Climate transition spillovers and sovereign risk: evidence from Indonesia

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Abstract

We study the macro-financial relevance of climate transition risks for sovereigns that can materialize as a result of the introduction of low-carbon policies in a trading partner country. We define this notion as climate transition spillover risk, and we apply it to the analysis of the introduction of carbon pricing in China on Indonesia, a major coal producer and exporter to China. By tailoring the EIRIN Stock-Flow Consistent model, we quantify the impact of a shock on Chinese demand for Indonesian coal, consistently with the scenarios of the Network for Greening the Financial System, on the Indonesian economic performance, fiscal and financial risk. We find that transition spillover risk directly weakens the Indonesian balance of payment, which decreases by 4.4 percent of GDP, leading to indirect and cascading effects on public finance and public debt, which increases up to 9.6 percent of GDP. Further, we find a trade-off between trade decarbonization and sovereign financial stability for 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 risk in their debt sustainability analyses and financial stability assessment programs.

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1 Introduction

Climate change represents a main threat to sustainable and inclusive development in several low-income and emerging countries (see e.g. IPCC, 2014; Hallegatte et al., 2016; UNDP, 2020). Countries in South- East Asia are already exposed to socioeconomic and financial losses induced by climate physical risk (Kling, Lo, et al., 2018), which are expected to worsen with climate change (IPCC, 2021). However, some South-East Asian countries 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).

Fossil fuel dependency increases the exposure to climate transition risk, which central banks, financial supervisors, and the literature refer to as a late and sudden introduction of climate policies (e.g. a carbon tax, see Hilaire and Bertram, 2019). Climate transition risk negatively affects the profits of fossil fuels and high-carbon firms and leads to corresponding changes in their contribution to fiscal revenues and GDP and in the value of financial contracts (Monasterolo, 2020; Gregor Semieniuk et al., 2021; Battiston, Dafermos, et al., 2021).

The analysis of the macroeconomic and financial relevance of climate transition risk occurring within the country or region's borders has received considerable research attention, see e.g. (Lamperti, Dosi, et al., 2018; Lamperti, Bosetti, et al., 2021; Dafermos et al., 2018; Monasterolo and Raberto, 2018; A. Jackson and T. Jackson, 2021; Carattini et al., 2021). However, the spillover effects of climate transition risks have still to be analysed. For instance, a country in which the production and export of fossil fuels play an important role in fiscal revenues and GDP can be exposed to climate transition risk as a result of the introduction of climate policies in its trading partner countries. We define this concept as "climate transition spillover risks" (shortened below as "spillover risk").

The analysis of the impact of spillover risk for sovereigns represents a main research gap to fill in order to inform the design of climate policies (such as a regional or global carbon tax) and carbon pricing instruments (such as Carbon Border Adjustment Mechanisms), as well as to better assess the fiscal and financial implications of climate risks for sovereigns. This information, in turn, is crucial for financial supervisors in the process of including climate risks in debt sustainability analyses and financial stability assessment programs, such as the case of the International Monetary Fund (IMF).

The IMF, as the only global institution charged with monitoring global and cross-border financial stability, has started to focus on climate risk, with 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 modelling tools to analyse their potential impacts.

This paper provides both a conceptual and a quantitative framework to analyse spillover risks in the economy and public finance. We analyse 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 consider spillover risk emerging from changes in Chinese demand for coal as a result of the introduction of carbon pricing, coherent with the NGFS scenarios' trajectories, on Indonesian macroeconomic and financial performance (e.g. GDP, unemployment, balance of payment, debt to GDP ratio). We focus on China since it is the biggest importer of Indonesian coal and has set out an ambitious low-carbon transition agenda including the introduction of carbon pricing schemes in its regions as well as support to the development of renewable energy sources with subsidies and regulations (IEA, 2021). In order to achieve its decarbonization targets, China would need to decrease its coal imports from Indonesia, because fewer fossil fuels will be needed in low-carbon transition scenarios.

Indonesia, in turn, is an interesting case study that can be representative of several other emerging economies. Indeed, Indonesia is both exposed to physical risks and to transition risks. In all low-carbon transition scenarios, including those developed by the Central Banks and Supervisors 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 cease, leading to the realization of carbon-stranded assets (Mercure, Hector Pollitt, et al., 2018; Cahen-Fourot et al., 2021; McGlade and Ekins, 2015; Dietz, Gardiner, et al., 2021).

To implement our analysis, we further develop and tailor the EIRIN Stock-Flow Consistent behavioural model (Monasterolo and Raberto, 2018; Monasterolo and Raberto, 2019; Gourdel et al., 2022), and we calibrate it on Indonesia. EIRIN is composed of heterogeneous agents and sectors of the economy, endowed with behavioural rules and heuristics, and interconnected through their balance sheet items. To consider the uncertainty of climate change and its impacts, EIRIN's agents can depart from perfect foresight and embed bounded rationality and adaptive expectations about the future. In addition, EIRIN's agents are subject to asymmetric access to information, depending on their skills and 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 model used for this paper is the first version to embed defaults happening endogenously within the real economy, and consistently with a sector-level SFC representation. This allows us to capture best how the financial system interacts with climate risk.

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 recommendations to the IMF and financial supervisors.

2 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, Bowen, et al., 2016; Battiston, Mandel, et al., 2017; BIS, 2021). An international network of over 120 central banks, financial regulators and observer institutions organized as the NGFS 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 the financial stability of individual investors and of the financial system (Battiston, Mandel, 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 in the revaluation of the portfolios of financial actors who own their financial contracts.

These studies focused on different jurisdictions and types of financial contracts. 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 in 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 the same strand, Beirne et al. (2021) and Klusak et al. (2021) find that climate vulnerability, i.e. physical risk, also matters for sovereign borrowing costs. The effect identified induces permanent changes in yields. 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.

2.1 The role of coal in the Indonesian energy system and economy

Indonesia is the world's fourth-largest producer of coal and South-East 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 a decrease in 2020 as a result of the COVID-19 crisis. Domestically, electricity production from coal reaches 53%, which is the highest share in the Southeast Asia region (ADB, 2021), while electricity production from renewable energy accounted for 26% (Grafakos et al., 2020). Out of the total energy mix, renewable energy made up only 16% in 2016, a share that reduces to 6% when hydropower sources are excluded (Island, 2016). Indonesia aims to reach 23% of renewable energy by 2025, and 31% 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 electrification covers only 91% 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 in Indonesia will still be coal-based in the medium 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 2040, as part of a pledge signed at the COP26 climate summit, Indonesia plans to 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 2021 governmental 10-year electricity procurement plan RUPTL.[2]

This is aligned with results by Ray et al. (2021) who found that Indonesia, and other countries that are part of the Association of Southeast Asian Nations (ASEAN), account for a large part of projected coal plants in the World. New investments in coal power plants are not aligned with the Paris Agreement's climate targets UNFCCC, 2015, and the report finds 64% 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).

2.2 Carbon stranded assets and sovereign financial stability in Indonesia

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

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

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

role of such activities on GDP and fiscal revenues and poverty reduction in low-income countries. This is particularly true as Sovacool (2010) finds that Indonesia, as well as its neighbours, 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 its governance in the mid-20$^{\text{th}}$ 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, and 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% of the Indonesian government's revenues over the 2014-2016 period, while the sector accounts for 5.8% of GDP (i.e. less than sectors such as manufacturing or agriculture). For other countries with large fossil fuel sectors, Welsby et al. (2021) finds that large decreases in public revenues can be expected from the slowdown of production in Latin America. In addition, fossil fuel subsidies are unequally distributed and show a procyclical pattern, yielding little social benefits and contributing to inequality. Furthermore, fiscal revenues from the fossil fuel industry have been declining over the last two decades, and this trend is expected to continue. Nevertheless, as recent experiences show, phasing out fossil fuels subsidies can be politically difficult and unfeasible both in high-income and emerging economies (Parry et al., 2021).

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

2.3 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. *climate transition spillover risk.* We define spillover risk as the cross-border macro-financial impacts of the introduction of low-carbon transition policies or regulations in one trading partner country or region. According to 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 from neighbouring China.

However, that does not need to stay so, and imports of coal and other pollutants could decrease in volume as a result of low-carbon transition policies. For instance, in an 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 fossil fuels in particular.

Figure 3 shows the risk transmission channels of the introduction of a carbon tax in China on the

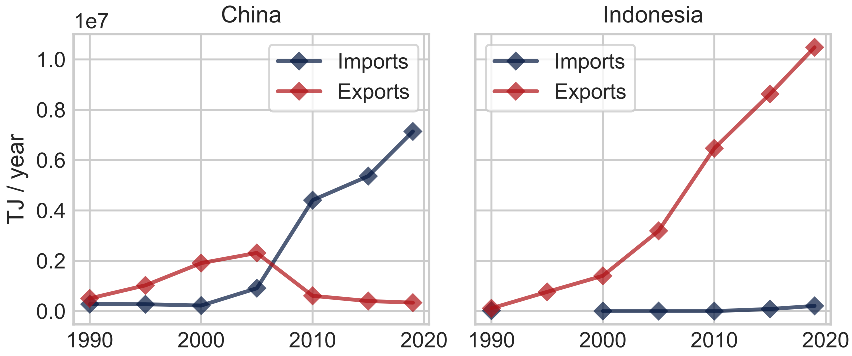


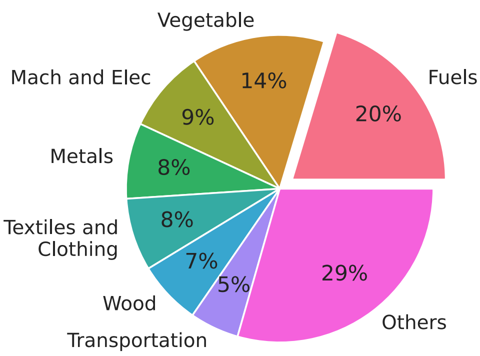
Figure 1: Exports and imports of coal by China and Indonesia.
Coal trade between the two countries has increased as a result of China becoming a primary importer, and Indonesia ramping up its production capacity.
The x-axis shows years of reporting, and the y-axis shows values imported or exported in tera Joul. Source: IEA.

Indonesian economy. We consider a shock in Chinese coal demand, that leads to a lower import of coal from Indonesia, negatively affecting coal production and export in Indonesia. Lower export affects the country's balance of payments, with negative implications on public finance, through lower fiscal revenues, which in turn affect the fiscal budget and debt service, with implications on the bond spread and debt sustainability. Lower corporate 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 the 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 on sovereign financial stability unfold also via the lower profitability of coal firms, which negatively affects 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.

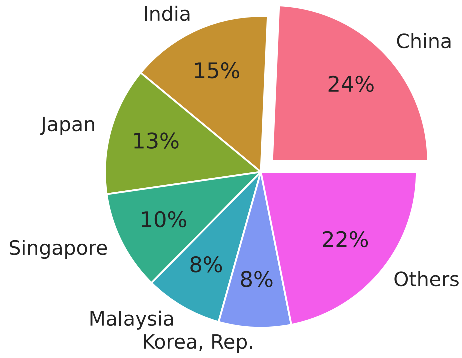
Thus, climate transition spillover risk can be of macro-financial relevance for Indonesia. The underlying motivation and reason why these spillovers might be macro-critical lies in the literature showing evidence of a debt ceiling (Adelino and Ferreira, 2016; Almeida et al., 2017; Borensztein et al., 2013), i.e. that credit ratings of sovereigns tend to cap that of their domestic corporations. Further evidence (Augustin et al., 2018; Baum et al., 2016; Gennaioli et al., 2014) demonstrates the significance of sovereign spillovers, whereby national location and institutional links are taken into account by markets so that shocks to sovereign ratings propagate. Lastly, empirical evidence has shown that this sovereign spillover exists when triggered by climate physical risk (Kling, Volz, et al., 2021), which backs the worries of similar effects in the case of transition spillover.

Within the SFC tradition, North-South models analysed 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 production 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, so far, no application studied the effects of forward-looking shocks in demand for fossil fuel energy, driven by low-carbon transition policy, and the sovereign risk implications.

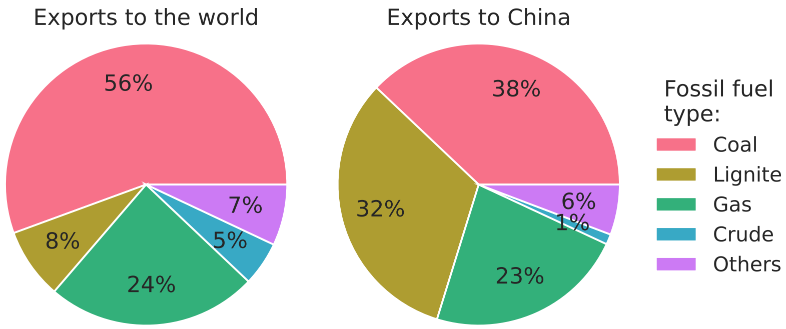
In this article, we contribute to filling this knowledge gap, addressing the following research ques-



(A) Exports by product



(B) Fuel importers



(C) Details of Indonesian fossil fuel exports, globally and to China.

