

Financing Green Energy Productive Capacity with a Central Bank Digital Currency: An Agent-Based Stock-Flow Consistent Analysis

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Abstract

This paper asks whether a central bank digital currency (CBDC) can help finance the accumulation of green energy productive capacity when banks operate under macroprudential regulation. We develop an agent-based stock-flow consistent (AB-SFC) model with heterogeneous energy utilities and banks subject to Basel III-type capital, leverage and liquidity ratios. We compare three scenarios: an economy without macroprudential regulation, a baseline in which the regulatory framework is enforced, and a scenario in which the central bank also finances part of green utilities' investment through a CBDC-based facility. We then compare this facility with an equivalent green fiscal policy based on public purchases of green bonds. Uniform macroprudential regulation reduces financial fragility at the cost of increasing inequalities and unemployment, and does not shift investment towards green capacity. The CBDC facility raises green relative to brown capacity, lowers unemployment and inequalities and preserves financial stability. The green fiscal policy produces similar macroeconomic and financial outcomes but yields a higher deficit and debt.

Keywords: CBDC, Green Monetary Policy, Macroprudential Policy, Green Productive Capacity, Financial Stability, Agent-Based Stock-Flow Consistent Model

JEL Classification: C63, E58, E61, Q43

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1. Introduction

Climate-related risks affect economic activity and financial markets through multiple channels, including physical damages, transition dynamics, and the devaluation of carbon-intensive assets, with significant implications for investment, credit conditions, and macroeconomic performance (D’Orazio and Popoyan, 2022). Addressing these challenges requires not only technological change, but also a substantial reallocation of financial resources toward sustainable activities.

However, current financial flows remain insufficient to meet climate objectives (IPCC, 2022). This “green finance gap” reflects structural frictions, such as uncertainty, short-termism, and risk assessment practices, that constrain the ability of financial systems to mobilise resources toward long-term green investments (D’Orazio and Popoyan, 2019; Granoff et al., 2016). Also, the exposure of financial institutions to carbon-intensive assets raises concerns about stranded assets and systemic financial risk (Monasterolo and Raberto, 2018).

Policy responses traditionally embrace carbon pricing, subsidies and public investment. However, even with appropriate price signals, banks may keep lending to established carbon-intensive sectors because of informational asymmetries, risk perceptions and regulatory incentives (D’Orazio and Popoyan, 2019, 2022). Institutions governing money and credit have a role to play in the transition (Campiglio, 2016).

Yet, much of the literature remains fragmented and often focuses on the substitution of brown with green energy in final use, paying less attention to the structural conditions that enable such a transition, namely the expansion of the productive capacity required to sustain it.

This paper adopts an agent-based stock-flow consistent (AB-SFC) modelling approach to capture the complex and non-linear dynamics of the ecological transition (Caiani et al., 2016; Carnevali et al., 2019; Popoyan et al., 2017; Reissl et al., 2024).

It examines whether and under what conditions the interaction between macroprudential regulation and CBDC-based interventions can support the expansion of green productive capacity while preserving financial stability. In doing so, it contributes to a more integrated understanding of how financial and monetary policies interact to support the acceleration of green energy productive capacities over brown capacities. The remainder of the paper is organised as follows. Section 2 develops the analytical framework and reviews the literature. Section 3 presents the model. Section 4 reports the results. Section 5 discusses and concludes.

2. Green Transition, Financial Constraints, and Monetary Innovation

Ecological macroeconomics provides a unified monetary, financial and biophysical framework to analyze transition scenarios. In particular, ecological stock–flow consistent models integrate macroeconomic, financial and environmental accounts, making it possible to examine how credit allocation and balance-sheet conditions shape the transition (Dafermos et al., 2018; Svartzman et al., 2019).

This literature cautions against treating green investment as sufficient in itself: its effectiveness depends on the technical and institutional conditions through which financing is mobilised and directed (Svartzman et al., 2019). Credit allocation depends on institutional arrangements, regulation and risk perceptions as well as on market conditions, so financial flows may keep favouring established carbon-intensive sectors despite policy efforts (Campiglio, 2016; D’Orazio and Popoyan, 2019). Macroprudential policy matters here because it sets the constraints and incentives under which banks lend. Instruments such as capital requirements affect both the volume and the allocation of credit (Klingelhöfer and Sun, 2019; Martinez-Miera and Repullo,

2019), as well as financing conditions across sectors (Dafermos and Nikolaidi, 2021). Because these rules are risk-sensitive and often backward-looking, they tend to favour borrowers with stable cash flows and established business models, and may discourage lending to long-term green investments (Bethlendi and Holczinger, 2026). Several greening options have been proposed for central banks acting within their existing mandates (Couppey-Soubeyran, 2020).

