BANCA D'ITALIA
EUROSISTEMA

Temi di discussione

(Working Papers)

Macroeconomic effects of the green transition in the euro area and critical mineral bottlenecks

by Anna Bartocci, Alessandro Cantelmo, Pietro Cova and Massimiliano Pisani

April 2026

Number 1531

BANCA D'ITALIA
EUROSISTEMA

Temi di discussione

(Working Papers)

Macroeconomic effects of the green transition in the euro area and critical mineral bottleneckss

by Anna Bartocci, Alessandro Cantelmo, Pietro Cova and Massimiliano Pisani

Number 1531 - April 2026

ISSN 2281-3950 (online)

Designed by the Printing and Publishing Division of Banca d'Italia

MACROECONOMIC EFFECTS OF THE GREEN TRANSITION IN THE EURO AREA AND CRITICAL MINERAL BOTTLENECKS

by Anna Bartocci*, Alessandro Cantelmo*, Pietro Cova* and Massimiliano Pisani*

Abstract

As the green transition accelerates, access to critical minerals is becoming a strategic vulnerability for advanced economies. This paper examines the macroeconomic effects of international critical mineral shortages on the euro area using a New Keynesian model calibrated to the euro area, China, and the rest of the world. A supply cut from China – the leading global supplier – raises mineral prices, offsetting the boost to activity and the decline in energy inflation driven by green energy subsidies. These adverse effects are mitigated when other countries expand supply, leading to diversification, and are also mitigated in the short run if the installed capacity of green energy is sufficiently large. While the macroeconomic impact of shocks to the prices of critical minerals is smaller than that of shocks to the price of fossil fuels, this assessment could change as the green transition accelerates and the demand for minerals needed to produce energy and goods rises.

JEL Classification: D58, E52, Q43.

Keywords: critical minerals, energy policies, dynamic general equilibrium model, monetary policy, euro area.

DOI: 10.32057/0.TD.2026.1531

---

* Bank of Italy, DG for Economics, Statistics and Research. We thank Fabio Busetti, Michele Caivano, Noëmie Lisack, Virginia Di Nino, Stefano Neri, Luigi Federico Signorini and participants at the Joint 4th Annual Workshop of the ESCB Research Cluster in Climate Change & NGFS EN Research (2025) for useful comments. The views expressed in this paper are those of the authors alone and should not be attributed to the Bank of Italy or the Eurosystem. All remaining errors are ours. Correspondence: anna.bartocci@bancaditalia.it, alessandro.cantelmo@bancaditalia.it, pietro.cova@bancaditalia.it, massimiliano.pisani@bancaditalia.it.

1 Introduction

Global demand for critical minerals is rising. EU Member States require increasing quantities of these minerals to mainly support the green transition—boosting renewable energy production while reducing reliance on fossil fuels.[1] However, European countries face an exceptional challenge: they lack sufficient domestic production of critical minerals and must rely on imports from non-EU nations. This dependency mirrors their reliance on imported fossil fuels. Unlike the fossil fuel market, the critical minerals market is more concentrated, with a few countries—most notably China (CH) accounting for a large share of the global supply.[2] As a result, disruptions in the international supply of critical minerals could potentially impact the macroeconomic stability of European countries.

This paper examines the macroeconomic impact of disruptions in the international supply of critical minerals on the euro area (EA). The analysis is conducted using a three-country model of the global economy, calibrated to represent the EA as a single economic bloc (not as a monetary union), CH, and the rest of the world (RW). The main features of the model are the following ones. First, critical minerals play a dual economic role: alongside capital and labor, they are essential inputs for green energy production and for manufacturing goods such as batteries of electric vehicles. The model also includes a brown energy sector that relies on capital, labor, and fossil fuels. Outputs from both energy sectors form an aggregated energy bundle that, together with capital, labor, critical minerals, and petrochemical products (obtained from fossil fuel)

[1]The digital transition and higher military spending will also lead to higher demand for critical minerals. However, in this paper our main focus rests on higher demand related to the green transition.

[2]CH is also the largest source of demand for key critical minerals, far ahead of Europe, the United States, and Japan, which are also major consumers. On the supply side, both mining and, especially, refining activities are geographically very concentrated. CH's shares of both production phases amounted in 2024 to around 70% and 90% for rare earths and graphite. Focusing on the "key energy minerals" (copper, cobalt, lithium, nickel, graphite, and magnet rare earths) covered by International Energy Agency (2025), CH alone accounted for roughly 30% of the mining and 70% of the refining activity in 2024. Advanced economies' extraction and refining shares amounted instead only to respectively around 10% and 5%.

is used to produce intermediate manufacturing goods. These energy types also feed into a composite energy basket for household consumption. Second, like fossil fuels, critical minerals are internationally traded and priced in RW currency. Each country is endowed with one type of critical mineral, producing three imperfectly substitute minerals. The model is calibrated so that the EA is a net importer, while most global supply comes from CH and the RW.

Our analysis is based on counterfactual simulations. We build three scenarios to assess the role of critical minerals in the green transition. First, we evaluate the macroeconomic effects of higher demand of critical minerals in the EA by means of public subsidies to the production of green energy (green subsidies). Then, we study the case of 'green' subsidies accompanied by a reduction in the global supply of critical minerals by CH. Finally, we let the RW increase its supply of critical minerals to mimic a scenario in which the EA is able to increase more easily its imports from the RW. To gain further insights into the potential relevance of critical minerals' supply disruptions, we also simulate an exogenous reduction in the international supply of critical minerals and compare its effects with those of an analogous reduction in the international supply of fossil fuels under alternative assumptions about the weights of critical minerals and fossil fuels in energy production and in consumption.

The main results are as follows.[3] The surge in the international price of critical minerals that materializes if CH reduces the supply offsets the positive impact on economic activity of EU subsidies to the production of domestic green energy. These effects are mitigated if the RW increases its supply of critical minerals, allowing the EA to 'diversify' more easily its imports away from CH and, in the short run, if the installed capacity of green energy (e.g., in solar panels, batteries, wind turbines, and smart electrical grids) is sufficiently large.[4] We further find that, under current technologies, supply shocks

[3]Our results are not forecasts nor projections, but illustrative counterfactual simulations.

[4]Concordel and Knittel (2026) also emphasize the differential impacts of shocks to critical mineral prices and to oil prices on the economy. In their model critical mineral price shocks have smaller and

to critical minerals have smaller macroeconomic effects than similar fossil fuel shocks. However, as the green transition progresses and reliance on these minerals grows, especially in the production of manufactured goods, their macroeconomic impact could exceed that of fossil fuels. [5]

To the best of our knowledge, ours is the first paper to evaluate the macroeconomic effects of changes in the international price of critical minerals using a New Keynesian model. Boer et al. (2024) use a VAR to identify metal-specific demand shocks, estimate supply elasticity, and study the price impact of the transition to a net-zero scenario. According to their results, the prices of the main critical minerals would increase rapidly and remain close to historical peaks in real terms for an extended period. Miranda-Pinto et al. (2024) examine the role of metals as economic inputs by using a production network model and by estimating local projections. Their findings indicate that metals price shocks have significant and persistent effects on core and headline inflation. Different from them, we simulate a New Keynesian model and focus on the impact on output and inflation in the EA. Taboga (2024) finds that, in a scenario of accelerated green transition, the total market value of the main critical materials could reach approximately 1% of world GDP by 2030, with their prices all at their historical peak levels.[6] However, the potential impacts on inflation and output could be mitigated by several factors, including the increasing substitutability of critical materials due to technological advancements.

The paper is organized as follows. The next section describes model setup and calibration. Section 3 illustrates the simulated scenarios. Section 4 reports the results. Section 5 concludes.

more gradual impacts than oil price shocks, as they influence the cost of creating new capital and not the cost of utilizing the existing capital stock.

[5] Our working assumption is that an increase in the price of critical minerals is gradually passed through to the cost of producing green energy, as these materials enter installed production capacities, which remains unaffected by higher prices in the short run. The pass-through then gradually increases over time as production capacities are expanded. However, as the use of critical minerals in manufactures will become more pervasive a more rapid pass-through is to be expected.

[6] Total market value of the main critical minerals, according to data published in International Energy Agency (2025), was around USD 330 billions in 2024 (approximately 0.3% of world GDP).

2 Model

We provide the overview of the model (Section 2.1), describe the production of energy (Section 2.2), the production of intermediate goods (Section 2.3), the households' consumption basket (Section 2.4), the fiscal sector (Section 2.5), the monetary policy (Section 2.6), and the calibration (Section 2.7).

2.1 Overview

The model is New Keynesian (nominal wage and price rigidities hold) and includes the EA economy as a single bloc, CH and the RW (which therefore includes the US). The size of the world economy is normalized to 1. The EA, CH and, the RW have sizes equal to s^{EA}, s^{CH} and $1 - s^{EA} - s^{CH}$, respectively (with $0 < s^{EA}, s^{CH} < 1$, $s^{EA} + s^{CH} < 1$).[7]

Fig.1 highlights the role of critical minerals by showing the links between intermediate manufacturing (non-energy) sector, energy sector, final consumption goods sector, and investment goods sector. There are firms that produce (i) 'green' energy, (ii) 'brown' energy, (iii) intermediate traded goods, (iv) three final non-traded goods (private consumption, public consumption, and investment goods). Firms in the energy sector act under perfect competition.

Critical minerals are the key novel feature of the model. Each region has an exogenous endowment of a 'representative' critical mineral. Therefore, there are three critical minerals, one in each country. They are imperfect substitutes among one another, are exchanged in the international market and are priced in the RW currency (the international law of one price holds).[8] Their prices are flexible.[9] The minerals are 'critical'

[7]For each country, size refers to the overall population and to the number of firms operating in each sector. It is calibrated to match the GDP shares of each country.

[8]For simplicity we assume that the RW currency proxies the US dollar, which is the currency in which commodities and critical minerals are usually priced.

[9]Note that due to the presence of nominal rigidities in intermediate and final goods prices — which in turn affect exchange rate movements via the modified uncovered interest parity condition — the choice of currency denomination matters even if the underlying prices of critical minerals are flexible.

because, in each region, they are essential inputs in the production of green energy and intermediate goods. The bundle of critical minerals enters as input joint with domestic capital and labor in the production functions of green energy and, with also the domestic energy bundle (see below) in that of manufacturing goods. Specifically, critical minerals enter as a durable in the production of green energy and as a flow in the production of manufacturing goods. In this way, critical minerals are modeled as a stock in the production of energy (e.g., critical minerals in the photovoltaic panels) subject to adjustment costs and as an intermediate goods flow in the production of manufacturing goods (e.g., critical minerals in the batteries of smart phones). Crucially, and consistent with empirical evidence, we calibrate the model so that the EA holds a very low amount of critical minerals (the EA endowment is set very close to zero) and imports them from CH and, to a lesser extent, the RW. Moreover, we assume that firms in the green energy sector finance spending for inputs by issuing intra-period bonds to domestic households. The bonds pay the (risk-free) policy rate augmented by a premium proportional to the rise in the price of critical minerals. This financial friction captures the idea that higher critical mineral prices would deteriorate financial conditions of green firms. Additionally, there is a commodity representative of fossil fuels. Each country has an exogenous endowment of it. The fossil commodity is exchanged at international level and is priced in RW currency (the international law of one price holds). Similarly to the critical minerals, we assume that the price of the fossil commodity is flexible. It enters the production function of brown energy jointly with domestic capital and labor. Moreover, the fossil commodity enters the production of petrochemical products. The latter are obtained from the former via a (deliberately stylized) linear production function. Consistent with empirical evidence, we calibrate the model so that the EA does not hold fossil fuels and imports them from the RW and, to less extent, CH.

