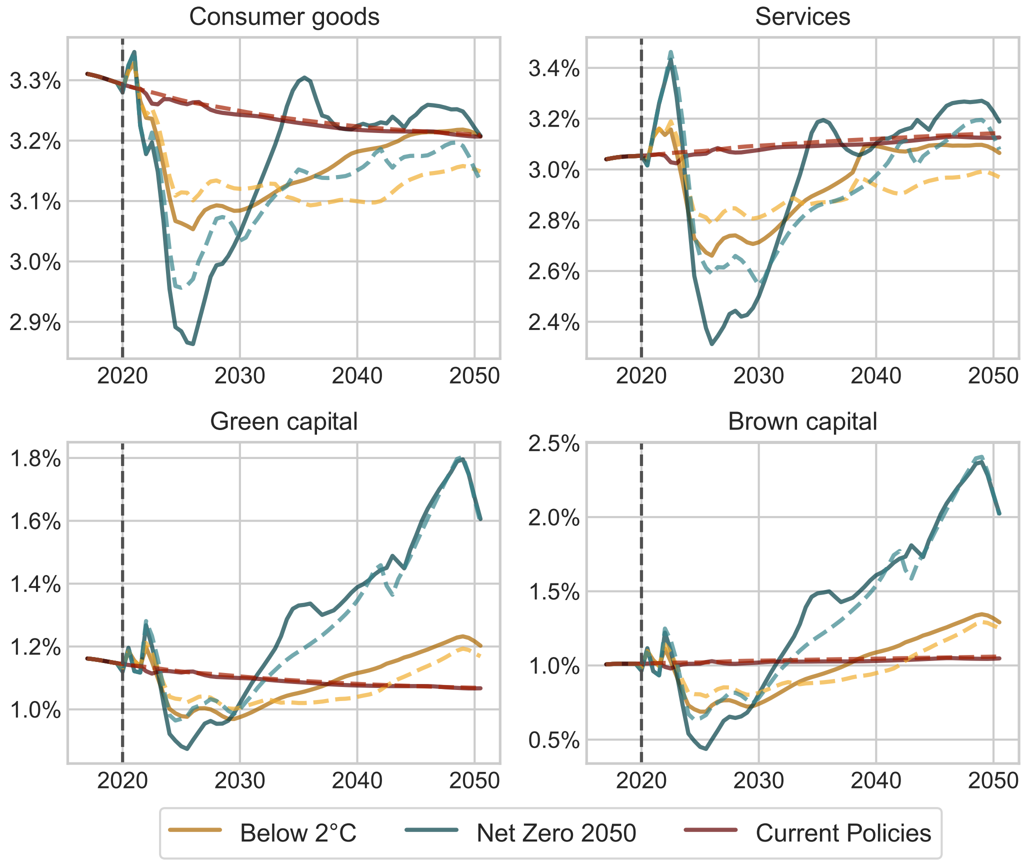
FIGURE 16 Sector breakdown of value added growth under different scenarios, year on year, with dashed lines representing the counterfactual with no spillover risk. "Consumption sector" aggregates both the consumption goods producers and the service sector.



observe a clear shrinkage of the sector's value added with the two transition scenarios. In line with the design of the shocks, this shrinkage happens more suddenly under the "Net Zero 2050" scenario and growth comes back in the early 2030's. Meanwhile the decrease with the "Below 2°C" scenario is more gradual and it starts growing again from 2040 only.

Then, we represent in Figure 17 the inflation of prices on different categories of products. The two on the first rows, i.e. consumer goods and services, are the ones taken into account in the standard inflation series, and therefore discussed in Section 5 The remaining two series represented correspond to the price of green and brown capital, which are the substitutable intermediary products used within the domestic economy. We can observe that the changes in prices are more complex in that case, apart from the "Current policies" scenario that is again broadly stable. For scenarios "Below 2°C" and "Net Zero 2050," there is an initial increase at the beginning of the simulation period. Then, the inflation establishes lower than the "Current policies" series for a period of almost ten years, up to 2033, before rising again to a higher level.

FIGURE 17 Yearly price inflation for different sub-category of products.



Next, in Figure 18, we display the changes in unemployment rates and show how it reacts to the inclusion of spillover risk in the model. In particular, the version of the model with no spillover tends to exhibit a decrease in unemployment under all scenarios, albeit a slow one for "Current Policies." As discussed above, the important budget reallocation through carbon tax and the production of green capital explain the important decrease in the climate transition pathways. Both reach the extreme value of 0 percent unemployment, which is again to be put in regard to the extreme – if not unrealistic for "Net Zero 2050" – values of the carbon tax introduced in both transition scenarios. However, introducing spillover risks leads to an increase in the unemployment level under all scenario, largely explained by the lower workforce needed in the oil and mining sector.

Looking now at the implications of scenarios in terms of inequalities, we represent in Figure 19 the share of household incomes earned through labor, compared to the total with capitalist earnings (firms' dividends and bonds' coupons). In that case, in spite of the fairly large changes in unemployment observed in Figure 18, the magnitude of changes is relatively small under all scenarios. This suggests tht the profits of capitalist households tend to follow trends broadly similar to the income of workers in all cases. However, the relative view does not imply that workers are better or worse off in absolute term.

FIGURE 18 Unemployment rate, in percentage points over total active population.