Figure 2: Details of Indonesian exports, looking at the breakdown of merchandise exported and the top trading partners for fuel.
The top panels show that fuel is the first category of products exported by Indonesia, and China is the first buyer of it. The bottom panel provides a breakdown by type of fossil fuel, whereby we see that coal and lignite together account for 64% of fossil fuel exports, and for 70% of that exported to China.
Source: WITS - UNSD Comtrade.

tions:

- To what extent and through which channels does the introduction of a carbon tax in China affect the Indonesian balance of payment and sovereign debt sustainability?
- Under which conditions shocks can be amplified and create spillover effects?

3 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 spillover effects. Then, we study conditions for climate risk amplification, considering the interplay between carbon pricing and the macro-financial characteristics. In 3.1, we provide a description of the key structural and behavioural characteristics of the EIRIN model, before introducing the innovations specific to this application.

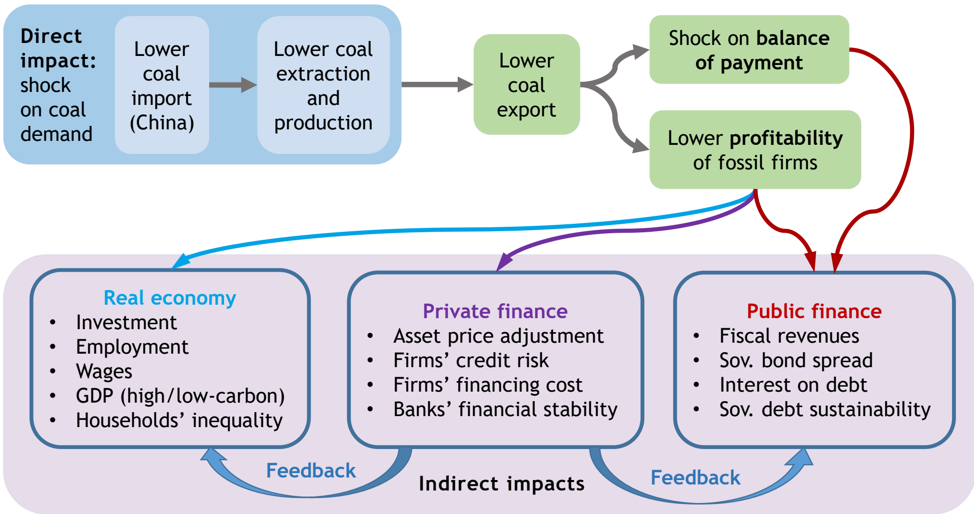


Figure 3: Transmission channels of from a shock on coal exports. We distinguish the direct impact (on the mining sector that is hit by export reduction), from the indirect impacts that stem from it (reduced workforce, lower profitability, etc).

3.1 Model overview

EIRIN is a Stock-Flow Consistent (SFC) behavioural model[3] of an open economy composed of a limited number of heterogeneous and interacting agents of the real economy and financial system. We use the EIRIN model because it embeds crucial features to address our research question, i.e. to what extent and through which channels climate transition spillover risk affects sovereign fiscal and financial stability. Indeed, accounting for the complexity and endogeneity of risks such as spillover and domestic transition policies requires relaxing underlying assumptions of equilibrium, market-clearing prices and agents' perfect foresight of traditional macroeconomic models.

We recall below the main modelling features of EIRIN that support our analysis:

- Agents and sectors are modelled as a network of interconnected balance-sheet items to identify climate risks' transmission channels in the economy and finance. Indeed, a clear understanding of the risk transmission channels is fundamental for the quantitative assessment of the direct and indirect impacts of climate risks on the economy, banking sector and sovereign.
- EIRIN agents and sectors are heterogeneous (e.g. in terms of skills, emissions and resource intensity, wealth and income) and are endowed with adaptive expectations to consider how the uncertainty of climate shocks affects agents' heterogeneous beliefs, inter-temporal preferences, and decisions in response to shocks.
- Climate impacts can be characterised by non-linearity and tipping points (Lenton et al., 2019; Steffen et al., 2018). To consider the potential non-linearity of climate risks in the economy, and understand the conditions for the persistency and amplification of shocks, EIRIN embeds agents' heuristics and behavioural patterns that contribute to the generation of emerging phenomena and out-of-equilibrium states of the economy.
- Access to finance plays a key role to scale up investments in climate mitigation and adaptation. Thus, EIRIN includes a banking sector, a central bank and a financial market connected to economic agents to analyse the impact of risk assessment on lending decisions, cost of capital, investments in high and low-carbon goods, prices and on consumption decisions.

[3]See for instance Caverzasi and Godin (2015), Dafermos et al. (2017), Dunz, Naqvi, et al. (2021), Naqvi and Stockhammer (2018), Ponta et al. (2018), Caiani et al. (2016), Carnevali et al. (2021), and Bovari et al. (2020).

- The accounting structure of SFC models ensures the identification and tracking of each financial and real economic transaction.

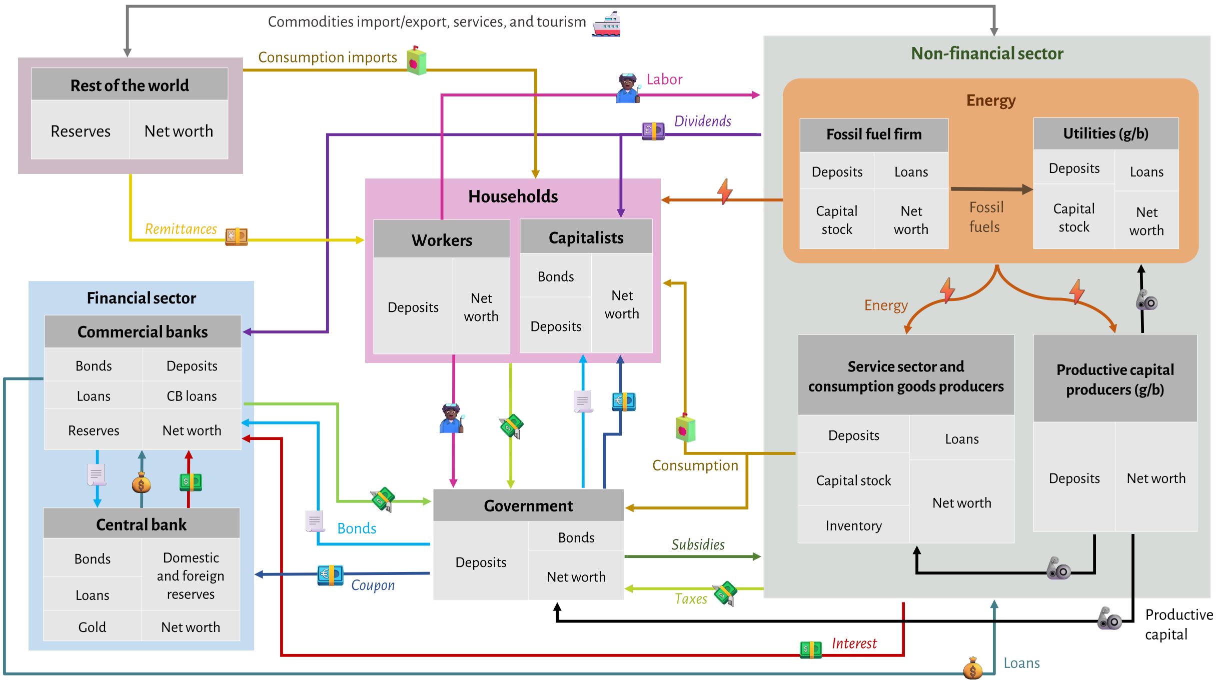


FIGURE 4: The EIRIN model framework: capital and current account flows of the EIRIN economy. For each agent, a representation in terms of assets and liabilities is provided. Agents are grouped according to the sector they belong to. We do not distinguish the high-carbon and low-carbon firms in utilities and capital producers, because the balance-sheet representations and flow dynamics are identical between them. Arrows are in the direction of the service provided, with cash payment flowing in reverse for all flows except the ones denoting direct cash transfers.

The capital and current account flow that structure the model are represented in figure 4. The model is composed of five sectors i.e. 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 ($E\mathfrak{b}$ and $E\mathfrak{g}$, brown and green respectively) that supply energy to households and to firms as an input factor for production (orange line);

(ii) an oil and mining firm that supplies $E\mathfrak{b}$ in fossil fuel;

(iii) a capital-intensive (for consumption goods) and a labour-intensive (for service, tourism, agriculture) producer that provides households heterogeneous consumption products (yellow solid line);

(iv) two productive capital producers ($Kp\mathfrak{b}$ and $Kp\mathfrak{g}$, brown and green respectively), which supply all the above.

The energy firms and the consumer goods producers require capital as an input factor for production. To build up their capital stock, they invest in capital goods (black lines), which are produced by the capital goods producers. To finance investment expenditures, firms can borrow from the commercial bank (teal blue lines), which applies an interest rate to their loans (red line). Households, firms and the government have deposits in the commercial bank. The commercial bank also holds reserves at the central bank, which itself can lend (refinance) with an attached interest. The government provides emergency relief or subsidies to firms of the real economy (dark green line), and it collects tax revenues from households and firms (light green line). The government also finances its current spending by issuing sovereign bonds (light blue lines) to banks and capitalist households, which can be bought later by the central bank. The government pays coupon interests on sovereign bonds (dark blue line). Households are divided into workers and capitalists, based on their functional source of income: workers provide labour to both the real economy and the government (pink lines); capitalists own domestic firms for which they receive dividend income (purple line) and coupon payments (dark blue line). The foreign sector provides remittances (yellow line) and consumption goods and services to households (dark gold line). The foreign sector also imports (tourism flows, services and purchases of domestic goods), and exports resources to firms as inputs for production (grey line).

3.2 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. Policymakers take their policy decisions. The central bank sets the policy rate according to a Taylor-like rule. The government adjusts the tax rates on labour and capital income, corporate earnings, and 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 negatively 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 *labour* market and the *raw materials* market. Prices of the exchanged goods or services are determined, and then the nominal or real demand and supply are provided by the relevant agents 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.

3.3 Behaviour of EIRIN agents

We detail below the core mechanisms and behaviours 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 $\mathfrak{p}_i$ is the price of the security issued by i. Let $D_{i,j}$ be 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 sold 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.

Building on Goodwin (1982), **households** are divided into two classes. Income class heterogeneity is useful to assess the distributive effects of the policies introduced in the low-carbon transition. 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 is 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 labour market mechanism determines the final workforce N_i of each agent based on the total N_{tot} of workers available and the demand for labour of firms (see Gourdel et al., 2022, for details). It also determines the salary level w_i paid by i, based on the required skills of employing firms. Second, the capitalist class (Hk) earns its income out of financial markets through government bonds' coupons and firms dividends:

$$Y_{\text{Hk}}^{\text{gross}} = \mathfrak{c} \times n_{\text{Hk,G}} + \sum_i \mathfrak{d}_i \times n_{\text{Hk},i}, \tag{2}$$

where $\mathfrak{d}_i$ are the dividends of i, $\mathfrak{c}$ is the coupon's rate, and $n_{i,j}$ is the number of securities in the portfolio of Hk issued by j (necessarily bonds from the government and stocks from firms). 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 the capital. Furthermore, both household classes receive net remittances Rem_i from abroad.[4] Households also pay their energy bill. This leaves them with Y_i^{disp} as net disposable income:

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

Households' consumption plans 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:

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

with $\rho, \phi \in \mathbb{R}_+$. This results in a quasi-target wealth level that households pursue. Then, households split their consumption budget between consumer goods (share ψ) and services:

$$D_{\text{Fk},i} = \psi \times C_i, \quad \text{and} \quad D_{\text{Fl},i} = (1 - \psi) \times C_i \,. \tag{5}$$

The **service firm** Fl (also called labour intensive) and **consumption goods producer** Fk (also referred to as capital intensive) produce an amount $\mathbf{Q}_j$ of their respective outputs by relying on a Leontief technology.[5] 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:

$$\forall i \in \{\text{Fl}, \text{Fk}\}, \quad \mathbf{Q}_i = A \times \min \left\{ \gamma_i^N N_i, \ \gamma_i^K K_i \right\}, \tag{6}$$

with A the total productivity factor, and γ_i^N, γ_i^K the productivity factors of labour and capital respectively. We fix γ_i^K in the simulation, while A follows a linear specification based on Philippon (2022), and γ_i^N follows a Verdoorn-type dynamic based on Lavoie (2022). The two firms set their consumption goods price as mark-up costs, which include labour, capital, energy, and input resources. Higher prices of consumption goods and services (driven by higher firms' interest payments on loans, more expensive imports, and more expensive energy and/or labour costs) constrain households' consumption budgets, which in turn lower aggregate demand. This represents a counterbalancing mechanism on aggregate demand.