The two types of energy, green and brown, are nested into a CES energy bundle. The latter enters, joint with domestic value added, critical minerals, and petrochemical products in the CES production function of domestic intermediate manufacturing goods. The value added is produced according to a Cobb-Douglas production function whose inputs are domestic capital and labor. Moreover, energy enters domestic households' consumption as a CES bundle of energy services. Energy is not internationally traded.

Intermediate manufacturing goods are traded across countries. Each firm in the intermediate manufacturing sector acts under monopolistic competition, thus it has market power and sets domestic and foreign prices of its intermediate good taking into account the demand by firms in the local (i.e., country-specific) final sector and subject to quadratic price adjustment costs, which introduce short-run nominal price rigidities in the model. It combines value added (domestic capital and labor), critical minerals, petrochemical products, and energy to produce the intermediate manufacturing goods. Domestic and imported intermediate goods are assembled in private consumption, public consumption, and investment goods by firms in the domestic final good sector, under perfect competition according to a CES production function.

In each country households consume (subject to external habit) and invest in domestic and international short-term riskless bonds, in domestic physical capital, and in domestic critical minerals (which is a durable good). International bonds are traded between households of the three countries, and are denominated in RW currency, implying that a modified uncovered interest parity (UIP) condition holds for EA and CH, that links the differential between domestic and RW monetary policy rates to the expected nominal exchange rate depreciation of the domestic currency vis-à-vis the RW currency.[10] Both investments in physical capital and in (the stock of) critical minerals are subject to quadratic adjustment costs. Households also trade in domestic intraperiod bonds, that finance firms in the green energy sector (see Section 2.2).

Households own domestic firms and get profits in a lump-sum way. They supply

[10]A standard adjustment cost in the net foreign asset position is added to the UIP condition to guarantee the stability of the model.

differentiated labor services to domestic firms and act as nominal wage setters in monopolistic competitive labor markets, as they charge a wage markup over their marginal rate of substitution between consumption and leisure. Nominal wage decisions take into account labor demand by firms and are subject to quadratic adjustment costs. Labor and capital are freely mobile across domestic sectors.

In each country, the fiscal authority can subsidize the inputs of the green energy production. Lump-sum taxes ensure that in each period the government budget constraint is balanced.

Finally, in each country, the central bank sets the policy rate according to a Taylor-type rule to stabilize domestic inflation and economic activity.

We consider a symmetric equilibrium. In each country there is a representative household and a representative firm in each sector. In what follows, we report key equations for the EA. Similar equations hold for CH and the RW.

2.2 Critical minerals in the production process

The supply of critical minerals, $CM_t^{s,j}$, is fixed, i.e., in every period each bloc (EA, CH, and RW) has an exogenous endowment which may be subject to exogenous variations. Moreover, the three blocs exchange the critical mineral in the international market. The endowment of critical mineral is:

$$CM_t^{s,j} = \overline{CM}^{s,j}(1 + \varepsilon_t^{CM^{s,j}}), \tag{1}$$

where $j = EA, CH, RW$. $\overline{CM}^{s,j}$ is the steady-state country-specific endowment and $\varepsilon_t^{CM^{s,j}}$ is the shock to the supply of critical minerals.[11]

For green energy we assume a CES production function with a low elasticity of substitution among inputs (see calibration in Section 2.7) to capture the complementarity

[11] The supply of fossil fuels is modeled in an analogous way.

between critical minerals, capital, and labor. Thus, green energy, denoted by $EN_{g,t}$, is produced by firms under perfect competition according to the production function

$$EN_{g,t}^{\frac{\rho_{EN_g}-1}{\rho_{EN_g}}} = \gamma_{g,CM}^{\frac{1}{\rho_{EN_g}}} CM_{g,t}^{S\,\frac{\rho_{EN_g}-1}{\rho_{EN_g}}} + \gamma_{g,K}^{\frac{1}{\rho_{EN_g}}} K_{g,t}^{\frac{\rho_{EN_g}-1}{\rho_{EN_g}}} + (1-\gamma_{g,K}-\gamma_{g,CM})^{\frac{1}{\rho_{EN_g}}} L_{g,t}^{\frac{\rho_{EN_g}-1}{\rho_{EN_g}}}, \tag{2}$$

where $CM_{g,t}^S$, $K_{g,t}$, and $L_{g,t}$ are the inputs, i.e. the stock of critical minerals, physical capital, and labor, respectively. The parameters $\gamma_{g,CM}$ and $\gamma_{g,K}$ $(0 < \gamma_{g,CM}, \gamma_{g,K} < 1, \gamma_{g,CM} + \gamma_{g,K} < 1\ )$ are the weights of critical minerals and capital, respectively. The parameter $\rho_{EN_g} > 0$ is the elasticity of substitution among the different inputs. In the above equation $CM_{g,t}^S$ is the installed stock of critical minerals - a proxy for installed capacity - which evolves according to a standard accumulation equation:

$$CM_{g,t}^S = (1-\delta_{critmin})CM_{g,t-1}^S + CM_{g,t}\left(1 - \frac{\psi_{CM,EA}}{2}\left(\frac{CM_{g,t}}{CM_{g,t-1}} - 1\right)^2\right) \tag{3}$$

where $0 < \delta_{critmin} < 1$ is the depreciation rate of the stock of critical minerals and $\psi_{CM,EA} > 0$ is a parameter governing the strength of the quadratic adjustment costs of changes in critical minerals. Also, the flows of critical minerals, $CM_{g,t}$, that add to the stock of critical minerals used in the production of green energy, $CM_{g,t}^S$,are both domestic and imported and are combined by a zero-profit bundler according to a CES structure:

$$CM_{g,t}^{\frac{\theta_{CM_g}-1}{\theta_{CM_g}}} = \gamma_{CM,EA}^{\frac{1}{\theta_{CM_g}}} CM_{g,EA,t}^{\frac{\theta_{CM_g}-1}{\theta_{CM_g}}} + \gamma_{CM,CH}^{\frac{1}{\theta_{CM_g}}} CM_{g,CH,t}^{\frac{\theta_{CM_g}-1}{\theta_{CM_g}}} + (1-\gamma_{CM,EA}-\gamma_{CM,CH})^{\frac{1}{\theta_{CM_g}}} CM_{g,RW,t}^{\frac{\theta_{CM_g}-1}{\theta_{CM_g}}}, \tag{4}$$

where $CM_{g,j,t}$, $j = EA, CH, RW$, are the country-specific components of the bundle with corresponding weights $\gamma_{CM,j}$ $(0 < \gamma_{CM,EA}, \gamma_{CM,CH} < 1, \gamma_{CM,EA} + \gamma_{CM,CH} < 1)$, and $\theta_{CM_g} > 0$ is the elasticity of substitution among critical minerals.

The demand for the country-specific critical mineral is

$$CM_{g,j,t} = \gamma_{CM,j} \left(\frac{p_{CM,j,t}}{p_{CM,t}} \right)^{-\theta_{CM_g}} CM_{g,t}, \tag{5}$$

where $p_{CM,j,t}$ is the price of the critical mineral from country j converted in domestic currency, while $p_{CM,t}$ is the corresponding price index for the bundle of imported critical minerals.

The firm producing green energy chooses critical minerals, capital, and labor to maximize profits subject to the technology constraint (Eq. 2), taking prices as given.

The first order condition with respect to the stock of critical minerals $CM_{g,t}^S$ is

$$CM_{g,t}^S = \gamma_{g,CM} \left(\frac{r_{CM,t} \times (1 - subs_{g,t})}{p_{g,t}} + r_t + \chi \left(\frac{p_{CM,t}}{\overline{p}_{CM}} - 1 \right) \right)^{-\rho_{EN_g}} EN_{g,t}, \tag{6}$$

The demand for the additional new stock of critical minerals depends thus negatively on its rental rate, $r_{CM,t}$, relative to $p_{g,t}$, the price of green energy, i.e. the marginal cost to producing green energy, net of $subs_{g,t} > 0$, a subsidy rate by the domestic government to the production of green energy. Demand also accounts for a financial friction incurred by firms, which is modeled as a spread over the (net) risk-free rate, r_t, proportional to the deviation of the price of critical minerals, $p_{CM,t}$ from its steady state value, $\overline{p}_{CM}$, with $\chi > 0$ the factor of proportionality.[12] Note that $p_{CM,t}$ is the price of critical minerals in domestic currency, which is equal to the international price of critical minerals, set in RW currency, times the nominal exchange rate of the EA currency vis-à-vis the RW currency.

[12]As explained in the main text this financial friction captures the fact that firms in the green energy sector need to finance their spending on inputs by issuing intra-period bonds to domestic households. These bonds pay the (risk-free) policy rate augmented by a premium proportional to the rise in the price of critical minerals.

A slightly more simplified structure applies to the production of brown energy, $EN_{b,t}$ and to the global supply and demand of the brown source (which is exchanged in the international market and priced in RW currency). The main difference compared to green energy production consists in the fact that the fossil input enters directly as a flow in the production function for brown energy.

In the simulations below we further assume that firms in the green energy sector only gradually adjust their input demands relative to the baseline (pre-shock) values in response to supply (price) shocks to critical minerals. This assumption is meant to capture that in the short run the installed capacity of green energy (e.g., in solar panels, batteries, and wind turbines) insulates firms from the increase in the price of critical minerals (and the other inputs used to produce green energy). Technically, we modify equation (6), the demand for inputs in the green energy sector, by modeling it as a weighted average of baseline (initial steady-state) values and after-shock values, with the weights summing to one. In the simulations we allow the weight on the steady-state (after-shock) value to gradually decrease (increase), in an exogenous way, from one to zero (from zero to one) in the first twelve periods. More specifically, the demand for the stock of critical minerals - the same formulation also holds for capital and labor - obeys the following equation:

$$CM_{g,t}^{S} = \Theta_t^S \overline{CM}_g^S + (1-\Theta_t^S)\gamma_{g,CM} \left(\frac{r_{CM,t} \times (1 - subs_{g,t} + r_t + \chi(\frac{p_{CM,t}}{\overline{p}_{CM}} - 1))}{p_{g,t}} \right)^{-\rho_{EN_g}} EN_{g,t}, \quad (7)$$

where $\overline{CM}_g$ is the installed stock of critical minerals - a proxy for installed capacity - which firms in the green energy sector gradually adjust over time at a speed that depends on $(1-\Theta_t^S)$ with $0 < \Theta_t^S < 1$. This formulation allows us to capture the feature that the installed stock of inputs, i.e. installed capacity, can only be gradually adjusted. Thus, adjustment depends temporally on how quickly $(1-\Theta_t^S)$ tends to 1 and, once adjustment has started, its intensity depends on how costly it is financially to adjust, which in turn depends on the parameter χ. In a model that also accounts for a gradual impact of critical minerals price shocks, Concordel and Knittel (2026) impose that investments in critical minerals can be directly converted, with some exogenous efficiency loss, into productive capital. Thus, differently from our setup, critical minerals do not enter as a separate input factor in the production process. Finally, they also assume that firms must recur to external borrowing and are subject to a risk premium, in order to finance their capital accumulation and hence their investments of critical minerals.[13]

2.3 Production of intermediate goods

There is a (representative) profit-maximizing firm that operates under monopolistic competition and produces the intermediate (non-energy) manufacturing good Y_t according to a technology that combines valued added $VA_{y,t}$, critical mineral $CM_{y,t}$, petrochemical products $PC_{y,t}$, and the energy bundle $EN_{y,t}$:

$$Y_t^{\frac{\rho_Y - 1}{\rho_Y}} = \gamma_{pr_{y,EN}}^{\frac{1}{\rho_Y}} EN_{y,t}^{\frac{\rho_Y - 1}{\rho_Y}} + \gamma_{pr_{y,CM}}^{\frac{1}{\rho_Y}} CM_{y,t}^{\frac{\rho_Y - 1}{\rho_Y}}$$
$$+ \gamma_{pr_{y,PC}}^{\frac{1}{\rho_Y}} PC_{y,t}^{\frac{\rho_Y - 1}{\rho_Y}} + (1 - \gamma_{pr_{y,EN}} - \gamma_{pr_{y,CM}} \gamma_{pr_{y,PC}})^{\frac{1}{\rho_Y}} VA_{y,t}^{\frac{\rho_Y - 1}{\rho_Y}}, \quad (8)$$

where the parameters $\gamma_{pr_{y,EN}}$ and $\gamma_{pr_{y,CM}}$ $(0 < \gamma_{pr_{y,EN}}, \gamma_{pr_{y,CM}}, \gamma_{pr_{y,PC}} < 1,\ \gamma_{pr_{y,EN}} + \gamma_{pr_{y,CM}} + \gamma_{pr_{y,PC}} < 1)$ measure the weight of energy, critical minerals, and petrochemical products, respectively.[14] The parameter $\rho_Y > 0$ is the elasticity of substitution among inputs. For simplicity we assume that the petrochemical products are produced from

[13] However, in their small open economy model the external finance premium depends on the aggregate debt-to-capital ratio and all lending is done by foreigners, who hold intertemporal claims (external debt) on the domestic economy. In our setup, as already explained, this financing premium depends on deviations of critical mineral prices from some reference (steady-state) value and is paid by firms in the green energy sector to finance their spending on inputs by issuing *intra-period* bonds to domestic households.

