

A Service of

ZBW

Leibniz-Informationszentrum Wirtschaft Leibniz Information Centre for Economics

Rapa, Noel

Working Paper The effects of increases in carbon prices in Malta: A study using MEDSEA-NRG

CBM Working Papers, No. WP/03/2024

Provided in Cooperation with: Central Bank of Malta, Valletta

Suggested Citation: Rapa, Noel (2024) : The effects of increases in carbon prices in Malta: A study using MEDSEA-NRG, CBM Working Papers, No. WP/03/2024, Central Bank of Malta, Valletta

This Version is available at: https://hdl.handle.net/10419/301976

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



WWW.ECONSTOR.EU

BANK ĊENTRALI TA' MALTA CENTRAL BANK OF MALTA

CENTRAL BANK OF MALTA WORKING PAPER



The Effects of Increases in Carbon Prices in Malta - A

study using MEDSEA-NRG

Noel Rapa^{*}

Central Bank of Malta

WP/03/2024

^{*}Research Department, Central Bank of Malta. I would like to thank Professor Edward Scicluna, Mr. Alexander Demarco, Dr. Aaron G. Grech for comments. Special thanks go to Matija Lozej, Massimo Giovannini, participants to internal seminars at the Economics Division of the Bank and participants to the 17th Annual Dynare Conference for lengthy discussions and suggestions. The usual disclaimer applies. The views expressed are those of the author and do not necessarily reflect the views of the Central Bank of Malta. Any remaining errors are the sole responsibility of the author. Correspondence: publicrelations@centralbankmalta.org.

Abstract

This paper documents the extension of MEDSEA, a small open economy DSGE model for Malta, with a detailed energy sector. The model contains relatively rich fiscal and energy blocks allowing the model to simulate the transitional costs related to the economy's decarbonisation, together with the effects of the possible recycling of carbon tax revenues. Temporary simulations show that taxing fossil-based energy leads to a prolonged drop in economic activity, together with a relatively short-lived increase in consumer price inflation. Energy taxes are found to have asymmetric effects on households, with poorer households being more heavily hit by higher energy prices. Policy experiments show that a decarbonisation policy based solely on increases in carbon taxes will lead to a substantial drop in economic activity with some pressures on inflation, with below target increases in green energy take-up and below target cuts in Green House Gasses. Effects are also expected to be asymmetric with poorer households projected to cut their consumption by more than average. The distributional effects of decarbonisation policies are well addressed by both symmetric and targeted increases in lump-sum transfers. However, recycling carbon revenues by increasing subsidies to green capital is most efficient in reducing the economic costs associated with increases in carbon prices and in attaining environmental targets in terms of reduced emissions and increased take-up of renewable energy.

JEL Classification: C54, E62, H23, Q43

Keywords: Climate change, carbon taxation, fiscal policy, DSGE models

Contents

1	Intr	roduction	5
2	Mo	del	7
	2.1	Setup of MEDSEA-fiscal	7
	2.2	MEDSEA-NRG	8
	2.3	Value added production	9
	2.4	Intermediate goods production	10
	2.5	Energy sector firms	12
		2.5.1 Energy bundle E_t	12
		2.5.2 Fuel energy pricing E_t^F	13
		2.5.3 Electrical energy bundle E_t^E	14
		2.5.4 Grid electricity bundle E_t^{EG}	15
		2.5.5 Renewable electricity bundle E_t^{ER}	17
		2.5.6 GHG emissions	18
	2.6	Households	19
		2.6.1 Ricardian Households	20
		2.6.2 Hand-to-mouth households	22
3	Cali	ibration	22
	3.1	Energy in the intermediate sector	23
	3.2	Energy production	24
	3.3	Energy in the consumption bundle	25
4	\mathbf{Sim}	nulations	26
	4.1	Temporary Shocks	26
		4.1.1 Brown energy taxes	26
		4.1.2 Green subsidies	29
	4.2	Policy scenarios	32
		4.2.1 Baseline	33
		4.2.2 Alternative scenarios	37
		4.2.3 Recycling proceeds from carbon pricing	43

5 Conclusion

 $\mathbf{50}$

Α	Main macroeconomic parameters	54
в	Energy specific parameters	56

1 Introduction

Under the Paris Agreement of the United Nations Framework Convention on Climate Change, all signatories have agreed to limit the increase in the global average temperature to well below 2°C above preindustrial levels and to pursue efforts to limit the temperature increase to 1.5°C. In line with this target, EU member states have pledged to cut their Green House Gas (GHG) emissions by 55% by 2030, in a bid to turn the EU into a carbon neutral economy by 2050.

With almost 75% of all GHG emissions linked to energy production, most climate policies are targeted at transforming the global energy sector from a fossil-based production system to one which relies on renewable energy sources. Undoubtedly, optimally managing this energy transition, will be a critical policy challenge for the foreseeable future. Along this transition, policy makers will often be faced with policy trade-offs as they seek to balance security of supply, affordability and sustainability of energy production.¹

Carbon taxing (i.e. taxing the carbon content of fuel used in energy production) has been touted as a key measure to reduce GHG emissions. Over the medium-run, this is likely to add upward pressures on energy prices which in turn will depend on the speed with which agents are willing to change the mix of fossil and renewable sources in energy production. These costs are also likely to asymmetrically affect poorer households which usually consume a consumption basket which is more heavily skewed towards energy consumption (See Darmanin, 2021). Taxing "brown" energy sources will on the other hand yield additional government revenue that can be recycled either across the board to all taxpayers or targeted to compensate economic agents that are mostly affected by energy inflation.

Against this backdrop, it is important for policymakers to have tools that are detailed yet flexible enough to map how energy polices affect the macroeconomy. In this light I extend a standard New Keynesian model with a detailed fiscal block (Rapa, 2017) with a multi-sectoral energy block. This version of the model uses a multisector setup for the production side in the spirit of Giovannini et al. (2019), Varga et al. (2021) and Coenen et al. (2023). I distinguish between the production of "green" and "brown" energy with the former depending on the production of electricity through renewable sources. The production of green electricity explicitly requires investment in "green" capital which is allowed to crowd out investment in conventional capital which is required for the production of intermediate goods and services.

The model seeks to model the peculiarities of Malta's energy sector, in particular its brown

 $^{^1{\}rm These}$ three policy goals of the energy transition have been termed as the energy policy triangle or trilemma, see for instance Schmidt et al., 2019

electricity generation which depends on a single Liquified Natural Gas (LNG)-fired complex, and its dependence on the Malta-Sicily interconnector, through which Malta imports a significant proportion of its electricity needs. Contrary to models in its class, this paper seeks to explicitly model the economy's dependency on fossil fuels, with electricity production relying explicitly on LNG, while other energy generation (most prominently used for transport) depending on other fossil fuels (such as petrol and gasoil). Finally, unlike similar models, MEDSEA-NRG explicitly models the asymmetric effects that energy price inflation is likely to have on poorer households. The latter is an important consideration especially when considering the type of revenue recycling policies to adopt following carbon tax hikes.

I use this augmented version of MEDSEA to perform a number of simulations. In a first instance, I perform a number temporary shocks that allow to uncover the main simulation properties of the model. In the second part, I perform a number of policy-relevant simulations that seek to estimate the macroeconomic effects of an increase in carbon taxes in Malta that are consistent with reaching the EU's target of cutting green house gasses by 55% by 2030. In this respect I simulate the model with gradual and permanent increases in brown taxes calibrated in line with carbon price paths consistent with global decarbonisation efforts. Under the baseline scenario, brown energy taxes are gradually raised to simulate increases in carbon prices to around EUR 135 per ton of CO_2 by 2030. This policy is broadly speaking contractionary with the fall in economic activity reaching a maximum of 0.9% in 2030. The policy is very marginally deflationary in the very short run, turning to mildly inflationary in the medium run, with annualised consumption inflation expected to be around 0.12pp higher than in steady state. Consumption inflation for non-Ricardian households is expected to be almost double that experienced by Ricardian households. This, together with considerable falls in labour income, is expected to give rise to negative income effects that lead to considerable distribution effects, with non-Ricardian households expected to cut private consumption my more than Ricardian households by the end of the simulation horizon. Despite the non-trivial economic costs (especially in terms of economic output) the baseline scenario is consistent with very small gains in terms of the increase in renewable energy and cuts in greenhouse gasses.

The sensitivity of these findings is tested using a number of alternatives scenarios, including using different assumptions surrounding the required increase in carbon prices, different adjustment paths in carbon prices, as well as assuming different fiscal revenue recycling options. Results show that there is a considerable degree of uncertainty surrounding the extent of economic losses of the decarbonisation process. Taking in consideration the highest carbon prices estimated in literature is consistent with a fall in economic activity that is double that estimated in the baseline scenario. Similarly, the impact of inflation under the worst-case scenario is projected to be more than twice that foreseen under the baseline scenario. Moreover, alternative paths, that either front-load or back-load carbon price increases, are consistent with considerably stronger consumer price inflation volatility. Front-loading carbon price increases is consistent with output falls that are stronger than the baseline scenario at each point of the simulation with the benefit of considerably more marked improvements in the Government's fiscal position. On the other hand, back-loading carbon price increases, leads to a more contained drop in economic activity, but is consistent with limited improvements in fiscal space.

The latter point could have considerable implications especially because simulations show that the recycling of additional tax revenues absorbed through higher carbon prices have significant macroeconomic effects. Using carbon proceeds to increase transfers to households (either symmetrically or through targeted approaches) considerably reduces the distributional costs associated with carbon prices. In fact even symmetrical transfers are able to considerably limit the negative income effects of carbon price policies, thus pushing up non-Ricardian type private consumption. On the other hand, recycling through transfers is consistent with further drops in overall economic activity on the back of slightly higher core inflation. Recycling carbon revenues through green capital subsidies are less effective at reducing the distributional issues associate with carbon taxes, but can considerably reduce the output costs associated with such policies. Perhaps more importantly given the motivation behind carbon price increases, a policy combining carbon price increases with green capital subsidies is very effective at reducing total greenhouse emissions in the economy and to increase the share of renewables in total energy in line with the Government commitments outlined in the National Energy and Climate Plan.