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

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

The minimum between the demand for the two consumption goods and their supply determines the transaction amount $\tilde{\mathbf{q}}_j$ that is traded in the goods market:

$$\tilde{\mathbf{q}}_{\mathrm{Fk}} = \min\left(\mathrm{IN}_{\mathrm{Fk}} + \mathbf{Q}_{\mathrm{Fk}},\ \frac{1}{P_{\mathrm{Fk}}}\left(D^{\mathrm{Fk}}_{\mathrm{Hw}} + C^{\mathrm{Fk}}_{\mathrm{Hk}} + D^{\mathrm{Fk}}_{\mathrm{G}} + D^{\mathrm{Fk}}_{\mathrm{RoW}}\right)\right) \tag{7}$$

$$\tilde{\mathbf{q}}_{\mathrm{Fl}} = \min\left(\mathbf{Q}_{\mathrm{Fl}},\ \frac{1}{P_{\mathrm{Fl}}}\left(D^{\mathrm{Fl}}_{\mathrm{Hw}} + D^{\mathrm{Fl}}_{\mathrm{Hk}} + D^{\mathrm{Fl}}_{\mathrm{G}} + D^{\mathrm{Fl}}_{\mathrm{RoW}}\right)\right) \tag{8}$$

The supply of capital-intensive consumption goods also takes firms' 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 adds up to the inventory stock of Fk's inventories. Finally, both consumption goods producers make a production plan $\hat{\mathbf{q}}_j$ for the next simulation step based on recent sales and inventory levels:

The **energy sector** is divided into renewable and fossil fuel energy producers ($\mathrm{E}\mathfrak{g}$ and $\mathrm{E}\mathfrak{b}$ respectively). It produces energy that is demanded by households for consumption and by firms for production. We assume that all demand is met, with the foreign sector covering the gap $\mathbf{D}_{\mathrm{En}} - \mathbf{Q}_{\mathrm{E}\mathfrak{b}} - \mathbf{Q}_{\mathrm{E}\mathfrak{g}}$. 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 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 set endogenously from the unit cost of both firms (see Gourdel et al., 2022, for details). To be able to deliver the demanded energy, the energy producers require capital stock. They invest to compensate for capital depreciation and expand their capital stock to be able to satisfy future energy demand (see Gourdel et al., 2022, for details). The **oil and mining** company MO supplies $\mathrm{E}\mathfrak{b}$ in oil and exports to the rest of the world as well. In turn, it buys capital from $\mathrm{E}\mathfrak{b}$ to operate and employs workers.

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 capital level $\hat{K}_i$ defines the target investment amount $I_i^{\dagger}$, considering the previous capital endowment $K_i(t-1)$ subject to depreciation $\delta_i \times K_i(t-1)$ and potential[6] capital destruction as a consequence of natural disaster shocks $\hat{\xi}(t) \times K_i(t-1)$, hence

$$I_i^{\dagger}(t) = \max\left\{\hat{K}_i(t) - K_i(t-1) + \delta_i \times K_i(t-1) + \hat{\xi}(t) \times K_i(t-1), 0\right\} \tag{9}$$

Differently from supply-led models (e.g. Solow, 1956), in EIRIN, investment decisions are fully endogenous and based on firms' Net Present Value (NPV). In turn, the NPV 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 $I_i^{\star}(t) = \left(\varphi_i \times M_i(t-1) + \Delta^+ L_i(t)\right) / P^{(i)}_{\mathrm{Kp}}(t)$, 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 $P^{(i)}_{\mathrm{Kp}}$ is the average price of capital, which depends on the ratio of green and brown, at unit prices $P_{\mathrm{Kp}\mathfrak{g}}$ and $P_{\mathrm{Kp}\mathfrak{b}}$ 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, the related NPVs per unit of capital are $\mathrm{NPV}^{\mathfrak{g}}_i(t)$ and $\mathrm{NPV}^{\mathfrak{b}}_i(t)$ respectively.

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

Details of the cash flow calculations are provided in appendix A.4. 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 the bank grants credit only if $\text{NPV}_i^{\mathfrak{g}}(t) \geq 0$ or $\text{NPV}_i^{\mathfrak{b}}(t) \geq 0$. The final realized investment I_i is divided into green and brown capital such that $I_i = I_i^{\mathfrak{g}} + I_i^{\mathfrak{b}}$. It is also potentially constrained by the supply capacity of the producers (see equation (10) below).

The **capital goods producers** (Kp, divided into green and brown capital producers, Kp$\mathfrak{g}$ and Kp$\mathfrak{b}$ respectively) supply capital goods to fulfil the production capacity of Fl, Fk and En:

$$\mathbf{Q}_{\text{Kp}\mathfrak{b}} = I_{\text{Fl}}^{\mathfrak{b}} + I_{\text{Fk}}^{\mathfrak{b}} + I_{\text{E}\mathfrak{b}} + I_{\text{MO}} \leq \mathbf{D}_{\text{Kp}\mathfrak{b}}, \quad \mathbf{Q}_{\text{Kp}\mathfrak{g}} = I_{\text{Fl}}^{\mathfrak{g}} + I_{\text{Fk}}^{\mathfrak{g}} + I_{\text{E}\mathfrak{g}} \leq \mathbf{D}_{\text{Kp}\mathfrak{g}} \,. \tag{10}$$

Newly produced capital goods will be delivered to the consumer goods producers and the energy firm at the next simulation step. Capital goods producers rely on energy and high-skilled labour as input factors that represent their unit costs. Capital good price is set as a fixed markup μ_{Kp} on unit costs (see details in appendix A.1).

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[7] rule (Taylor, 1993). The 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 $\bar{u}$):

$$\nu(t) = \omega_\pi(\pi(t) - \bar{\pi}) - \omega_u(u(t) - \bar{u}) \,. \tag{11}$$

The interest rate in EIRIN indirectly affects household consumption via price increases 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 inter-temporally maximize their consumption behaviour. This prevents monetary policy to have a crowding-out effect on household consumption.

In 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):

$$\pi(t) = \frac{\mathbf{Q}_{\text{Fl}}(t)}{\mathbf{Q}_{\text{Fk}}(t) + \mathbf{Q}_{\text{Fl}}(t)} \left(\frac{P_{\text{Fl}}(t)}{P_{\text{Fl}}(t-m)} \right)^{1/m} + \frac{\mathbf{Q}_{\text{Fk}}(t)}{\mathbf{Q}_{\text{Fk}}(t) + \mathbf{Q}_{\text{Fl}}(t)} \left(\frac{P_{\text{Fk}}(t)}{P_{\text{Fk}}(t-m)} \right)^{1/m} - 1 \,. \tag{12}$$

[7]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 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 a 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. This supply is are provided in infinite quantity and at a given price to meet internal production needs. Tourism inflows consist of the consumption of labour-intensive consumption goods. Raw material, consumption goods and intermediate goods exports are a calibrated share of the country's GDP and are sold at world prices. The demand by the foreign sector is influenced by several factors, namely the GDP of the domestic economy, its demand of the previous period, the change in domestic interest rates, and the change in domestic inflation.

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 consumers. To cover its regular expenses the government raises taxes and issues sovereign bonds, which are bought by capitalist households, by the commercial bank and by the central bank. The government pays a coupon rate $\mathfrak{c}$ on its outstanding bonds n_G. Taxes are applied to labour income (wage), capital income (dividends and coupons), and corporate profits. The government can also hold equity shares of private firms. The government does not trade them, so their number is fixed at the start of the simulation, and the government perceives dividends. As explained in section 2, these revenues are substantial for the Indonesian government.[8]

If government deposits are lower than a given positive threshold $\bar{M}$, i.e., $M_\mathrm{G} < \bar{M}_\mathrm{G}$, the government issues a new amount $\Delta \mathbf{n}_\mathrm{G} = \frac{\bar{M}_\mathrm{G} - M_\mathrm{G}}{\mathfrak{p}_\mathrm{G}}$ of bonds to cover the gap, where $\mathfrak{p}_\mathrm{G}$ is the endogenously determined government bond price. All newly-issued bonds are bought by capitalist households and the commercial bank. The government can issue green sovereign bonds to fund new low-carbon investments. We consider a government that repays bonds at maturity[9] to better capture the development of sovereign risk in the longer run. Improving on previous versions of the model, the government issues sovereign bonds with different maturities. The technical description of this is provided in appendix A.2. In this model setting, we can also 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).

Government spending $C_\mathrm{G} = \kappa R_\mathrm{G}$ is a fixed percentage κ of revenues from taxes R_G. Government spending during crises contributes to avoiding credit crunch and compensates households' and firms' liquidity constraints (Brunnermeier et al., 2020).

Figure 5 presents the interactions between agents, sectors and markets of the EIRIN economy. For a detailed description of all sectors, market interactions and behavioural equations, refer to Monasterolo and Raberto (2018), Monasterolo and Raberto (2019), Dunz, Essenfelder, et al. (2021), and Gourdel et al. (2022).

3.4 Bank's credit channel

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

Let ν be the risk-free interest rate, which is the sum of the policy rate and the bank's net interest

[8]In EIRIN, this dividends income is calibrated so that, when added to seignorage, it corresponds to the gap between the tax revenues and the total government revenues, both of which have known times series (as ratios to GDP).

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

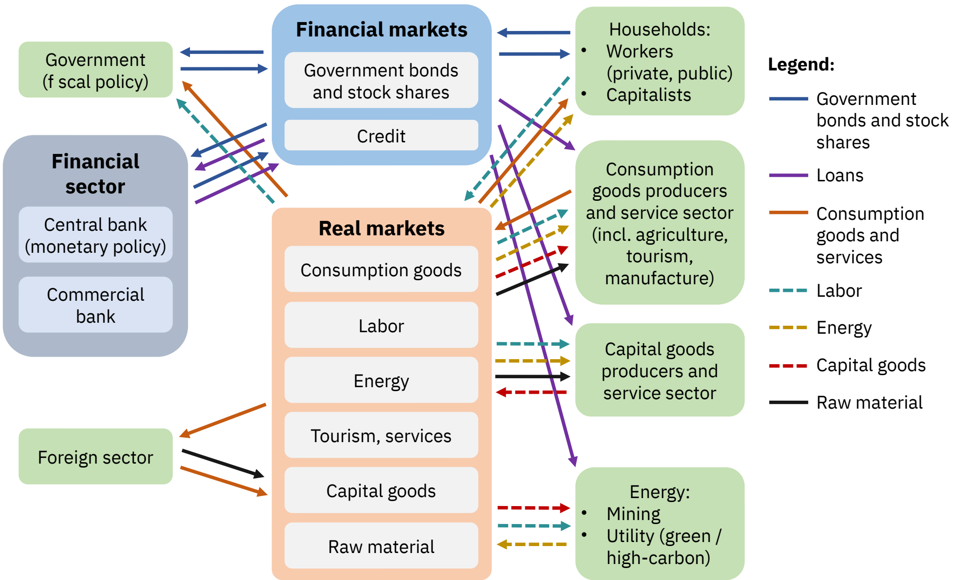


Figure 5: Interaction of agents, sectors and markets in EIRIN.
Green boxes include agents and sectors while the light blue box contains financial markets, and the light orange box includes the real markets. Source: authors' own elaboration.

margin (NIM). Given the annualized probability of default PD_i of sector i, we seek to determine its interest rate $\hat{\kappa}_i$ on loans from the bank. We set it to verify

$$\underbrace{\hat{\kappa}_i - \nu}_{\text{credit spread}} = \mathrm{PD}_i \times (1 - \mathfrak{r}_i), \tag{13}$$

where $\mathfrak{r}_i$ is the expected recovery rate[10] 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 κ_i the realized 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 $\mathfrak{R}_{\mathrm{CAR}}$, in order to comply with banking regulator provisions. The other important information is the demand for new credit $\mathbf{D}_{\mathrm{BA}}(t)$ 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 value of loans already outstanding, so that the total of loans makes its realized capital adequacy ratio remains over $\mathfrak{R}_{\mathrm{CAR}}$:

$$\Delta^+ \mathbf{L} = \min \left\{ \mathbf{D}_{\mathrm{BA}}(t), \frac{E_{\mathrm{BA}}(t-1)}{\mathfrak{R}_{\mathrm{CAR}}} - \mathbf{L}(t-1) \right\} . \tag{14}$$

3.5 Defaults and non-Performing Loans (NPL)

The financial risk of investment is represented via two channels in EIRIN: part of the companies within a given sector can default on their loans, while some other loans can become non-performing, i.e. the

[10] See Hamilton and Cantor (2006) on the model itself, and Bruche and González-Aguado (2010) on the macroeconomic determinants of recovery rates. The recovery rates are partially endogenous in EIRIN and relate to the default mechanism described in 3.5.

borrowers have stopped paying the agreed instalments or interest.[11]

First, as a novelty to previous versions of the model, and advancing on SFC research in general, we include a mechanism for within-sector defaults. The ratio of defaulting firms in a sector i is given by

$$\mathrm{Def}_i \sim \mathrm{Beta}\left(a, a(1/\mathrm{EDF}_i - 1)\right) \tag{15}$$

where EDF_i is the expected default frequency for one simulation period, calculated based on contemporaneous accounting variables. The value Def_i is also interpreted as the share of the debt affected by defaults. Moreover, we operate with the following assumptions:

- Given that the assets of the sector are divided between liquidity, productive capital, and inventory, we assume that the firms defaulting hold assets in the same proportions as the sector as a whole.
- The defaults happen due to *insolvency*, and not illiquidity. This means that defaults happen because the cumulated value of the assets of defaulting firms reaches the value of their total debt.
- When a firm defaults, it can sell a share of its capital at a *fire sales discount* to other firms in the same sector. Nonetheless, this discount is assumed not to affect the medium-term price of capital. The remaining share gets *stranded* and is completely written off.
- The bank recovers part of the defaulted firms' liquidation value, which is their cash and the proceeds from the sale of their capital.