[14] Note that, differently from green energy production, in Eq.(8) critical minerals enter as a flow and not as a stock.

fossil fuels according to a linear production function. The value added is

$$VA_{y,t} = K_{y,t}^{\gamma_{pr_{va,k}}} L_{y,t}^{1-\gamma_{pr_{va,k}}}, \tag{9}$$

where $K_{y,t}$ is physical capital and $L_{y,t}$ is labor. The parameter $\gamma_{pr_{va,k}}$ $(0 < \gamma_{pr_{va,k}} < 1)$ is the elasticity of value added with respect to capital.

The production of intermediate goods uses both domestic and imported critical minerals, combined according to a CES bundle, as in Eq.(4). The demand of critical minerals is determined by the following first order condition

$$CM_{y,t} = \gamma_{pr_{y,CM}} \left(\frac{p_{CM,t}}{mc_{y,t}} \right)^{-\rho_Y} Y_t, \tag{10}$$

where $mc_{y,t}$ is the marginal cost of producing manufacturing goods.

The energy bundle used in the production of the intermediate (non-energy) good combines the two sources of energy, $EN_{g,t}$ and $EN_{b,t}$:

$$EN_{y,t}^{\frac{\rho_{EN}-1}{\rho_{EN}}} = \gamma_{pr_{y,g}}^{\frac{1}{\rho_{EN}}} EN_{g,t}^{\frac{\rho_{EN}-1}{\rho_{EN}}} + (1-\gamma_{pr_{y,g}})^{\frac{1}{\rho_{EN}}} EN_{b,t}^{\frac{\rho_{EN}-1}{\rho_{EN}}}, \tag{11}$$

where $\gamma_{pr_{y,g}} (0 < \gamma_{pr_{y,g}} < 1)$ measures the weight of green energy in the bundle and the parameter $\rho_{EN} > 0$ is the elasticity of substitution among the different types of energy.

Given the marginal cost of production, the firm in the intermediate manufacturing sector acts under monopolistic competition, thus it has market power and sets domestic and foreign prices of its intermediate good taking into account the demand by firms in the local (i.e., country-specific) final sector and subject to quadratic price adjustment costs, which introduce short-run nominal price rigidities in the model.

2.4 Final consumption basket

The final consumption basket C_t is a CES bundle of (non-energy) intermediate manufacturing consumption basket $C_{manu,t}$ and of energy basket $C_{EN,t}$:

$$C_t^{\frac{\rho_C - 1}{\rho_C}} = \gamma_{pr_{c,manu}}^{\frac{1}{\rho_C}} C_{manu,t}^{\frac{\rho_C - 1}{\rho_C}} + (1 - \gamma_{pr_{c,manu}})^{\frac{1}{\rho_C}} C_{EN,t}^{\frac{\rho_C - 1}{\rho_C}}, \tag{12}$$

where the parameter $\gamma_{pr_{c,manu}}$ $(0 < \gamma_{pr_{c,manu}} < 1)$ measures the weight of the non-energy final consumption basket in the overall consumption bundle. The parameter $\rho_C > 0$ is the elasticity of substitution between non-energy and energy consumption. The non-energy consumption basket is a CES of domestic and foreign consumption manufacturing goods. The latter are bundles of goods produced by firms in the domestic and foreign intermediate sectors, respectively.[15]

The energy consumption bundle $C_{EN,t}$ has the same structure as the energy bundle used in the production of the intermediate (non-energy) good (see Eq. 11).

2.5 Government budget constraint

The EA (representative) government budget constraint is assumed to be balanced on a period-by-period basis:

$$\begin{aligned} TAX_t &= p_{EA,t} G_t \\ &+ s^{EA} \times subs_{g,t} \times (r_{k,t} \times K_{g,t} + w_t \times L_{g,t} + p_{CM,t} \times CM_{g,t}), \end{aligned} \tag{13}$$

where TAX_t are lump-sum taxes paid by the domestic household, G_t is government purchases of goods and services (i.e. public spending for consumption), $r_{k,t}$ and w_t are the return on capital and labor wage, respectively. Consistent with the empirical

[15] The final investment good is a CES bundle of domestic and foreign investment manufacturing goods. Differently from the consumption good, the investment good does not have an energy component.

evidence, G_t is fully biased towards the domestic intermediate manufacturing good. Therefore, it is multiplied by the corresponding price index $p_{EA,t}$.[16] Moreover, it is kept constant at its steady-state level when simulating the model.

2.6 Monetary policy

We assume the following specification for the monetary policy rule:

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_r} \left(\frac{\pi_t}{\bar{\pi}}\right)^{(1-\rho_r)\rho_\pi} \left(\frac{y_t}{y_{t-1}}\right)^{(1-\rho_r)\rho_y} . \tag{14}$$

The rule describes how the central bank conducts its monetary policy. The variable R_t is the gross policy rate and $\bar{R}$ its steady-state value. The parameters $0 \leq \rho_r \leq 1$, $\rho_\pi > 0$, and ρ_y measure the sensitivity of the policy rate to its lagged value, to the domestic (quarterly) gross inflation rate (in deviation from the target $\bar{\pi}$), and to the quarterly gross growth rate of domestic output y (y_t/y_{t-1}), respectively. The lagged interest rate ensures that the policy rate is adjusted smoothly and captures the idea that the central bank prefers to avoid large sudden changes in its policy instrument.

2.7 Calibration

The model is calibrated at quarterly frequency. The chosen calibration allows our model to adequately capture the dynamics of the main EA variables.[17] It is assumed that CH and the RW have the largest endowment of critical minerals and fossil fuels, respectively. EA corresponding endowments are assumed to be close to zero.

Table 1 reports the (flexible-price) steady-state equilibrium. Private consumption, public consumption, investment, and imports in the EA are set to 60%, 20%, 20%, and 25% of GDP, respectively. These values are in line with the literature. For the case of

[16] See Corsetti and Müller (2006).

[17] For example, we check that the dynamics following a monetary policy shock in the EA are in line with Warne et al. (2008)

CH investment is calibrated to a lower value than in the data for numerical reasons. The EA is a net importer of critical minerals, amounting to about 0.1% of GDP. The shares of critical minerals within the production of green energy and within the production of the intermediate good are set to 4.4% and 0.2%, respectively.[18] The energy share in the firms' production cost is set to 7.8% and to 4.9% in the households' consumption basket. These shares allow for a response of inflation and economic activity to an oil price shock in line with the literature.

Table 2 shows parameters regulating preferences and technology of intermediate and final goods. The elasticity of intertemporal substitution is set to 1 (i.e., log preferences in consumption). The discount factors is set to 0.995. The consumption habit parameter is set to 0.9, while the Frisch labor elasticity is set to 0.4. The production functions and the consumption baskets are calibrated in line with the literature and according to the following criteria. The elasticities of substitution between inputs in the production function of the intermediate manufacturing good and between non-energy and energy consumption in the final consumption basket are lower than one. The elasticity of substitution between the domestic and imported critical minerals is set to 1.50. For final goods, the elasticity of substitution between domestic and imported intermediate manufacturing goods is 1.5, in line with Varga et al. (2022)

Table 3 contains parameters of the energy production technologies.

The elasticity of substitution among energy types is higher than one ($\rho_{EN} = 1.20$), in line with Papageorgiou et al. (2017) and Jo (2025).[19] The elasticity of substitution between production factors is 0.3. Thus, we assume high complementarity.[20] As for intermediate goods, the elasticity of substitution between the domestic and imported

[18] These shares are consistent with the average values reported in International Monetary Fund (2023). While in general critical minerals are very pervasive in goods' production, some goods (electric vehicles, batteries, and wind turbines) are highly dependent on critical minerals, while for most other goods the share of critical minerals is very low.

[19] Jo (2025) estimates that in the long run the elasticity is around 3.

[20] A value lower than one is in line with Golosov et al. (2014), Annicchiarico et al. (2017) and International Monetary Fund (2023).

critical minerals is set to 1.50.

Table 4 reports the markups and the elasticities of substitution among intermediate brands and among labor varieties. They are set to 6 and 4.3, respectively, which correspond to steady-state mark-ups of 1.2 and 1.3.

Table 5 contains the adjustment costs. The investment adjustment cost is equal to 5 for investment in physical capital and to 15 for investment in critical minerals (which is a durable good).[21] Concerning nominal rigidities, the parameter measuring the cost for adjusting the price of goods is set to 600. The one for adjusting nominal wages is set to 300. The parameter that measures the degree of indexation to previous-period inflation is set to 0.8 for prices and 0.75 for wages.[22]

Table 6 reports the parameters of the monetary policy rule. The response to inflation, ρ_π, is relatively large and equal to 1.7, consistent with the estimated value reported by Warne et al. (2008). The policy rate is adjusted gradually, given that the coefficient measuring the inertia in interest rate setting, ρ_r, is set to 0.90. The response to output growth, ρ_y, is set to 0.1.

3 Scenarios

We initially simulate a sudden and permanent increase, from 0% to 30%, in government subsidies to the inputs of green energy production (i.e., green capital, green labor, and critical minerals).[23] This way we can generate an endogenous increase in the demand of critical minerals for the green transition in the EA and evaluate the implied macroeconomic effects. In the second scenario, we add to the first scenario an illustrative (sudden

[21] This higher value, compared to the adjustment cost for investment in physical capital, is needed to guarantee the stability of the model.

[22] The corresponding Calvo (1983) probabilities of not adjusting prices and wages are 0.91 and 0.75, respectively.

[23] According to available estimates, additional investments in capital expenditure and low-carbon emitting durable consumption goods should amount each year between 2.7% and 3.7% of GDP, to reduce greenhouse gas (GHG) emissions by 55% from 1990 levels by 2030 (Andersson and Nerlich (2025)).

and permanent) 30% reduction in the international supply of critical minerals by CH (the RW supply of critical minerals is kept constant). The size of this shock is chosen such as to obtain a doubling in the prices of critical minerals prices exported by CH. This doubling of prices corresponds approximately to the historical peak in the prices of critical minerals documented in Taboga (2024). In the third scenario we assume that the supply of critical minerals increases by 10% in the RW while still decreasing by 30% in CH. This way it is easier for the EA to diversify across suppliers, whereby the reduced supply of critical minerals by one bloc is, at least partly, compensated by higher EA imports from the other bloc. The size of the shock is chosen to account for the fact that global production (i.e. mining and refining) is controlled for an estimated 60%-90% by CH (International Energy Agency, 2025), depending on the specific mineral considered. As such, in the short term the RW could at most make up for one third of the supply cut from CH. In all scenarios we assume that in the eighteen quarters after the shock firms in the green energy sector change only gradually their (optimal) input demands relative to the baseline (pre-shock) values. Thus, their output also gradually changes. In this way we capture the notion that in the short run the installed capacity of green energy shields firms from the increase in the price of critical minerals. Starting from the nineteenth quarter firms fully adjust their input demand, which, thus, fully incorporates the higher price of critical minerals. We then run a robustness analysis by changing the values of the elasticity of substitution among the critical minerals and the weights of critical minerals in the productions of green energy and manufacturing goods.