The role of prudential policy in redirecting credit has been examined in a growing literature, reviewed by Campiglio et al. (2018). Dafermos and Nikolaidi (2021) find that green supporting factors and brown penalising factors can reduce climate-related risks, although their quantitative effects are modest and depend on their calibration; the effects become stronger when the two measures are combined or accompanied by green fiscal policy. In an agent-based setting, Lamperti et al. (2021) similarly show that green capital requirements, public credit guarantees and carbon-risk adjustments in credit ratings produce moderate and sometimes uneven effects when used separately, while a particular policy mix performs better across environmental, real and financial outcomes. Xing et al. (2024) further show that the effect of green supporting factors depends on the composition of individual banks' balance sheets, cautioning against a uniform calibration across heterogeneous institutions.

More ambitious designs reinforce the conditional nature of these results. Lagoarde-Ségot et al. (2026) show that prudential ratios tied to planetary boundaries can redirect bank balance sheets and curtail brown investment, but may entail substantial short-run macroeconomic costs. Chan et al. (2024) identify a related tension between the speed of the transition and financial stability; under their modelled conditions, combining a dual interest rate with fiscal redistribution can attenuate this trade-off. Sawyer and Passarella (2021) also address the interaction between fiscal and monetary stabilisation within SFC frameworks and confirm the complementary roles of these instruments in sustaining macroeconomic stability. Taken together, these studies show that outcomes depend on instrument design, calibration and the wider policy setting, and that complementarity between instruments has to be demonstrated.

These limited effects also reflect structural features of the financial system, which favours low-risk, short-term and debt-based investment and struggles to finance innovation (Polzin, 2017). Risk-based approaches and market neutrality may therefore reinforce a carbon bias (Kedward et al., 2022). The radical uncertainty surrounding climate-related risks limits what disclosure and stress testing can achieve, which supports a precautionary approach (Chenet et al., 2021). Institutional arrangements also shape which instruments are adopted in practice (Baer et al., 2021).

In this context, the emergence of Central Bank Digital Currencies (CBDCs) can contribute to expanding the policy toolkit available to accelerate the green transition. CBDCs can be defined as a form of central bank money accessible to the public (Bindseil, 2019; Cesaratto and Febrero, 2022), and their relationship to endogenous money creation and bank intermediation has begun to attract theoretical scrutiny from a post Keynesian perspective (Bibi and Canelli, 2023, 2025; Malherbe and Montalban, 2026). By allowing for targeted distribution and differentiated access, CBDCs may provide new channels through which central banks can influence financial flows and support specific types of investment. Recent stock-flow consistent modelling has begun to formalise these transmission channels, showing how CBDC-based disintermediation affects bank credit supply and macroeconomic dynamics (Bhattacharjee et al., 2025). At the same time, their introduction raises concerns related to financial intermediation and stability, particularly in the absence of appropriate design features (Bindseil, 2019).

A limited literature treats central bank digital currency as an allocative rather than solely a payment instrument. Within a post-Keynesian stock–flow consistent framework, Lagoarde-Ségot and Revelli (2023) combine central bank reserves issued against certificates measuring the ex-post sustainability of banks' loan portfolios with digital central bank money directed towards green and social enterprises. Didier and Lagoarde-Ségot (2024) embed targeted CBDC issuance in a broader sustainable monetary architecture that also includes impact-based rediscounting and complementary currencies, and report improvements in sustainable productive capital and financing conditions. These contributions provide the closest precedents for our analysis, but they do not examine how a CBDC financing facility interacts with prudential constraints on bank lending. The present paper addresses this narrower question, without claiming that a CBDC is unique or necessarily superior to alternative policy instruments. Nor does it claim that without a CBDC the monetary and financial transmission channels that we identify would fail to materialize. We consider CBDCs as a technological change in the monetary infrastructure that makes it easier to implement a green monetary policy along transmission channels that already exist, rather than creating new transmission channels.