The net effect of defaults is that the equity of banks decreases because the loss they incur on their loan book (total of the defaulted debt) is larger than the decrease of their liabilities (the liquidity recovered that the sector was holding before). The effect on the equity of the real economy sector itself is non-negative. Indeed, even in the case where all assets are recovered by the bank or get stranded, the total value lost cannot exceed that of the debt written off due to the insolvency characterization.

Second, we compute NPL ratios on a sector-level basis, based on sector-level accounting variables and macroeconomic factors identified in the literature (Louzis et al., 2012):

$$\mathrm{NPL}(t) = \beta_0 + \beta_1 \times \mathrm{NPL}(t-1) + \beta_2 \times \Delta\mathrm{GDP}(t-1) + \beta_3 \times \Delta\mathrm{UN}(t-1) \tag{16}$$

where ΔGDP is the real GDP growth, ΔUN is the change in unemployment, and $\beta_0, \beta_1, \beta_2, \beta_3$ are coefficients. Therefore, the computation of the NPL ratio is completely endogenous in the model, as no predictor variable is part of the scenario.

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:[12]

$$\mathrm{ID}_i(t) = \kappa_i(t) \times L_i(t-1) \times (1 - \mathrm{NPL}(t)) \tag{17}$$

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:

$$\Delta^{-} L_i(t) = \chi_i \times L_i(t-1) \times (1 - \mathrm{NPL}(t)) \tag{18}$$

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

[11] The definition used by the European Central Bank is that loans are classified as non-performing when the delay exceeds 90 days. Given that we use simulation periods of six months, we consider that the borrowers stop paying in the same period where the loans are classified as NPL.

[12] 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.

the sector. In effect, the NPLs create a delay in repayment, which corresponds to additional credit granted by the bank to the sector. Thus, while it is at the advantage of the real economy and reduces the immediate profits of the bank, the added leverage also motivates higher interest rates, acting as a compensating mechanism.

4 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 the EIRIN model, focusing on the Indonesian carbon tax and the demand for coal by China. The latter is channelled into EIRIN as a shock on the Indonesian export of coal (section 4.3).

4.1 Model calibration

To ensure that the shocks' dimensions are quantitatively meaningful, we initialize, calibrate and empirically validate the EIRIN model to selected characteristics and data from Indonesia. The model depends on more than 100 parameters, and the calibration is split into two groups, which rely on two separate sets 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).[13] The parametrization for both steps is detailed in the appendix, tables 2 and 3 respectively. For the second-step calibration we compare the model's indicator means with observed data means covering 10 years. Beyond these macroeconomic 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 their relation with the rest of the world through imports and exports.

Some discrepancies may persist between the calibrated values and the real ones since the model is simplified to an extent. Thus, as shown in table 3, 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 a value lower in our simulations. On inflation in particular, a strong downward trend has been observed in recent years, with an inflation rate of 3.03% in 2019. Thus, although the value we reach is lower than the average of the period, it is higher than the most recent observations. Moreover, Bank Indonesia has a target of 3 ± 1% 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.

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

4.2 NGFS scenarios selection and implementation in the EIRIN model

We use 3 scenarios (out of six available[14]), 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 "hothouse world" or "business-as-usual" scenario.
- *Below 2°C*: gradually increases the stringency of climate policies, with an immediate start, giving a 67% chance of limiting global warming to below 2°C.
- *Net-zero 2050*: an ambitious scenario that limits global warming to 1.5°C by the end of the century (with a 50% 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 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 climate physical damages in our base simulations because our analysis focuses on transition risk. The latter is implemented through an increasing carbon tax, represented in figure 6a. Model-wise, it comes as a rate $\tau_{\mathrm{GHG}}(t)$ such that the revenues generated by a sector i at t are given by $\mathrm{Em}_i(t) \times \tau_{\mathrm{GHG}}(t)$ where Em_i denotes the (scope 1) GHG emissions of i.

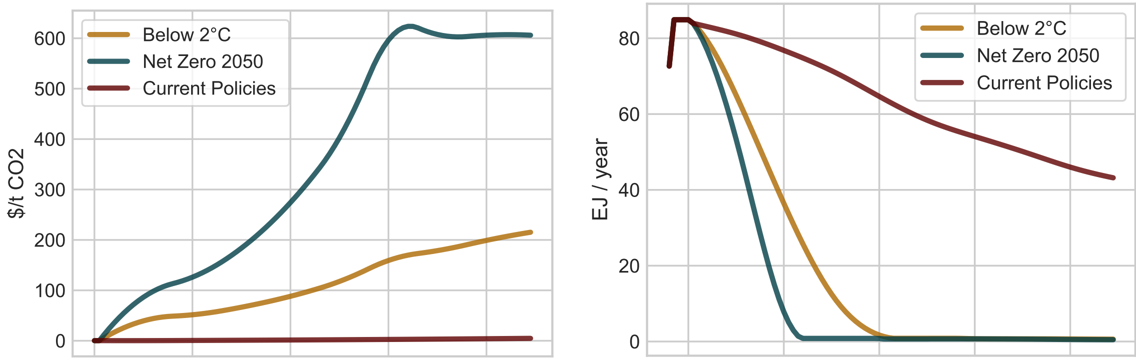
The paths for the carbon tax are very different between scenarios. First, Net-zero 2050 exhibits a very sharp increase until the beginning of the 2050s (also the end of our simulation horizon), and a plateau at a high value after. The increase is more moderate for the Below 2°C scenario, with a value in 2050 less than a third of that of Net-zero 2050. Finally, under current policies, some level of carbon tax exists, but it remains very close to zero over the whole simulation period. Due to the relative absence of an initial carbon tax 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. To get a comparison point, consider that the GHG emissions of real economy sectors in 2019 in Indonesia were 559 million tonnes (from the International Energy Agency). Meanwhile, the GDP in current US dollars was 1.119 trillion in the same year (from World Bank data). Considering these two values, it comes that a carbon tax of USD 200 per tonne of CO_2 would yield an additional revenue corresponding to 10% of GDP. This is superior to the total tax revenues reported for that year (9.75% of GDP, from IMF data).

4.3 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. To align with the NGFS's below 2°C or Net Zero scenarios, Indonesia should massively decrease the volume of coal it produces and sells to other countries. This, in turn, represents a potential threat to its current accounts and budget. At the same time, Indonesia's export of coal would shrink from the decrease in Chinese coal demand, due to China's low-carbon transition, as represented in figure 6b.

In line with dynamics observed for carbon taxation, 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

[14] The other three scenarios 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 concerning available series.



(A) Carbon tax in Indonesia

(B) Demand of coal by China

FIGURE 6: Key variables from NGFS scenarios used to define the transition shock.
Left panel: evolution of the Indonesian carbon tax in USD 2010 per ton of CO_2-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.

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

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

5 Results

In this section, we present the results for macroeconomic and public finance indicators. We first discuss the direct and indirect impacts of spillover risk and the related transmission channels, and then we present results on macroeconomic indicators and public finance.

5.1 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 section 4.2). 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 the production costs of high-carbon firms while adding to the government's budget, and the reduction in Chinese coal demand *(b)* affects Indonesian exports.

With regard to transmission channel *(b)*, the decrease in the demand for coal by China is shown by the scenarios Below 2°C and Net-zero 2050 (figure 6b) and is 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. Such effects are not yet captured adequately in the literature.

As China is the first importer of coal from Indonesia (see section 2.3), the latter suffers a reduction in its 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 4.3). Furthermore, in Current Policies scenario, exports of coal and other fossil fuels still slightly increase in value.

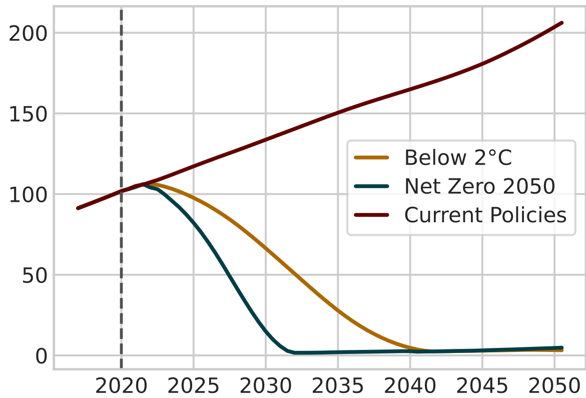


Figure 7: Real value of coal and other fossil fuel exported by Indonesia. The y-axis presents the total value, indexed at 100 at the start of the scenarios and adjusted for inflation.

Then, we compare the baseline simulations with 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 some 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". Thus, we can identify the scope of changes attributable to spillover risk. In several figures, we represent the difference *(a + b)* - *(a)* in order to single out the effect of the spillover risk conditioned on a certain scenario.

Regarding the greenhouse gases (GHG) emissions, figure 8a 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.

More details are provided in the appendix (figure 12), 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 lower 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.

A key factor 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 9, where we observe a sharp increase of the renewables share under the Net-zero 2050 scenario, reaching close to 50% of the total energy mix in 2050, and a slower increase under the scenario Below 2°C, close to 40% in 2050.

5.2 Macroeconomic indicators

We discuss here the results of the simulated scenarios on key macroeconomic indicators for Indonesia. Figure 10 shows the real GDP at different points in time relative to the scenario of current policies with no spillover risk, which is the closest to a "business-as-usual" among the six scenarios simulated. 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 with respect to Current Policies in the absence of spillover. The result is driven by larger investments in green capital both by the consumption good producers and by the green utility firms, in order to foster the transition to a low-carbon economy. Green investments lead to an increase in employment (by up to 4% of the total workforce) and, thus, in wages and households' consumption.

Crucially, when the carbon price is very high – above USD 200 in the case of the scenario Net-zero 2050 – the government's budget increases significantly, following the introduction of the policy.[15] The only exception is represented by government 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. Nevertheless, sustainability expenses are dwarfed by the carbon tax revenue in these two scenarios. For instance, there is a ratio of 53 between both by 2040 in the Below 2°C scenario (see appendix, figure 17). Therefore, most of the additional budget can be considered as being re-injected into the general expenses. Thus, the differences observed in figure 10 are also influenced by the government's budget allocation, which fosters economic growth in the short and medium term, compared to the "natural" money flow circulation.

With regard to spillover risk, figure 10 shows that the reduction in exports driven by lower coal demand from China (figure 6b) negatively affects Indonesian real GDP in all the NGFS scenarios considered. At most, in the Net Zero 2050 scenario, the cumulative effect of spillover is GDP being 20% lower than in the scenario without spillover. Lower Chinese demand for Indonesian coal has both a direct and indirect (negative) impact on the Indonesian economy. Indeed, the lower export of coal reduces the activity of the mining company, in turn decreasing its demand for labour as well as the profits reversed to the government. In turn, higher unemployment and lower government revenues negatively affect the Indonesian economy, as highlighted by the growth in sectors' value added presented in figure 13. Because of this feedback effect, the difference between the spillover simulations and their no-spillover counterparts increases over the whole simulation period for all scenarios.

Furthermore, as from figure 8b, low-carbon transition scenarios are characterized by lower inflation in the medium term, relative to the current policies scenario. Moreover, spillovers accentuate this effect, lowering inflation. This effect can be explained in part by the difference in employment between the scenarios with and without spillover, with a difference of up to 12% in the Below 2°C scenario. Spillover risk leads to job losses in the mining sector, and to lower economic output in general, as explained above.

There is a positive feedback from the employment level into wage prices, to reflect job market

[15] We do not allocate the added carbon tax income to specific policies, so it is allocated to the general fiscal budget.

pressure. Spillover risk tames this effect, meaning that wages do not increase as fast as in the no-spillover scenario. Inflation, in turn, is comparatively lower, because wages are an input to the pricing of goods. Figure 14 in the appendix shows a breakdown of inflation by sub-categories of products. The series represented in figure 8b corresponds to a CPI-like indicator, including the downstream sectors of consumer goods and services. The sector breakdown shows lower inflation in some products such as services, which is the most labour-intensive sector and less carbon-intensive, thus a lesser increase in carbon tax expenses.

As a result, interest payments on debt and capital depletion in total expenses decrease.[16] 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.

5.3 Public finance indicators

In this section we discuss the effects 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.[17]

The difference in the balance of payments induced by the spillover risk, represented in figure 8c, is material and negative by 4.4 percent of GDP. The decreasing demand by China affects Indonesia's coal exports (figure 6b). Thus, while values are stable in the no-spillover counterfactual case, we observe a 4% decrease (in GDP points) when including the export shock in the Net-zero 2050 and Below 2°C scenarios. This magnitude is coherent with known data showing the importance of fossil fuel export in the Indonesian economy (see figure 2 and calibration table 3). The relative slopes conditioned to the transition scenarios are comparable in trend to those of exports in figure 7. The shock is more moderate in the Current Policies scenario, with a maximum reduction of around 1.5% relative to GDP. Overall, given the importance of fossil fuels in the initial volume of exports, the impact of the shock is very significant for Indonesian trade.

Not surprisingly, figure 11a shows larger government deficits in spillover risk scenarios. In the scenarios Below 2°C and Net-zero 2050, the budget balance to GDP sets to around 3% 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, but remains lower, in the range of 1.5% at the end of the simulation period. Low-carbon transition measures are also characterized by indirect effects on the economy. Regarding the deficit level, we find that scenarios Below 2°C and Net-zero 2050 are similar (with a difference of 0.2% of GDP with spillover), suggesting that enforcing more stringent low-carbon transition measures does not necessarily lead to a higher fiscal cost for Indonesia.