The rest of the paper is structured as follows: section 2 provides a detailed view of the model structure, section 3 discusses the calibration of the main parameters governing the model's steady state and dynamics while section 4 seeks to outline the main properties of the model by providing a number of policy simulations. Section 5 concludes.

2 Model

2.1 Setup of MEDSEA-fiscal

MEDSEA-fiscal (Rapa, 2017) is a small open economy DSGE model containing key modifications designed to account for Malta's characteristics. The Maltese economy is modelled within a monetary union, thereby lacking an independent inflation targeting rule. The model contains five types of agents: households, intermediate good producers, final good firms, aggregators and the government. There are two types of households; Ricardians, which are allowed to intertemporally optimise their consumption through the holding of riskless bonds and non-Ricardians which can only consume their current disposable income. The former type of households also own all firms and capital in the economy and therefore, apart from labour income also receive remunerations on their capital as well as the dividends earned by firms.

The model allows for two types of intermediate good producers, one producing goods and services meant for local consumption and another type producing output designed to be directly exported. This distinction is important to reflect the fact that Maltese output produced by exporting firms is intrinsically different from output demanded locally. Moreover, the final goods structure is quite detailed, allowing the model to pin down the different import intensities of each final demand type. This is an important feature considering the fact that the import intensities of Maltese GDP aggregates are very high and quite heterogeneous across final demand components.

The fiscal block is quite detailed. On the revenue side, the government levies four types of taxes; a tax on labour income, one on capital income and dividends, one on consumption and a lump sum tax and issues government bonds on the local market.² These are used to finance government investment, government transfers to both types of households, government purchases and government employment.

Government recurrent expenditure (made up of government purchases and government wage bill) is then transformed into the production of public goods which are allowed to directly enter the utility function of both households.

2.2 MEDSEA-NRG

MEDSEA-NRG builds on this setup by introducing a disaggregated energy block. To do this I assume that intermediate goods are produced in two stages. In the first step intermediate good firms choose the optimal allocation of labour and capital to produce value added which is then combined with an energy input in a second stage. Energy is in turn produced using a multistage production process where energy firms optimally combine different energy types. Each energy type is in turn associated with a specific GHG intensity depending on the fuel and technology

²This assumption is based on the fact that virtually all government debt is owned by Maltese residents.

used in its production.³

Contrary to most models in this class, the energy sector does not simply distinguish between "green" and "brown" energy. In the first layer of energy production I distinguish between electrical and fuel-based energy with the latter proxying the energy produced directly by economic agents when they burn fuels to produce either heat or kinetic energy.^{4,5} Electrical energy is in turn produced as an optimal combination of grid energy and renewable electricity. The former is a combination of locally produced electricity and electricity imported using the Malta-Sicily interconnector. This distinction is quite important since the fuels used in the production of local electricity are quite different from those utilised in the rest of the continent and have therefore a different GHG footprint.⁶ The latter is produced by the optimal allocation of green capital and labour. The former is distinct from capital used in the production of value added, and can potentially have a different rate of return depending on the technology used in its production, rate of depreciation, import intensity and most importantly on lower rates of taxation (or even subsidies) on the return of green capital.

2.3 Value added production

I assume that for each intermediate production type (domestic and foreign oriented), there are two intermediate stages. In the first stage, I assume there are an infinite number of firms that produce a non-energy intermediate product or value added within a perfectly competitive setup. Tradable and domestic-oriented firms produce non-energy value added using analogous production Cobb-Douglas technologies that combine labour N_t^i and capital K_t^i for $i \in [N, XD]$

 $^{^{3}}$ Within this setup, all GHG emissions are assumed to be produced within the energy sector. While this is of course a simplifying assumption, it is based on two facts: first, more than 75% of global GHG emissions are attributable to energy production (see Ritchie, 2020) and as such, most of the policy initiatives meant to reduce GHG emissions are likely to be focused on changing the energy mix. Secondly, a detailed energy sector would make the model more flexible in terms of policy use, especially at a time of increasing energy supply shocks.

⁴This type of energy is produced by directly burning gas for heating or cooking purposes or more importantly from a GHG-footprint point of view, petrol/diesel for transportation.

 $^{^{5}}$ The distinction between these two energy types is important as data shows that the GHG emissions per MWh of electricity production is lower than that of energy produced by directly burning fuels. Indeed this fact is behind the push for the electrification of transportation and the greater use of heatpumps (as opposed to gas burners) for heating purposes. The effects that electrification will have on the cutting down on GHG emissions will however depend on the fuel sources and technology used for the production of electrical energy.

⁶The distinction between local and imported electricity is important due to a number of reasons. All electricity produced by Malta's sole electricity producer, is the output of an LNG-burning powerplant. On the contrary, electricity imported from the interconnector is produced using a mix of fuels, ranging from LPG, nuclear and renewable fuels. This distinction is important first because the GHG intensity of locally produced grid electricity is generally higher than imported electricity. Moreover, GHG emissions are accountable to the country in which the process responsible for the creation of the emissions takes place. In this light emissions attributable to imported electricity are not accounted for as GHGs generated in Malta. Second, the price dynamics of LNG and LPG (the type of gas that powers most of continental Europe gas powerplants) can be quite different as the former is not dependent on pipeline infrastructure for transportation making it less prone to supply shocks due to continental geopolitical issues. Moreover, locally produced electricity prices with those of continental Europe, such that spot prices of electricity bought from the interconnector can vary considerably from those of locally produced grid power.

$$V_{t}^{i} = A_{t}^{i} K_{t-1}^{i} {}^{1-\gamma_{i}} N_{t}^{i\gamma_{i}} K_{t-1}^{G\gamma_{g}} \quad \text{for } i \in [N, XD]$$
(1)

where V_t^i denotes the value added of firms operating the the i^{th} sector and where superscripts N and XD denote non-tradable (domestic) firms and export-oriented firms.

Domestic oriented firms take the price of capital and wages as given and optimally choose labour and capital inputs by minimising a cost function.

$$\min_{N_t^N, K_t^N} \mathcal{C}_t^N = W_t N_t^N + R_t^K K_{t-1}^N$$
(2)

Forming the Lagrangian I can write:

$$\min_{N_t^N, K_t^N} \mathcal{L}_t^{N_1} = W_t N_t^N + R_t^K K_{t-1}^N + \kappa_t^{VN} [V_t^N - A_t^N K_{t-1}^{N-1-\gamma_N} N_t^{N\gamma_N} K_{t-1}^{G\gamma_g}]$$
(3)

where κ_t^{VN} is the Lagrange multiplier associated with the production function, which represents marginal costs of production.

The F.O.C.s of the above problem are:

$$\frac{\partial \mathcal{L}_t^{N_1}}{\partial L_t^N} = 0 \Leftrightarrow W_t - \kappa_t^{VN} A_t^N K_{t-1}^{N-\gamma_n} N_t^{N\gamma_n} N_t^{N-1} \gamma_n = 0 \Leftrightarrow W_t = \kappa_t^{VN} \frac{V_t^N \gamma_n}{N_t^N}$$
(4)

$$\frac{\partial \mathcal{L}_{t}^{N_{1}}}{\partial K_{t-1}^{N}} = 0 \Leftrightarrow R_{t}^{K} - \kappa_{t}^{VN} A_{t}^{N} K_{t-1}^{N-1-\gamma_{n}} N_{t}^{N\gamma_{n}} K_{t-1}^{N-1} (1-\gamma_{n}) = 0 \Leftrightarrow R_{t}^{K} = \kappa_{t}^{VN} \frac{V_{t}^{N} (1-\gamma_{n})}{K_{t-1}^{N}}$$
(5)

Export oriented firms face an analogous problem, with the only exception being that in line with with Doojav and Batmunkh (2018), Lozej (2019) and Rapa (2017), I assume that capital input in this sector, K_{t-1}^{XD} , is decided exogenously, reflecting the fact that in very small open economies, capital input decisions in the export-oriented sectors are not necessarily made domestically. To this end, shocks to K_{t-1}^{XD} can be interpreted as exogenous influxes of capital in the Maltese tradable sector, decided, for example, by the parent branch of multinational corporations operating within the Maltese economy.

2.4 Intermediate goods production

In a second intermediate step, I assume that for each sector $i \in [N, XD]$ there are a continuum of differentiated firms operating in a monopolistic market indexed by $n \in [0, 1]$ and $j \in [0, 1]$ respectively.⁷ Firms in this stage of production produce intermediate goods Y_t^i by combining value added V_t^i supplied in the previous step, with an energy composite good E_t^i . At this stage of production firms operate in a perfect competition in the factors market, thus taking factor prices as given. Thus firms minimise their costs by choosing the optimal levels of V_t^i and E_t^i subject to a CES production function:

$$\min_{V_t^i, E_t^i} \mathcal{C}_t^i = P_t^E E_t^i + \kappa_t^{Vi} V_t^i \tag{6}$$

st.

$$Y_{t}^{i} = \left[(\epsilon_{t}^{E} \iota_{i})^{\frac{1}{\eta_{i}}} E_{t}^{i\frac{\eta_{i}-1}{\eta_{i}}} + (1 - (\epsilon_{t}^{E} \iota_{i}))^{\frac{1}{\eta_{i}}} V_{t}^{i\frac{\eta_{i}-1}{\eta_{i}}} \right]^{\frac{\eta_{i}}{\eta_{i}-1}} \quad \text{for } i \in [N, XD]$$
(7)

The FOCs for this problem are:

$$E_t^i = \iota_i \left(\frac{P_t^E}{\kappa_t^i}\right)^{-\eta_i} Y_t^i; \qquad V_t^i = (1 - \iota_i) \left(\frac{\kappa_t^{Vi}}{\kappa_t^i}\right)^{-\eta_i} Y_t^i; \text{ for } f \in [N, XD]$$
(8)

where ι_i is the bias on energy in the output mix while ϵ_t^E are preference shocks that exogenously change the value added-energy mix in output, κ_t^i is the marginal cost of production of the intermediate good (including oil) and κ_t^{Vi} is the marginal cost of the first stage of production and represents the marginal cost of producing value added V_t^i .

