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## Article

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European Journal of Economics and Economic Policies: Intervention (EJEEP)

## **Provided in Cooperation with:** Edward Elgar Publishing

*Suggested Citation:* Schoder, Christian; Tercioglu, Remzi Baris (2024) : A climate-fiscal policy mix to achieve Türkiye's net-zero ambition under feasibility constraints, European Journal of Economics and Economic Policies: Intervention (EJEEP), ISSN 2052-7772, Edward Elgar Publishing, Cheltenham, Vol. 21, Iss. 2, pp. 331-359, https://doi.org/10.4337/ejeep.2024.02.07

This Version is available at: https://hdl.handle.net/10419/304378

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## Invited Article

European Journal of Economics and Economic Policies: Intervention, Vol. 21 No. 2, 2024, pp. 331-359

## A climate-fiscal policy mix to achieve Türkiye's net-zero ambition under feasibility constraints

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This paper employs an estimated dynamic stochastic open-economy macro framework to identify policy interventions that allow Türkiye to achieve net-zero emissions by 2053 while respecting important feasibility constraints such as fiscal consolidation and sovereign debt stability as well as compensation of low-income households. The policy mix includes a carbon tax, a renewable energy subsidy, transfer payments, public infrastructure investments, a bad bank for stranded fossil fuel assets, and the phase-out of fossil fuel subsidies and public investment. Although the proposed policy package has only moderate effects on gross domestic product, transition risks involve declining exports and fossil asset stranding. The paper highlights the importance of transparent policy communication and a credible commitment to the net-zero agenda to ensure an orderly transition. Improving the rule of law and access to green finance considerably support the private sector-led low-carbon transition.

**Keywords:** climate-fiscal policy, net-zero pathway, low-carbon transition, Bayesian estimation, Türkiye

JEL codes: Q43, Q48

### 1 INTRODUCTION

Türkiye faces several climate-related risks. Recent extreme weather events, including floods and wildfires, have exposed the country's vulnerability to climate change. Türkiye is highly dependent on fossil fuel imports which amount to 87 per cent of its total primary energy supply.<sup>1</sup> This poses significant risks for energy security, as the oil and gas market turmoil after the Russian invasion of Ukraine have forcefully illustrated. Moreover, the European Union's ambitious low-carbon agenda will have considerable repercussions for the primary export market for Turkish manufacturing, which is more carbon-intensive than its European counterpart. In light of these climate-related risks, Türkiye has increased its climate ambition in recent years. Türkiye's renewable energy capacity grew by more than 50 per cent since 2016 (IEA 2021). As a top-20 emitter, Türkiye submitted its Intended Nationally Determined Contribution in 2015, setting the target to reduce

1. See release 055 of the GLORIA Global Environmentally-Extended Multi-Region Input-Output (MRIO) database constructed in the Global MRIO Lab (Lenzen et al. 2017, 2022).

Received 26 February 2024, accepted 6 June 2024

greenhouse gas emissions by 21 per cent relative to the business-as-usual (BAU) benchmark by 2030. In 2021, the country ratified the Paris Agreement and announced the net-zero target of 2053.

Türkiye's development progress since the early 2000s has been remarkable. Per-capita GDP has more than tripled within 20 years, making Türkiye the 19th largest economy in the world. Since 2015, however, the growth dynamics have cooled down considerably. Unemployment has exceeded the 10 per cent mark ever since 2015 despite a low labor force participation rate, especially among women, and a significant informal sector (World Bank 2023). While formally independent, the central bank's monetary policy is subject to severe government interference, which let inflation explode to a two-decade-high value of 85.5 per cent in October 2022 (TurkStat 2022).

Addressing structural deficits is critical for the low-carbon transition as they constrain the effectiveness of climate policy in mobilizing private finance. Structural deficits of the Turkish economy include low credibility of policy commitments, high costs of contract enforcement combined with low business confidence in public institutions, and uneven access to bank finance (OECD 2021; Gürkaynak et al. 2022). Dechezleprêtre et al. (2022) provide compelling evidence that transparency and commitment raise acceptance of climate policy. Regarding the business climate, a weak rule of law drives up equity risk premia, making capital-intensive, productivity-enhancing technology less appealing than labor-intensive, low-value-added activities. Finance constraints further impede private investment in low-carbon technology and limit the power of market signals.

This paper aims to project the paths of climate-fiscal policy interventions that allow Türkiye to grow along the 2053 net-zero pathway while honoring significant feasibility constraints. The policy instruments include a carbon tax, a renewable energy subsidy, transfer payments, public infrastructure investment, a bad bank for stranded assets, and the phase-out of fossil fuel subsidies and public investment. To study the role of supporting structural policies in the low-carbon transition, we explore how the macroeconomic effects of the policy interventions differ in counterfactual scenarios of a fully credible commitment to net zero, an improved rule of law, and facilitated access to green bank finance.

We address these research questions using an empirical dynamic stochastic open-economy macro framework similar to the European Commission's *E-QUEST* model presented by Varga et al. (2022) but shifts the focus on an emerging-market context by addressing explicitly labor market regulation, equity risk, and finance constraints.<sup>2</sup> The model is designed for data-driven policy analysis and the simulation of low-carbon transitions. Renewable and fossil public investment can be channeled into energy production or infrastructure. Infrastructure improves the marginal product of private capital but only up to a satiation point. To allow the model to capture deep transformations such as the low-carbon transition, it includes two critical features: *a learning-by-doing externality* in the generation of renewable energy (Mercure 2012; Rubin et al. 2015); and the distinction between *short- and long-term elasticities of substitution between renewable and fossil energy* (Guerrieri et al. 2008). On the labor market, the model allows for the possibility of *dis-equilibrium unemployment* at the steady state, which provides flexibility regarding model closures and minimizes the impact of theory on the results for the long run.<sup>3</sup> The model features various

<sup>2.</sup> Our modeling framework also connects to the literature on optimal environmental policy in a general equilibrium setting (Fischer/Springborn 2011; Annicchiarico/Di Dio 2015; Dissou/Karnizova 2016; van der Ploeg/Rezai 2021).

<sup>3.</sup> Dis-equilibrium unemployment is known, among many others, from dynamic stochastic disequilibrium models (Schoder 2017, 2020) as well as dis-equilibrium theory (Barro/Grossman 1971; Chiarella et al. 2005).

financial instruments, bank lending constraints, and a financial accelerator mechanism along the lines of Kiyotaki/Moore (1997). The interested reader is referred to Appendix 1, which presents the details of the model. We fit the model to Turkish data using standard Bayesian techniques as outlined in Herbst/Schorfheide (2015). The dataset covers the period from 2000Q2 to 2022Q3 and includes 31 time series in mixed frequency. Appendix 2 reports the details of the model estimation. We run all estimations and simulations in *Dynare* 5.3 (Adjemian et al. 2022).

The simulation results suggest that Türkiye needs to employ a dynamic policy mix to achieve the steady decline of 12 million (mn) tonnes of  $CO_2$  emissions per year required for net zero by 2053 while observing the following constraints: (a) keeping sovereign debt at 34 per cent of trend GDP; (b) fully compensating low-income households for consumption lost relative to BAU; (c) public financing of necessary infrastructure investments which amounts to an average of 2 billion (bn) of 2015 USD (\$) per year (World Bank 2022); and (d) buying up private stranded assets.

Under these constraints and the phase-out of fossil subsidies and public investment, our results suggest that Türkiye should kick off the decarbonization of its economy with a carbon or fuel tax reaching \$70 per tonne of CO<sub>2</sub> by 2027. By then, public debt will be stabilized at the desired level. The carbon tax will then generate excess revenues that can be recycled as renewable energy subsidies to minimize the rise in energy prices. Renewable subsidies of up \$1,400 per tonne of oil equivalent (toe) trigger a renewable energy boom reinforced by endogenous productivity gains from scaling up renewable generation. As fossil energy consumption is reduced, the carbon tax will find it increasingly challenging to generate fiscal revenues. By 2037, debt stability will require the government to phase out renewable subsidies of up sidies completely and adjust another instrument to keep public debt stable. In our simulation, government consumption declines by 1.8 percentage points of trend GDP between 2037 and 2053. Over the projection period, the government will also increase the required spending on renewable infrastructure and phase out investment in fossil energy production and infrastructure. Finally, transfer payments to low-income households increase by 1 percentage point of trend GDP over the projection period.