Finally, we run a set of simulations to compare the transmissions to the EA macroeconomic variables of shocks to the international supply of critical minerals and of shocks to the international supply of fossil fuels.

All simulations are run under perfect foresight. Households and firms perfectly anticipate the path of the shocks and are surprised only in the initial period of the simulations.

4 Results

4.1 Benchmark scenario

Fig. 2 reports the effects of an increase, from 0% to 30%, in the EA subsidies ($subs_{g,t}$ in Eq. 13) to the inputs - physical capital, labor, and critical minerals - for producing domestic green energy (solid lines). Capital to produce green and brown energy increases and declines, respectively. Similar responses hold for corresponding labor inputs. Crucially, firms producing green energy increase their demand for critical minerals. Given the constant global supply of critical minerals, the higher demand induces a 6% increase in the international price (denominated in the RW currency) of critical minerals. Production of green and brown energy respectively increases and declines, because the former has become cheaper than the latter. Given the limited substitutability between the brown and green energies (the elasticity of substitution ρ_{EN} is calibrated to 1.2), the fall in brown energy (and its inputs) is more limited than the increase in green energy. Overall production of energy increases.

Production of the manufacturing goods rises, in a rather limited way. The subsidy to green energy makes energy overall cheaper and, thus, also the production of manufacturing goods. Firms increase their demand for labor and capital. They reduce demand for critical minerals, that have become more expensive, because of the higher demand of the green energy sector. However, the reduction is rather contained, because the elasticity of substitution among inputs is rather limited.

Fig. 3 shows the effects on the EA macroeconomic variables. Notwithstanding the decline in the energy component of inflation, overall headline inflation slightly rises, roughly by 0.1 percentage points (pp) at the peak after 8 quarters. The central bank, consistent with the Taylor rule, increases the policy rate. The higher aggregate demand driven by the green subsidies induces firms to increase production, which leads to a sustained and prolonged increase in investments. Consumption rises as well both of energy and manufacturing goods, because of the complementarity among them. Overall, GDP rises by around 0.4% in the medium run. The expansion in the EA economic activity is persistent, because the increase in subsidies is long-lasting.

The higher monetary policy rate drives the persistent appreciation of both the EA real exchange rates vis-à-vis CH and the RW. Consistent with the higher EA aggregate demand and with the domestic appreciation the EA imports of manufacturing goods increase. At the same time, EA exports fall because CH and RW aggregate demands fall to increase savings and, thus, finance the higher EA aggregate demand.

Overall, the EA green energy subsidies induce higher EA imports of critical minerals, needed to produce green energy. Even if the price of critical minerals significantly increases, the subsidy has expansionary macroeconomic effects on the EA, because it has persistent expansionary effects on the EA supply side. The latter favors the EA households' permanent income and thus the EA aggregate demand.

4.2 Disruptions in the international supply of critical minerals

Fig. 2 also reports responses of the EA sector-specific variables when the EA green subsidies, that generate higher EA demand of critical minerals, are accompanied by an illustrative 30% sudden and permanent (exogenous) reduction in the (international) supply of critical minerals in CH (red-dashed lines).

Relative to the benchmark scenario, the international prices of critical minerals increase by more. Thus, firms in the green energy sector reduce the use of critical minerals. They partially substitute labor and capital - both inputs are subsidized as well - for critical minerals to increase the production of green energy. The rise in the production of green energy is significantly smaller, because of the higher price of critical minerals. The combination of smaller increase in green energy and the drop in brown energy reduces the availability of the overall energy. Manufacturing production remains virtually unchanged, because of the higher production costs.

Fig. 3 shows the responses of the EA macroeconomic variables. Relative to the benchmark scenario, households reduce overall consumption, the consumption of energy and, given the complementarity relationship, the consumption of the non-energy basket (the two components are not reported to save on space). Households increase investment in physical capital to a less extent. The lower aggregate demand limits the increase output (relative to the benchmark scenario). Inflation rises to a lower extent than in the benchmark scenario, because of the reduced increase in aggregate demand. Thus, the EA central bank needs to increase the policy rate by less to guarantee the stabilization of inflation. Correspondingly, the real exchange rate appreciates by less than in the benchmark scenario and the EA experiences a smaller contraction in its exports of manufacturing goods to CH and RW. Similarly, EA imports of manufacturing goods from both CH and the RW are both lower, consistent with the now weaker expansion in EA aggregate demand.

Overall, when the EA demand of critical minerals increases in a context of reduced international supply, the real effects on the EA economic activity can be persistently negative. The EA is an importer of critical minerals. Thus, it suffers a negative wealth effect associated with the persistent increase in the international price of critical minerals. This negative effect on the EA economy can, if sufficiently large, offset the favorable effect of the higher green subsidies.

4.3 Diversification of supply sources

We now simulate a scenario in which, suddenly and permanently, CH reduces its supply of critical minerals by 30% and, at the same time, the RW increases its supply by 10%[24]. In this (illustrative) scenario the higher RW supply allows the EA to diversify in an easier

[24] We only consider a 10% increase due to the relatively small RW endowment of critical minerals and its relatively larger size compared to CH

way across international suppliers of critical minerals.

Fig. 2 reports the results (scenario 'diversification', blue line with crosses). The international prices of the critical minerals paid by the EA increase to a lesser extent than in the scenario 'lower supply', as now prices of critical minerals imported from the RW fall. The new price levels are nonetheless higher than the corresponding levels in the benchmark scenario.

Relative to the previous 'lower supply' scenario, green energy increases, favoring the increase in overall energy. The relatively cheaper energy limits the rise in production costs of manufacturing goods. Thus, firms in the manufacturing sector raise capital and labor more in line with the benchmark scenario. Their production expansion is close to that observed in the benchmark case.

Fig. 3 contains the responses of the main EA macroeconomic variables. Relative to the scenario 'lower supply', inflation rises more and in line with the benchmark scenario, because of the stronger increase in aggregate demand. Consumption and investment rise relatively more. EA imports increase more than in the scenario 'lower supply', given the relatively higher EA aggregate demand. The latter and the stronger increase in the policy rate also induce the euro to appreciate by more in real terms than in the scenario 'lower supply'.

Overall, the EA can limit the domestic macroeconomic damages due to the international supply restriction of critical minerals by one trade partner if it can diversify across international suppliers.

4.4 The role of installed capacity

Fig. 4 compares responses to an exogenous increase in the international price of critical minerals, due solely to a sudden supply cut by CH of 30%, under the alternative assumptions that (a) the firms in the green energy sectors immediately adjust their input demand and, thus, their production (red dashed lines) and (b) they adjust inputs (only) gradually over time (our benchmark assumption, black continuous line). In this way we investigate the role of installed capacity for the propagation of the shock. The short-run impact of the shock is stronger when firms immediately adjust their inputs. Green energy production immediately drops, driving down overall energy. This immediately and negatively affects labor and capital in the manufacturing sector, that immediately decreases.

Fig. 5 compares the macroeconomic effects. In the sudden adjustment case GDP immediately falls, as both consumption and investment decrease more rapidly. Inflation instantly spikes, inducing the central bank to raise the policy rate. Instead, in the case of a gradual adjustment, inflation barely increases, as the costs of producing green energy do rise only in a gradual way and the central bank mildly decreases the policy rate to offset the (smaller) reduction in economic activity.

Overall, the installed capacity of green energy can thus isolate in the short run the EA from the increase in the price of critical minerals.

4.5 Robustness analysis

We conduct a robustness analysis of the results of the scenario 'diversification' by changing the values of two parameters. Relative to the benchmark calibration, we initially assume a lower value of the elasticity of substitution among critical minerals. Then, we keep the elasticities at their benchmark values and we increase the weight of critical minerals in the production of manufacturing goods and green energy. Thus, we adopt, in principle, the most unfavorable calibration with respect to the benefits of diversification. However, we cannot rule out that, under an accelerated ecological transition, the substitutability of critical materials may increase as a result of technological progress (Taboga, 2024).

4.5.1 The elasticity of substitution among critical minerals

We reduce the elasticity of substitution among critical minerals to 0.5 (1.5 in the benchmark calibration) and newly run the scenario 'diversification'.

Fig. 6 contains the responses of the main EA variables. The results (red dashed line) are not very different from those in the benchmark scenario (black continuous line). The EA output increases slightly more, driven by the bigger increase in consumption and investment. Inflation rises on impact slightly more than in the benchmark calibration. The additional increase in economic activity is due to the stronger drop in the price of the RW critical minerals, that has a favorable effect on the EA purchasing power. The RW critical minerals' price has to decline, in the aftermath of the increase in its supply, to clear the market, because it is more difficult to substitute one critical mineral for another. The favorable effect of the lower price on the EA is large enough that the EA firms can import both CH and RW critical minerals to a larger extent.

4.5.2 The weight of critical minerals in the production of manufacturing products and green energy

Next, we check the robustness of the results to the weights of critical minerals in the production of green energy and manufacturing goods. We increase them by 30% to mimic a scenario in which the use of critical minerals is permanently higher due to the green transition. Specifically, in Eq. (2) we increase $\gamma_{g,CM}$ from 0.36 to 0.47 and at the same time we reduce $\gamma_{g,K}$ from 0.5 to 0.39 (so that the sum of the three weights continue to be equal to 1). Similarly, in Eq. (8) we increase $\gamma_{pr_{y,CM}}$ from 0.05 to 0.065 and reduce the weight of value added from 0.84 to 0.73.

Fig. 7 reports the responses of the main EA variables (red line with dots is the case of higher weight of critical minerals, black line the benchmark calibration). Under the new calibration the increase in GDP is slightly smaller because of the more contained rise in consumption and investment. Inflation does not greatly change across the two scenarios, because the additional effect of the larger weight is absorbed to a large extent by the firms' (short-run) mark-ups.

4.6 Comparing lower supply of green and brown energy commodities

To gain further insights into the potential relevance of critical minerals' supply disruptions, we compare the transmission of a shock to the supply of critical minerals with that of a similar shock to the supply of fossil fuels.[25] Each shock to the corresponding international supply is modeled as an AR(1) process, with persistence equal to 0.90. The size of the shock is such that on impact the corresponding international price (denominated in the RW currency) rises by roughly 10% of its (before-shock) value.

Fig. 8 contains the results. The effects of both shocks are stagflationary (black line and red line with dashes in the case of the shock to fossil fuel and critical mineral supply, respectively). Both shocks induce a short-lived increase in EA headline inflation and a persistent output decline in the medium run. Consumption and investment drop, because of the adverse effects of the shocks on the income of households. For the same reason, households initially increase their supply of labor. The central bank raises the policy rate in the short run, to stabilize inflation. The macroeconomic effects of the lower supply of fossil fuels are bigger than those of the lower supply of critical minerals. Brown energy has a larger weight than green energy in the overall energy basket, used in the production of manufacturing goods and for consumption purposes. Moreover, fossil fuels also directly affect the cost of production of intermediate goods via petrochemicals. Thus, fossil fuels affect to a larger extent the production costs and prices of manufacturing goods and the energy component of the consumption baskets.