Direct evidence on green applications of CBDCs comes mainly from China. Yang et al. (2023) find that cities in the e-CNY pilot issue more green bonds than cities outside it, and provincial branches of the People's Bank of China have settled green loans in digital wallets to make the use of funds verifiable. These remain pilots of limited scale. They matter because they identify what distinguishes a CBDC from an untied refinancing operation, namely earmarking, conditionality enforced at the level of the payment, and verifiable end use (Kontzinos et al., 2025).

Against this background, three features of the facility we model are relevant: access to central bank financing, the technology governing the disbursement and use of funds, and the institutional setting. The first feature is the perimeter of access. The facility does not fit neatly into the wholesale or general-purpose categories (BIS, 2018). Eligibility is limited to green utilities in the model, but access is not restricted to financial intermediaries and could be extended to any non-financial entity meeting predefined environmental and financial criteria. Settlement resembles a wholesale arrangement. The central bank holds a direct claim on the eligible borrower, while the corresponding central bank liability is transferred to the borrower's commercial bank, where it is treated as reserves. In conventional refinancing operations, represented by central bank advances in our model, the central bank's claim is instead on a bank. We therefore describe the facility as functionally *hybrid*.

The second feature is technological. What counts as green is a regulatory matter, established outside the central bank and taken as given in our model. The technology concerns how a given classification (green or brown) is enforced. Conditional payments make a transfer depend on predefined events, such as the delivery of capital equipment, while programmable money can also restrict the later use of funds, at some cost in terms of fungibility and privacy. Both can be supported by standardised application programming interfaces (APIs) linking public settlement infrastructure to supervised private intermediaries (Auer and Böhme, 2020; BIS, 2021; BIS Innovation Hub; Bank of England, 2023). Eligibility rules can thus be enforced at the level of the payment rather than through ex post reporting, which is what distinguishes the facility from an untied refinancing operation (Kontzinos et al., 2025).

The third feature is institutional. Once environmental objectives and eligibility criteria fall within a legally established mandate, including a possible secondary mandate to support government policy priorities (Dikau and Volz, 2021), the facility can be activated and recalibrated through the central bank's balance sheet without a new budgetary authorisation for each intervention. This still depends on democratic authorisation and

fiscal-monetary coordination, and it does not allow the central bank to set environmental objectives on its own.

The paper examines whether the facility can help green projects overcome the financial barriers raised by macroprudential rules, which impose stringent capital and liquidity requirements on banks, thus forcing firms and utilities to deleverage and raise internal liquidity to compete for financial resources. In particular, we analyse the potential of such a facility to accelerate the green transition while preserving sound socio-economic and financial conditions.

3. The AB-SFC Model Framework

We develop an AB-SFC model to study the macroeconomic and financial effects of a CBDC facility that gives green investment access to additional and more favourable credit conditions, while other investment remains entirely dependent on private banks and, therefore, fully exposed to macroprudential constraints. The AB-SFC approach combines decentralised heterogeneous agents with the accounting structure of the stock-flow consistent tradition.

The model represents the financing of green energy infrastructure. It does not represent resource depletion, land use or physical climate damages. We treat as a good policy outcome faster growth of green relative to brown capacity, which would allow a later phase-out of brown resources without reducing overall energy supply. The indicators used to assess each scenario are described in Section 4.2.

Fig. 1 summarises the circular structure of our artificial economy. The model includes 8 distinct institutional sectors: final consumers, consumer goods firms, energy producers (utilities), capital goods firms, energy distributors, commercial banks, the Central bank and the public sector. Energy utilities and commercial banks are fully disaggregated in order to separate green energy producers from brown energy producers, and to model the effects of heterogeneous macroprudential compliance on credit supply. The remaining institutional sectors are synthesized by a representative agent in order to focus explicitly on the interaction among heterogeneous financial intermediaries and energy producers. In the following, we provide a narrative description of the model by focusing on the main behavioural assumptions concerning the heterogeneous agents, the macroprudential structure that affects banks' credit supply and the proposed green CBDC monetary policy (refer to Appendix A.2 for the complete equations of the model, to Appendix A.3 for the calibration of the model and to Appendix A.4 for the SFC matrices).