This policy package is projected to mobilize a considerable amount of green finance. Private investment in renewable energy increases from 0.2 per cent of trend GDP in 2022 to almost 4 per cent by 2053. Renewable energy consumption will increase from around 20 million toe in 2022 to 420 million by 2053. This is 460 per cent higher than the baseline projection.

The projected impacts on GDP are moderate. During the fiscal consolidation phase, the carbon tax will briefly reduce GDP, peaking in 2027 with a GDP loss of 0.7 per cent compared to the no-policy baseline. Between 2031 and 2037, GDP is projected to exceed the baseline slightly. By 2037, the declining government consumption will increasingly reduce GDP, reaching a projected loss of 1 per cent compared to the baseline in 2053. Regarding welfare, low-income households are broadly indifferent to the transition as long as they receive sufficient compensation for the consumption lost relative to the baseline. In contrast, high-income households considerably benefit from the transition as the renewable capital assets created translate into higher household wealth.

Despite the overall moderate GDP effects and positive welfare effects, there are transition risks: while the low-carbon transition eliminates the dependence on fossil fuel imports, core goods exports will decline by up to 11 per cent compared to the baseline. Moreover, there is a manageable but non-negligible risk of fossil asset stranding. In our simulation, stranded assets amount to almost 0.1 per cent of trend GDP in 2053. Delaying the transition until 2030 will considerably increase the risk of stranded assets: 0.65 per cent of trend GDP in 2043.

Our simulations stress the positive role of complementary policy. Consistent with Nemet et al. (2017), Battiston et al. (2021), Diluiso et al. (2021), and Campiglio et al. (2023), we show that transparent policy communication and a credible commitment to the net-zero agenda benefit the low-carbon transition. It allows the private sector to adjust ahead of time, reducing economic friction. A lack of commitment and the expectation of policy reversals make the transition considerably more costly. Moreover, we find that implementing institutional reforms that improve the rule of law and thereby reduce equity risk premia to the average of China, India, and South Africa drastically improves the macroeconomic outlook of the low-carbon transition, with GDP peaking at 2.6 per cent above the no-policy baseline. Finally, reforms that facilitate access to green finance boost renewable energy investment and generation. Overall, complementary structural reforms reduce the required climate-policy interventions and improve the macroeconomic consequences of the low-carbon transition.

This paper seeks to contribute to the literature on the macroeconomic implications of climate-fiscal policy in an emerging-market context. World Bank (2022) estimates the additional investment and renewable energy capacity needed for achieving the net-zero pathway in Türkiye. Hallegatte et al. (2023) impose these investment and capacity needs in a Computational General Equilibrium (CGE) and a macro-structural model and study the sectoral and macroeconomic repercussions under various scenarios regarding private/public financing, crowding-out of investment, and labor-market frictions. We seek to complement these contributions by identifying the dynamic climate-fiscal policy mix needed for net zero by 2053 while observing critical feasibility constraints. The integrated framework used in this paper allows us to compute endogenous projections for investment needs, finance, and, to some extent, productivity gains. Exploiting the value-added of a structural model with intertemporal decision-making, we seek to offer additional insights on the roles of private sector incentives, policy credibility, and structural reform in supporting the lowcarbon transition. The model used in this paper is similar to the E-QUEST and GM models of the European Commission (Varga et al. 2022; Albonico et al. 2019) and the New Area Wide Model of the ECB (Christoffel et al. 2008) but puts the focus on market imperfections relevant for middle-income countries. Our framework is also related to global models such as the Global Macroeconomic Model of the Energy Transition (GMMET) and the Integrated Policy Framework developed by the IMF (Benjamin Carton et al. 2022; Vitek et al. 2022) as well as G-Cubed developed by McKibbin/Wilcoxen (1998), but it is considerably smaller in scale to allow for Bayesian estimation.

Since estimating the model was a priority, data availability and computational capacity imposed restrictions on its size. Hence, several qualifications are to be addressed in future research: first, while the model comprehensively tracks macroeconomic interactions and includes the critical climate-fiscal policy instruments, it abstracts from sector-specific decarbonization challenges and features only emissions that arise from fossil fuel combustion. As outlined in World Bank (2022), additional policy interventions such as norms and regulations may be required to improve energy efficiency and address other emissions sources such as industrial processes and land use. Second, we assume that a well-designed energy market regulation is in place such that renewable energy is profitable despite the significant up-front capital costs and volatility in energy prices. This includes complete future markets, access to the power grid, and the absence of excessive administrative obstacles in commissioning renewable energy generation facilities. Finally, the relative costs and benefits of the low-carbon transition depend on the choice of the baseline scenario. This paper uses the BAU scenario as the baseline for Türkiye. This ignores the Carbon Border Adjustment Mechanism the European Union intends to impose on imports. It also neglects potential technology spillovers from other decarbonizing parts of the world.

The remainder of the paper proceeds as follows. Section 2 provides the intuition of the empirical macro framework. It motivates modeling and calibration choices for Türkiye. Appendix 1 reports the model in detail. Section 3 discusses the Bayesian estimation results. Appendix 2 details the data sources, parameter calibration, and estimation. Section 4 identifies a policy mix projected to set Türkiye on track to net zero and studies its macro-economic implications. It also investigates how policy credibility and structural reforms can support the low-carbon transition. Section 5 concludes the paper.

#### 2 AN EMPIRICAL MACROECONOMIC FRAMEWORK FOR TÜRKIYE

The underlying model is designed for data-driven climate policy analysis in Türkiye.<sup>4</sup> It is calibrated and estimated using quarterly and annual data covering the period from 2000 to 2022. It comprises a high-skilled household sector, a low-skilled household sector, a core good sector, an energy sector, a public sector, and the Rest of the World (RW). Households use energy for consumption (on average around 48 per cent of total final energy consumption) and firms for non-energy production (around 52 per cent), which can be fuel, heat, or electricity. The energy sector consists of renewable energy (with a sample average of 0.9 per cent of GDP and 17 per cent of total energy consumption) and fossil energy (6.2 per cent of GDP and 83 per cent of total energy consumption). A carbon mining sector (3.4 per cent of GDP) extracts and imports carbon (such as coal, crude oil, and gas) which is an input to fossil energy production.  $CO_2$  emissions arise from the combustion of fossil fuels and have fluctuated around 0.46 kilogram (kg) per 1 constant 2015 USD of GDP since the early 2000s.<sup>5</sup>

The model features various financial instruments. Households are assumed to be net creditors holding their wealth as bonds, deposits, and private equity. Firms are net debtors financing investments by borrowing from households and issuing equity. The government finances its deficit by issuing bonds. The RW is a net creditor from Türkiye's perspective. The public, corporate, and RW's net debt–GDP ratios are moderate on average: around 36 per cent, 57 per cent, and –35 per cent of GDP, respectively. Yet, these debt levels have increased sharply in recent years (OECD 2022). Despite a low net debt vis-à-vis the RW, Türkiye imports around 87 per cent of its total primary energy supply.

#### 2.1 High- and low-skilled labor households

Capturing to some extent how the low-carbon transition affects households differently, the model features *high-skilled labor* H-households (50 per cent of the labor force) and liquidity-constrained *low-skilled labor* L-households (50 per cent of the labor force). We assume that L-households hold no financial wealth. In Türkiye, the 50 per cent top-income households account for two-thirds of all consumption expenditures. Hence, we assume H-households consume twice as much as L-households while providing the same labor hours. The former receive capital income as well as a higher real wage. The overall wage share in total income (household income and retained earnings) is around 50 per cent. L-households also receive transfer payments from the government (around 7.3 per cent of GDP).