To further evaluate the macroeconomic effects of the shock to the international supply

[25] We assume that the shock originates from the largest supplier, i.e. CH in the case of critical minerals and RW in the case of fossil fuels.

of critical minerals, we assume that green energy and brown energy have equal weights in the aggregate energy bundle and that the weight of critical minerals in the production function of intermediate goods doubles, compared to the baseline calibration (to 0.10 from 0.05). This doubling is roughly consistent with the most optimistic projections on the uptake of critical minerals in International Energy Agency (2025).[26] Fig. 9 shows that in this case the macroeoconomic effects of a negative supply shock to critical minerals are larger compared to the ones associated to a negative supply shock to fossil fuels. In particular, GDP contracts by roughly 0.1% compared to 0.06%. The peak increases in headline inflation are roughly similar (inflation is slightly more persistent in the case of the supply shock to critical minerals). The energy component of inflation rises less in the case of the supply shock to critical minerals than in the case of the supply shock to fossil fuel. Instead, the non-energy component rises more. This stems from the fact that critical minerals directly affect the cost of producing intermediate goods, whose prices are sticky and as such have a more persistent effect on headline inflation via the 'no energy' core inflation rate.[27]

Overall, the macroeconomic effects of a lower supply of critical minerals are smaller than those of a comparable lower supply of fossil fuels, under current production technology conditions. However, as the green transition will proceed, the use of critical minerals will increase, both for producing energy and as inputs in goods production, while, likely, the use of fossil fuels will decline. Thus, the macroeconomic effects of negative supply shocks to critical minerals could become even stronger than that of comparable shocks to the supply of fossil fuels. Moreover, for the EA the relevance of the 'fossil fuels and critical minerals import' channels could be not negligible, as long as the EA imports of both fossil fuels and critical minerals will remain significant over time.

[26] According to the Net Zero Emissions by 2050 scenario, the demand for key critical minerals would roughly double by 2050.

[27] We have also simulated the case of green energy and brown energy having equal weights in the aggregate energy bundle, keeping constant the weight of critical minerals in the production function of intermediate goods. The impacts on GDP and inflation of the negative shock to the supply of critical minerals are then more contained. Results are available upon request.

5 Conclusions

We have assessed the macroeconomic effects on the EA caused by the decline in the supply of critical minerals. A cut to the supply leads to higher prices for these minerals and generates stagflationary pressures—slower growth combined with rising inflation. As a net importer, the EA is exposed to foreign supply shocks through the critical minerals channel. However, the ability to diversify import sources helps contain the price increases faced by EA households and firms, thereby mitigating the stagflationary impact. Similarly, a sufficiently large installed capacity of green energy can shield the EA in the short run from higher prices of critical minerals. Under current technological conditions, supply shocks to critical minerals have a smaller macroeconomic footprint than comparable shocks to fossil fuels. Yet, as the green transition deepens and reliance on these minerals intensifies, their economic significance may eventually exceed that of fossil fuels.

Further insights can be gained by simulating a model with more detailed sectoral disaggregation, allowing for a richer representation of input-output relationships across industries. Some sectors are particularly dependent on critical minerals. For them, supply shortages could significantly raise production costs, triggering cascading effects throughout the economy—especially for consumption goods that rely heavily on critical minerals and carry an increasing weight in households' consumption baskets (e.g. electric vehicles and consumer electronics). Additionally, targeted fiscal policy measures to mitigate the impacts on consumers stemming from these rising costs could be explored. These important extensions are left for future research.

References

A., Ho P. Concordel and C.R. Knittel, "The Differential Impacts of Critical Mineral Prices and Oil Prices on the Economy," NBER Working Papers 34847, National Bureau of Economic Research, Inc February 2026.

Annicchiarico, Barbara, Susan Battles, Fabio Di Dio, Pierfrancesco Molina, and Pietro Zoppoli, "GHG mitigation schemes and energy policies: A model-based assessment for the Italian economy," *Economic Modelling*, 2017, *61* (C), 495–509.

Boer, Lukas, Andrea Pescatori, and Martin Stuermer, "Energy Transition Metals: Bottleneck for Net-Zero Emissions?," *Journal of the European Economic Association*, 2024, *22* (1), 200–229.

Calvo, Guillermo A., "Staggered prices in a utility-maximizing framework," *Journal of Monetary Economics*, September 1983, *12* (3), 383–398.

Corsetti, Giancarlo and Gernot J. Müller, "Twin deficits: squaring theory, evidence and common sense," *Economic Policy*, October 2006, *21* (48), 597–638.

Golosov, Mikhail, John Hassler, Per Krusell, and Aleh Tsyvinski, "Optimal Taxes on Fossil Fuel in General Equilibrium," *Econometrica*, January 2014, *82* (1), 41–88.

International Energy Agency, "Global Critical Minerals Outlook 2025," `https://www.iea.org/reports/global-critical-minerals-outlook-2024` 2025. Accessed: 2024-06-30.

International Monetary Fund, "Fragmentation and Commodity Markets: Vulnerabilities and Risks," in "World Economic Outlook, October 2023," Washington, DC: International Monetary Fund, 2023, chapter 3. Accessed: 2025-07-01.

Jo, Ara, "Substitution between clean and dirty energy with biased technical change," *International Economic Review*, 2025, *66* (2), 883–902.

M., Koehler-Ulbrich P. Andersson and C. Nerlich, "Green investment needs in the EU and their funding," *European Central Bank, Economic Bulletin Issue 1, 2025*, 2025.

Miranda-Pinto, Jorge, Andreas Pescatori, Martin Stuermer, and Xueliang Wang, "Beyond Energy: Inflationary Effects of Metals Price Shocks in Production Networks," IMF Working Paper 2024/215, International Monetary Fund October 2024. Posted 30 Oct 2024.

Papageorgiou, Chris, Marianne Saam, and Patrick Schulte, "Substitution between Clean and Dirty Energy Inputs: A Macroeconomic Perspective," *The Review of Economics and Statistics*, 05 2017, *99* (2), 281–290.

Taboga, Marco, "The potential macroeconomic relevance of critical materials: some preliminary evidence," Questioni di Economia e Finanza (Occasional Papers) 897, Bank of Italy, Economic Research and International Relations Area December 2024.

Varga, Janos, Werner Roeger, and Jan in 't Veld, "E-QUEST – A Multi-Region Sectoral Dynamic General Equilibrium Model with Energy Model Description and Applications to Reach the EU Climate Targets," *Economic Modelling*, 2022, *114.*

Warne, Anders, Günter Coenen, and Kai Christoffel, "The new area-wide model of the euro area: a micro-founded open-economy model for forecasting and policy analysis," Working Paper Series 944, European Central Bank October 2008.

Table 1: Main variables

	EA	CH	RW
Macroeconomic variables			
Private consumption	60.1	55.0	60.0
Public consumption	20.0	25.0	20.0
Investment	20.0	20.0	20.0
Imports	25.0	20.3	7.2
Imports of consumption goods	15.6	12.5	5.9
Imports of investment goods	5.6	5.7	2.5
Imports of critical minerals	0.1	-0.4	0.1
Imports of fossil fuels	3.8	2.5	-1.3
Shares of critical minerals			
Green energy production	4.4	3.5	3.6
Manufacturing goods production	0.2	0.2	0.2
Shares of energy			
Firms' production costs	7.8	7.1	7.2
Energy share in households' consumption	4.9	4.9	4.9
GDP share of world GDP s^j	14.3	19.1	66.6
Inflation rate	2.0	2.0	2.0
Financial variables			
Nominal interest rate	4.0	4.0	4.0
Net foreign asset position	0.0	0.0	0.0

Note: EA = Euro area. CH=China. RW= rest of the world. Consumption, investment, and imports are in % of GDP. Inflation and interest rates are in %, annualized term. Shares are in %. Critical minerals and fossil fuels: net imports (thus, they can be negative).

Table 2: Preferences, intermediate and final goods technology

Parameter	EA	CH	RW
Households			
Discount factor β	0.995	0.995	0.995
Intertemporal elasticity of substitution $1/\sigma$	1.0	1.0	1.0
Habit bb	0.9	0.9	0.9
Inverse of Frisch elasticity of labour supply τ	2.5	2.5	2.5
Depreciation rate of capital δ	0.025	0.025	0.025
Depreciation rate of critical minerals $\delta_{critmin}$	0.025	0.025	0.025
Firms-intermediate goods			
Bias towards capital $\gamma_{pr_{va,k}}$	0.30	0.30	0.30
Bias towards energy $\gamma_{pr_{y,EN}}$	0.11	0.11	0.11
Bias towards critical minerals $\gamma_{pr_{y,CM}}$	0.05	0.05	0.05
Bias towards petrochemical products $\gamma_{pr_{y,PC}}$	0.01	0.01	0.01
EoS btw. factors in output production ρ_Y	0.20	0.20	0.20
EoS btw. dom. and imported critical minerals θ_{CM_y}	1.50	1.50	1.50
Firms-final consumption goods			
EoS btw. manufacturing good and energy ρ_c	0.30	0.30	0.30
Bias towards manufacturing goods $\gamma_{pr_{c,manu}}$	0.96	0.96	0.96
EoS btw. dom. and imported manuf. goods η_T	1.50	1.50	1.50
Bias towards domestic tradable goods $a_{EA,C}$	0.70	0.77	0.90
Firms-final investment goods			
EoS btw. dom. and imported goods η_T	1.50	1.50	1.50
Bias towards domestic tradable goods $a_{EA,I}$	0.71	0.74	0.88

Note: EA = Euro area. CH= China. RW= rest of the world. EoS: elasticity of substitution,

Table 3: Energy production technology

Parameter	EA	CH	RW
Eos among energy types ρ_{EN}	1.20	1.20	1.20
Bias towards fossil fuel energy $\gamma_{pr_{y,oil}}$	0.86	0.86	0.86
Brown energy			
EoS btw. factors of production $\rho_{EN,foss}$	0.30	0.30	0.30
Bias towards capital $\gamma_{foss,k}$	0.40	0.40	0.40
Bias towards fossil fuel $\gamma_{foss,source}$	0.50	0.50	0.50
Green energy			
EoS btw. factors of production $\rho_{EN,res}$	0.30	0.30	0.30
Bias towards capital $\gamma_{res,k}$	0.50	0.50	0.50
Bias towards critical minerals $\gamma_{res,source}$	0.36	0.36	0.36
EoS btw. dom. and imported critical minerals θ_{CM_y}	1.50	1.50	1.50

Note: EA = Euro area. CH=China. RW= rest of the world. EoS: elasticity of substitution,

Table 4: Gross markups (elasticities of substitution among goods and labor varieties)

	EA	CH	RW
Intermediate goods	1.2 ($\theta_T = 6.0$)	1.2 ($\theta_T = 6.0$)	1.2 ($\theta_T = 6.0$)
Labour	1.3 ($\psi = 4.3$)	1.3 ($\psi = 4.3$)	1.3 ($\psi = 4.3$)

Note: EA = Euro area. CH=China. RW= rest of the world.

Table 5: Adjustment costs

Parameter	EA	CH	RW
Households			
International bond ϕ_b	0.01	0.01	–
Investment in physical capital ψ	5.0	5.0	5.0
Investment in critical minerals $\psi_{critmin}$	15.0	15.0	15.0
Nominal wages κ_W	300	300	300
Wage indexation to past inflation ind_W	0.75	0.75	0.75
Firms			
Price κ	600	600	600
Price indexation to past inflation ind_p	0.80	0.80	0.80
Wage indexation to past inflation ind_w	0.75	0.75	0.75

Note: EA = Euro area. CH=China. RW= rest of the world.

Table 6: Monetary policy rules

Parameter	EA	CH	RW
Lagged interest rate ρ_R	0.90	0.90	0.90
Inflation ρ_π	1.70	1.70	1.70
Output growth ρ_y	0.10	0.10	0.10

Note: EA = Euro area. CH = China. RW = rest of the world.