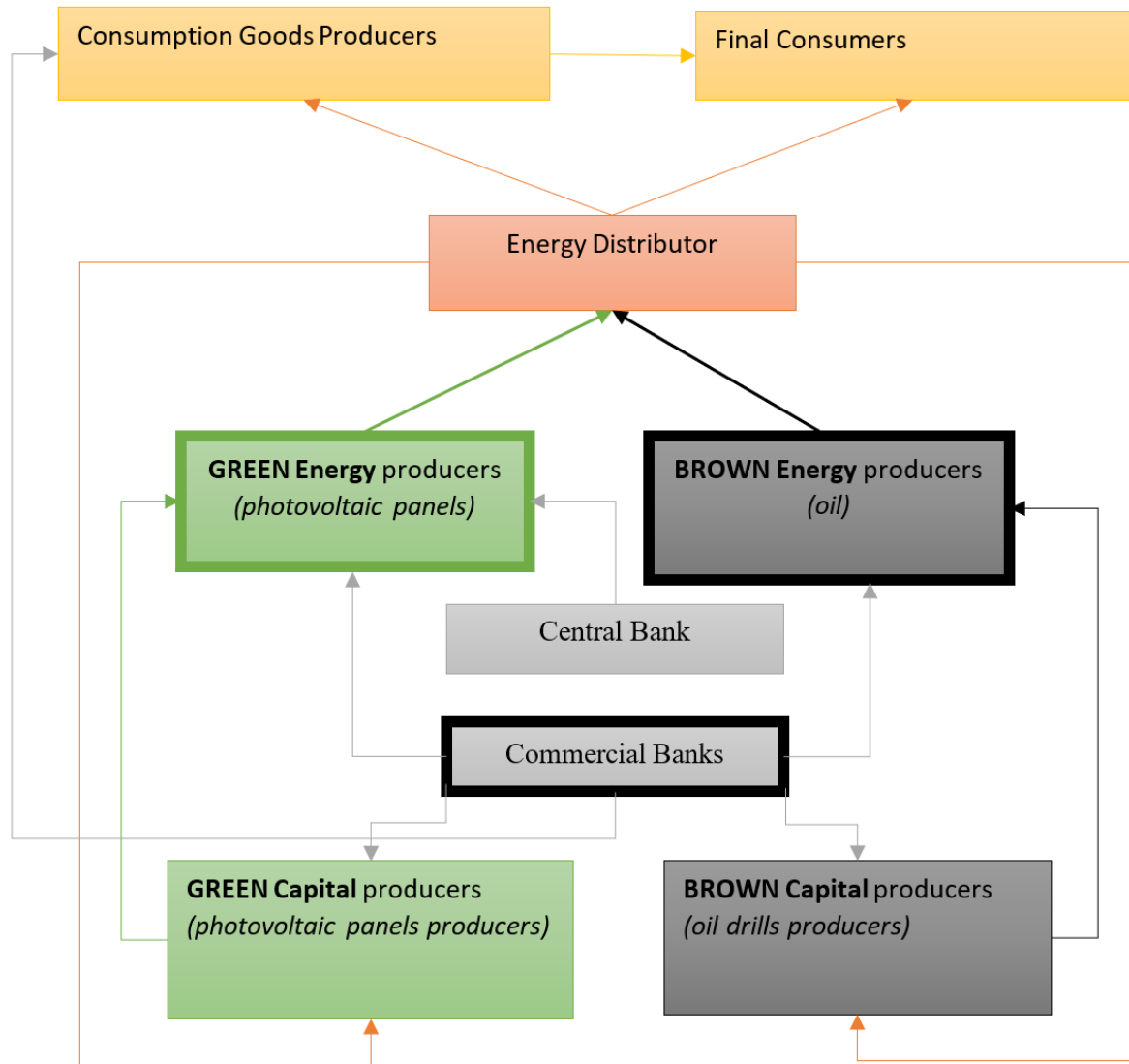


Fig. 1. Sectoral Structure and Inter-Agent Linkages of the AB-SFC Model.

Legend. Arrows starting from commercial banks and the central bank are credit flows. Arrows starting from capital producers to energy producers are productive capital flows. Arrows starting from utilities and from the energy distributors are energy flows. The arrow starting from the consumption good firm is a consumption good flow.

3.1 Monetary and macroprudential policy

The macroprudential policy of the Central bank, inspired by the Basel III framework, consists of enforcing three main regulatory ratios to commercial banks (see also Popoyan et al., 2017). The first ratio is the Leverage ratio (LR), which is the ratio of bank's equity to bank's assets. This ratio aims to ensure that banks are sufficiently capitalized. The second macroprudential ratio is the Capital adequacy ratio (CAR), which is a risk-weighted leverage ratio. Banks have to provide a risk analysis of their assets by overweighting assets that are riskier compared to assets that are safer. The aim of the CAR is to push banks to substitute risky projects with safer projects to release credit constraints. Finally, the Liquidity coverage ratio (LCR) aims to

assess the liquidity of a bank and its capacity to resist a 30-day financial distress, characterized by lower than expected cash inflows and higher than expected cash outflows (BIS, 2013). If the internal liquidity of the bank is not enough to overcome one month of financial distress, the bank has to increase internal liquidity and provide a convincing adjustment plan.