5. Appendix 2 reports the model calibration and lists the respective data sources and references.

<sup>4.</sup> Appendix 1 reports the model in detail. We limit the main text to the discussion of nonstandard and climate-relevant features.

H-households own the firms and domestic carbon mines (oil, coal, and natural gas), provide high-skilled labor services, and save. Because a specific household's labor variety is unique, each H-household has market power. Wage adjustment costs à *la* Rotemberg (1982) allow the model to capture the persistence in high-skilled wage contracts as observed in empirical data (Taylor 1980, 2016). Utility from consumption is subject to external habit formation, which helps the model capture the hump-shaped response of consumption to macro shocks as identified in empirical studies (Christiano et al. 2005).

L-households are *hand-to-mouth consumers*. Hence, they hold no wealth and cannot smooth consumption over time. This assumption helps the model capture the empirical co-movement of government spending and private consumption (Christiano et al. 2010).

The model includes wealth in the utility function reflecting precautionary saving motives (Michaillat/Saez 2021). To see the implications of this assumption, consider the Euler equation (neglecting productivity growth for the sake of clarity),

$$\lambda_{H,t} = \Psi_A + \beta E_t \frac{R_{B,t}}{\prod_{V t+1}} \lambda_{H,t+1}$$

where  $\lambda_{H,t}$  equals marginal consumption utility,  $\Psi_A$  is the wealth utility scaling parameter,  $R_{B,t}$  is the gross bond return, and  $\Pi_{Y,t}$  is the gross inflation rate. Because saving yields utility by itself, the utility from wealth drives a wedge between the value of a unit of income in *t* to the expected value that this unit would yield if saved and consumed in  $t + 1.^6$  A critical implication of this modeling choice for Türkiye is that the determinacy of the rational-expectation equilibrium does not necessitate the Taylor principle. That is, the inflation elasticity of the policy rate can be lower than one (Schoder 2020).

While government bonds and deposits are assumed to be risk-free, equity shares or international bonds are not. These assets are associated with financial intermediation costs which depend on the net-debt position of the issuer and have the interpretation of risk premia (Christoffel et al. 2008). The equity risk premium on top of risk-free government bonds has been around 5.2 per cent in Türkiye. The international risk premium is assumed to increase with the net-debt position of the RW vis-à-vis Türkiye. With a persistent Turkish current account deficit, the RW has accumulated net assets of around 40 per cent of Turkish GDP (World Bank 2023). Hence, the international risk premium is negative.

One core assumption of the model is that the low-skilled nominal wage is administered or partly exogenous, as in Benigno/Fornaro (2018). This is equivalent to the conventional assumption in New Keynesian Dynamic Stochastic General Equilibrium (DSGE) models that the nominal interest rate is a policy variable. In particular, the low-skilled wage rate is determined by a Phillips curve relationship. Low-skilled wage inflation responds to employment (to capture the effects of labor-market tightening on wage formation) and to the price inflation rate (to capture wage indexing). This assumption generates dis-equilibrium unemployment (around 10 per cent) in the low-skilled segment of the labor market. With idle labor, the economy can swiftly respond to demand shocks by adjusting low-skilled employment, given constraints and costs imposed by input substitution technologies. Schoder (2020) provides a detailed review of the macroeconomics of disequilibrium models. It is

6. As Schoder (2020) explains in detail, wealth-in-utility and a policy rule for nominal wages (discussed below) jointly break the so-called *classical dichotomy*. Nominal shocks have real long-term effects because the model's Euler equation links consumption to the real interest rate. In contrast to standard models, the *natural* rate of interest is no longer uniquely determined by the Euler equation alone but linked to the monetary economy.

critical to note that an estimated parameter determines where the model settles between two extremes: perfectly inelastic low-skilled wage (constant wage or pure Keynesian case) and perfectly elastic low-skilled wage (labor market clearing or pure Walrasian case).

#### 2.2 CES aggregators

The production sector is decomposed into multiple layers along the value chain, as illustrated in Figure 1. The economy is populated by four different representative Constant Elasticity of Substitution (CES) aggregators: Retailers (Y-firms), wholesale firms (W-firms), energy firms (E-firms), and labor firms (L-firms). Each combines two different input goods into an output good using a CES aggregator without generating value-added. Moreover, the economy features three value-added sectors: core goods firms, renewable energy firms, and fossil energy firms. They use capital and labor as production inputs. Finally, a carbon mining sector extracts carbon without inputs or costs and sells it on a world market. The value-added in this sector is matched by rents split between the household and RW sectors.



Figure 1 Schematic representation of the supply side of the model

Production functions are of the CES type. The advantage of this functional form is that only two parameters (input share and elasticity of substitution) characterize the technology. Moreover, extreme cases such as perfect complements or perfect substitutes are nested. At every node in Figure 1 an elasticity controls the degree by which inputs can be substituted with each other for the given price changes. The more rigid the production structure or the higher the cost at which input substitutes can be produced, the greater will be the extent by which cost increases of a particular input are passed through the value chain and translate into overall inflation.

The model features the following aggregators: at the end of the value chain, Y-firms produce the homogeneous final good used for private and public consumption as well as investment by combining wholesale goods and energy.

W-firms produce wholesale goods and sell them to the Y-firms. As inputs, they combine domestic and international core goods. Note that, apart from carbon imports, only core goods are traded, which is a strong simplification of the complexity of international trade. Yet, it allows the model to capture the *domestic-demand* and *competitiveness* transmission channels of domestic and international shocks. Non-carbon imports in Türkiye amount to around 22.8 per cent of GDP (and to 26 per cent including coal, crude oil, and gas).

E-firms produce an energy service (with a value of around 7.1 per cent of GDP) using renewable energy (with a share of 12 per cent) and fossil energy (with a share of 88 per cent). The energy service is input to two sectors: intermediate core Z-good production (around 52 per cent of total energy consumption or 3.7 per cent of GDP) and final Y-good production (around 48 per cent of total energy consumption or 3.4 per cent of GDP).<sup>7</sup> E-firms pay a fuel tax on their fossil energy input (1.4 per cent of GDP) and receive fossil energy subsidy (0.4 per cent of GDP). They also receive a subsidy for each unit of renewable energy input. Finally, we allow E-firms to accrue zero-mean wind-fall profits which are distributed to the H-households.

Given the transformational nature of the low-carbon transition, a simple CES production structure is too restrictive for the energy sector. Similar to Guerrieri et al. (2008), we, therefore, introduce input adjustment costs which add short-run friction to the long-run elasticity of substitution between renewable and fossil energy.

L-firms combine high-skilled and low-skilled labor (both measured in hours) to produce a labor service. High-skilled households receive, on average, 61 per cent of the total wage bill, and low-skilled labor the remaining 39 per cent. The labor service is sold to all sectors that use labor inputs for production: core goods (98.64 per cent), renewable energy (0.23 per cent), and fossil energy (1.13 per cent).

#### 2.3 Core good producers

Core goods are exported or sold domestically to the W-firms. They operate under monopolistic competition and, therefore, have price-setting power. They face standard nominal and real rigidities: adjusting the output price and investment is costly. Utilizing the installed capital stock beyond the technological optimum accrues costs at an increasing rate.

Production is subject to a hierarchical CES structure. At the top of the hierarchy, core goods are produced by combining a capital–labor composite and energy services (purchased

<sup>7.</sup> In reality, 46 per cent of the Turkish energy output is used by the energy sector itself as an input. For the sake of simplicity, we neglect this share and only consider the energy used for final consumption and non-energy production.

from E-firms and amounting to 3.7 per cent of core good revenues). The capital–labor composite is produced by combining a capital service and labor (purchased from L-firms and amounting to 45.6 per cent of the revenues including payroll taxes). The capital service is produced using private and public physical capital measured in units of the final Y-good. While the public capital stock is a free input to production, the private capital expenditures amount to 22.5 per cent of the revenues.