Figure 1: Critical minerals for production and consumption purposes

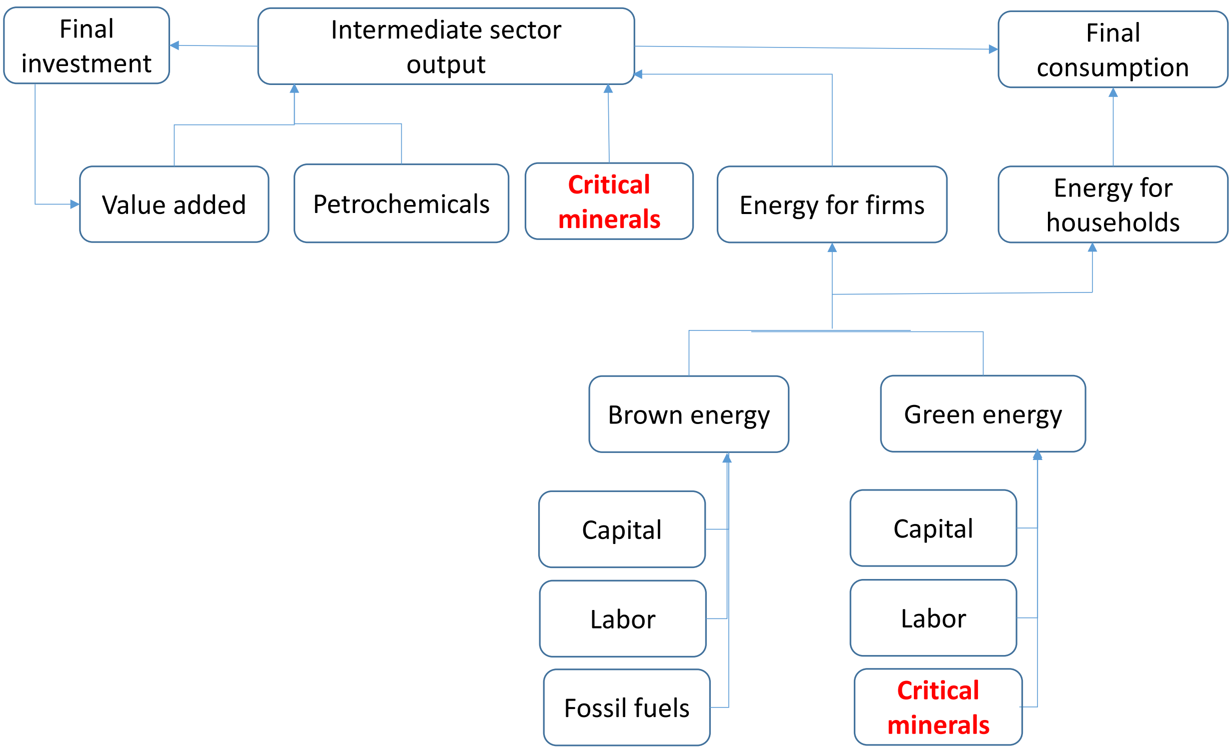
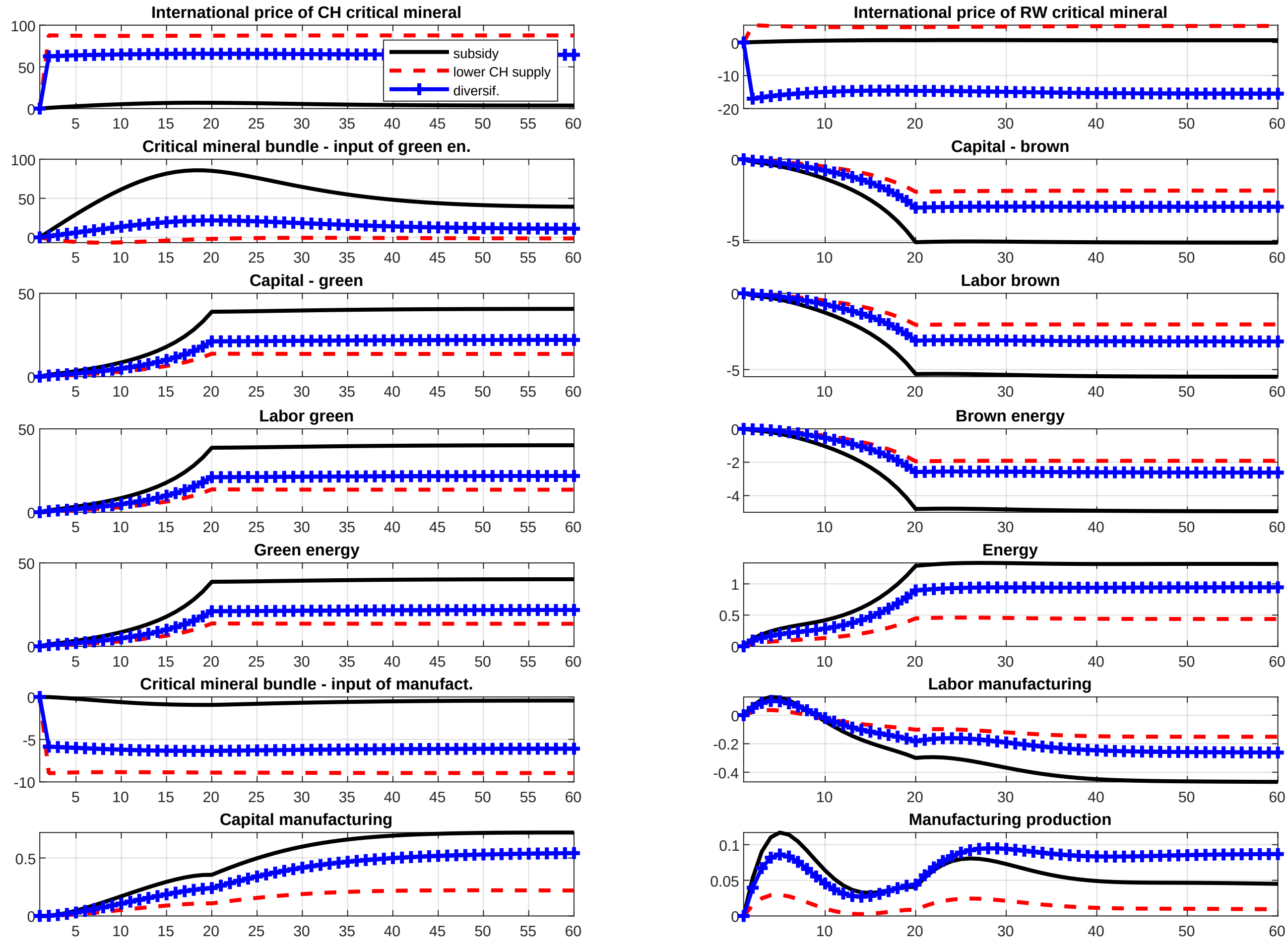
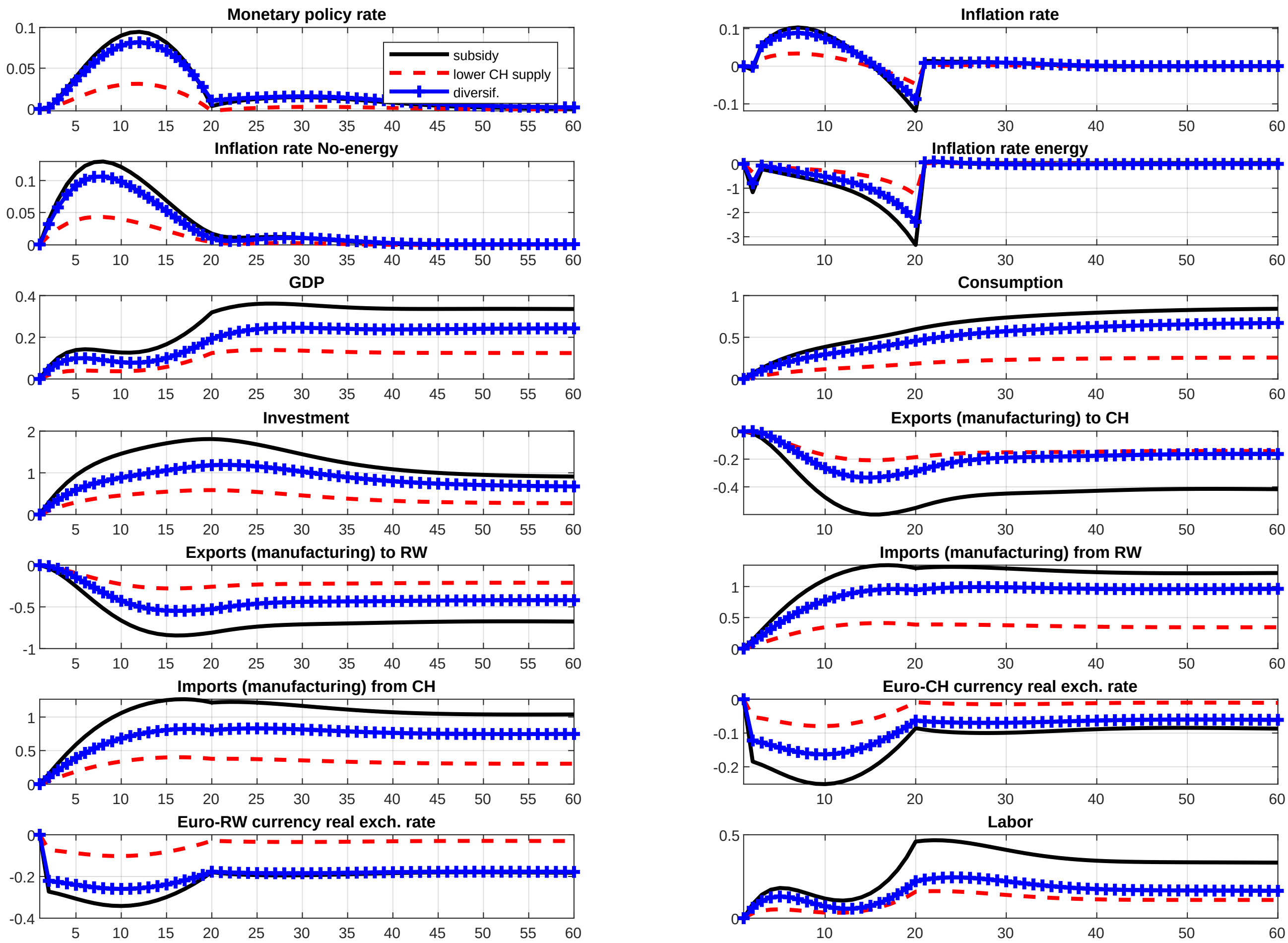


Figure 2: EA green subsidies, low international supply of critical minerals, and diversification: EA sector-specific variables