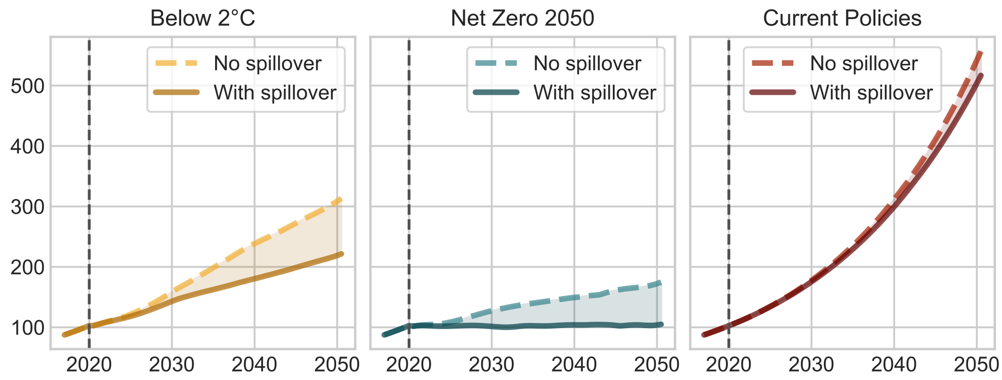
The worsening of the budget balance is primarily due to the loss of revenues generated by the mining sector, which is largely owned by the State and also pays taxes on its profits.[18] Consistently, public debt increases the most in all scenarios characterized by spillover risk (figure 11b), up to 10% of GDP. Nevertheless, given the country's relatively low initial level of debt, its increase is still manageable. The debt is taken on to compensate for the government deficit. This result highlights the importance of considering all risk channels when studying the macroeconomic and financial implications of low-

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

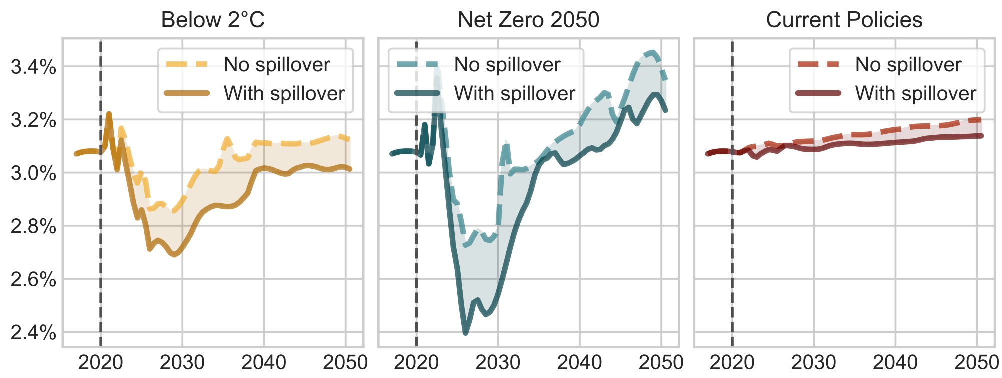
[17]The balance of payment is measured as the difference between exports and imports for the regions of interest. Remittances are not included (and are stable as a share of domestic GDP by calibration).

[18]In our simulations, we do not assume additional changes in fiscal policies (e.g. welfare measures) in response to the shock.

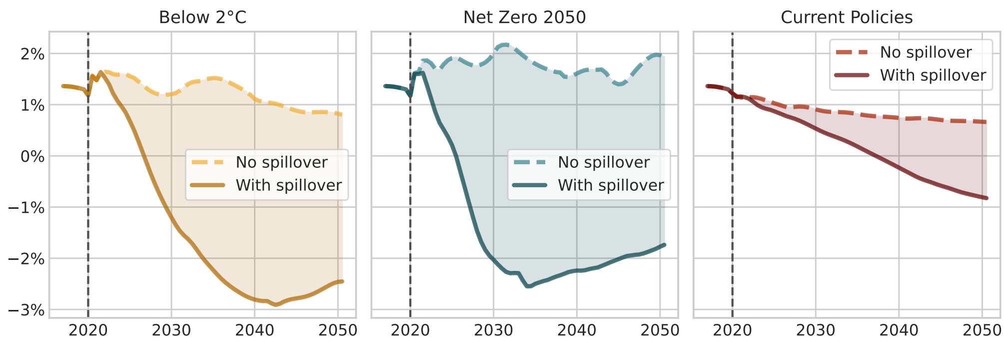
carbon transition scenarios. Overlooking spillover risks could erroneously lead us to level up public debt across scenarios, with implications for financial risk assessment and debt sustainability analyses.



(A) Total GHG emissions from the domestic economy



(B) Inflation rate in the NGFS scenarios.



(C) Difference in the balance of payment when introducing spillover

FIGURE 8: Main results by scenario, with a distinction between the cases with and without spillover. The x-axis for both panels displays years of simulation. For panel a, the GHG emissions are indexed at 100 at the starting time of the scenarios. For panel b, the y-axis displays the yearly inflation rate based on a representative and adaptive basket of services and consumer goods. For panel c, the y-axis displays the balance of payment as a percentage of GDP.

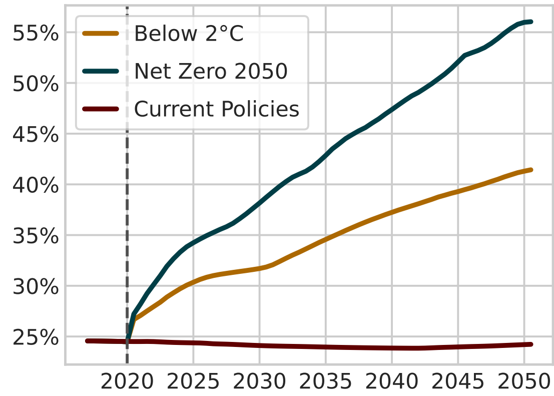


FIGURE 9: Share of renewable energy over the total produced under the different scenarios, with spillover.

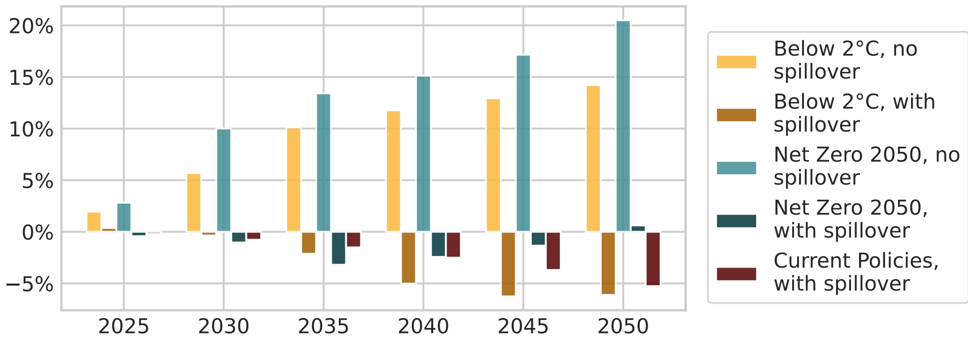
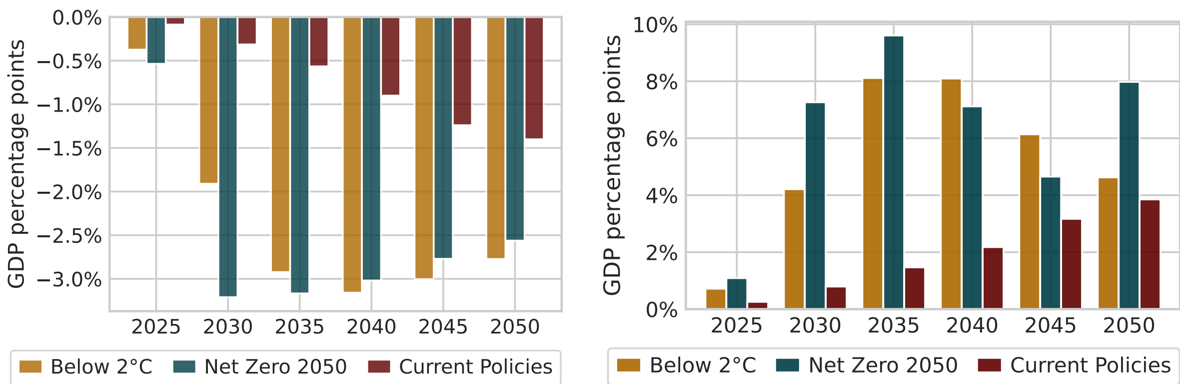


FIGURE 10: Real GDP compared to the scenario of current policies without spillover.
The x-axis for both panels displays selected years of the simulation, and the y-axis displays the difference relative to the reference scenario, i.e. NGFS current policies with no spillover risk.



(A) Spillover effects on the fiscal budget balance

(B) Spillover effects on the public debt

FIGURE 11: Debt and deficit: difference in the three scenarios when introducing transition spillover. In both panels, the y-axis is a measure in percent of GDP. Panel (a): for each year reported and each scenario, the value given represents the difference in public budget balance to GDP with and without the inclusion of the shock on fossil fuel exports. Panel (b): difference (in ratios of GDP) of the debt level with spillover to the one without spillover.

6 Conclusion

In this paper, we introduced the concept of climate transition spillover risk (shortened in the paper as "spillover risk"). Then, we analysed its macro-financial criticality for sovereign fiscal and financial stability, with an application to Indonesia. Spillover risk emerges from a shock in Chinese demand for Indonesian coal as a result of the introduction of ambitious climate policies (carbon pricing) for economic decarbonization in China.

We identified the spillover risk transmission channels that can have macro-critical implications, and then we quantitatively assessed their impacts on the Indonesian economy. To do so, we tailored and calibrated the EIRIN SFC behavioural model. With EIRIN, we analysed and compared the impact of climate transition scenarios provided by the NGFS, and the impact of spillover risk, on key macroeconomic and public finance indicators. We covered both the direct impacts (i.e. shrinking export markets), and the indirect impacts (including adjustments in asset prices, investment, and fiscal revenue) for Indonesia.

Variable	Spillover risk	Low-carbon transition policies
GDP	↓	↑
Balance of payments	↓	~
Public debt	↑	↑
Unemployment	↑	↓
GHG emissions	↓	↓

Table 1: 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.

Our results are summed up in Table 2 and show that spillover risk can induce trade-offs in terms of sovereign economic, financial stability, and decarbonization. On the one hand, spillover risk negatively affects GDP growth and the main macroeconomic indicators in Indonesia: the lower growth results in a GDP 20% lower by the end of the simulation period. The slowdown in economic growth is driven by the drop in coal production (virtually reduced to zero in the most stringent case), which can lead to the realization of carbon-stranded assets for the mining sector. Given the important role played by the mining sector in Indonesia, the shock negatively affects the Indonesian balance of payments, fiscal budget and public debt (increasing by up to 10% of GDP in our simulations). The impact on the Indonesian fiscal budget is large and thus could trigger public debt imbalances in absence of fiscal measures and/or external financing. Nevertheless, the introduction of more stringent domestic decarbonization policies (i.e. from mild to ambitious climate targets), does not significantly worsen the fiscal position of Indonesia. This shows that such climate policies can and should be pursued even when the economy is under pressure from transition spillovers.

Beyond public financing, our results suggest important real-economy effects. In particular, spillover risk negatively affects employment, resulting in our simulation of unemployment in the range of 10% for most of the time horizon, a lot higher than the no-spillover counterparts where the domestic green stimulus pushes down unemployment. This has potential social implications (e.g. inequality and poverty) that could slow down the progress toward a low-carbon economy. On the other hand, spillover risk contributes to lower GHG emissions in Indonesia. Nevertheless, the decrease induced by the introduction of carbon pricing in China is not enough alone to allow Indonesia to reach its 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, Salas, 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 fuels energy.

Implications for the governance of the low-carbon transition at the regional and global levels follow. At the regional level, the coordinated introduction of policies for the low-carbon transition in the South-East Asia region, and the support from regional institutions, such as the Chang Mai Initiative for Multilateralization, the Asian Infrastructure Investment Bank, the Asian Development Bank, among 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 monitoring of 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 into various parts of the IMF toolkit. This, in turn, can help to strengthen the representation of climate transition and spillover risks in the modelling tools that support the IMF's Financial Stability Assessment Programs (FSAPs) and Article IV surveillance activities. A better assessment of climate transition risks for sovereigns, in turn, is fundamental for financial supervisors to identify the right financial package and, potentially, the fiscal and financial reform tools. It is also crucial for governments to design fiscal policies to smooth the negative effects of spillover risk in their economies while fostering their low-carbon transition. Finally, it is relevant for national central banks and financial regulators to identify an effective short-term monetary response to tame the impacts of spillover risks in the national economy and banking sector.