On the output market, firms operate in a monopolistic setup. Firms therefore choose their current price P_t^i , by maximising the real value of their firm at time t, subject to a downward sloping demand function of good types (n) for non-tradable and (j) for export oriented production. Firms face quadratic costs whenever they choose to change prices. The expected value of the firm's future value is constructed as a discounted sequence of gross profits less adjustment costs paid as a proportion of current output. Since firms are owned by households, their payoffs are discounted by the stochastic discount factor derived from the household problem, $\Lambda_{t,t+k} = \beta^k \frac{\lambda_{t+k}}{\lambda_t}$. Since this problem is symmetric for both domestic and foreign oriented firms, I will only show the problem for the former.

$$\max_{P_t^N(n)} \Pi_t^N(n) = \mathbb{E}_t \sum_{k=0}^\infty \Lambda_{t,t+k} \left[\left(P_{t+k}^N(n) - \kappa_{t+k}^N(n) \right) \frac{Y_{t+k}^N(n)}{P_{t+k}^N} - \frac{\psi^N}{2} \left(\frac{P_{t+k}^N(n) / P_{t+k-1}^N(n)}{\pi_{t-1}^N \bar{\pi}^{(1-\iota)}} - 1 \right)^2 P_{t+k}^N \frac{Y_{t+k}^N}{P_{t+k}^N} \right]$$
(9)

st.

⁷To save on notation, I am suppressing the n and j subscripts. FOCs are equivalent after imposing symmetry.

$$Y_t^N(n) = \left(\frac{P_t^N(n)}{P_t^N}\right)^{-\varepsilon_t^N} Y_t^N \tag{10}$$

After imposing symmetry the FOC for this problem is given by:

$$P_{t}^{N} = \frac{\mathcal{M}_{t}^{N}}{\mathcal{M}_{t}^{N} - 1} \kappa_{t+k}^{N} \left\{ \begin{array}{c} \left(\frac{1}{\mathcal{M}_{t}^{N} - 1}\right) + \psi_{N} \left(\frac{\pi_{t}^{N}}{\pi^{N_{t}} - 1\bar{\pi}^{1-\iota}} - 1\right) \left(\frac{\pi^{N}}{\pi^{N_{t}} - 1\bar{\pi}^{1-\iota}}\right) \\ - \mathbb{E}_{t} \Lambda_{t+1} \left[\psi_{N} \left(\frac{\pi^{N} t + 1}{\pi^{N_{t}} \pi^{1-\iota}} - 1\right) \left(\frac{\pi^{N} t + 1}{\pi^{N_{t}} \pi^{1-\iota}}\right) \frac{Y_{t+1}^{N}}{Y_{t}^{N}} \right] \end{array} \right\}^{-1}$$
(11)

where \mathcal{M}_t^n is equal to $\frac{\varepsilon_t^N}{\varepsilon_t^N - 1}$.

2.5Energy sector firms

The energy sector is quite detailed and is made up of a multistage production structure. The model breaks down energy production in five stages. In the first stage of production, firms produce an overall energy bundle E_t by optimally combining energy from fossil fuels E_t^F and electrical energy E_t^E . Fuel energy is simply produced by burning fossil fuels that are imported by importing firms. Electrical energy is on the other hand another bundle made up of electrical energy aggregators which are tasked with optimally combining grid electricity E_t^{EG} (produced by Malta's sole electricity producer using LNG fuel) with electricity produced with renewable resources E_t^{ER} . E_t^{EG} is produced by aggregators (that proxy the country's sole electricity distributor) which are tasked with optimally combining locally produced electrical energy E_t^{EEGL} and electricity imported from the Malta-Sicily interconnector E_t^{EEGI} . The former is produced by electricity producers which combine LNG with (exogenous and fixed) capital stock.⁸ Renewable electricity is produced by producers that combine labour services, green capital and some land resource.

Energy bundle E_t 2.5.1

Energy is produced by an infinite number of monopolistically competitive firms that bundle together electrical E_t^E and fossil fuel driven energy E_t^F (the latter including heat and kinetic energy directly derived by burning liquid gas, diesel, petrol or other similar fuels).⁹ Given the energy requirements derived from the intermediate good production E_t , energy firms in this stage choose the optimal energy allocation by minimising their present value of future costs subject

⁸Local grid electricity is produced by a state-controlled firm. Labour and capital inputs are therefore largely exogenously set through public sector decisions. Against this backdrop the only decision which is modelled is the optimal choice of LNG that is used to satisfy the demand for E_t^{EEG} . ⁹From the demand side, overall energy is made up of the energy demanded by both types of intermediate good producers and by consumers ($E_t = E_t^N + E_t^{XD} + E_t^C$).

to a CES aggregator. In order to model the progressive adjustments in the energy mix following a change in relative prices, I assume that firms face quadratic adjustment costs whenever they choose to change the ratio of electrical energy to fossil fuels.

$$\min_{E_t^E, E_t^F} \mathcal{C}_t^E = \mathbb{E}_t \sum_{k=0}^{\infty} \Lambda_{t,t+k} \left\{ P_{t+k}^{EE} E_{t+k}^E + P_{t+k}^{EF} E_{t+k}^F + A C_{t+k}^E + A C_{t+k}^F \right\}$$
(12)

st.

$$E_{t} = \left[\iota_{E}^{\frac{1}{\eta_{E}}} E_{t}^{E\frac{\eta_{E}-1}{\eta_{E}}} + (1-\iota_{E})^{\frac{1}{\eta_{E}}} E_{t}^{F\frac{\eta_{E}-1}{\eta_{E}}} \right]^{\frac{\eta_{E}}{\eta_{E}-1}}$$
(13)

where $AC_{t+k}^E = AC^E(\Phi^E; E_t^E)$ and $AC_{t+k}^F = AC^F(\Phi^F; E_t^F)$ represent adjustment costs paid by electricity aggregators when they choose to change E_t^E and E_t^F respectively.

The FOCs for this problem are:

$$E_t^E = \iota_E \left(\frac{P_t^{EE} + ADJ_t^E}{MC_t^E}\right)^{-\eta_E} E_t; \qquad E_t^F = (1 - \iota_E) \left(\frac{P_t^{EF} + ADJ_t^F}{MC_t^E}\right)^{-\eta_E} E_t; \qquad (14)$$

where: ADJ_t^E and ADJ_t^F are analytical expressions derived from the energy adjustment costs and MC_t^E corresponds to the Lagrange multiplier of the above minimisation function.¹⁰

In the pricing decision, firms choose the optimal price P_t^E to maximise their future profits subject to a downward sloping demand curve provided by aggregators and price adjustment costs a-la Rotemberg (1982). This gives rise to the following New Keynesian Phillips curve:

$$P_t^E = \frac{\mathcal{M}_t^E}{\mathcal{M}_t^E - 1} M C_t^E \left\{ \begin{array}{c} \left(\frac{1}{\mathcal{M}_t^E - 1}\right) + \psi_E \left(\frac{\pi_t^E}{\pi^{E_{t-1}} \bar{\pi}^{1-\iota}} - 1\right) \left(\frac{\pi^E_{t}}{\pi^{E_{t-1}}}\right) \\ -\mathbb{E}_t \Lambda_{t+1} \left[\psi_E \left(\frac{\pi^{E_{t+1}}}{\pi^{E_t} \bar{\pi}^{1-\iota}} - 1\right) \left(\frac{\pi^{E_{t+1}}}{\pi^{E_t} \bar{\pi}^{1-\iota}}\right) \frac{E_{t+1}}{E_t} \right] \end{array} \right\}^{-1}$$
(15)

2.5.2 Fuel energy pricing E_t^F

Fuel energy E_t^F is imported by fuel importers that operate in a monopolistic setup, taking the international price of fuel P_t^{EF*} as given and maximising profits by choosing their optimal wholesale price $P_t^{EF,W}$ facing a downward sloping demand curve derived from aggregators. This problem is analogous to the importers' problem as discussed in Rapa (2017) and Rapa (2016) and serves to introduce nominal rigidities that slow down the transmission of foreign fuel prices

$$ADJ_{t}^{j} = P_{t}^{E}E_{t}\Phi^{j} \left[\frac{E_{t}^{j}}{E_{t-1}^{j}} - 1 \right] \frac{1}{E_{t-1}^{j}} - \mathbb{E}_{t}\Lambda_{t+1} \left\{ P_{t+1}^{E}E_{t+1}\Phi^{j} \left[\frac{E_{t+1}^{E}}{E_{t}^{E}} - 1 \right] \frac{E_{t+1}^{E}}{E_{t}^{E}} \right\} \text{ for } j \in [E, F]$$

¹⁰In the baseline specification of the model, these adjustment costs take the following functional form: $AC_{t+k}^{j} = P_{t+k}^{j}E_{t+k}^{j}\frac{\Phi^{j}}{2}\left[\frac{E_{t+k}^{j}}{E_{t-1+k}^{j}}\right]$ for $j \in [E, F]$. The analytical expressions for the adjustment costs that feature in these FOCs and that are consistent with the above functional form for adjustment costs are

to local ones. This problem leads to the following FOC, which pins down wholesale fuel prices:

$$P_{t}^{EF,W} = \frac{\mathcal{M}_{t}^{EF}}{\mathcal{M}_{t}^{EF} - 1} P_{t}^{EF*} \left\{ \begin{array}{c} \left(\frac{1}{\mathcal{M}_{t}^{EF} - 1}\right) + \psi_{EF} \left(\frac{\pi_{t}^{EF}}{\pi^{EF'}_{t-1}\bar{\pi}^{1-\iota}} - 1\right) \left(\frac{\pi^{EF}}{\pi^{EF}_{t-1}\bar{\pi}^{1-\iota}}\right) \\ -E_{t}\Lambda_{t+1} \left[\psi_{EF} \left(\frac{\pi^{EF}}{\pi^{EF'}_{t}\bar{\pi}^{1-\iota}} - 1\right) \left(\frac{\pi^{EF}}{\pi^{EF'}_{t}\bar{\pi}^{1-\iota}}\right) \frac{E_{t+1}^{F}}{E_{t}^{F}} \right] \end{array} \right\}^{-1}$$
(16)

Retail fuel prices P_t^{EF} are then equal to $P_t^{EF} = (P_t^{EF,W} + \tau_t^{EF} - S_t^{EF})$ where τ_t^{EF} is an excise duty levied on the volume of fuels utilised and S_t^{EF} are subsidies that can be occasionally used by Government to cancel out excessive variations in foreign fuel prices. Apart from matching the data, the distinction between retail and wholesale prices is meant to capture the administrative nature of fuel prices in Malta by introducing a tax/subsidy wedge that is occasionally used by the fiscal authority to stabilise fuel prices against the backdrop of changing foreign fuel prices. To this end, S_t^{EF} can be adjusted endogenously in the model to smoothen out any changes in wholesale prices of fuel. This stabilisation mechanism have been actively utilised in Malta since 2016.