The central bank's monetary policy also consists of three main policy tools. The first tool is a standard regulatory reserve requirement that consists of a fixed ratio of banks' reserves over banks' deposits. The second tool is the interest rate at which banks borrow reserves, which varies according to a conventional, dual mandate monetary policy rule that consists of minimizing employment and inflation compared to policy targets. The third tool is a Green CBDC. The Green CBDC policy consists of granting preferential credit access to green energy utilities that plan to increase their productive capacity by financing part of their investment project through the CBDC-based facility described in Section 2: the Central bank first opens a deposit to the green utility as a counterpart for the loan, then transfers the deposit to the commercial bank of the green utility together with an equivalent amount of CBDCs. The goal of the Central bank is not to substitute commercial banks in their evaluation of business risk: the Central bank guarantees a partial credit based on a fixed rate of total investment, thereby forcing the green utility to seek for bank credit and internal financing to complete the investment. While applying for a commercial bank loan, the bank assesses the business risk of the project and sets a maximum loan-to-value ratio that the utility can obtain, net of the CBDC financial contribution and internal liquidity. If this is enough to cover the entire value of the project, the utility can send a production order to the capital goods supplier to finance the whole investment. Otherwise, the actual value of the investment will be limited by the availability of internal resources.

Our Green CBDC policy is particularly generous: the Central bank does not apply any interest rate on CB loans and does not require green utilities to repay the central bank loans. In other words, the green CBDC policy is a form of green helicopter money (Temperini et al., 2024). A more realistic approach would imply a positive interest rate and a positive depreciation rate of CB loans⁴. We made this assumption because we wanted to observe the liquidity transmission channels of this policy in order to capture as much as possible the interaction effects with the macroprudential policy. Moreover, we do not aim to calibrate the model with a particular area of the world nor to evaluate the effects of an already existing green monetary policy. The main motivation of this paper is the observation that there is a correlation between Central banks engaging in greening the monetary policy and Central banks running CBDC pilots. We thus highlight the transmission channels that would allow *green* Central banks to use CBDCs as an additional policy tool, which preserves financial stability despite being a *green supporting* rather than a *brown penalising* policy (our green CBDC improves green utilities' credit access without directly worsening brown utilities' credit access). We thus suggest a potential channel for legitimizing CBDCs beyond pure technological or privacy motives, as it creates a payment infrastructure that facilitates the implementation of a *green* monetary policy to pursue a socio-economically and financially sustainable energy transition.

3.2 Banks' credit supply

⁴ Green applications of the e-CNY have so far settled loans granted by commercial banks rather than involving direct central bank lending. Since 2026 banks may also remunerate e-CNY balances, so our zero-interest assumption is a simplification and not a description of current design.

When evaluating the investment project of a utility (brown or green), the commercial bank assesses the liquidity and the profitability of the borrower by comparing its internal liquidity with the average cash outflows, and by comparing the profitability of the borrower with respect to direct competitors. If a borrower's liquidity is larger than average cash flows and its return on equity (ROE) is higher than the average ROE of the utilities' sector, then the utility obtains a loan-to-value ratio of 100%. Otherwise, the loan-to-value ratio will be lower than 100%. In this case, if the utility has enough internal liquidity or access to additional external finance sources to close the financing gap, it can finance the whole investment. Otherwise, the utility will be credit rationed and will have to downsize its investment plans.

In addition, banks can reduce the maximum loan-to-value ratio that they grant to their customers if they do not comply with macroprudential ratios and need to implement an adjustment plan. In this case, only highly liquid and profitable businesses will be able to obtain full external financing.

Non-compliance with macroprudential ratios has other consequences on banks financial decisions. In case of non-compliance with all macroprudential ratios, banks have to increase retained profits by cutting dividends to shareholders. In addition, if they do not comply with the LCR, they have to borrow reserves from the Central bank.