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A Model methodology

A.1 Corporate production pricing

The two firms selling to households set their consumption goods price as a mark-up μ_j on their labour costs w_j/γ_j^N, capital costs $\kappa_j L_j$, energy $P_{\text{En}} q_{\text{En},j}$ and resource costs $P_R q_{R,j}$, such that $\forall j \in \{\text{Fl}, \text{Fk}\}$,

$$P_j = (1+\mu_j)(1+\tau_{\text{VAT}}) \frac{w_j N_j + \kappa_j L_j + P_{\text{En}} q_{\text{En},j} + P_R q_{R,j}}{\mathbf{Q}_j} \,. \tag{19}$$

For the capital producers, the principle is similar, assuming that they apply the same markup and with no VAT added as they sell to other firms:

$$\forall i \in \{\text{Kp}\mathfrak{g}, \text{Kp}\mathfrak{b}\}, \quad P_i = (1+\mu_{\text{Kp}}) \times \frac{w_{\text{Kp}} N_i + D_{\text{En},i} P_{\text{En}}}{\mathbf{Q}_i} \,. \tag{20}$$

A.2 Sovereign debt repayment

Thus, 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 $s_1 \geq s_2 > 0$.

$$\text{DR}(t) = \frac{1}{s_1 - s_2 + 1} \sum_{\tau = t - s_1}^{t - s_2} \Delta^+ \mathbf{n}_{\text{G}}(\tau) \times \mathfrak{p}_{\text{G}}(\tau) \tag{21}$$

where $\Delta^+ \mathbf{n}_{\text{G}}$ denotes the number of bonds newly issued, and $\mathfrak{p}_{\text{G}}$ 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

$$\Delta^- \mathbf{n}_{\text{G}}(t) = \frac{1}{s_1 - s_2 + 1} \sum_{\tau = t - s_1}^{t - s_2} \Delta^+ \mathbf{n}_{\text{G}}(\tau) \,. \tag{22}$$

Then, the amount repaid is redistributed between the three bondholders in the EIRIN model (i.e. central bank, capitalist households and banks) proportionally to their current bond holdings.[19]

A.3 Defaults

NFC firms have two types of assets: cash with value M and productive capital with value K. We abstract from inventories here, considering that they are sufficiently liquid to be sold directly at no discount. The firms defaulting have assets m^{Def} and k^{Def}.

Assumption 1. *The firms defaulting have the same asset allocation as the whole sector, i.e.*

$$\frac{m^{\text{Def}}}{m^{\text{Def}} + k^{\text{Def}}} = \frac{M}{M + K} \,. \tag{23}$$

Assumption 2. *The firm held a share* Def *of the total debt L, i.e.*

$$l^{\text{Def}} = \text{Def} \times L \,. \tag{24}$$

[19] 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 sectors 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.

This is the most intuitive setting, corresponding for instance to a set of firms having all the same debt, and the PD being homogeneous on them.

Assumption 3. *The defaults happen due to* insolvency*, and not illiquidity, which means we have*

$$m^{\text{Def}} + k^{\text{Def}} = l^{\text{Def}} . \tag{25}$$

The assets of defaulting firms is determined by equations (23), (24), and (25), such that

$$m^{\text{Def}} = \text{Def} \times \frac{M}{M+K} \times D \quad \text{and} \quad k^{\text{Def}} = \text{Def} \times \frac{K}{M+K} \times D . \tag{26}$$

Assumption 4: when a firm defaults, it can sell a share $\beta \in [0,1]$ of its capital, with a *fire sales discount* $\rho \in [0,1]$. The remaining $1-\beta$ get *stranded* and are completely written off.

Assumption 5: the bank recovers a share $\alpha \in [0,1]$ of the defaulted firms' liquidation value, which is their cash and the proceeds from the sale of their capital

$$R = \alpha \left(m^{\text{Def}} + \beta \times \rho \times k^{\text{Def}} \right) . \tag{27}$$

The meaning of $\alpha < 1$ would be to take into account recovery costs and frictions. The sale of capital is internal and does not affect the regular prices, so other NFC firms make a profit from buying at a discount. In EIRIN, parameters α and ρ are common to all sectors, while β is sector-specific as it pertains to the specific nature of the capital owned.

The total debt of the firms evolves such that $\Delta L = -d^{\text{Def}}$. The capital is only affected by the stranding $1-\beta$, with the assumption that the effect of the fire sales discount reverts quickly and does not affect the long-run book value of productive capital, hence $\Delta K = -(1-\beta) \times k^{\text{Def}}$. Cash decreases due to the recovery payment, with $\Delta M = -R$. The role of α is not clear-cut here, in so far as we assume the sector pockets its own recovery cost, but it is not quite clear who should cash in from that.

When firms repay a debt l, in an SFC setting with endogenous money creation, both the loans and the deposits on the balance sheet of the bank decreased by l, i.e. the money disappears. We consider below the balance-sheet effect of defaults, without considering, for now, the repayment of other loans or the interest rates payment. The bank writes l^{Def} off its loan book (asset side), i.e. $\Delta \mathbf{L} = -d^{\text{Def}}$, and its deposits (liabilities side) decrease such that $\Delta \text{Dep} = -R$. There is no effect on the cash holdings of the bank.

Finally, we examine the effect of this mechanism on the equity of both sectors. For the firms, we have

$$\begin{aligned} \Delta E = \Delta M + \Delta K - \Delta D &= d^{\text{Def}} - (1-\beta) k^{\text{Def}} - R \\ &= m^{\text{Def}}(1-\alpha) + k^{\text{Def}} \beta (1-\alpha\rho) > 0 . \end{aligned}$$

Thus, the real-economy benefits even though some of its members default. This is due to having heterogeneity within sectors and justifies charging higher rates in a Post-Keynesian setting given non-zero PDs. For the banks, we get

$$\Delta E_{\text{BA}} = \Delta \mathbf{L} - \Delta \text{Dep} = R - d^{\text{Def}} < 0 . \tag{28}$$

A.4 NPV calculations

We start by detailing the calculation of the net present value for new investment by the consumption goods producers or the service firms, i.e. $j \in \{\text{Fk}, \text{Fl}\}$. First, we calculate the NPV for high-carbon investments, which we defined as

$$\text{NPV}_i^{\mathfrak{b}}(t) = -P_{\text{Kp}\mathfrak{b}}(t) + \sum_{s=t+1}^{+\infty} \frac{\text{CF}_i^{\mathfrak{b}}(t,s)}{(1+\kappa_i)^{s-t}},$$

where $\text{CF}_i^{\cdot}(t,s)$ describes total expected cash flows expected at s from the new investment. The anticipated total cash flow from a unit of high-carbon investment at time $s > t$ is

$$\begin{aligned}\text{CF}_j^{\mathfrak{b}}(t,s) = & \frac{\hat{p}_j(s)}{1+\tau_{\text{VAT}}(t)} \times \Delta\hat{\mathbf{q}}_j - \hat{w}_j(s) \times \Delta N_j(t,s) - P_R(s) \times \Delta^{\mathfrak{b}}\hat{q}_{R,j}(t,s) \\ & - \hat{p}_{\text{En}}(s) \times \Delta^{\mathfrak{b}}\hat{D}_{\text{En},j}(t,s) - \Delta^{\mathfrak{b}}\hat{\text{Em}}_j(t,s) \times \tau_{\text{Em}}(t')\end{aligned}$$

where we distinguish four cash flows. In doing so, we take into account the depreciation with rate δ_j of the capital bought when computing the future expected cash flows.

First, a positive cash flow is given by the additional sales due to investment, with $\Delta\hat{q}_j$ the additional expected production (and sale) due to the unit investment, and $\hat{p}_j$ is the expected sale price. The latter is adjusted for VAT, which is assumed constant. They are given respectively by

$$\Delta\hat{\mathbf{q}}_j(t,s) = (1-\delta_j)^{s-t} \times A(s) \times \gamma_j^K \quad \text{and} \quad \hat{p}_j(s) = P_j(t) \times (1+\pi_j)^{s-t}$$

with γ_j^K the productivity of capital, A the TFP, and π_j the expected growth rate of the price.

Second, three negative cash flows include:

- The additional labour costs required to match the need for increased production capacity. This is made of the expected wages $\hat{w}_j(s)$ to be paid and of the additional number ΔN_j of workers to match the additional production capacity due to investments. We get

  $$\Delta N_j(t,s) = \gamma_j^K \times (1-\delta_j)^{s-t} / \hat{\gamma}_j^N(s)$$

  with $\hat{\gamma}_j^N$ the expected productivity of labour. Since both wages and productivity are endogenously determined, we use the estimated growth rate $\pi_{N,i}$ of their ratio, such that $\hat{w}_j(s)/\hat{\gamma}_j^N(s) = \hat{w}_j(t)/\hat{\gamma}_j^N(t) \times (1+\pi_{N,i})^{s-t}$.
- The additional raw materials costs incurred to produce the additional output. It is described by the expected price $P_R(s)$ and the additional amount $\Delta q_j^R(s)$ of raw materials required to match the increase in production capacity due to investments. We get

  $$P_R(s) = P_R(t) \times (1+\pi_R)^{s-t} \quad \text{and} \quad \Delta^{\mathfrak{b}}\hat{q}_{R,j}(t,s) = \Delta\hat{\mathbf{q}}_j(t,s) \times \phi_j^R$$

  where π_R is the raw material price growth rate, assumed constant and known to the agent, and ϕ_j^R is the coefficient of raw material necessary per unit of output.
- The extra energy requirements for producing additional output. It is composed of the expected energy price $\hat{p}_{\text{En}}$, and the additional quantity $\Delta D_{\text{En},j}$ of energy required to match the additional production capacity due to investments. We get

  $$\hat{p}_{\text{En}}(s) = P_{\text{En}}(t) \times (1+\pi_{\text{En}})^{s-t} \quad \text{and} \quad \Delta^{\mathfrak{b}}\hat{D}_{\text{En},j}(t,s) = \Delta\hat{\mathbf{q}}_j(t,s) \times \phi_j^{\text{En}}$$

where π_{EN} is the estimated energy price growth rate, and ϕ_j^{En} is the coefficient of energy necessary per unit of output.

- The extra tax on GHG emissions that follow from the use of high-carbon capital bought and the consumption of energy that accompanies the surplus of production. For the tax rate, the default setting is that the value $\tau_{\mathrm{Em}}(t')$ is used, with $t' \geq t$, i.e. agents can have information or beliefs about future carbon prices and use this value. As for the quantity of emissions, it depends on the added production from high-carbon capital and the consumption of energy from non-renewable sources, such that

$$\Delta^{\mathfrak{b}}\hat{\mathrm{Em}}_j(t,s) = \Delta\hat{\mathbf{q}}_j(t,s) \times \theta_j^{\mathrm{Em}}$$

where θ_j denotes the carbon intensity of production by i.

Note that in practice endogeneity arises in how some of these variables will be defined. In particular, as detailed in equation (19), the price P_j is a variable of P_R, w_j, P_{En}, and the carbon tax. Moreover, most of the inflation/growth rates are endogenous to the model. Therefore, they have to be estimated from recent values of the corresponding time series.

Let $\Upsilon_j = (1-\delta_j)/(1+\kappa_j)$. Then, the set of conditions for the NPV to be properly defined is

$$\Upsilon_j(1+\pi_j) < 1, \quad \Upsilon_j(1+\hat{\gamma}_j^N) < 1, \quad \Upsilon_j(1+\pi_R) < 1, \quad \text{and} \quad \Upsilon_j(1+\pi_{\mathrm{En}}) < 1 \,. \tag{29}$$

Using the closed form solution for the sum of arithmetico-geometric series, and given ΔA the TFP increments, we define

$$S_{t,j} : r \mapsto \frac{A(t)}{1-\Upsilon_j(1+r)} + \frac{\Delta A \times \Upsilon_j(1+r)}{(1-r)^2} \,.$$

When conditions (29) are verified, from the formula for sums of geometric series we get

$$\begin{aligned}\mathrm{NPV}_j^{\mathfrak{b}}(t) = -P_{\mathrm{K}\mathfrak{p}\mathfrak{b}}(t) + \gamma_j^K \Bigg(& \frac{P_j(t)}{1+\tau_{\mathrm{VAT}}(t)} S_{t,j}(\pi_j) - \frac{w_j(t)/\gamma_j^N(t)}{1-\Upsilon_j(1+\hat{\gamma}_j^N)} - P_R(t)\phi_j^R S_{t,j}(\pi_R) \\ & -P_{\mathrm{En}}(t)\phi_j^{\mathrm{En}} S_{t,j}(\pi_{\mathrm{En}}) - \tau_{\mathrm{GHG}}(t)\theta_j S_{t,j}(0)\Big) \,.\end{aligned}$$