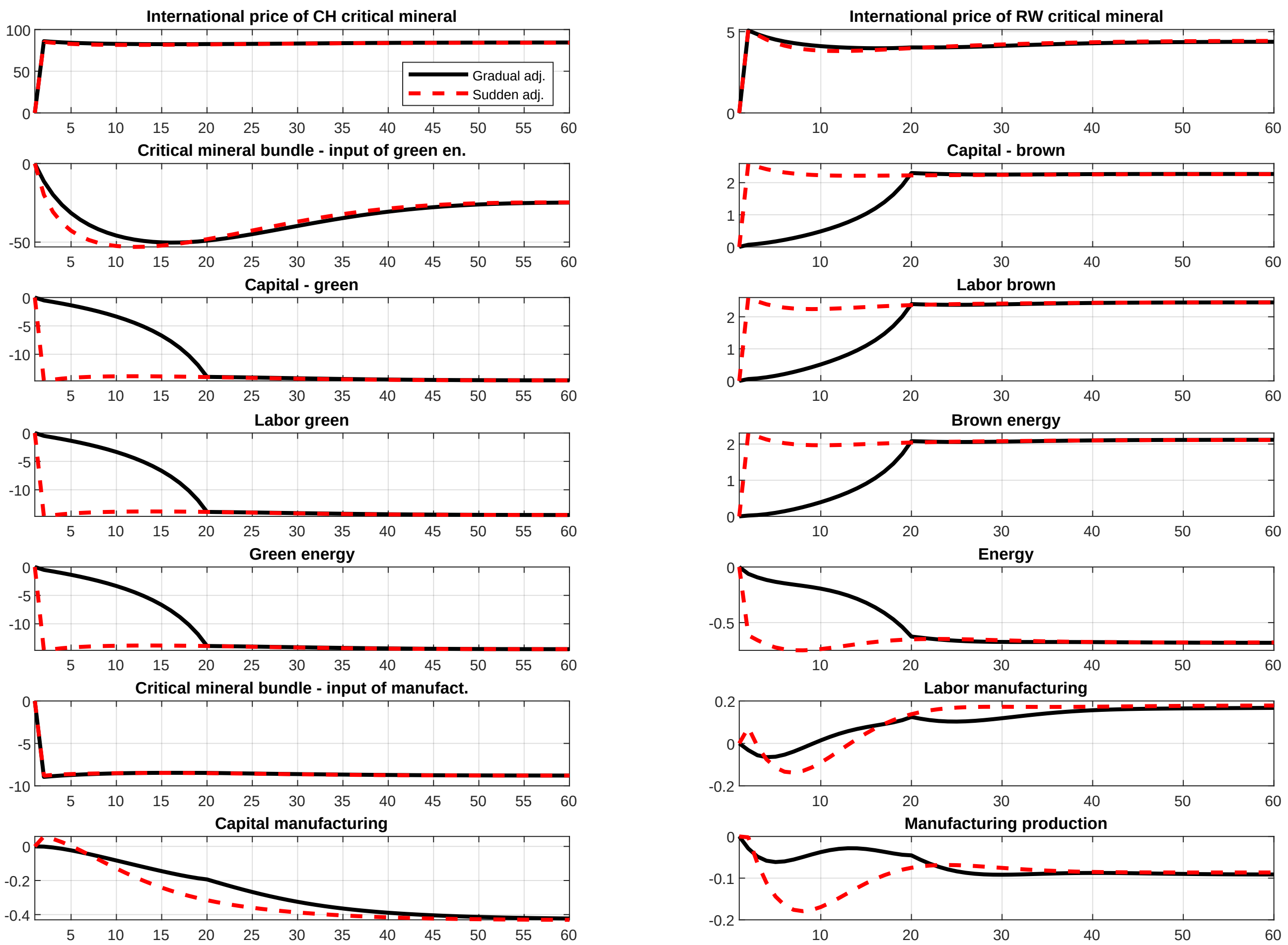
Notes: quarters on the horizontal axis; on the vertical axis, % deviations from the baseline.

Figure 3: EA green subsidies, low international supply of critical minerals, and diversification: EA macroeconomic variables



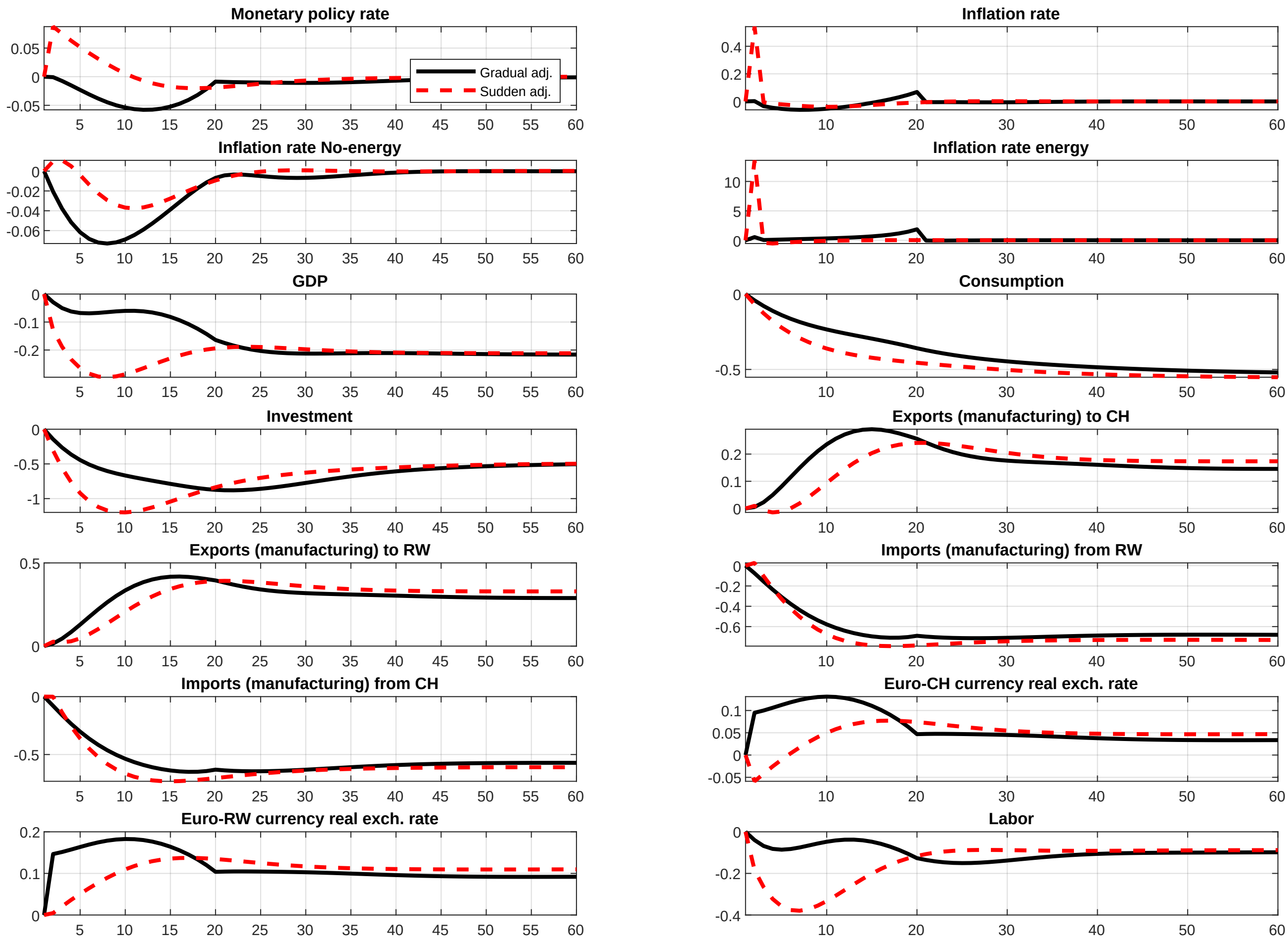
Notes: quarters on the horizontal axis; on the vertical axis, deviations from the baseline; inflation and interest rates: annualized pp deviations; GDP and its components in real terms (constant steady-state prices); real exchange rates: +=depreciation.

Figure 4: Gradual vs sudden adjustment of green capital: EA sector-specific variables



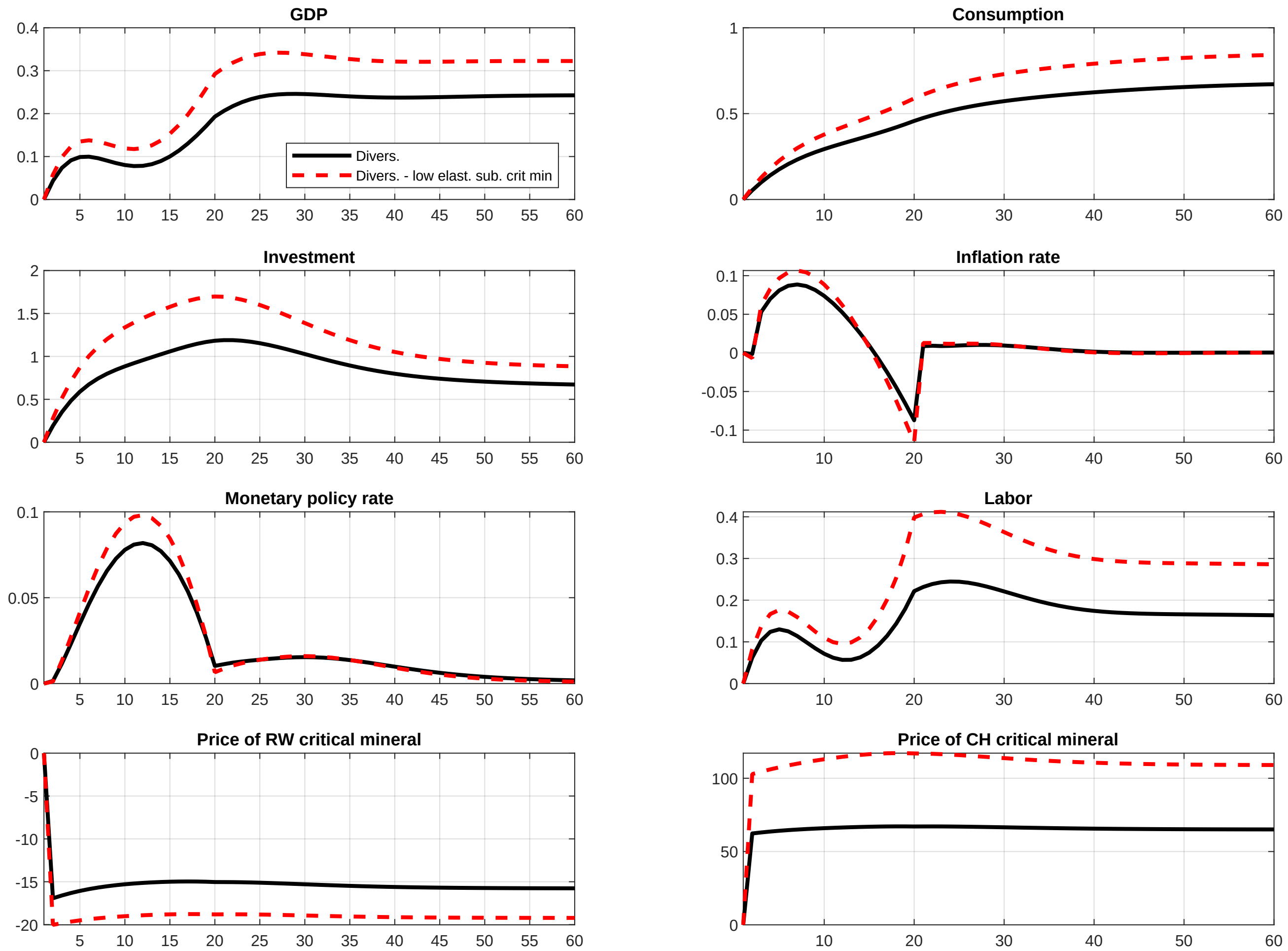
Notes: quarters on the horizontal axis; on the vertical axis, % deviations from the baseline.