About 3.7 per cent of the revenues are used for purchasing energy. The compensation of employees including payroll taxes amounts to 45.6 per cent of the revenues. The remaining 50.7 per cent of the revenues constitute the gross operating surplus which is used for capital expenditures (22.5 per cent of revenues), corporate income tax (1.7 per cent of revenues), and dividends plus interest payments (26.5 per cent of revenues).

Similar to Albonico et al. (2019), we assume capital is firm-specific rather than traded on a spot market. Hence, capital is not rented out to the most productive enterprise but sits with the firm. Capital can only be changed by investing and disinvesting. This adds critical frictions to the low-carbon transition and creates the problem of *asset stranding* in the fossil energy sector.

Borrowing constraints are crucial. Because of equity risks, equity shareholders ask for a premium over the risk-free rate. This has implications for the firm's preferred source of finance. Firms prefer to boost the cash flow in the short run by borrowing. This is because future profits are discounted by a rate  $R_{S,t}$  (with discount factor  $1/R_{S,t}$ ) that is higher than the rate of interest for new borrowing  $R_{B,t}$ . In other words, the benefit of an additional unit of cash flow today exceeds the value of the debt repayment due tomorrow. Firms exploit all available credit lines until borrowing constraints become binding. Following Gerali et al. (2010), we assume that the debt obligation in t + 1 cannot exceed a given fraction  $\lambda$  of the expected value of capital in t + 1 which serves as the collateral. That is, we impose

$$R_{B,t}B_{Z,t} \leq \lambda E_t P_{Y,t+1} Q_{Z,t+1} (1-\delta) K_{PZ,t},$$

in the firm's profit maximization problem where  $R_{B,t}$  is the gross interest rate for corporate borrowing,  $B_{Z,t}$  is corporate debt,  $\lambda$  is a constant,  $P_{Y,t}$  is the price level,  $Q_{Z,t}$  is Tobin's q or the value of capital,  $\delta$  is the rate of capital depreciation, and  $K_{PZ,t}$  is the private capital stock in the core good sector Z. This introduces to our model a financial-accelerator mechanism along the lines of Kiyotaki/Moore (1997): borrowing constraints are pro-cyclical as they vary with capital valuation.  $\lambda = 33.8$  is calibrated to achieve the empirical corporate debt–GDP ratio of 57 per cent at the steady state.

#### 2.4 Renewable energy, fossil energy, and carbon mining

Renewable energy firms (R-firms) are broadly symmetric to Z-firms, with a few important exceptions: they produce renewable energy using capital and labor only, without energy inputs. In contrast to Z-firms, R-firms operate under perfect competition. Nevertheless, R-firms accrue profits because of the assumption of firm-specific capital. Consistent with a large body of literature on renewable *learning rates*, total factor productivity is subject to a *learning-by-doing* externality which increases with renewable energy production (Mercure 2012; Rubin et al. 2015; Way et al. 2022). This feature allows the model to capture economies of scale in renewable energy production.

Fossil energy firms (F-firms) are symmetric to R-firms with one crucial difference: the underlying primary energy source – carbon – is a costly input to energy production. We allow some substitution between the capital–labor composite and carbon to capture the

switching between coal, oil, and gas. The corresponding elasticity of substitution is estimated. As with renewable sources, we assume that the supply of carbon is perfectly elastic.

We distinguish between public investment in energy production and infrastructure to capture the critical role of adequate green infrastructure as emphasized by Way et al. (2022). The capital stock associated with the former adds to the private capital stock as a perfect substitute. Hence, increasing public investment in energy production tends to crowd out private capital. Public infrastructure, however, complements production capital and tends to crowd in private investment as it increases its marginal return. Yet, there are limits: we impose a satiation level of public infrastructure beyond which additional public investment does not increase private capital returns.

The cost structures of renewable and fossil energy production are quite different since R-firms are more capital-intensive than F-firms. The compensation of employees, including payroll taxes as a share of total revenues, amount to 12.7 per cent and 11.9 per cent, respectively. The F-sector spends around 71 per cent of its revenues on raw coal, oil, and gas – the primary energy sources. The gross operating surplus in the R-sector is sizable (88.3 per cent of revenues) compared to F-sector (17.1 per cent of revenues). Yet, the bulk of it is needed for purchasing capital goods (58.8 per cent of revenues in the R-sector vs. 8.2 per cent in the F-sector). The corporate income tax shares are 1.9 per cent and 0.6 per cent, respectively. Differences in the dividend and interest payment shares reflect the different capital intensities: 26.6 per cent and 10.4 per cent, respectively.

For the sake of simplicity, we assume one global market for carbon sourced by domestic and international carbon mining. Carbon mines are owned by high-skilled households (13 per cent) and the RW (87 per cent). Any demand is fully accommodated at constant shares and a given exogenous world-market price denominated in USD. This implies that the domestic use of domestically extracted carbon is subjected to exchange rate fluctuations. We assume that domestically produced and imported carbon is used only by the fossil energy sector.<sup>8</sup> We further assume that carbon can be extracted without capital or labor input. Hence, carbon sales constitute pure rents.

CO<sub>2</sub> emissions are linked to the combustion of fossil fuels. There is a direct relationship between carbon input and emissions. The model captures the fact that coal, oil, and gas have different carbon intensities by allowing the F-firms to substitute carbon with capital and labor, thereby adjusting the carbon intensity of fossil energy (for instance, in response to an upstream carbon tax).

#### 2.5 The public sector and monetary policy

The public sector features a rich set of revenue and expenditure instruments. The revenue side comprises final consumption taxes (on average around 11 per cent of GDP), taxes on the H-households' stock of wealth (1 per cent of GDP), taxes on capital income including capital gains, high- and low-skilled labor income taxes (4 per cent of GDP), payroll taxes (7 per cent of GDP), corporate income taxes (2 per cent of GDP), fuel taxes (1.4 per cent of GDP) and upstream carbon taxes (which Türkiye does not currently have).

The expenditure side of fiscal policy consists of public consumption of the final good (on average around 14 per cent of GDP) and public investment in the core good sector (3.7 per cent of GDP) as well as in the renewable and fossil energy production (0.1 per cent and 0.1 per cent of GDP, respectively) and infrastructure (0.1 per cent and 0.1 per cent of

<sup>8.</sup> In reality, about 14 per cent of the carbon mining output goes into sectors different from fossil energy.

GDP, respectively). In the short run, public consumption and investment respond endogenously to the final output to capture automatic stabilizers. Finally, the government grants fossil and renewable energy subsidies to E-firms and transfers to L-households.

A possible deficit is financed by issuing government bonds. Even though government bonds (and domestic deposits) are assumed to be risk-free, the Turkish short-term bond returns has exceeded the policy rate by around 0.4 per cent. We model this as a *flight-to-safety* premium as in Smets/Wouters (2003).

The monetary authority sets the policy rate according to the Taylor rule. Given an average inflation rate of around 8 per cent over 2010–2016, which is close to the central bank's target of 5 per cent, the corresponding policy rate consistent with a 10 per cent long-term unemployment rate is around 8.8 per cent. The simulation will adjust these numbers to reflect the current monetary policy stance.

Over the business cycle, the policy rate responds to core inflation and the output gap. In the model, inflation targeting and exchange rate targeting are observationally equivalent as the uncovered interest rate parity condition implies that inflation and exchange rates move together. Note further that the Taylor principle does not necessarily hold in the model due to dis-equilibrium unemployment and steady-state wealth. With a sufficiently low labor-market sensitivity of low-skilled wages, the inflation sensitivity of the policy rate may be smaller than one (Schoder 2020). Note that around 50 per cent of Turkish wage earners receive the statuary minimum wage (DISK 2022).