2.5.3 Electrical energy bundle E_t^E

Total electrical energy E_t^E is produced by an infinite number of perfectly competitive firms that bundle together grid electricity E_t^{EG} (which is a mix of electricity produced in Malta's LNG-fired plants and electricity imported through the Malta-Sicily interconnector, both of which are, to varying degrees, regarded as "brown energy") and electricity produced from renewable sources E_t^{ER} . Firms take the demand of electricity as given and choose the optimal energy mix whilst also taking as given the prices of the two energy types, P_t^{EER} (the price of renewable electrical energy) and P_t^{EEG} (the price of grid electricity).

$$\min_{E_t^{EG}, E_t^{ER}} \mathcal{C}_t^{EE} = P_t^{EEG} E_t^{EG} + P_t^{EER} E_t^{ER}$$
(17)

st.

$$E_t^E = \left[\iota_{EE}^{\frac{1}{\eta_{EE}}} E_t^{ER \frac{\eta_{EE}-1}{\eta_{EE}}} + (1 - \iota_{EE})^{\frac{1}{\eta_{EE}}} E_t^{EG \frac{\eta_{EE}-1}{\eta_{EE}}} \right]^{\frac{\eta_{EE}-1}{\eta_{EE}-1}}$$
(18)

where ι_{EE} is a parameter controlling the intensity of renewable electrical energy in the electricity bundle, and η_{EE} governs the elasticity of substitution between the two electricity types. The FOCs for this problem are:

$$E_t^{ER} = \iota_{EE} \left(\frac{P_t^{EER}}{P_t^{EE}}\right)^{-\eta_{EE}} E_t^E; \qquad E_t^{EG} = (1 - \iota_{EE}) \left(\frac{P_t^{EEG}}{P_t^{EE}}\right)^{-\eta_{EE}} E_t^E; \tag{19}$$

Imposing a zero profit condition on the above provides us with the energy price level P_t^{EE} :

$$P_t^{EE} = \left[\iota_{EE} P_t^{EER(1-\eta_{EE})} + (1-\iota_{EE}) P_t^{EEG(1-\eta_{EE})}\right]^{\frac{1}{(1-\eta_{EE})}}$$
(20)

2.5.4 Grid electricity bundle E_t^{EG}

Grid electrical energy¹¹ E_t^{EG} is produced by a continuum of differentiated firms operating (on the output side) in a monopolistic market indexed by $e \in [0, 1]$. Firms in this stage of energy production, produce grid electricity E^{EG} by combining locally produced electricity E^{EGL} and electricity imported from the Sicily-Malta interconnector.

On the input side, these firms operate in a perfectly competitive setup taking the quantity of type e grid electricity demand $E_t^{EG}(e)$ as well as prices of locally produced and interconnector electricity P_t^{EEGL} and P_t^{EEGI} as given and choose the optimal electricity mix by minimising costs subject to a CES technology. The price of electricity imported through the interconnector P_t^{EEGI} is exogenously determined and is a function of the mix of the energy flowing through the interconnector and other factors.

The problem faced by grid electricity producers can therefore be written as:

$$\min_{E_t^{EGL}, E_t^{EGI}} \mathcal{E}_t^{E^{EG}} = P_t^{EEGI} \mathcal{E}_t^{EGI} + P_t^{EEGL} \mathcal{E}_t^{EGL}$$
(21)

st.

$$E_t^{EG} = \left[\iota_{EEG}^{\frac{1}{\eta_{EEG}}} E_t^{EGI \frac{\eta_{EEG}-1}{\eta_{EEG}}} + (1 - \iota_{EEG})^{\frac{1}{\eta_{EEG}}} E_t^{EGL \frac{\eta_{EEG}-1}{\eta_{EEG}}} \right]^{\frac{\eta_{EEG}-1}{\eta_{EEG}-1}}$$
(22)

where ι_{EEG} is a parameter controlling the intensity of internationally produced electrical energy in the electricity bundle, and η_{EEG} governs the elasticity of substitution between the two grid electricity types. The FOCs for this problem are:

$$E_t^{EGI} = \iota_{EEG} \left(\frac{P_t^{EEGI}}{\kappa_t^{EEG}} \right)^{-\eta_{EEG}} E_t^{EG}; \qquad E_t^{EGL} = (1 - \iota_{EEG}) \left(\frac{P_t^{EEGL}}{\kappa_t^{EEG}} \right)^{-\eta_{EEG}} E_t^{EG}; \quad (23)$$

where κ_t^{EEG} is the marginal cost of producing the grid electricity bundle E_t^{EG} .

¹¹Electricity distributed through Malta's national grid includes also a small proportion of excess renewable energy; that is renewable energy that is produced by private agents but not consumed directly and thus sold back to the grid. In this model, grid electrical energy captures solely the energy that is either produced locally using the Enemalta and Electrogas power plants or that is imported by Enemalta through the Malta-Sicily interconnector. In this light, the name "grid" energy should be interpreted loosely and not literally. Nonetheless the production of all renewable energy (even excess renewable energy that is sold to the grid) is fully taken in consideration by this model through the correct calibration of the renewable intensity parameter ι_{EE} in equation (18).

On the output market, firms operate in a monopolistic market 12 . Firms therefore choose their current wholesale electricity price $P_t^{EEG,W}$, by maximising the real value of their firm at time t, subject to a downward sloping demand function of grid electricity type (e) and quadratic costs that need to be paid whenever they choose to change prices. This gives rise to the following FOC:

$$P_{t}^{EEG,W} = \frac{\mathcal{M}_{t}^{EEG}}{\mathcal{M}_{t}^{EEG} - 1} \kappa_{t}^{EEG} \left\{ \begin{array}{c} \left(\frac{1}{\mathcal{M}_{t}^{EEG-1}}\right) + \psi_{EEG} \left(\frac{\pi_{t}^{EEG}}{\pi^{EEG}_{t-1}\bar{\pi}^{1-\iota}} - 1\right) \left(\frac{\pi^{EEG}_{t}}{\pi^{EEG}_{t-1}\bar{\pi}^{1-\iota}}\right) \\ -\mathbb{E}_{t} \Lambda_{t+1} \left[\psi_{EEG} \left(\frac{\pi^{EEG}_{t+1}}{\pi^{EEG}_{t}\bar{\pi}^{1-\iota}} - 1\right) \left(\frac{\pi^{EEG}_{t+1}}{\pi^{EEG}_{t}\bar{\pi}^{1-\iota}}\right) \frac{E_{t+1}^{EG}}{E_{t}^{EG}} \right] \end{array} \right\}^{-1}$$

$$(24)$$

where \mathcal{M}_{t}^{EEG} is the markup in grid electricity production and is equal to $\frac{\varepsilon_{t}^{EEG}}{\varepsilon_{t}^{EEG-1}}$.

The retail price of grid electricity P_t^{EEG} is then equal to $(1 + \tau_t^{EEG})(P_t^{EEG,W} - S_t^{EEG})$. Mirroring the discussion about retail fuel prices in Malta, the distinction between wholesale and retail grid electricity prices is also important as it helps to capture the administrative nature of the electricity prices. Indeed, I also allow S_t^{EEG} to vary endogenously, if required, so as to smoothen wholesale electricity prices. This policy has been adopted since 2021 in Malta and allows to fully smoothen out changes in electricity prices emanating either from the interconnector or through a higher price of LNG used to fire local power plants.

Grid electricity E_t^{EGL} is produced locally by a continuum of firms that import LNG, GAS_t at an exogenous price P_t^{GAS} and produce electrical power by combining it with a fixed level of capital K^{EEGL} and an efficiency parameter γ_{GAS} .¹³ Energy producing firms choose the optimal level of LNG taking as given the demand for locally produced grid energy E_t^{EEGL} , the price of imported gas P_t^{GAS} and electricity generation capital K^{EEGL} by minimising costs subject to a CES production function.¹⁴

$$\min_{GAS_t} \mathcal{C}_t^{E^{EGI}} = P_t^{GAS} GAS_t \tag{25}$$

 $^{^{12}}$ Electricty distribution in Malta is the controlled by a single entity which is responsible for combining imported and locally produced electricity nad distribute it to the local market. In this light, the setup of monopolistically competitive firms is solely a modelling device to allow the introduction of frictions that slow down the passthrough of factor prices in the retail grid prices and is not meant to reflect the actual market structure of electricity distribution in Malta.

 $^{^{13}}$ Electricity production in Malta is produced through a single Power Station complex. The complex is made up of four gas-fired units. Despite the fact that the companies operating the plants are private entities, any additional investment in power generation capital is usually decided by the central government. To this end I choose to model local grid energy capital K^{EEGL} as constant. ¹⁴The price of imported gas P_t^{GAS} is determined by an exogenously set law of motion that links it with

variations in Brent oil prices in euro.

$$E_t^{EGL} = \gamma_{GAS} * \left[\iota_{EEGL}^{\frac{1}{\eta_{EEGL}}} GAS_t^{\frac{\eta_{EEGL}-1}{\eta_{EEGL}}} + (1 - \iota_{EEGL})^{\frac{1}{\eta_{EEGL}}} K^{EEGL}^{\frac{\eta_{EEGL}-1}{\eta_{EEGL}}} \right]^{\frac{\eta_{EEGL}-1}{\eta_{EEGL}}}$$
(26)

This problem pins down the optimal level of LNG imports given by:

$$GAS_t = \gamma_{GAS} * \iota_{EEGL} \left(\frac{P_t^{GAS}}{\kappa_t^{EEGL}} \right)^{-\eta_{EEGL}} E_t^{EGL};$$
(27)

where κ_t^{EEGL} is the marginal cost of producing local gried (or brown) electricity.