Thanks to the linearity of the NPV we compute only the above ratio, which eases intertemporal comparisons as this value reflects profitability independently of the amount invested. The calculation for the green NPV is similar, with the following equations:

$$\begin{aligned}\mathrm{NPV}_i^{\mathfrak{g}}(t) &= -P_{\mathrm{K}\mathfrak{p}\mathfrak{g}}(t) + \sum_{s=t+1}^{+\infty} \frac{\mathrm{CF}_i^{\mathfrak{g}}(t,s)}{(1+\kappa_i)^{s-t}} \\ \mathrm{CF}_j^{\mathfrak{g}}(t,s) &= \frac{\hat{p}_j(s)}{1+\tau_{\mathrm{VAT}}(t)} \times \Delta\hat{\mathbf{q}}_j - \hat{w}_j(s) \times \Delta N_j(t,s) - P_R(s) \times \Delta^{\mathfrak{g}}\hat{q}_{R,j}(t,s) - \hat{p}_{\mathrm{En}}(s) \times \Delta^{\mathfrak{g}}\hat{D}_{\mathrm{En},j}(t,s)\end{aligned}$$

where the differences in the terms of the cash flows are due to lower consumption of energy and raw materials when using green capital (with constant discount rates given by $\eta_{\mathrm{En}}^{\mathfrak{g}}$ and $\eta_R^{\mathfrak{g}}$ respectively), as well as an absence of GHG emissions from the use of capital. This gives us the following:

$$\begin{aligned}\Delta^{\mathfrak{g}}\hat{q}_{R,j}(t,s) &= \Delta\hat{\mathbf{q}}_j(t,s) \times \phi_j^R(1-\eta_R^{\mathfrak{g}}) \\ \Delta^{\mathfrak{g}}\hat{D}_{\mathrm{En},j}(t,s) &= \Delta\hat{\mathbf{q}}_j(t,s) \times \phi_j^{\mathrm{En}}(1-\eta_{\mathrm{En}}^{\mathfrak{g}}) \,.\end{aligned}$$

Note that the condition for the green NPV to be well-defined is then the same as for the high-carbon one, given that only constant factors are added. Thus, the final formula for the green NPV is

$$\mathrm{NPV}_j^{\mathfrak{g}}(t) = -P_{\mathrm{Kp}\mathfrak{g}}(t) + \gamma_j^K \Bigg(\frac{P_j(t)}{1+\tau_{\mathrm{VAT}}(t)} S_{t,j}(\pi_j - \frac{w_j(t)/\gamma_j^N(t)}{1-\Upsilon_j(1+\hat{\gamma}_j^N)} \\ -P_R(t)\phi_j^R(1-\eta_R^{\mathfrak{g}})S_{t,j}(\pi_R) - \phi_j^{\mathrm{En}}(1-\eta_{\mathrm{En}}^{\mathfrak{g}})P_{\mathrm{En}}(t)S_{t,j}(\pi_{\mathrm{En}})\Big) \ .$$

We then move on to calculate the NPV for the energy producers. Starting with the green energy producer we get

$$\mathrm{NPV}_{\mathrm{E}\mathfrak{g}}(t) = \sum_{s=t+1}^{+\infty} \frac{\hat{p}_{\mathrm{En}}(s) \times \Delta\hat{\mathbf{q}}_{\mathrm{E}\mathfrak{g}}(t,s)}{(1+\tau_{\mathrm{En}})(1+\kappa_{\mathrm{E}\mathfrak{g}})^{s-t}} - (1-\eta_K)P_{\mathrm{Kp}\mathfrak{g}}(t)$$

where $\Delta\hat{\mathbf{q}}_{\mathrm{E}\mathfrak{g}}(t,s) = (1-\delta_{\mathrm{E}\mathfrak{g}})^{s-t} \times \gamma_{\mathrm{E}\mathfrak{g}}^K$ is the expected future production added, τ_{En} is the VAT rate on energy, and η_K is the government-financed rebate on capital for E$\mathfrak{g}$. Let $\Upsilon_{\mathrm{E}\mathfrak{g}} = (1-\delta_{\mathrm{E}\mathfrak{g}})/(1+\kappa_{\mathrm{E}\mathfrak{g}})$. If $\Upsilon_{\mathrm{E}\mathfrak{g}}(1+\pi_{\mathrm{En}}) < 1$ then the series in the above sum converges, and we get

$$\mathrm{NPV}_{\mathrm{E}\mathfrak{g}}(t) = \frac{\gamma_{\mathrm{E}\mathfrak{g}}^K \hat{p}_{\mathrm{En}}(t)}{1+\tau_{\mathrm{En}}} S_{t,\mathrm{E}\mathfrak{g}}(\pi_{\mathrm{En}}) - (1-\eta_K)P_{\mathrm{Kp}\mathfrak{g}}(t) \ .$$

For the high-carbon energy sector, which buys high-carbon productive capital, we get

$$\mathrm{NPV}_{\mathrm{E}\mathfrak{b}}(t) = -P_{\mathrm{Kp}\mathfrak{b}}(t) + \sum_{s=t+1}^{+\infty} \frac{\mathrm{CF}_{\mathrm{E}\mathfrak{b}}(t,s)}{(1+\kappa_{\mathrm{E}\mathfrak{b}})^{s-t}},$$

where we have the expected cash flow that is made up of revenues from energy production (except for what is consumed in the process itself), the expenses from oil consumption and the tax on added carbon emissions:

$$\frac{\mathrm{CF}_{\mathrm{E}\mathfrak{b}}(t,s)}{(1-\delta_j)^{s-t}} = \frac{\hat{p}_{\mathrm{En}}}{1+\tau_{\mathrm{En}}} \times \frac{\gamma_{\mathrm{E}\mathfrak{b}}^K}{1+\rho_{\mathrm{E}\mathfrak{b}}} - \hat{p}_{\mathrm{MO}} \times \frac{\gamma_{\mathrm{E}\mathfrak{b}}^K}{\gamma_{\mathrm{E}\mathfrak{b}}^o} - \tau_{\mathrm{Em}}(t')\gamma_{\mathrm{E}\mathfrak{b}}^K\theta_{\mathrm{E}\mathfrak{b}} \ .$$

so that, if we set $\Upsilon_{\mathrm{E}\mathfrak{b}} = (1-\delta_{\mathrm{E}\mathfrak{g}})/(1+\kappa_{\mathrm{E}\mathfrak{g}})$, then the NPV is correctly defined when we verify $\Upsilon_{\mathrm{E}\mathfrak{b}} < 1$,

$$\mathrm{NPV}_{\mathrm{E}\mathfrak{b}}(t) = -P_{\mathrm{Kp}\mathfrak{b}}(t) + \gamma_{\mathrm{E}\mathfrak{b}}^K \left(\frac{P_{\mathrm{En}}(t)}{1+\tau_{\mathrm{En}}} S_{t,\mathrm{E}\mathfrak{b}}(\pi_{\mathrm{En}}) - \frac{P_{\mathrm{MO}}(t)}{\gamma_{\mathrm{E}\mathfrak{b}}^O} S_{t,\mathrm{E}\mathfrak{b}}(\pi_{\mathrm{MO}}) - \tau_{\mathrm{GHG}}(t)\theta_{\mathrm{E}\mathfrak{b}}S_{t,\mathrm{E}\mathfrak{b}}(0) \right) \ .$$

B Calibration for Indonesia

We present here the details of the calibration, with some parameters being directly fixed (table 2), and some others set to provide dynamics in line with observed data (table 3).

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. We use lower values to take into account the share of informal work that is not present directly in the model.[20] For instance, the actual VAT rate is 11%. This is because informal work is otherwise not explicitly integrated into the model. Through these changes, we reach a size of the government that is more in line with the data.

Additional tests are made to ensure that the EIRIN economy remains in a quasi-stable state that provides a good counterpart to the scenarios we apply. Thus, we verify that variables in the model all remain in a reasonable range, i.e. broadly in line with the historical trends, also between the end of the calibration period and the end of the whole simulation time. There are some limits to it, as the economy features a declining productivity growth rate by design for instance.

Variable	Value	Source, if any
Energy consumption of households as a share of total budget	10%	
Share of goods ψ in households consumption	36%	
Ratio of savings to revenue for households	4	
Markup of consumption goods producers	1.06	
Markup of service firms	1.33	
Depletion rate for the capital of consumption goods producers (by semester)	2.8%	
Depletion rate for the capital of service firms (by semester)	2.8%	
Depletion rate for the high-carbon energy firm	3%	
Depletion rate for the renewable energy firm	3%	
Replacement rate for unemployed households (using previous period income as a base)	50%	
Labour tax	6%	
Corporate tax	22%	taxfoundation.org, 2022 data
Tax on dividends	10%	PWC
Share of public employees over total active population	3.4%	ADB
VAT on consumption goods and services	5%	
Tax on energy consumption	4%	

Table 2: Parameters of the model that are taken directly from available data or set at levels in line with international standards.

[20] See https://www.bps.go.id/.

		Simulation values		Real values	
		Mean	Standard deviation	Mean	Standard deviation
Energy	Share of renewable (% of total energy consumption)	24.52	0.05	25.04	3.38
Exports breakdown (% of total exports)	Share of goods in exports	62.37	0.24	61.61	2.24
	Share of mining commodities in exports	23.83	0.30	24.68	2.97
	Share of services in exports	13.80	0.06	13.71	1.46
Financial indicators	Deposit rate of the central bank (%)	0.44	0.01	7.27	1.05
	Lending rate from the commercial bank (%)	6.44	0.01	11.52	1.01
Investment and credit	Firms' total credit (% of GDP)	26.31	0.58	38.37	1.11
	Share of investment financed through credits (% of total investments)	31.61	0.74	12.80	0.00
	Share of investment financed through own liquidity (% of total investments)	68.39	0.74	66.00	0.00
Key indicators	Inflation (%)	3.08	0.01	4.39	1.57
	Real GDP growth (%)	4.40	0.15	5.03	0.10
	Share of unemployment (% of total workforce)	4.87	0.18	4.12	0.34
National accounts (% of GDP)	Government revenues from taxes	14.21	0.06	10.30	0.44
	Level of the public debt	25.24	0.97	30.53	1.58
	Net remittances received	0.50	0.00	0.51	0.10
	Revenues from tourism	1.74	0.00	1.55	0.16
	Total exports	20.40	0.10	20.59	1.84
	Total government expenditures	15.52	0.23	17.08	0.84
	Total government revenues	15.25	0.05	14.79	0.89
	Total imports	19.67	0.03	20.63	2.30
Share of GHG emissions (%)	Energy sector	0.46	0.01	0.43	0.01
	Industry (all except service firms)	0.24	0.00	0.24	0.02
Share of employees (% of total employees)	Consumption goods sector	23.16	0.16	35.60	2.14
	Service sector	55.92	0.06	46.68	1.84
	Upstream sectors	17.33	0.10	17.72	0.34
Value added (% of GDP)	Consumption goods sector	31.51	0.07	20.89	0.57
	Service sector	43.79	0.12	43.41	0.65
	Upstream sectors (non consumption goods/services)	22.70	0.04	32.17	0.85

Table 3: Calibration table.
"Real values" come from real data time series, with observations from 2014 to 2019 where available.

C Appendix: additional results

In this appendix we analyse more detailed results, extending on what is presented in section 5. First, we represent the GHG emissions of the different sectors in figure 12. 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.

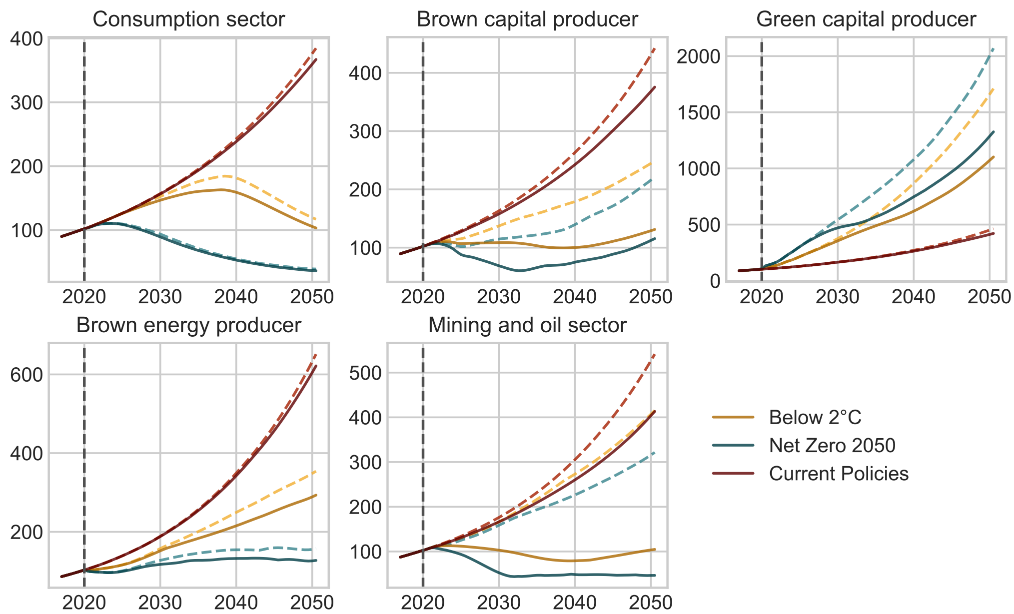

Figure 12: Sector breakdown of carbon emissions under different scenarios, with dashed lines representing the counterfactual with no spillover risk. "Consumption sector" aggregates both the consumer goods producers and the service sector.