Figure 5: Gradual vs sudden adjustment of green capital: EA macroeconomic variables



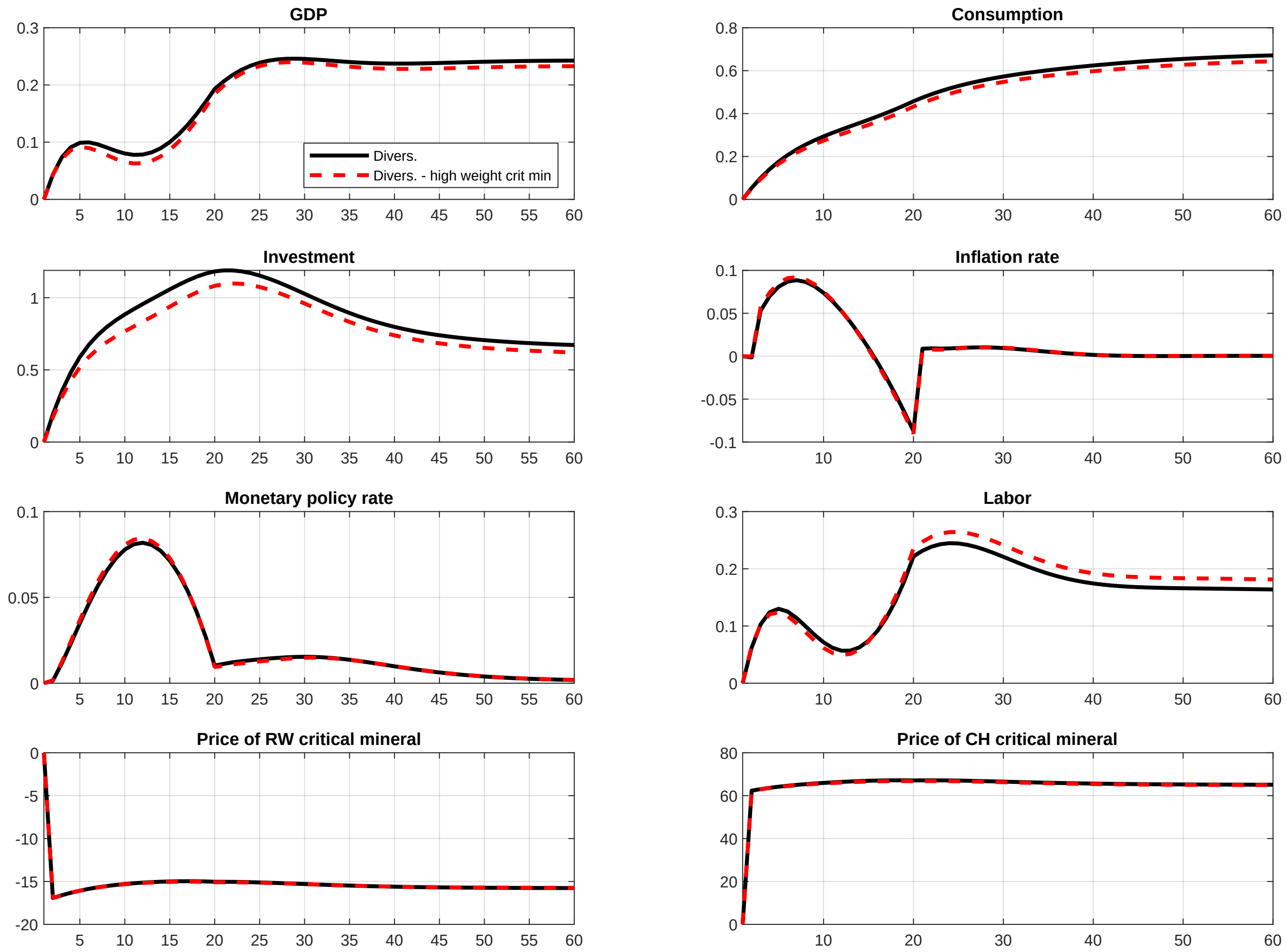
Notes: quarters on the horizontal axis; on the vertical axis, deviations from the baseline; inflation and interest rates: annualized pp deviations; GDP and its components in real terms (constant steady-state prices); real exchange rates: +=depreciation.

Figure 6: Diversification with lower elasticity among critical minerals: EA macroeconomic variables



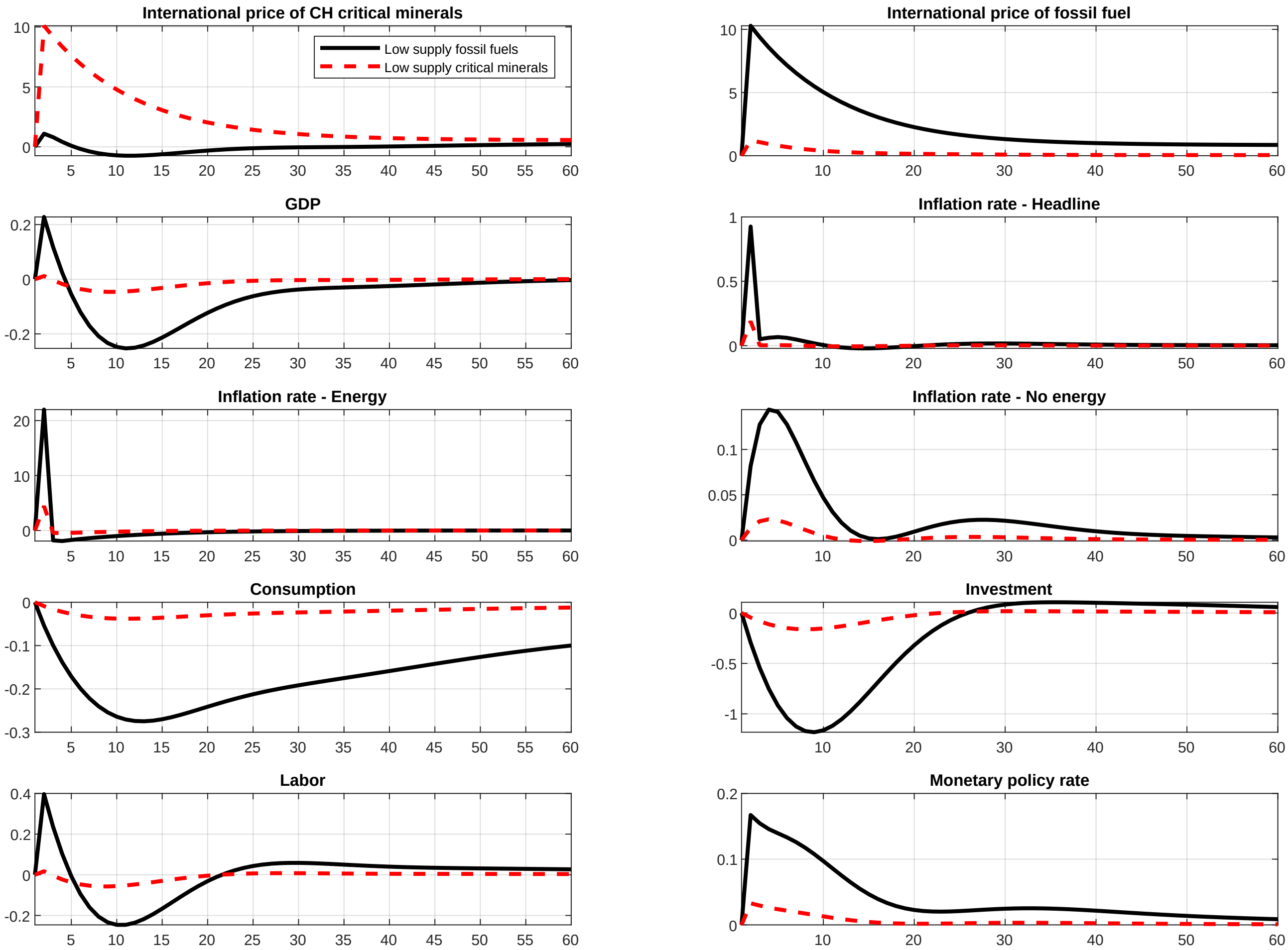
Notes: quarters on the horizontal axis; on the vertical axis, % deviations from the baseline; inflation and interest rates: annualized pp deviations; GDP and its components in real terms (constant steady-state prices).

Figure 7: Diversification with higher weight of critical minerals: EA macroeconomic variables



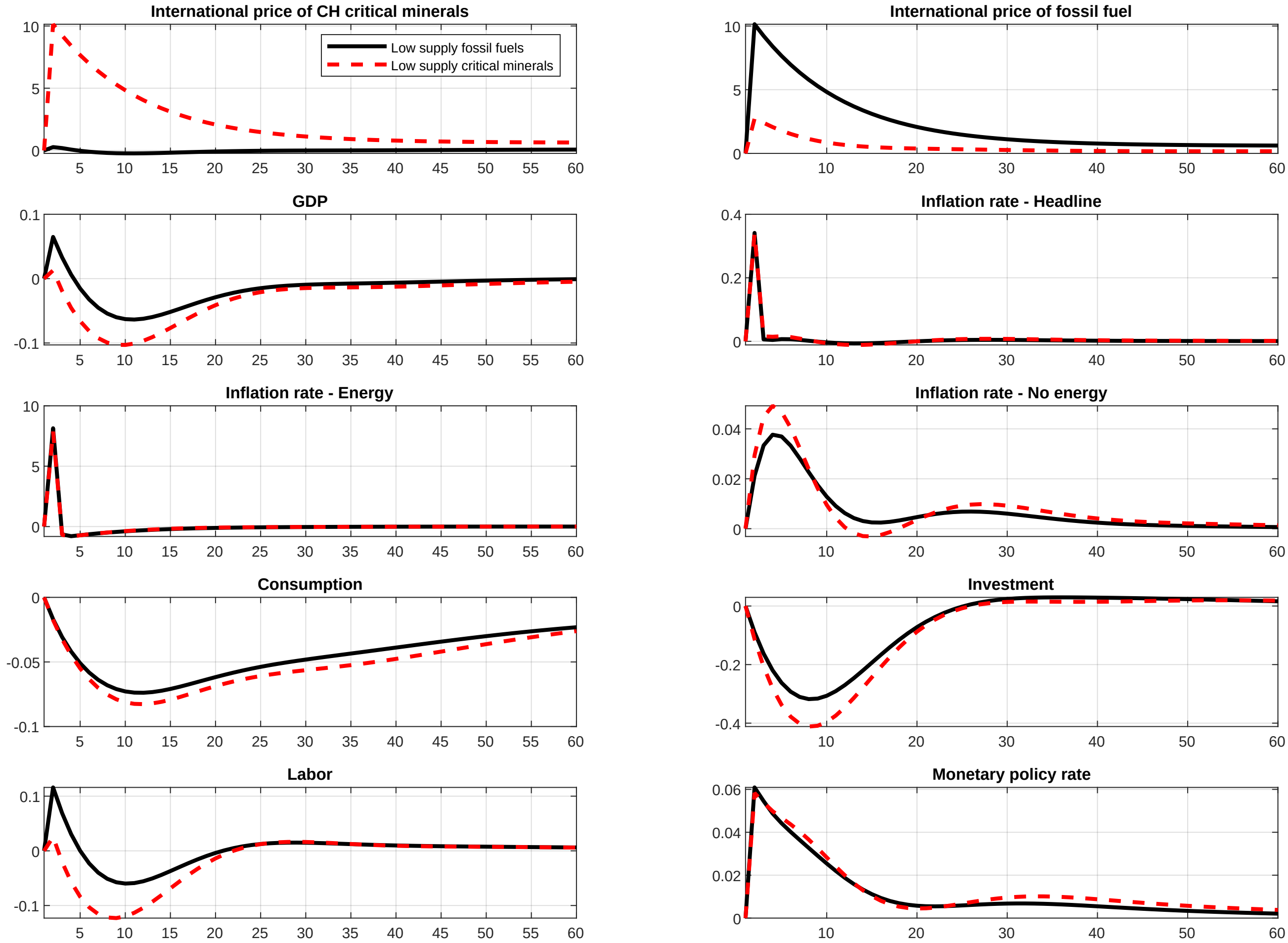
Notes: quarters on the horizontal axis; on the vertical axis, % deviations from the baseline; inflation and interest rates: annualized pp deviations; GDP and its components in real terms (constant steady-state prices).

Figure 8: Low supply of energy sources: EA macroeconomic variables



Notes: quarters on the horizontal axis; on the vertical axis, deviations from the baseline; inflation and interest rates: annualized pp deviations; GDP and its components in real terms (constant steady-state prices).

Figure 9: Low supply of energy sources with equal shares of green and brown energy and higher demand of critical minerals for final consumption: EA macroeconomic variables



Notes: quarters on the horizontal axis; on the vertical axis, deviations from the baseline; inflation and interest rates: annualized pp deviations; GDP and its components in real terms (constant steady-state prices).