Firms operate in a monopolistic setup, thus maximising profits subject to a downward sloping demand curve and adjustment costs a-la Rotemberg, giving rise to the Phillips Curves in line with those shown above.¹⁵

2.5.5 Renewable electricity bundle E_t^{ER}

Renewable energy is produced by a continuum of differentiated firms operating in a perfectly competitive setup in the input market and in a monopolistic setup in the output market.

$$E_t^{ER} = A_t^{ER} L_t^{\gamma_L} \left[N_t^{ER\gamma_{ER}} K_t^{ER(1-\gamma_{ER})} \right]^{(1-\gamma_L)}$$
(28)

On the input side, these firms take the demand of total renewable energy E_t^{ER} as given and choose capital and labour inputs K_t^{ER} and N_t^{ER} by minimising a cost function subject to the production function in equation (28). Moreover, the production of green electricity requires the utilisation of land L_t which is in fixed supply. In this case, this modelling choice captures the fact that Malta has very limited physical space where to install green capital for the production of renewable electricity. Moreover, under current land development policies, the installation of green capital, like photovoltaic or wind-powered generation units, can only occur on alreadydeveloped parcels of land or land that is already earmarked for development. The installation of green capital over land which extends beyond the existing development boundaries would require a policy change, which in this setup can be modelled as a shock to L_t .¹⁶ The problem gives rise to the following FOCs:

st.

¹⁵Maltese locally produced grid electricity is produced by two private entities which however operate under considerable government control. Moreover, local brown electricity production is governed by a (confidential) purchase agreement that limits changes in electricity prices that are charged to the Maltese electricity distributor. The modelling of local brown electricity production within a monopolistic setup is simply a modelling device that allows for an imperfect pass-through of changes in marginal costs to locally produced brown electricity prices and does not necessarily mirror the actual market structure of local brown electricity production.

¹⁶The scenario of an extension of development boundaries for the sole purpose of green capital installation is one of the simulations performed in this paper.

$$W_t = \kappa_t^{ER} \frac{E_t^{ER} \gamma_{ER} \gamma_L}{N_t^{ER} K_t^{ER1 - \gamma_{ER}}}; \qquad R_t^{KER} = \kappa_t^{ER} \frac{E_t^{ER} (1 - \gamma_{ER}) \gamma_L}{K_{t-1}^{ER} N_t^{ER} \gamma_{ER}}$$
(29)

In their dynamic problem firms choose the *wholesale* price $P_t^{EER,W}$ (excluding any subsidies or taxes given to or levied on the users of this energy) in an effort to maximise profits subject to a downwards sloping demand curve. This problem gives rise to the usual Rotemberg Phillips Curve.

Again, the distinction between the wholesale and retail price faced by energy aggregators when determining the energy mix between conventional or grid energy and renewable energy is meant to capture any subsidies (or taxes) levied by government. Thus retail prices of renewable energy are found as $P_t^{EER} = P_t^{EER,W}(1 + \tau_t^{EER})$ where $\tau_t^{EER} < 0$ when government is subsidising renewable energy prices.

2.5.6 GHG emissions

Energy GHG emissions of the Maltese economy are accounted for by burning LNG fuel, GAS_t , to produce local grid electricity, E_t^{EGL} , and the burning of other fossil fuels to produce fossil fuel energy E_t^F .

Thus I assume that total energy GHGs emitted at time t, GHG_t , are given as the sum of GHGs produced by burning LNG, GHG_t^{GAS} and fuel GHG_t^F , both of which are assumed to be a linear function of the calorific value of the LNG and fuel burnt:

$$GHG_t = GHG_t^{GAS} + GHG_t^F \tag{30}$$

where:

$$GHG_t^{GAS} = \xi_{GAS}GAS_t; \qquad GHG_t^F = \xi_F E_t^F; \tag{31}$$

where ξ_{GAS} and ξ_F represent the amount of GHG per unit of fossil fuel burnt.

The stock of GHG emissions, GHG_t^S , is found as in Acemoglu et al. (2012) and is therefore assumed to increase by the the new emissions at time t, GHG_t , net of the proportion of emissions that are naturally absorbed with rate δ_{GHG} .

$$GHG_t^S = (1 - \delta_{GHG})GHG_{t-1}^S + GHG_t \tag{32}$$

2.6 Households

The economy is populated by two types of households; *i* type households indexed by $i \in [0, \omega]$ and *j* type households indexed by $j \in [\omega, 1]$. The former have unlimited access to financial markets and can thus smoothen consumption, whereas the latter are excluded from financial markets and can only consume their budget at any given time *t*.

Both households derive utility from consuming a bundled consumption C_t and from leisure $1 - N_t$. For both types of households, the consumption bundle is constructed in line with Forni et al. (2010):

$$C_t(k) = \left[\phi^{\frac{1}{\nu}} C_t^P(k)^{\frac{\nu-1}{\nu}} + (1-\phi)^{\frac{1}{\nu}} Y_t^{G^{\frac{\nu-1}{\nu}}}\right]^{\frac{\nu}{\nu-1}} \quad \text{for } k \in [i,j]$$
(33)

where $\nu > 0$ measures the degree of substitutability between private consumption C_t^P and public goods Y_t^G and $(0 \le \phi \le 1)$ is the weight of private goods in the consumption bundle. This part of the bundle is assumed to be completely symmetric between Ricardian and non-Ricardian households.

In turn, C_t^P is another bundle made up of private non-energy consumption $C_t^{P,NE}$ and consumption of energy E_t^C . In this case the composition of the bundle is different across households reflecting the fact that the weight of energy in the private consumption basket of liquidity constrained households is larger than that of richer households. This modelling choice reflects recent evidence that poorer households might be more negatively affected by carbon price shocks in view of their higher energy share in consumption (See Kanzig, 2022).¹⁷

$$C_t^P(k) = \left[\phi_E(k)^{\frac{1}{\nu_E(k)}} E_t^C(k)^{\frac{\nu_E(k)-1}{\nu_E(k)}} + (1-\phi_E)^{\frac{1}{\nu_E(k)}} C_t^{P,NE}(k)^{\frac{\nu_E(k)-1}{\nu_E(k)}}\right]^{\frac{\nu_E(k)}{\nu_E(k)-1}} \quad \text{for } k \in [i,j]$$
(34)

For any given level of private consumption $C_t^P(k)$, *i* and *j*-type households purchase nonenergy private goods and services, $C_t^{P,NE}$, (which is in itself a composite of domestic and imported goods and services) and energy goods, E_t^C . The optimal demand for energy within the private consumption bundle is given by minimising the cost of the consumption basket subject to the aggregator in equation (34) and adjustment costs $AC_t^{CE}(k) = AC^{CE}(\Phi^{CE}(k); E_t^C(k))$ and $AC_t^{CNE}(k) = AC^{CNE}(\Phi^{CNE}(k); C_t^{NE}(k))$, which are imposed on households each time they

¹⁷In the model I proxy households at the higher end of the income spectrum with Ricardian type households, while the non-Ricardians are assumed to be the poorer set of households. This simplistic assumption is based on the fact that the liquidity constrained households have a lower steady state level of consumption and can therefore be assumed to be poorer than their Ricardian counterparts.

choose to change the composition of their consumption bundle. This gives rise to the following two demand functions for each household type:

$$E_t^C(k) = \phi_E(k) \left(\frac{P_t^E + ADJ_t^{CE}(k)}{P_t^C(k)}\right)^{-\eta_E(k)} C_t^P(k),$$

$$C_t^{P,NE}(k) = (1 - \phi_E(k)) \left(\frac{P_t^{C,NE} + ADJ_t^{CNE}(k)}{P_t^C(k)}\right)^{-\phi_E(k)} C_t^P(k) \quad \text{for } k \in [i,j] \quad (35)$$

where P_t^E is the price of the energy aggregate (found in equation (15)), while $P_t^{C,NE}$ is the non energy private consumption price, derived from final good perfectly competitive aggregators. Moreover, $ADJ_t^{CE}(k)$ and $ADJ_t^{CNE}(k)$ are analytical expressions derived from adjusting energy and non-energy private consumption within the consumption basket.¹⁸

Imposing a zero-profit condition gives rise to the relation determining the overall (householdtype dependent) consumer prices:

$$P_t^C(k) = \left[\phi_E(k)(P_t^E + ADJ_t^E(k))^{(1-\nu_E(k))} + (1-\phi_E(k))(P_t^{C,NE} + ADJ_t^{NE}(k))^{(1-\nu_E(k))}\right]^{\frac{1}{(1-\nu_E(k))}} \quad \text{for } k \in [i,j] \quad (36)$$

The consumer price level in steady state faced by the two types of households are symmetric in case the weight of energy in the consumption basket is the same for the two household types, that is $\phi_E(i) = \phi_E(j)$. Moreover, for the dynamics of the two prices to be symmetrical (that is off steady state), the adjustment costs should also be calibrated symmetrically as follows $ADJ_t^{CE}(i) = ADJ_t^{CE}(j)$ and $ADJ_t^{CNE}(i) = ADJ_t^{CNE}(j)$ thus requiring the parameters dictating the extent of adjustment costs to be equal across households, thus: $\Phi^{CE}(i) = \Phi^{CE}(j)$ and $\Phi^{CNE}(i) = \Phi^{CNE}(j)$. Under such a calibration, the household problem collapses to the more standard case where both households face the same extent of price inflation.

2.6.1 Ricardian Households

The optimising household problem is in line with Rapa (2017), where agents seek to maximise an intertemporal utility function in consumption $C_t(i)$ relative to a consumption habit defined

 $^{^{18}}$ The functional form of the adjustment costs are symmetric to the ones affecting the energy bundle composition described in section 2.5.1.

as a proportion of the household's consumption in the previous period, $\chi C_{t-1}(i)$, and in leisure $(1 - N_t(i))$.

Preferences for Ricardian households are given by:

$$E_0 \sum_{(t=0)}^{\infty} \beta^t U_t(i) = E_0 \sum_{(t=0)}^{\infty} \beta^t \{ \epsilon_t^c (1-\chi) \ln[C_t(i) - \chi C_{t-1}(i)] - \frac{1}{1+\eta} N_t(i)^{1+\eta} \}$$
(37)

Where $\beta \in (0, 1)$ is the discount factor, ϵ_t^c represents a general shock to preferences that affects the intertemporal elasticity of substitution of households, η is the inverse of the elasticity of work relative to the real wage and $(0 \le \chi \le 1)$ measures the degree of external habit formation.