#### 3 MODEL ESTIMATION

Given the limited information in macroeconomic data, not all model parameters can be estimated. A few weakly identified parameters have been calibrated according to microeconomic evidence; others have direct counterparts in the data and have been calibrated accordingly. Some parameters have been restricted for specific model variables to match their empirical counterpart at the steady state. All structural parameters have been estimated using standard Bayesian techniques as outlined in Herbst/Schorfheide (2015). We exploit annual and quarterly time series for 31 observed variables over 2000Q2– 2022Q3. Appendix 2 discusses all the details of our estimation strategy: data and sources, calibration, prior distributions, and the estimated posterior distributions. It also compares our findings to the empirical literature.

Almost all structural parameters are identified and broadly in line with the literature. A few findings are worth noting: first, we estimate the households' risk aversion parameter lower than what Çebi (2012), Smets/Wouters (2007), and Albonico et al. (2019) find for Türkiye, the US, and the EU, respectively. This is unsurprising given that our model explicitly features wealth in the utility function to capture precautionary saving motives.

Second, all elasticities of substitution are identified by data except the capital-labor elasticities for renewable energy firms. We keep unidentified parameters in the estimation to consistently account for parameter uncertainty in the simulation results below.

Third, we estimate the value-added and energy elasticity as 0.75, slightly above the industry estimates range in Van der Werf (2008). This is because our core goods sector is a mixture of sectors with different degrees of energy intensity. Therefore, our elasticity is also capturing substitution between sectors.

Fourth, our estimate for the elasticity of substitution between carbon and value-added in the fossil energy sector is very low (0.05), which indicates the difficulty of substituting out carbon in fossil energy production and implicitly the low degree of substitution



Figure 2 Mean and 90 per cent credibility interval of the time-varying elasticity of substitution between renewable and fossil energy

between fossil fuels with different carbon contents in Türkiye. Note that this makes the incidence and effects of carbon and fuel taxes almost identical in our model.

Fifth, the data strongly identify the long-run elasticity of substitution between renewable and fossil energy with a posterior mean of 18.5 and a 90 per cent High-Density Interval (HDI) of [10.1, 26.6]. As Figure 2 shows, our short-run elasticity starts from low values, covering the low elasticity case of Acemoglu et al. (2012) and estimations of Papageorgiou et al. (2017), and converges to its long-term mean in around 20 quarters.<sup>9</sup>

Sixth, the employment elasticity of low-skilled wage inflation is around 1.29. Recall that an elasticity of zero corresponds to the *pure* Keynesian case of dis-equilibrium unemployment while an elasticity going to infinity captures the *pure* Walrasian case of a general equilibrium (Schoder 2017, 2020). The estimated elasticity is relatively high and favors the Walrasian case over the Keynesian case. This is not surprising, however, given the rapid growth of the Turkish economy during the sample period.

#### 4 THE MACROECONOMIC EFFECTS OF A CLIMATE-FISCAL POLICY MIX FOR NET ZERO

Employing the estimated macro model outlined above, this section identifies a climatefiscal policy mix to achieve net zero in Türkiye by 2053 while observing significant feasibility constraints and reports its projected macroeconomic repercussions.

For this endeavor, we use conditional forecasts. This method restricts the future paths of constrained variables such as carbon emissions and computes the policy shocks needed to achieve the predetermined paths. Regarding the information set of the agents, we assume they do not anticipate the policy changes but, once implemented, perceive them as permanent. Conditional forecasting requires a linear approximation of the model. To capture the non-linearity of the transition path, we iteratively update the steady state around which the model is linearized.<sup>10</sup>

9. Acemoglu et al. (2012) consider the value of 3 as low and 10 as a high elasticity. Papageorgiou et al. (2017) estimate the short-run elasticity of substitution between dirty and clean energy around 2 for electricity and around 3 for non-energy sectors. Argentiero et al. (2017) find an elasticity around 1.2 for EU countries. We need to note, however, that the empirical literature is rather thin on the elasticity of substitution between clean and dirty energy.

10. In the last period of the sample, we obtain the smoothed value of each variable. We then linearize around the estimation sample's steady state and obtain a one-period ahead forecast starting from the economy's current position and imposing the policy changes necessary to achieve the The benchmark for the low-carbon transition scenario is a no-policy or business-as-usual baseline scenario. Because of persistence in macroeconomic adjustment, the dynamics at the end of the estimation sample spill over to the projection period. Consistent with OECD (2022), we limit the policy rate hike, which the model predicts, to capture the current monetary policy stance in Türkiye. This affects the public debt trajectory, too. Hence, we adjust government consumption to maintain the initially projected path of public debt. This path matches the recent IMF (2022) forecast. In the baseline, variables converge to their steady growth path in the long run. Labor productivity is assumed to grow by 4 per cent per year, which drives the growth of all trending variables, including baseline emissions.<sup>11</sup>

#### 4.1 Dynamic multiplier effects of climate-fiscal interventions

To identify a climate-smart policy mix under feasibility constraints, it is conducive to first study the macro implications of the core climate-fiscal policy interventions. We consider a carbon tax, a renewable energy subsidy, public investment in renewable energy generation, and public investment in renewable energy infrastructure below and above the satiation point. The policy interventions are permanent and phased in with an auto-regressive parameter of 0.8. We normalize each policy shock to 1 billion (bn) 2015 USD before any macroeconomic adjustment occurs. This corresponds to around 0.1 per cent of 2021 GDP.

Figure 3 reports the impulse-response functions (IRFs) for critical macroeconomic indicators. First, note that while the policy impulse of \$1 bn is the same for each instrument, the fiscal implications differ over time. For instance, the carbon tax decreases the public deficit only by around \$0.7 bn. This is because the tax successfully reduces emissions and erodes its base. In contrast, raising the renewable subsidy rate increases the fiscal stimulus over time as renewable energy expands. Hence, the primary deficit slightly overshoots 1 bn after ten years. Renewable infrastructure investments of \$1 bn cause a primary deficit of \$1.5 bn after ten years, assuming the satiation point is unmet. This is because of the decline in fuel tax revenues.

Second, infrastructure investment below the satiation point is highly effective in reducing emissions. This is consistent with Way et al. (2022) who argue that insufficient infrastructure investment may be a bottleneck for the low-carbon transition. Ten years after the policy change, \$1 bn of additional annual spending reduce emissions by around 40 million (mn) tonnes per year. By the same time, annual renewable energy production increases to around 6 mn toe, and annual fossil energy production decreases by 5 mn toe. In comparison, the carbon tax and the renewable energy subsidy reduce emissions only by around 6 mn tonnes per year after 10 years. The carbon tax achieves this mainly by reducing the energy intensity of production and the subsidy by spurring renewable energy production. Both public investment in renewable generation and infrastructure at the satiation point only have minor effects on  $CO_2$  emissions. For better comparability, consider the 10-year cumulative emission multiplier effects of the carbon tax, the renewable subsidy, and infrastructure investment below the satiation point. Moving \$1 bn over ten years reduces

targeted paths. Taking these policy shocks as permanent, we update the steady state and linearize around it. We obtain another one-period ahead forecast from the previously predicted position of the economy. The process is repeated until the end of the forecast horizon.

11. Note that the baseline scenario abstracts from two important developments: first, it neglects the Carbon Border Adjustment Mechanism which the European Union intends to implement on its imports. Hence, the baseline projections of Turkish exports may be too optimistic. Second, the baseline neglects the productivity spillovers from scaling up renewable energy production in the RW. It is, therefore, likely to underestimate the baseline emission reductions.





Note: Each policy shock is normalized to move 1 billion of constant 2015 USD before any macroeconomic adjustment.

The macroeconomic effects of selected permanent climate-fiscal policy interventions Figure 3

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emissions by 4.3 mn, 3.9 mn, and 22.2 mn tonnes, respectively. These results are highly consistent with Deleidi et al. (2020), whose panel study covering 17 countries suggests that public investment is considerably more effective in mobilizing private finance than carbon taxes or renewable subsidies.