To better explain the differences in growth between the different scenarios discussed in figure 10, we represent in figure 13 the yearly changes in value added for sectors in the economy. Thus, we observe that the consumption sector is the one that best absorbs 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 in 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 capital goods 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. During most of the remaining period, it grows at a rate above its previous baseline

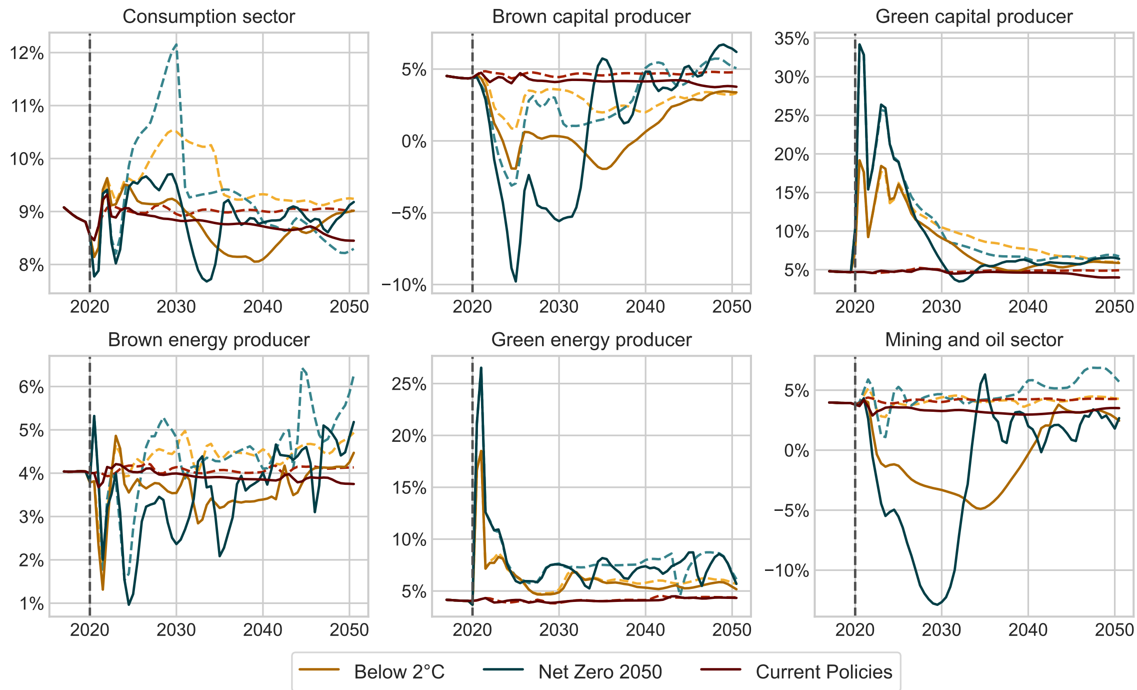

FIGURE 13: Sector breakdown of value-added growth under different scenarios, year-on-year, with dashed lines representing the counterfactual with no spillover risk. "Consumption sector" aggregates both the consumer goods producers and the service sector.

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 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 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 scenario Net-zero 2050 and growth comes back in the early 2030s. Meanwhile, the decrease with the scenario Below 2°C is more gradual, and it starts growing again from 2040 only.

Then, we represent in figure 14 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 subsection 5.2. 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 scenario Current Policies 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.

Next, in figure 15 we display the changes in unemployment rates and show how it reacts to the inclusion of spillover risk in the model. Introducing spillover risks leads to an increase in the unemployment level under all scenarios, largely explained by the lower workforce needed in the oil and mining sector. Moreover, the version of the model with no spillover tends to exhibit a decrease in

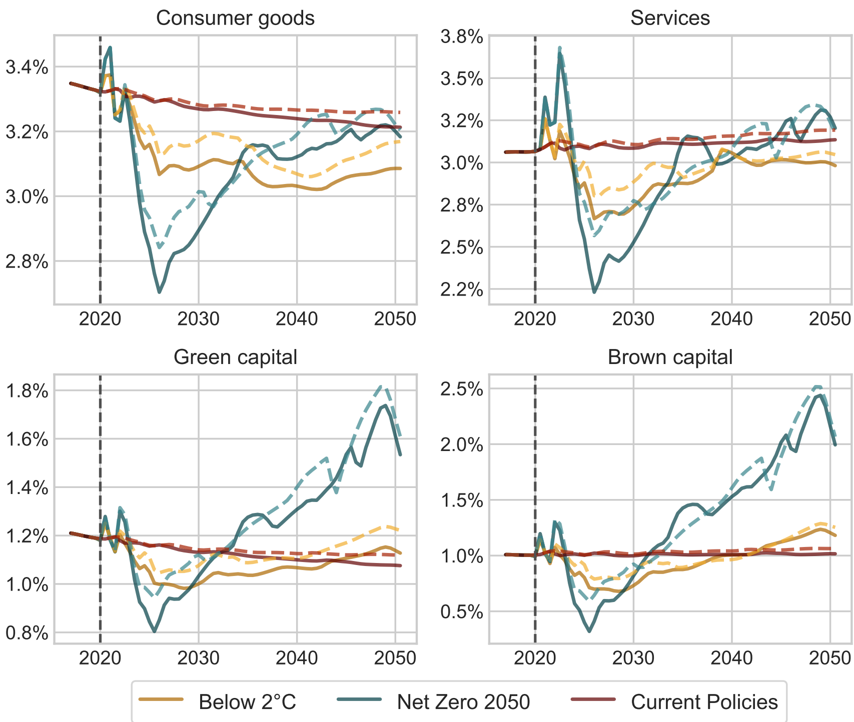

Figure 14: Yearly price inflation for different sub-categories of products.

unemployment under all scenarios, albeit a slow one for "Current Policies". As discussed above, the important budget reallocation through a carbon tax and the production of green capital explains the important decrease in the climate transition pathways. Both reach the extreme value of 0% 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.

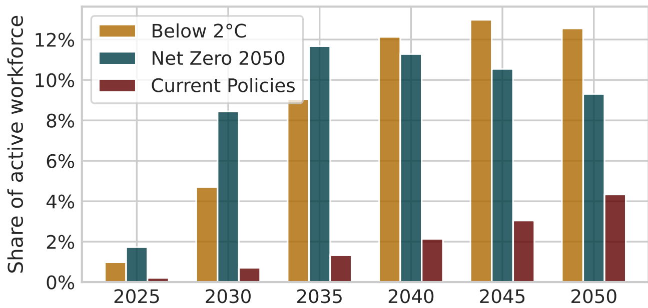

Figure 15: Difference in unemployment rate induced by the transition spillover risk for the different scenarios, in percentage points over total active population.

Looking now at the implications of scenarios in terms of inequalities, we represent in figure 16 the share of household incomes earned through labour, 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 15, the magnitude of changes is relatively small under all scenarios. This suggests that the profits of capitalist households tend to follow trends broadly similar to the income of workers in all cases. However, this relative view does not imply that workers are better or worse off in absolute terms.

To add to the analysis of the government balance sheet, we then look at the impact of the different

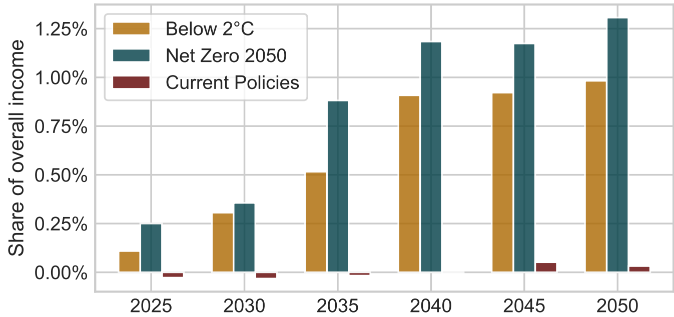

FIGURE 16: Difference induced by spillover risk in the share of income generated from labour compared to the total of income from labour and capital.

low-carbon transition measures. These measures can be decomposed into one source of income – the carbon tax – and two expenses: the subsidies to green capital and green energy. This is represented in figure 17, with all values in percentage points of GDP. First, 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 scenarios 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 the denominator. On the other hand, in the scenario Current Policies, the income and expenses are more balanced. Then, the increase in the carbon tax is sufficiently small that the government can break even from these policies only at the end of the simulation period.

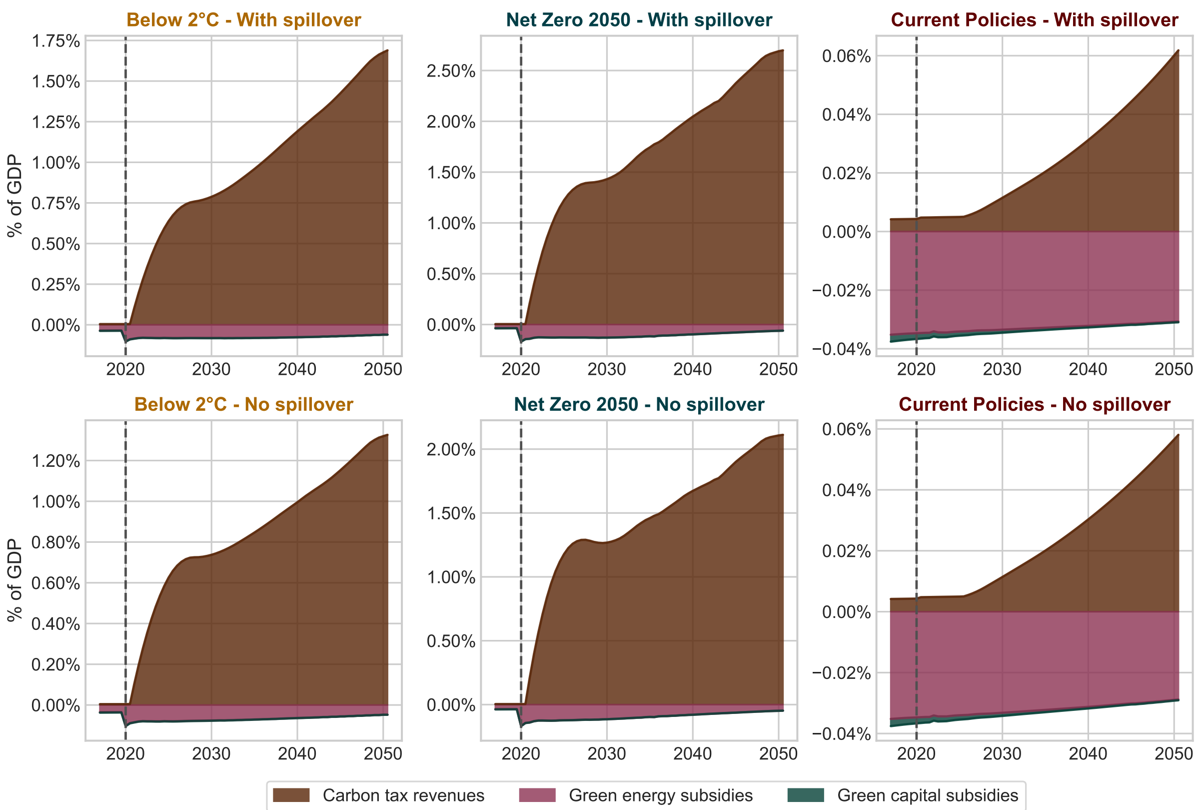

FIGURE 17: Revenues and expenses for the government linked to environmental sustainability.

Finally, to better identify the role of the carbon tax and test the sensitivity of our model to it, we conduct an additional exercise with deviations in the carbon price path around that of the scenario Below 2°C. The alternatives scenarios are defined such that the carbon tax applied is equal to $\tau_{\text{GHG}}^{(\text{alt.})}(t) = \tau_{\text{GHG}}(0) + (1+\zeta) \times (\tau_{\text{GHG}}(t) - \tau_{\text{GHG}}(0))$, where ζ is the coefficient that defines the scenario deviation. For instance, for "Below 2°C - 10%" we have $\zeta = 0.9$. Figure 18 shows how these deviations affect the economic output observed, i.e. the relative difference in GDP relative to the original scenario. We can derive two observations from it. First, the effect of carbon price deviations remains contained, with a cumulative effect on relative GDP differences over three decades in the range of 2%. This is in line with our main results, whereby the scenarios Below 2°C and Net-Zero 2050 do not show large differences in that respect, even though the latter has a carbon tax path more ambitious than the "Below 2°C + 20%" tested here. Second, the direction of the impacts observed goes in the sense already observed in previous applications (Gourdel et al., 2022), which is that transition policies can be costly in the short-term cost but are the ones with the highest economic output in the long run.

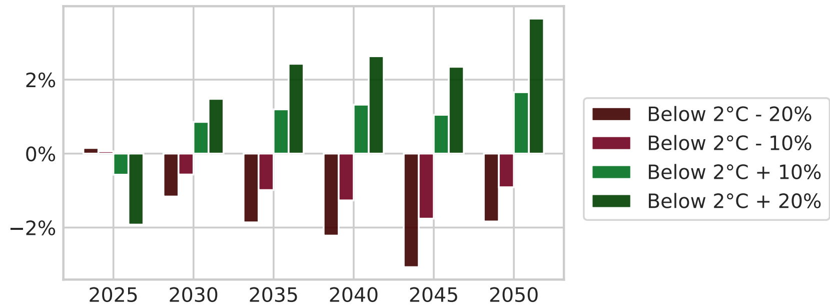

Figure 18: Difference in economic output to the baseline of the Below 2°C scenario from alternatives with variations of the carbon tax.
The y-axis shows the deviation in GDP from the baseline in percentage points, i.e. the value $(\text{GDP}_{\text{alt.}}(t)/\text{GDP}(t) - 1) \times 100$.