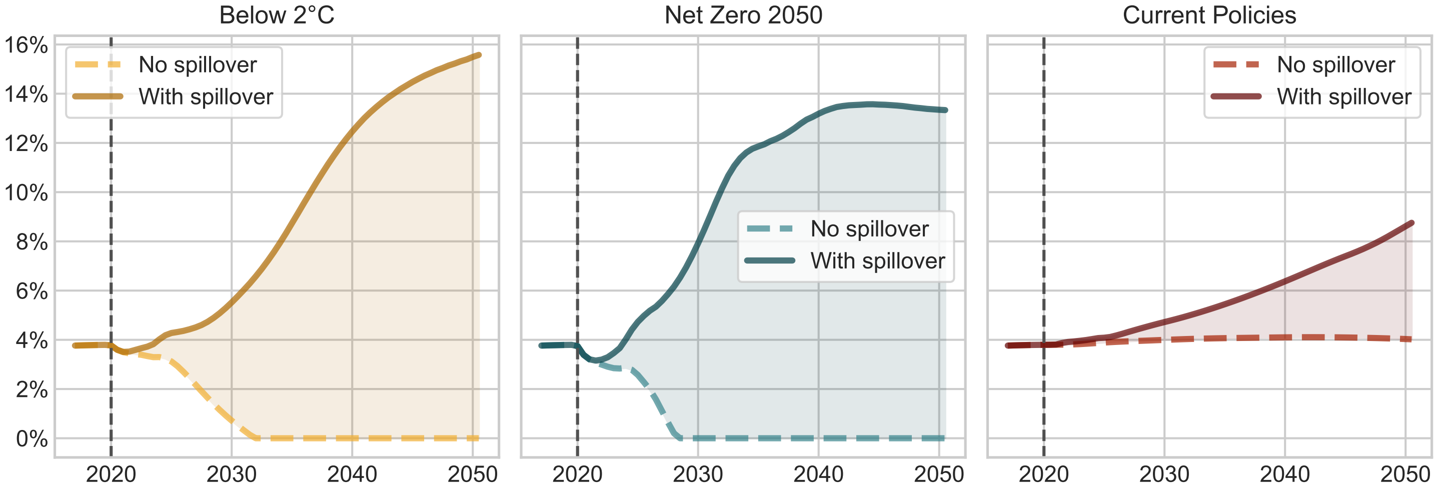
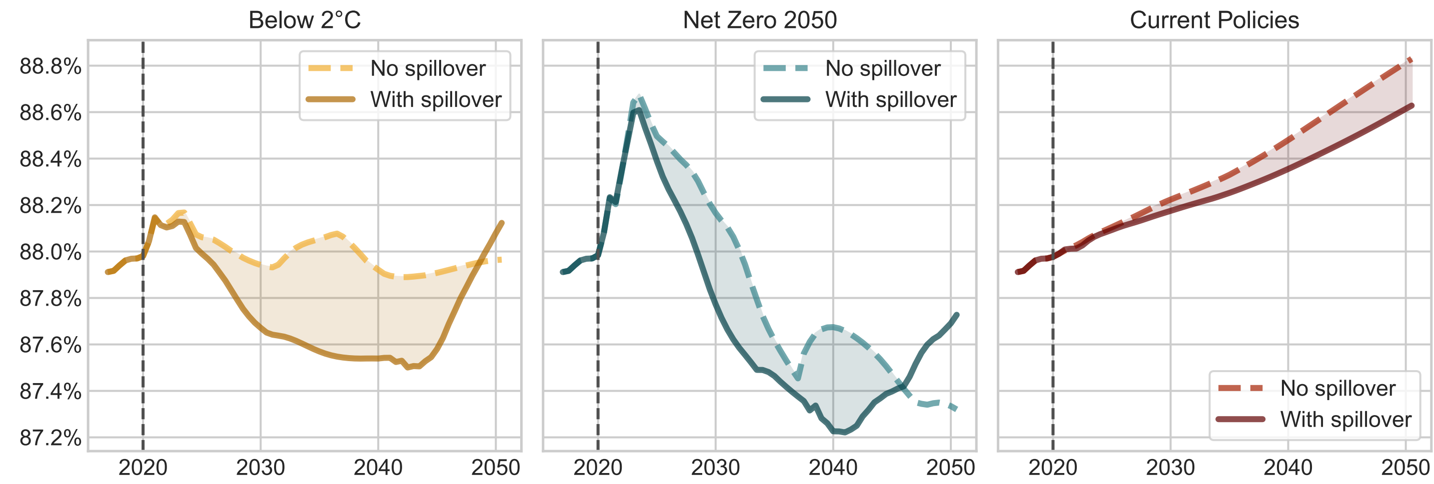


FIGURE 19 Share of income generated from labour compared to the total of income from labor and capital



To add on the analysis of the government balance-sheet, we then look at the impact of the different low-carbon transition measures. These measures can be didtilled into one source of income – the carbon tax – and two expenses: the subsidies to green capital and green energy. This is represented in Figure 20, with all values in percentage points of GDP. First of all, we notice that the revenues from the carbon tax exceed by a large margin the sustainability expenses in the scenarios "Below 2°C" and "Net Zero 2050." The expenses themselves increase slightly by design at the start of these two scenario as subsidies are reinforced. For these two scenarios, including spillover risk has the effect of increasing the importance of these different budgets relative to GDP, which presumably reflects the differences in denominator. On the other hand, in the "Current Policies" scenarios, the income and expenses are more balanced. Then, the increase in carbon tax is sufficiently small that the government can break even from these policies only at the end of the simulation period.

FIGURE 20 Revenues and expenses for the government linked to environmental sustainability.