Third, there are critical macroeconomic differences between the policy instruments. The carbon tax contracts GDP by around \$0.4 bn after ten years. The renewable subsidy raises GDP by around \$1 bn. At the margin, green infrastructure investment below the satiation point boosts GDP even by \$5.6 bn. These instruments' 10-year cumulative GDP multipliers are -0.4, 0.74, and 3.37, respectively. Public investment in generation and infrastructure at the satiation point only have minor GDP effects. The economics behind these results is straightforward: the carbon tax increases energy prices and reduces private consumption and investment. The subsidy encourages private activity by lowering energy prices and stimulating the demand for renewable energy. Public infrastructure investment not only stimulates aggregate demand but also increases the marginal returns of private capital.

Fourth, none of the climate-fiscal instruments considered here affects net exports considerably. Nevertheless, the composition of trade changes fundamentally, causing significant friction. Depending on the policy instrument, exports decrease by up to \$0.6 bn. Only public investment in renewable energy generation has no impact on exports. Infrastructure investment below the satiation point raises non-oil imports strongly by up to \$1.5 bn. Given an import share of fossil fuels of 87 per cent, the responses of the oil imports mirror those of  $CO_2$  emissions. The carbon tax and the renewable subsidy reduce oil imports by up to \$0.4 bn. Infrastructure investment reduces oil imports by up to \$2.6 bn.

Fifth, to the extent that climate-fiscal policy instruments push the unemployment rate below (or above) the non-accelerating inflation rate of unemployment (NAIRU), headline inflation may settle above (or below) the inflation target. For instance, the carbon tax increases the labor intensity of production. This tightens the low-skilled labor market and translates into higher wages and, eventually, price inflation of around 0.08 percentage points above target. Infrastructure investment at the satiation point has the same effect. The renewable subsidy reduces the labor intensity of production, causing inflation to settle 0.1 percentage points below target. Infrastructure investment below the satiation lowers inflation considerably by up to one percentage point. As discussed in the sensitivity analysis of Appendix 2, the central bank's response to transition-induced deviations of inflation from the target critically determines the GDP response.

#### 4.2 A climate-fiscal policy mix for net zero under constraints

The net-zero scenario involves the following targets and constraints: broadly consistent with IPC (2021) and World Bank (2022), we require  $CO_2$  emissions to decrease linearly from 400 mn tonnes in 2022 to 68 mn tonnes in 2053. Regarding debt stability, we require public debt to decrease until it reaches 34 per cent of trend GDP. After that, it stays at this level. For political economy reasons, we require that low-skilled consumption is not lower than in the baseline scenario. We also require that public investment ensures fossil and renewable infrastructure are at their respective satiation levels. Finally, a public bad bank is assumed to purchase stranded private assets at replacement cost.

Figure 4 illustrates how Türkiye can achieve the pathway to net zero by 2053 under the above-mentioned constraints. It displays projections at the posterior mean as well as an approximation of the 90 per cent HDI reflecting posterior parameter uncertainty.<sup>12</sup> Simulations start

12. The HDI approximation has been obtained from a Monte Carlo simulation of the conditional forecasts. In particular, we took 500 draws from the posterior distribution and ran the conditional forecasts. We excluded draws that resulted in explosive forecasts or computational errors.



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in 2022Q4. We broadly distinguish between three phases: (a) the fiscal consolidation, (b) the renewable energy boom, (c) and the final push.

The phase of *fiscal consolidation* starts in 2022Q3 and lasts for about five years. Türkiye seeks to achieve the twin goals of reducing emissions and public debt. Fossil fuel subsidies, amounting to 0.4 per cent of GDP in 2022, are gradually phased out within ten years. The government introduces a carbon tax that quickly increases to \$70 per tonne of  $CO_2$  until 2026Q4. With economies of scale kicking in only at higher levels of renewable generation, the initial phase requires a big-push policy (Ploeg/Venables 2022). Note that, in the initial phase, the posterior parameter uncertainty illustrated in Figure B1 of Appendix 2 does not translate into considerable forecast uncertainty of the projected carbon tax.

Public investment in fossil infrastructure decreases from 0.1 per cent of trend GDP to 0.01 per cent. Note that private investment is sensitive to public infrastructure investment. Hence, the phase-out of fossil infrastructure investment – including the sharp decline in the first few quarters – is designed to keep the risk of private asset stranding small.<sup>13</sup> Nevertheless, the 90 per cent HDI of stranded asset purchases indicates a considerable risk of asset stranding already in the early stages of the transition.

To compensate for the negative effect of the carbon tax on low-skilled consumption, transfer payments increase from 8.1 per cent of trend GDP in 2022 to 8.7 per cent in 2026Q4. While the rapid phase-out of fossil investment reduces the risk of asset stranding, it generates uncertainty regarding the required public support of low-skilled house-holds as indicated by the wide 90 per cent HDI during the fiscal-consolidation phase.

Renewable infrastructure investment rises from 0.1 per cent of trend GDP to 0.195 per cent within ten years. We assume that this exactly matches the renewable infrastructure satiation level. It corresponds to the \$2 bn of annual investment needs in renewable infrastructure identified in World Bank (2022). By 2027, emissions decline below 340 mn tonnes – the reference value calculated for Türkiye to stay on the 2°C path in 2030 (Voyvoda/Yeldan 2015).

At the posterior mean, the target public debt–GDP ratio of 34 per cent is achieved in 2027Q1. This is when the phase of the *renewable energy boom* starts.<sup>14</sup> Instead of reducing public debt, carbon tax revenues are now used to finance renewable energy subsidies while keeping public debt at a constant share of trend GDP.<sup>15</sup> The subsidy peaks in 2029Q1 at \$1,400 per toe, which amounts to a sizable bill of 0.62 per cent of GDP. As emissions decrease, the revenues from the fuel tax and the carbon tax decline. To continue meeting the public debt target, renewable subsidies are phased out gradually until 2037. During the renewable energy boom, carbon taxes can be temporarily lowered as the renewable subsidies sufficiently reduce emissions to stay on target.

Note that there is considerable parameter uncertainty regarding the size of the renewable subsidy and the duration of the boom. At the peak, the 90 per cent HDI ranges from \$300 to \$2,800 per toe. Regarding phase-out time, the 90 per cent HDI ranges from 2032 to 2042. Given strict public debt and low-skilled consumption targets, the uncertainty about the macroeconomic effects of the policy mix considered translates into uncertainty about how much public funds there will be available for renewable subsidies.

<sup>13.</sup> We define stranded capital assets as the private capital stock which F-firms do not wish to hold any longer. Stranded assets are valued at replacement costs.

<sup>14.</sup> In the Monte Carlo simulation of the 90 per cent HDI, we fix the start date of the renewable subsidy to 2027Q1 and hold the public debt–trend GDP ratio constant at whatever value it has in that period.

<sup>15.</sup> To ensure a smooth transition, the subsidies are phased in already in 2026Q2.

At the posterior mean, revenues will be insufficient to sustain a constant debt-trend GDP ratio, even without subsidies, by 2037. This is the beginning of the phase of the *final push*. The carbon tax increases from \$90 in 2037 to \$175 in 2053. The carbon tax required to stay on the path to net zero is subject to only moderate parameter uncertainty. For instance, the 90 per cent HDI in 2053 ranges from \$160 to \$220.

Despite increasing tax rates, carbon tax revenues decline. To ensure debt stability, government consumption declines from around 14 per cent of trend GDP in 2037 to 12.1 per cent in 2053. Low-skilled households are compensated with transfers up to 9.1 per cent of trend GDP until 2053 – one percentage point higher than in 2022.

During the final push, the risk of fossil asset stranding is high. In our posterior-mean simulation, the public bad bank's annual purchases of stranded capital assets almost reach 0.02 per cent of trend GDP in 2053.

#### 4.3 Macroeconomic repercussions of the net-zero policy mix

The policy package proposed for the Turkish pathway to net zero is projected to critically affect key macroeconomic indicators. We focus on energy investment and consumption, GDP, trade, household welfare, fossil equity share prices, and stranded assets.