The Green CBDC policy therefore interacts with macroprudential regulation. When the central bank transfers CBDCs to the bank of a green utility, together with the corresponding deposit, the bank's liquidity coverage ratio improves. The bank can then reduce its demand for advances and increase its profit, thereby also improving the capital adequacy ratio, since CBDCs are risk-free assets, hence they do not contribute to the CAR. In other words, the policy has a direct effect, by financing green utilities that would otherwise be rationed, and an indirect effect, by easing banks' compliance with macroprudential ratios, on credit supply.

3.3 Utilities investment decisions and production plans

Energy utilities invest based on demand expectations and profitability. Demand expectations are captured by the rate of capacity utilization: an increased rate of capacity utilization suggests that demand is increasing and that productive capacity is likely to become short. In addition, investment can be stimulated by a rising return on equity (ROE) so long as investment decisions are taken by managers who target capacity expansion as a means of increasing power and legitimacy within the firm, but whose legitimacy with shareholders' depends on their capacity to generate profits and increase shareholders' value (Crotty, 1993; Jensen, 1993; Schoenberger, 1994; Hein et al., 2012). In this case, low profitability would push managers to intensify capacity utilization and postpone investments in order to satisfy shareholders demand for dividends.

Utilities production decisions depend, instead, on direct demand from the energy distributor, which purchases energy directly from utilities and then redistributes energy through its infrastructure to households, consumers and firms. The distributor selects utilities based on their relative price, such that the relative demand of energy to a utility is proportional to its relative competitiveness: if utility A charges half the price of utility B, utility A will have twice as much demand. If the demand for energy accruing to a utility is larger than its productive capacity, then the remaining demand is redistributed to the other utilities, such that ex post the demand of energy accruing to each utility can deviate from the relative price. Overall carbon emissions depend, therefore, on utilities' energy production and on the carbon content of each energy resource (green or brown), this latter being approximated by a fixed carbon content coefficient applied to every unit of energy produced, following Carnevali et al. (2024).

3.4 Utilities pricing decisions

Utilities set prices as a markup on unit labour costs. Wage growth results from bargaining with unions, whose demands reflect a national objective of reducing wage inequality across sectors (Piasna et al., 2024) and who benefit from low unemployment rates to exert higher pressures. It also results from workers' ability to negotiate higher wages within the firm, captured by the relative size and the cost competitiveness of the firm. Labour productivity grows with capital accumulation (Kaldor-Verdoorn effect), with wage growth, especially when unit labour costs rise above those of competitors and firms feel the pressure to increase productivity gains, and through imitation of sectoral leaders. The markup, as it is standard in the post Keynesian literature, depends on aggregate unemployment as well as on the market share and the rate of capacity utilisation. The full specification is reported in the appendix.

3.5 Fiscal policy

Government total spending consists of government consumption goods spending, unemployment subsidies paid to unemployed workers and interest payment on bonds. Moreover, the Government might be forced to bail out banks that default. Government fiscal receipts consist, instead, of total taxes on wages and dividends, and Central bank's dividends. Consequently, the fiscal deficit follows straightforwardly by summing up total expenditures and subtracting total tax and dividend revenues.

To finance the fiscal deficit, the Government issues treasury bonds that are purchased by commercial banks proportionately. In case of banks bailout, the Central bank purchases the treasury bonds issued to bail out commercial banks.

The Government can also implement a green fiscal policy consisting of purchasing green bonds issued by green energy utilities up to a fixed percentage of green utilities' investment plan. This possibility is explored in the second policy scenario (see section 4.3) in order to compare the specific macroeconomic and financial effects of a green fiscal policy compared to our green CBDC policy.

The main functions of fiscal policy, except when a green fiscal policy is explicitly introduced in scenario 2, are thus to create safe financial assets (bonds) for the banking sector and to stabilize business cycles by providing a stable flow of government consumption, by taxing wages and dividends and by financing unemployment subsidies.

3.6 Sequence of events

The model simulates the continuous interaction between the 8 institutional sectors of the economy. Every period of the model consists of a sequence of procedures:

- 1) Industrial relations take place. Labour unions bargain the wage rate, while businesses change labour organization to obtain labour productivity gains and set the mark-up and the price.
- 2) Businesses set their production and investment plans and ask for credit to finance their investment projects. After financing their investment, they send their production orders to suppliers.
- 3) The energy market opens. Firms buy energy from the distributor to launch production.
- 4) The labour market opens. Businesses hire workers based on their production plans and pay wages.