However, there are two important differences when compared to the base MEDSEA. First, households are able to invest in both conventional capital, K_t^N , and "green" capital used in the production of renewable energy, K_t^{ER} . Secondly, the consumption deflator is household-type dependent, implying that the deflator used to deflate the budget constraint (of both types of households) in terms of consumption units, depends on the household-dependent weight of energy in the respective private consumption basket.

The budget constraint of agent i expressed in units of private consumption of Ricardian households is given by:

$$\frac{B_t^G(i)}{R_t^C P_t^C(i)} + \frac{B_t(i)}{R_t P_t^C(i)} + \frac{B_t^*(i)}{R_t^* \xi(\phi_t, \epsilon_t^R) P_t^C(i)} = \frac{B_{t-1}^G(i)}{P_t^C(i)} + \frac{B_{t-1}(i)}{P_t^C(i)} + \frac{B_{t-1}^*(i)}{P_t^C(i)} + (1 - \tau^l) \frac{W(i)N_t(i)}{P_t^C(i)} + (1 - \tau^l) \frac{W(i)N_t(i)}{W$$

Households receive net labour income $(1 - \tau^l)W(i)N_t(i)$ as a reward for their labour effort. This type of households own all firms within the economy, including those responsible for the production of energy and non-energy goods and services. Households are also responsible for investing in general capital (for non-tradable domestic firms) K_t^N , and green capital used in the production of renewable electricity K_t^{ER} . They therefore receive dividend income from firm profits¹⁹ and a rate of return on capital rented to firms.

Moreover, the following two laws of motion describe the accumulation of $K_t^N(i)$ and $K_t^{ER}(i)$:

$$K_t^N(i) = (1-\delta)K_{t-1}^N(i) - I_t^P(i) + \frac{1}{2}\Psi^I \left(\frac{I_t^P(i)}{I_{t-1}^P(i)}\right)^2$$
(39)

 ${}^{19}Div_t^{oth} = Div_t^M + Div_t^{EEG} + Div_t^{EF}$

$$K_t^{ER}(i) = (1 - \delta_{er}) K_{t-1}^{ER}(i) - I_t^{ER}(i) + \frac{1}{2} \Psi^{IER} \left(\frac{I_t^{ER}(i)}{I_{t-1}^{ER}(i)}\right)^2$$
(40)

These type of households make decisions on optimal private consumption $C_t^P(i)$, risk-free bonds $B_t(i)$, net foreign assets holdings $B_t^*(i)$, government debt holdings $B_t^G(i)$, conventional investment $I_t^P(i)$, green investment $I_t^{IER}(i)$, conventional capital stock $K_t^N(i)$ and green capital stock $K_t^{ER}(i)$, by maximising equation (37) subject to the budget constraint given by equation (38) and the law of motion of the two private capital types given by equations (39) and (40) and the definition of the consumption bundle (equation (33)), whilst taking as given the composition of the private consumption bundle.

2.6.2 Hand-to-mouth households

This type of households derive utility from preferences that are symmetric to Ricardian households. This implies that they derive utility from consuming a consumption bundle $C_t(j)$ and disutility from labour $N_t(j)$. Contrary to Ricardian households however, *j*-type households do not own firms and neither physical nor financial capital, implying that they cannot smooth their consumption over time. This in turn implies that in each time period *t*, hand-to-mouth households consume their disposable income, defined in terms of non-Ricardian consumption units, so taking in consideration their household-dependent consumer inflation, whilst taking as given the composition of their overall and private consumption bundles²⁰:

$$(1+\tau^c)C_t^P(j) = (1-\tau^l)\frac{W_t(j)N_t(j)}{P_t^C(j)} + \frac{TR_t(j)}{P_t^C(j)} - \frac{T_t(j)}{P_t^C(j)}$$
(41)

3 Calibration

The model is calibrated on Maltese data. The standard macroeconomic variables are calibrated in line with previous iterations of MEDSEA. I therefore follow Rapa (2016), Rapa (2017) and Gatt et al. (2020) and calibrate all macroeconomic variables on long-run averages sourced from national accounts data. Unlike previous studies, all steady-state ratios (including fiscal ratios and effective tax rates) are based on long-run averages spanning the period 2000-2019, thus updating the sample period with four additional years of data. This has resulted in very marginal changes

 $^{^{20}}$ The consumption problem is therefore split into two parts. First, each household chooses the optimal consumption of energy and non-energy consumption whilst taking overall private consumption as given. Given the household-dependent optimal composition of private consumption, Ricardian households choose the optimal allocation for overall private consumption taking as given the price of their overall consumption bundle. Non-Ricardians allocate overall private consumption through their budget constraint whilst taking as given the price of their consumption bundle.

in the main great ratios and fiscal instruments (see Appendix A). Parameters governing the dynamics of the main part of the model have remained largely unchanged when compared to previous versions of the model.

The parameters within the energy block are calibrated using a variety of data sources and also draw on the available evidence in literature. A summary of energy-specific parameters is provided in Appendix B.

All parameters governing the steady-state of the energy production sector are calibrated in line with 2019 data. Between 2015 and 2016, the energy sector in Malta has undergone profound transformations with the setting up of a completely new power plant and the installation of the interconnector linking the islands to the European grid. These energy reforms, have led to a considerable fall in the use of local electricity production, a considerable increase in imported energy and a drop in the green house gasses emitted by the electricity production sector. In light of these changes to the energy supply structure, I choose to calibrate the energy block of the model on a single year. In this respect, 2019 was judged to be a year that was stable enough to correctly reflect the new supply structure for energy in Malta.

The main data source for the calibration of energy ratios is the database of Energy Balance Flows published on Eurostat. This database is quite detailed and allows the user to trace the source of all energy products entering and exiting the national territory of a country. It also allows the user to trace the transformation of energy products to different energy types. This granularity is important as it allows the netting out of energy products that enter the Maltese territory for the sole purpose of being re-exported (for example through bunkering). Since the model solely captures the use of energy for productive purposes, all energy ratios are calibrated using the energy flows net of marine bunkering operations. The data also shows a breakdown of energy in oil (and oil derivatives) and electricity, together with the main sector that absorbs each energy type, thus differentiating between energy used in the production process and energy directly consumed by households.

3.1 Energy in the intermediate sector

The size of the energy sector is calibrated as a share of nominal output. In this respect, I find the overall expenditure in energy as the sum of energy expenditure by type. The total expenditure on electrical energy is found as the product of the electricity consumed in Malta by both households and industry in Kilo-ton of oil equivalent (KTOE) and the average retail price sourced from the

Regulator for Energy and Water Services website.²¹ Similarly, the total expenditure on fuel energy is estimated as the sum of all expenditures on petrol, diesel and LPG incurred by both Maltese industry and households. Each of these expenditures is estimated as the product of the calorific value of petrol, diesel and electricity multiplied with their respective prices. Retail prices of fuel by type are sourced from Eurostat. I then compute the total nominal expenditure on energy as the sum of the expenditure on fuel and electricity energy. I then calibrate the energy intensity in the intermediate sector, ι_N and ι_{XD} so as to match the actual share of nominal energy expenditure in GDP estimated at 7%.

3.2 Energy production

The shares of each energy type in total energy are calibrated in a two step approach. First, since GHG emissions are a function of the calorific value of energy consumed by type (and not of the total nominal expenditure), it is important to correctly calibrate the relative energy typespecific calorific values consumed in the economy. To this end, I calibrate the energy type-specific intensities governing the share of electrical, renewable and locally produced grid energy in total energy, ι_E , ι_{EE} , and ι_{EEG} respectively, so as to match their respective actual shares in terms of KTOE. While the real calorific intensities are important from an environmental perspecitve, nominal shares are more important from an economic perspective, as the expenditure that each type of energy has as a share of total energy production has profound implications on the cost structure of firms and households. To this end, I match nominal expenditure share by energy type (as a percent of total energy consumption), by normalising a number of relative energy prices. This is done by calibrating three parameters. First, I calibrate a technology shifting parameter, γ_{GAS} governing the efficiency with which LNG is transformed into electrical energy so as to match the amount of electrical energy produced by each KTOE of LNG purchased by Enemalta (data sourced from Energy Balances Flows statistics). This step is important to correctly account for the amount of GHG emissions that are accountable to electrical energy produced by burning LNG. Moreover, it moves the relative average price of electrical energy per KTOE to that of fuel energy $\frac{P_t^{EE}}{P^{EF}}$ closer to the actual ratio. This ratio is then exactly pinned down by calibrating the markups of grid electricity producers $\overline{\mathcal{M}}^{EEG}$. Moreover, I use the markups enjoyed by importers of electricity $\bar{\mathcal{M}}^{EEGI}$ to pin down the share of average local grid prices to imported prices $\frac{P_t^{EEGL}}{P_t^{EEGI}} 2^2$.

 $^{^{21}}$ Website for Maltese utility tariffs found in https://www.rews.org.mt//en/fa/31. Prices in kWh are transformed in terms of KTOE using the conversion factor: 1kWh =8.59845e-5KTOE.

 $^{^{22}}$ This is a reduced form way to proxy the calibration of the efficiency of electricity of foreign sources. Given that this version of the model does not explicitly model the production of electrical energy in the euro area, I

The elasticity of substitution between electricity imported through the Malta-Sicily interconnector and that locally produced by the local electricity producer, η_{EEG} , is set to 1. Similarly the elasticity of substitution between the natural resource (LNG) and capital within the production of local electricity, η_{EEGL} , is assumed to be unity.

The elasticity of substitution between electricity sourced through the national grid E_t^{EEG} (that is dirty electricity as it is sourced by burning fossil fuels) and electricity produced using renewable sources E_t^{ER} is set to 1.8, in line with Papageorgiou et al. (2017) and Coenen et al. (2023). Finally, the elasticity of substitution between fuel energy E_t^F and electrical energy E_t^E , η_E is set to 1.5. The coefficients governing the adjustment costs faced by the energy aggregator when changing the fuel/electricity combination in the energy bundle (ϕ_E and ϕ_F) are set to 10.