#### 4.3.1 Energy investment and consumption

Figure 5 plots the historical and projected paths of private investment and production in the renewable and fossil energy sectors. The climate-fiscal policy mix previously discussed is projected to induce considerable private investment – especially during the *renewable energy boom* triggered by the renewable subsidy. We project private investment in renewable energy to increase from around \$4 bn in 2022 to \$150 bn in 2053. This is almost 4 per cent of trend GDP or around 12 times the renewable investment of the baseline scenario. Note that it is also about ten times the baseline fossil investment. It matches the annual investment needs of 4 per cent to 4.5 per cent of GDP identified by Ranger/ Volz (2023).

The overall energy capital requirements of the transition exceed the baseline needs because renewable energy is entirely produced domestically. Recall that, in the baseline, Türkiye imports 87 per cent of its total primary energy supply. Moreover, the renewable energy sector is considerably more capital-intensive than the fossil energy sector (which, in our model, excludes carbon extraction). It is important to emphasize that the projected expansion of renewable investment presumes ideal energy market regulation for energy production to be profitable.

Private investment in the fossil energy sector starts from \$4 bn in 2022 and disappears entirely. Given the policy mix, fossil investment is expected to turn negative by 2042. That is, capital assets are stranding. They are decommissioned and purchased by the public bad bank.

Renewable energy consumption increases from around 20 mn toe in 2022 to 420 mn toe by 2053. This is 460 per cent higher than the baseline projection. By the early 2030s, renewable energy will reach 50 per cent of the energy mix. This is similar to net-zero pathway findings of IPC (2021) for 2030. Fossil energy consumption will decrease from 130mn toe in 2022 to around 20 mn toe by 2053. This is 96 per cent below the baseline projection. By 2053, the overall energy consumption will be 20 per cent below the baseline. The carbon tax not only triggers the substitution from fossil energy to renewable energy but also to capital and labor, reducing the energy intensity of GDP.





#### 4.3.2 GDP and components

For the climate-fiscal policy mix previously identified, the first three panels in Figure 6 plot the projected responses of GDP, consumption, investment, exports, and imports. Overall, the GDP effects are moderate, staying within 1 per cent of GDP. While consumption does not deviate significantly from the baseline, investment reaches levels of 4 per cent above baseline by 2030 and almost 6 per cent by 2053. The low-carbon transition is investment driven. On the flip side, net exports decline to a similar extent. Overall, considerable parameter uncertainty exists regarding the net effects on GDP and its components.

During the phase of *fiscal consolidation*, GDP declines by up to 0.7 per cent in 2027 compared to baseline – a finding that is small but in line with the literature (Voyvoda/Yeldan 2015). The significant expansionary effect of public spending on renewable infrastructure considerably dampens the contractionary effects of the carbon tax and the fossil subsidy phase-out. During the *renewable energy boom*, GDP recovers slightly, exceeding baseline until the mid-2030s. This is driven by the renewable energy subsidy, which stimulates GDP through two important channels: lower energy prices and an investment boom. Note that endogenous productivity gains from scaling up renewable production reinforce the subsidy effects on energy prices and investment. During the *final push*, when government consumption declines to maintain public debt stability, GDP decreases to 1 per cent below baseline in 2053.

To put the GDP effects in context, we consider a pure fiscal-consolidation scenario that does not seek to decarbonize the economy but adjusts public consumption to achieve the same public-debt trajectory we obtain from the decarbonization scenario. It is worth noting that the initial contraction of GDP is much more substantial: 4.5 per cent below baseline in 2025Q1. Hence, combining carbon pricing and public investment in renewable infrastructure is a cost-effective and climate-smart way of fiscal consolidation.

Trade is subject to transition risks. On the positive side, the low-carbon transition will allow Türkiye to eliminate its dependence on fossil fuel imports which currently amount to 87 per cent of the total primary energy supply. Total net exports decrease by around 4 per cent of GDP, which may be considered moderate. Yet, exports will steadily decline by up to 11 per cent in 2053 compared to the baseline. The inflationary pressure of higher energy prices will lead to a real appreciation of the Turkish lira. The loss in competitiveness translates into a decline in exports, whose stabilization may require additional policy measures that support exporting firms. As a qualification of this result, note that our baseline scenario (against which the losses of the policy scenarios are measured) does not reflect the EU's Carbon Border Adjustment Mechanism. Given that half of the Turkish exports are going to the EU, the baseline, no-transition exports are likely to be overestimated.

#### 4.3.3 Household welfare

Even though the GDP effects of the low-carbon transition are expected to be moderate in Türkiye, this may not hold for household welfare. At the first order, households care about how much they can consume in goods and services and how much leisure they can enjoy. High-skilled households additionally care about how much financial wealth they hold. Therefore, we follow the method of Born/Pfeifer (2020) and assess unconditional welfare effects over time using the concept of *consumption equivalence*.<sup>16</sup>

16. The welfare difference between the transition and baseline scenario is measured as the share of consumption which a household living in the baseline has to receive to be indifferent between the baseline and the low-carbon transition. Note that we evaluate welfare only at the first order.





As shown in the fourth panel of Figure 6, the low-skilled household welfare effects along the transition path are moderate, with the consumption equivalent moving between -1.5 per cent and 2 per cent of baseline consumption. This is because of the transfer payments that keep low-skilled consumption at the level of the baseline scenario. Without these payments, low-skilled households would strongly prefer the baseline over the transition scenario. The consumption equivalent would reach around -5 per cent (not shown). That is, they would have to forsake up to 5 per cent of their baseline consumption to be indifferent between the baseline and the transition.

Overall, high-skilled households benefit more from the transition than low-skilled households – even though they do not receive transfers. For comparison, we first consider the case in which high-skilled households do not derive utility from wealth.<sup>17</sup> The aggregated high- and low-skilled utility functions are identical in that case. We find that the decline in GDP initially translates into a reduction in high-skilled consumption, reducing welfare. Starting with the *renewable energy boom*, the high-skilled household's welfare improves with a consumption equivalence of up to 2 per cent by 2053.

In the case of wealth utility, welfare effects are much more substantial. The consumption equivalent during the *fiscal consolidation* reaches –14 per cent in 2025. Yet, during the renewable boom, it goes up to 43 per cent and later stabilizes around 20 per cent. To be indifferent between the baseline and the transition scenario, high-skilled households of the baseline would require a significant amount of additional consumption. The welfare effects are substantial because the policy interventions, which are perceived as permanent once implemented, significantly affect the net present value of wealth. Since the renewable energy sector is more capital-intensive than the fossil energy sector, the low-carbon transition implies a net increase in capital assets which are held by the high-skilled households. Since wealth is a source of utility, high-skilled households benefit from the transition. As shown in the fourth panel of Figure 6, the wealth channel is a major driver of household welfare.

While these results highlight the importance of studying the welfare impacts of the low-carbon transition on households, they likely draw too gloomy a picture as the model leaves out critical transmission channels: First, as many studies have shown, the benefits of the reduction in  $CO_2$ -related air pollution are sizable and outweigh the purely consumption and leisure-related welfare loss of the low-carbon transition (Parry et al. 2015; Karlsson et al. 2020). Second, the model's assumption that the high- and low-skilled consumption bundles are identical further distorts the picture as the former tends to be more energy- and carbon-intensive than the latter (Sager 2019; Dorband et al. 2019).

#### 4.3.4 Stranded assets

Financial risks arise from the devaluation of private equity shares and the stranding of productive capital assets in the fossil energy sector. These risks are manageable because the volume of fossil capital assets in Türkiye is relatively tiny. Recall that Türkiye imports most of its fossil fuels. Nevertheless, a disorderly transition and lousy policy communication may increase these transition risks.

<sup>17.</sup> Assume, for instance, that household-level wealth enters the utility function as the difference to aggregate wealth. The first-order conditions remain the same, but the wealth term in the utility function now has the interpretation of *keeping up with the Joneses* rather than *precautionary saving*.

The last two panels in Figure 6 show the responses of equity share prices and stranded assets to an orderly and delayed transition. The longer the transition is delayed, the more sudden the drop in asset prices and the higher the financial risks. Regarding asset stranding, the public bad bank needs to purchase excess capital assets only starting in 2044, according to our simulation of an orderly transition. Evaluated at replacement costs, the volume of the stranded capital stock will reach almost 0.1 per cent of trend GDP by 2053. In comparison, the total public capital stock is 29 per cent of trend GDP. A delayed transition and an ill-timed phase-out of public fossil infrastructure investment increase the risk of asset stranding. For instance, delaying the start of the transition until 2030 will generate significant stranded assets already by 2033, and the volume will reach 0.63 per cent of trend GDP in 2043. Policy communication and commitment to the net-zero agenda reduce the risk of asset stranding (Bretschger/ Soretz 2022).

#### 4.4 Supporting policies: policy commitment and structural reforms

This section investigates how policy commitment and structural reforms can support the low-carbon transition and improve the macroeconomic outlook of the climate policies implemented. In particular, we simulate the macroeconomic effects of the policy mix identified in Section 4.3 in various counterfactual scenarios: (a) credible policy commitment, (b) expected policy reversal, (c) lower risk premia due to improved rule of law, (d) and facilitated access to green finance.

#### 4.4.1 Expectations regarding policy commitment

In the benchmark policy forecast reported above, we assumed that agents do not anticipate the policy interventions required to achieve net zero or do not deem the government's netzero commitment credible. Yet, once implemented, agents expect the policy changes to be permanent. No policy reversal is expected. In this section, we consider two additional scenarios regarding the credibility of the net-zero pledge. In each expectation scenario, we take the same dynamic policy mix as identified above and simulate its macroeconomic effects. This allows us to isolate the effects of expectations regarding policy commitment. In the credible-commitment scenario, the entire path of future policy interventions is communicated to the public. The government is fully committed to the announcement and the public deems it credible. In the *policy-reversal* scenario, agents observe a policy change once implemented but, instead of perceiving it as permanent, they expect it to slowly phase out again - for instance, due to anticipated social unrest or vested interests. We assume an auto-regressive parameter of 0.95. That is, agents expect that any given policy change will be reversed by 50 per cent after about four years. As Campiglio et al. (2023) points out, there are multiple real-world examples of policy reversals that justify this type of expectation.

As shown in Figure 7, transparent policy communication and fully credible commitment can crowd in private sector behavior, slightly raising renewable investment and generation. Net zero is already reached in the late-2040s. Since the different stages of the transition phase are anticipated, agents can smooth behavior and reduce adjustment costs and friction. This reduces the GDP contraction of the fiscal-consolidation phase and raises and prolongs the GDP expansion during the scaling-up phase.

The private-sector expectation that a future government will take back already implemented measures makes the transition considerably more costly. Even with an expected





slow policy reversal of 5 per cent each quarter, GDP is projected around 0.5 per cent below the benchmark policy scenario for most of the transition period. Even worse, the policy mix that is sufficient for net zero in the benchmark scenario, will fail to achieve the transition in the weak-commitment scenario. Emissions are projected to decline by only 55 per cent compared to the no-policy baseline. Hence, to achieve net zero the carbon tax would have to be considerably higher than in the benchmark policy scenario further reducing GDP.

Credible commitment reduces the costs of decarbonization. Yet, as is well-understood since Kydland/Prescott (1977), policy commitments are credible only with the corresponding institutional setting. Barrett (2008) suggests to amend climate treaties with an enforcement mechanism, such as a trade restriction. Nordhaus (2015) proposes a climate club intended to eliminate the problem of free-riding. On a national level, Chile pioneers sustainability-linked sovereign bonds, which link the bond return to green performance indicators and partly align the government's interests with the low-carbon agenda (Giráldez/Fontana 2021). Our results suggest that these measures would considerably lower the costs of the low-carbon transition by anchoring private-sector expectations.

#### 4.4.2 Structural reforms

OECD (2021) has identified a weak rule of law as a main obstacle for private-sector investment dynamics in Türkiye. To assess the role of the business uncertainty for the low-carbon transition, Figure 7 also illustrates the scenario in which the government implements reforms that reduce the equity risk premium to the average of China, India, and South Africa within five years. These reforms drastically improve the macro-economic outlook of the low-carbon transition, with GDP peaking at 3 per cent above the no-policy baseline. Renewable energy investment and generation are considerably higher than in the scenario with the benchmark risk premium. The economics of these results is straightforward: with a lower equity-risk premium, firms reduce the discounting of future profits. Capital investment becomes more appealing. Since renewable energy is very capital-intensive, this sector mainly benefits from a lower risk premium.

Regarding bank lending, the OECD's recommendation for Türkiye is to reduce privatesector debt (OECD 2021). Nevertheless, we consider the counterfactual scenario in which the government implements reforms that gradually reduce constraints on green finance within five years. In particular, we assume that the share of capital which banks accept as collateral for lending to renewable energy firms increases by 20 percentage points. Figure 7 illustrates the results. Similar to the scenario of an improved rule of law, renewable energy investment and generation increase considerably. The GDP response demonstrates the importance of the financial accelerator mechanism forcefully. With a higher debt–capital ratio and borrowing constraints proportional to the value of capital, business activity becomes more pro-cyclical. As the value of the renewable capital stock decreases in the fiscal-consolidation phase, borrowing constraints tighten up, and GDP contracts considerably. On the flip side, the subsequent boom initiated by the renewable energy subsidy alleviates borrowing constraints, reinforcing the expansion of GDP.

#### 5 CONCLUDING REMARKS

In conclusion, this paper examines the feasibility of Türkiye's net-zero emissions target by 2053, given the country's structural deficits and recent climate-related risks. The country's

dependence on fossil fuel imports and the volatility of energy prices due to exchange rate fluctuations pose significant risks to energy security. The European Union's low-carbon agenda threatens Türkiye's access to its primary export market if production does not become less carbon-intensive. Therefore, it is in Türkiye's national interest to implement effective climate-fiscal policy interventions that enable the country to grow along the 2053 net-zero pathway, taking into account feasibility constraints.

The analysis employs an empirical dynamic stochastic open-economy macro framework, allowing for the simulation of low-carbon transitions. The policy instruments evaluated include a carbon tax, a renewable energy subsidy, transfer payments, public infrastructure investment, a bad bank for stranded assets, and the phase-out of fossil fuel subsidies and public investment. The study also explores how the macroeconomic effects of the policy interventions differ in counterfactual scenarios of a fully credible commitment to net zero, an improved rule of law, and facilitated access to green bank finance.

The study finds that Türkiye's transition to net zero is feasible with a mix of policy instruments that address the country's structural deficits. The model simulations show that a credible commitment to net zero, improved rule of law, and access to green bank finance would improve the effectiveness of climate-fiscal policy interventions in mobilizing private finance. Moreover, renewable energy subsidies and public infrastructure investments have a positive effect on economic growth, while the carbon tax and phase-out of fossil fuel subsidies contribute to the decarbonization of the economy.

Therefore, the study suggests that Türkiye's climate policy should focus on the implementation of an integrated set of policy interventions that take into account the country's structural deficits, particularly the weak rule of law, and low business confidence in public institutions. A credible commitment to net zero, improvements in access to finance and the rule of law, coupled with a mix of policy instruments, can provide a path to sustainable and equitable economic growth while meeting Türkiye's climate goals.

#### ACKNOWLEDGEMENTS

We would like to thank János Varga, Charl Jooste, Florent McIsaac, and two anonymous referees for valuable comments and suggestions. The paper has been presented at the 27th conference of the Forum for Macroeconomics and Macroeconomic Policies (FMM) and has greatly benefited from comments by participants. The views expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the organizations the authors are affiliated with.

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