3.3 Energy in the consumption bundle

The quasi-share of energy in the consumption basket of non-Ricardian households ϕ_{enr} , is calibrated so as to pin down the energy consumption of hand-to-mouth households with the actual share of nominal energy expenditure in the average consumption of households found in the lowest income quartile, which according to Darmanin (2021) is estimate to around 11%. I set the intensity of energy in the consumption basket of Ricardian households, ϕ_{er} to 0.04 such that the average nominal share of energy in per-capita consumption is 5.9%, that is in line with the weight of energy in Malta's overall HICP.

Following Bodenstein et al. (2013), Coenen et al. (2023) calibrate the elasticity of substitution between the non-energy and energy consumption bundles to 0.4. In our case, contrary to most models in its class, the elasticity of substation between energy and non-energy consumption is dependent on the household type. In this respect, the baseline calibration of the model assumes that wealthier households are able to substitute to a greater extent energy for non-energy consumption. The rationale behind this choice stems from the a-priori belief that the energy consumption. In this light, relatively poorer households is necessary to sustain the non-energy type of consumption. In this light, relatively poorer households are unable to substitute away from energy consumption in favour of the non-energy basket. I therefore calibrate the elasticity of substitution between energy and non-energy consumption bundle of the non-Ricardian households, ν_{ENR} to 0.1, while that for Ricardian households, ν_{ER} is set to 0.6. For the same reason I further assume poorer households to face stronger adjustment costs in the short run to adjust their energy consumption within their overall consumption basket. To this end, I calibrate ϕ_{CE}^{NR} resort to the calibration of markups. to 150, while ϕ_{CE}^R is set to 50.

The elasticity of substitution between the energy bundle and non energy value added bundles in the domestic and export-oriented sectors, η_n and η_n , are calibrated to 0.25, in line with Coenen et al. (2023).

4 Simulations

To understand the properties as well as potential uses of the new model, I provide a number of simulations, focusing on energy related shocks. All shocks shown in this section are performed in a deterministic setup, thus assuming that all agents in the economy know the path of the shocks that will be hitting the economy.

4.1 Temporary Shocks

4.1.1 Brown energy taxes

First, in order to understand the main transmission channel to energy taxes, I show a very temporary increase in fuel and grid (brown only) electricity taxes calibrated such as to increase energy prices by 10%. The shock decays through a simple AR process. In all temporary simulations, I assume a passive fiscal policy, implying that following the shock, all fiscal instruments are held constant, such as all results are only reflecting the change in the shocked instrument.

An increase in energy taxes translates into a one-to-one rise in the retail price of fuel and electrical energy types. Firms aggregating the final energy product face an increase in the price of brown electrical and fuel energy leading them to utilise a higher proportion of green energy. However, this substitution is largely imperfect. First, green and brown electricity are imperfect substitutes. Also, firms face adjustment costs whilst substituting away from fuel energy into electricity, thus limiting the pace of the adjustment. Moreover, an increase in the production of green electricity is largely dependent on the accumulation of green capital. Households choosing to invest in green capital face adjustment costs reducing the speed of adjustment of green capital accumulation. Moreover, under the baseline assumption of fixed availability of land resource, the change in the optimal green capital allocation is also somewhat contained. This implies that firms producing intermediate goods face a rise in the costs of their energy bundles, increasing marginal costs and leading to a reduction in supply. This increase in production costs leads to a rise in intermediate prices, both domestic and export oriented, with the former then reflected into an increase in core inflation.



Figure 1: Macroeconomic responses to a transitory brown energy tax shock

The rise in intermediate prices, leads to a worsening of Malta's international competitiveness, leading to a fall in exports. Higher marginal costs lead to a reduction in the demand for factors of production, including energy. Lower demand for capital goods and labour inputs lead to a reduction in conventional investment and labour hours. The latter leads to a gradual fall in real wages (due to both nominal and real stickiness in wage formation). Higher inflation as well as the effects of lower labour and capital nominal income leads to a negative income effect for both Ricardian and rule of thumb households who cut back on private consumption. This leads to a peak fall in real GDP of almost 0.4% by the second year after the shock. This implies that a sudden rise in brown energy taxes is stagflationary, mimicking the effects of a negative technology shock.

Overall consumer inflation increases by 0.6% in annualised terms on impact.²³ Looking at the disaggregation by household type, one can see that rule of thumb households experience a considerably higher consumption inflation rate when compared to Ricardian households. The higher inflation rate, driven by the higher proportion of energy in the consumption bundle of

²³This magnitude is in line with internal simulations produced using satellite models at the Bank.



Figure 2: Sectoral responses to a transitory brown energy tax shock

these types of households, leads to considerable deeper cuts in the real wages of non-Ricardians.²⁴ This, coupled with the fact that these type of households are unable to smooth their consumption using financial assets, leads non-Ricardians to cut back considerably on both overall and non-energy consumption.

Overall energy demand falls by slightly more than 1% within 5 quarters after the start of the shock. Energy used in the intermediate stage of production, that is used by domestic and export oriented firms falls by almost 2% on the back of higher energy costs and lower demand for energy as overall production falls. Energy directly demanded by households falls considerably less. When compared to their Ricardian counterparts, rule of thumb households face stronger adjustment costs when changing the share of energy in their consumption basket. Hand-to-mouth households are therefore unable to cut back on energy consumption as much as Ricardians, implying that the share of energy in the consumption basket of non-Ricardians

 $^{^{24}}$ The labour market within this model is symmetric across Ricardians and non-Ricardians, implying that the hours worked as well as the nominal wages received by the two types of households are equal. In this light, the difference in the dynamics of Ricardian and non-Ricardian real wages is driven exclusively by the different inflation dynamics of their respective consumption baskets.

falls considerably less than average. In turn this implies that poorer households will be forced to devote a larger share of their total expenditure to energy, thus reducing the income to be used on non-energy consumption. This result suggests that allowing for heterogeneity in the composition of households consumption basket leads to non-trivial effects on the final results. The asymmetric impact that fossil fuel taxes might have on poor and rich households suggests that apart from the well documented aggregate costs associated with transitioning the global economy towards a net-zero target, policymakers must also internalise the distributional impact that such policies might have. This insight is especially important when governments are devising optimal recycling policies for the revenue generated when taxing carbon emitting energy production.

Looking at the environmental impact of these tax hikes, one notes that the share of energy produced using renewable sources increases steadily as the relative price of renewable energy falls relative to retail grid electricity and fuel prices. The increase in the production of renewable energy is however gradual. This is explained by the fact that the production of green energy is almost solely dependent on the accumulation of green capital. Increases in brown energy prices lead to an increased demand for renewable energy leading to an increase in the demand for green capital. This leads to an increase in the rate of return to green capital translating to a spike in private investment in capital used in the production of electricity through renewable sources. Thus following an increase in brown energy taxes, the model predicts diverging dynamics for green and conventional private investment. Turning to emissions, the cut in overall energy demand as well as the increase in the share of green energy in the energy mix leads to a fall in GHG emissions of around 1.2% by the second year after the shock.

Fiscal developments are positive with a consistent drop in the government debt to GDP ratio. The increase in energy tax rates outweighs the fall in energy demand across the horizon, leading to an increase in the energy tax revenues. These more than outweigh the reduction in other tax revenues which are expected to fall following the drop in economic activity. The government debt to GDP ratio is expected to fall consistently across the horizon reaching -1.5% by the end of the fourth year of the shock.

4.1.2 Green subsidies

As a second exercise, I show a very temporary increase in green capital subsidies. The shock is calibrated to increase government expenditure on such subsidies by 1% of GDP on impact. In interpreting the results, one needs to consider that the steady state level of green energy subsidies as percent of GDP is less than 1% of GDP, implying that the relative size of the shock is significant. Similar to the previous simulation, I assume no change in the other fiscal instruments.



Figure 3: Macroeconomic responses to a transitory green capital subsidy shock

Green capital subsidies lead to an increase in the net return to green capital, leading Ricardian households to increase the supply of green investment. The increase in green investment leads to very subdued demand side effects, driven by the relatively large import content of green investment goods. These positive demand-side effects lead to upward pressures in the demand for labour and conventional private investment. Despite the increase in the relative return of green investment when compared to conventional capital, the increase in green investment does not crowd-out conventional private investment. This result is driven by the fact that the production (and installation) of green capital requires an element of local labour as well as some local production which utilises conventional capital. Thus all-in-all, the response of private conventional investment is marginally positive.

The increase in green investment slowly builds up the supply of green capital leading to a drop in the marginal cost of producing renewable energy, and consequently in renewable electricity



Figure 4: Sectoral responses to a transitory green capital subsidy shock

prices P_t^{EER} . Electrical energy aggregators increase demand for green electricity increasing the share of renewables in electric energy. This leads to a drop in the price of electrical energy P_t^{EE} peaking at around 2% by the third year into the shock. In turn, energy good aggregators start to diversify away from fuel energy and increase the share of electrical energy into total energy leading to a fall in overall energy prices of around 0.5% by the fourth year of the shock. In total, the share of renewables in total energy is expected to increase by around 1.5 percentage points, in turn contributing to a fall in GHG emissions of around 1.4% by the fourth year of the shock.

Despite the downward pressures driven by lower energy inflation, the increase in green capital subsidies lead to some short-lived and very subdued upward pressures on consumer prices. The latter are driven by the marginal but positive demand-side effects that an increase in green investment has on the local economy, mainly leading to an increase in wages and capital prices, in turn positively affecting marginal costs of intermediate production. Throughout the second year of the simulation, as lower energy prices start to permeate throughout the economy, both core and headline inflation start to drop. Turning to household-specific inflation, the negative pressures in energy inflation are beneficial mainly to the non-Ricardians who enjoy consistently lower consumer inflation than their counterparts, mainly due to the greater share of energy consumption in their private consumption basket.

Turning to the macroeconomic outcomes of this simulation, the model predicts a fall in Ricardian private consumption, fuelled by the need of Ricardian households to finance the increase in private investment as well as by the negative wealth effects associated with an increase in government debt. This negative wealth effect leads to an increase in the labour hours supplied, which is however outweighed by an increase in labour demand, as outlined by an increase in the real wage. This negative wealth effect is therefore expected to outweigh the positive income effects perceived by Ricardian households through higher dividends paid by the green electricity firms. On the other hand, the positive change in real wages and hours worked lead to positive income effects that boost private consumption of non-Ricardian households. These effects are amplified by the lower consumer price inflation in the medium run perceived by the non-Ricardians, which leads to stronger real wage increases for the latter type of households. Nonetheless, effects on per capita private consumption are expected to be slightly negative. The short-run increase in marginal costs is expected to negatively impact Malta's competitiveness in the first three years of the simulation. However, the downward pressures on marginal costs of production driven by lower energy prices, eventually lead to an improvement in international competitiveness, leading to an increase in exports. All-in-all, the effects on GDP are always positive. In fact, in the short-run, the increase in green private investment is expected to outweigh the falls in overall private consumption and exports. As the positive effects on green investment start to dissipate, positive income effects start to exert stronger net positive pressures on Ricardian private consumption, while reductions in marginal costs improve the net trade balance of the economy. As expected, this simulation leads to a worsening in the government fiscal position, with the government to debt ratio increasing by almost 2 percentage points by the end of the simulation horizon considered.

4.2 Policy scenarios

This section documents the first attempts at estimating the macroeconomic effects that will follow the decarbonisation efforts of the Maltese energy sector. The consensus across all scientific communities, is that in order to achieve the required cuts in emissions, carbon prices across the EU would need to increase significantly throughout this decade. In this light, I calibrate an increase in the taxes levied on brown energy (both fuel-derived energy and locally and foreign produced brown electricity) calibrated in line with the increase in carbon emission prices that will be required by 2030 so as to reach the EU's target of cutting emissions by 55% by the same date and that are consistent with achieving carbon neutrality by 2050. In view of the uncertainty surrounding the technologies that will be available in the future, together with that surrounding the projected increases in the carbon taxes that will be required in the medium to long run, I focus our study on exploring the macroeconomic effects that are likely to materialise by 2030 and abstracting from the dynamics that will ensue beyond this date.

There is a vast body of literature that estimates the increases in carbon taxes and carbon credit prices that will be required by 2030 and that are consistent with decarbonising the economy by 2050. However, as expected, there is considerable heterogeneity across different scenarios and institutions in the projected carbon price levels that will prevail by end of 2030. The divergences between the simulated carbon price increases are driven by the assumptions surrounding the scenario, namely differences in the elasticity of substitution between traditional and renewable energy sources, whether the transition will be an orderly (that is roughly linear) or disorderly (with delayed but less gradual transition) and also whether the policy actions across different sectors and jurisdictions are convergent (that is synchronised) or divergent (that is asynchronous leading to carbon leakages and therefore requiring further mitigation measures).

4.2.1 Baseline

For the baseline scenario, I take the average (across studies) of the lower part of the range of carbon price increases that are estimated by IEA (2022), IMF (2022) and NGFS (2021). In this respect, the baseline scenario can be interpreted as the best-case or the conservative scenario which is consistent with the lowest projected increases in carbon prices that will be required to reduce carbon emissions by the internationally agreed deadlines. Under this scenario, energy taxes are increased so as to simulate a linear increase in carbon prices reaching the level of EUR 135 per ton of CO2 emitted by 2030, up from around EUR 70 registered between 2021 and 2022. The increments in carbon taxes are then assumed to start in 2024, assuming a seven year period of gradual increments in energy taxes.²⁵ Thereafter, I assume no further increases in carbon prices.²⁶

²⁵Despite the fact that the calibration of carbon tax increases is estimated relative to the 2021-2022 average, I assume that any energy price increases start in 2024, thus reflecting the energy stabilisation policy enacted by government and that was active between 2021 and 2023. I am therefore assuming that the increase in carbon prices that occurred between 2022 and 2023 will be passed on to retail energy prices from 2024 onwards.

 $^{^{26}}$ It is important to note that all studies project that further increases in carbon prices beyond 2030 will be required so as to fully decarbonise the global economy by 2050. However, since the main aim of the study is to estimate the transitional dynamics over the next seven to ten years that will ensue due to the green transition of the energy sector in Malta, and in view of the considerable uncertainty surrounding the carbon prices that are to be reached by 2050, I refrain from imposing further increases in carbon taxes beyond 2030.

Using internal studies, I estimate that the increase in carbon emission prices assumed under the baseline scenario will lead to roughly 9% increase in the marginal costs of energy production. To achieve this, I calibrate the appropriate increase in grid electricity taxes (τ_t^{EEG}) and assume a full and immediate pass-through of these increases in costs onto intermediate electricity prices. It is imporant to note that in order to avoid changes in the relative prices between local and foreign electricity prices (that would lead to a change in the share of local vs imported electricity) and relative prices of electricity and fuel energy (that would lead to a change in the intensity of electricity vs fuel energy) I assume that all intermediate prices of all brown energy types increase by the same magnitude.²⁷ Moreover, for the baseline scenario I assume no redistribution of energy tax-related revenues for the first 20 years of the simulation, thus ten years after the simulation.²⁸

In this baseline scenario, I further assume that the tax increases will be gradually implemented across a linear trajectory, with taxes on local grid electricity and fuel energy increasing linearly over the period of 7 years. Thereafter the fossil fuel taxes are kept constant. In this baseline scenario, I further assume that government chooses not to recycle any fiscal space created through these policies. Similar to the previous section, all simulations are performed in a deterministic setup, thus assuming that Government preannounces the policies that will be undertaken in a fully credible and transparent way.

The aggregate and sectoral effects of this policy are shown in figures 5 and 6 respectively. At an aggregate level the fossil-based energy tax leads to a long-lasting fall in GDP, peaking at around 0.9% of a pre-policy-change steady state output. This result is qualitatively in line with a temporary increase in energy taxes. However, the permanent nature of this scenario leads to quite a different result in the short-run when it comes to the inflationary effects of this shock. While a temporary energy tax shock was found to be stagflationary, a gradual but permanent tax increase first leads to a short-term drop in core inflation. This is contrary to what documented in Coenen et al. (2023) but in line with results by Bartocci et al. (2022) who show that a temporary but sudden increase in carbon taxes is stagflationary in the short run, while a permanent yet gradual implementation of a carbon tax is recessionary in the short run leading to a drop in output and prices. As the fossil-based energy taxes increase, energy aggregators are faced with

 $^{^{27}\}text{I}$ therefore calibrate a shock on taxes of fuel energy τ_t^{EF} so as to keep the price of fuel energy relative to that of electricity as constant. This is a simplifying assumption since the increase in carbon emissions projected by international studies depends on the emitting sector, with road transport, for instance, foreseen to be affected by steeper increases in carbon prices. ^{28}All simulations done in this paper assume that all economic agents are aware and are able to anticipate

²⁸All simulations done in this paper assume that all economic agents are aware and are able to anticipate the future increases in carbon prices. Moreover, simulations further assume that these foreseen paths are fully credible, abstracting from issues related to uncertainty surrounding these paths or to lack of commitment of local and international institutions.



Figure 5: Macroeconomic responses to a baseline carbon scenario

higher brown energy costs, leading to a reduction in demand for grid and fuel energy and a somewhat higher demand for green energy. Due to the imperfect substitutability between green and brown resources, and also due to the inability of green energy to increase enough to make up for the drop in the demand of fossil-based energy, overall demand for energy starts to fall. Due to the complementarity between value added and energy, this leads to a drop in the demand for value added services, leading to a reduction in the demand for conventional labour hours and capital. This leads to a fall in wages and rental rate of capital. Despite this fall in wage and rental rate of capital components, marginal costs are expected to increase by the second year of the simulation due to the upward pressures on the energy component of intermediate production.

Ricardian households are faced by both a negative income and negative wealth effect as they are able to foresee the long-run drop in economic activity resulting from this policy. This leads them to cut back on (non-energy) consumption aggressively even in the short-run. Indeed in the short run, the fall in Ricardian household consumption is stronger than that recorded by rule-of-



Figure 6: Sectoral responses to a baseline carbon scenario

thumb households, despite the fact that the the latter are faced with stronger negative income effects on the back of higher household specific overall inflation which leads to a larger drop in the purchasing power of this class of households. The slow adjustment in energy consumption of non-Ricardians is also driven by the relatively stronger adjustment costs faced by these type of households when changing their private consumption bundle composition.

The anticipatory behaviour of most agents leads to a very fast drop in economic activity in the short run which explains the dip in core inflation in the first year and a half of the shock, notwithstanding the higher energy costs. Nonetheless, as higher energy costs start to permeate across the production stages of the economy, core inflation starts to rise peaking to almost 0.05% in annualised terms. On the back of strong energy price inflation, overall consumer prices increase even in the short run, peaking at almost 0.15% in annualised terms. This overall figure hides considerable heterogeniety with overall annual inflation for Ricardian households peaking slightly higher than 0.1%, while that for rule-of-thumb or poorer households peaking at more than 0.2%. Focusing on sectoral results, the increase in energy prices relative to those of value added lead to a drop in overall energy demand leading to an increase in energy efficiency. By 2030, energy demanded by households for consumption purposes falls slightly more than energy demanded for intermediate production. This dynamic is driven solely by Ricardian households, who are expected to cut back on energy consumed by almost 4% by 2030, while non-Ricardian households, in view of their inability to effectively reduce energy demand are projected to cut back on energy consumption by less than 2% by 2030.

The production of green electricity increases substantially by almost 12% driven by a 15% increase in green investment. These dynamics increase the share of green energy in the electricity mix by more than 1pp. This, together with the increase in energy efficiency and overall drops in economic activity, leads to a reduction in the GHG emissions of slightly more than 4%, around 10 years after the start of the shock. The fiscal position of government, worsens marginally in the short run, as the drop in aggregate demand leads to a reduction in non-energy tax revenues and to a negative denominator effect. From the third year onwards, increases in energy tax revenues outweigh the falls driven by other revenue sources leading to a considerable improvement in the government's fiscal position.

4.2.2 Alternative scenarios

As stated earlier, the baseline scenario taken in consideration above, is consistent with the bestcase scenario in which I assume the most conservative increases in global carbon emission prices that are consistent with reducing global emissions by the internationally agreed magnitudes by 2030. This scenario implicitly assumes an orderly transition where actions across different jurisdictions are synchronised limiting carbon leakages. In this subsection, I run a number of different policy scenarios that differ in a number of dimensions.

Higher global carbon prices: As a first exercise, I re-calibrate the baseline shocks in order to reflect a higher projected increase in global carbon prices. For this worst-case scenario, I take the highest carbon prices envisaged by IEA (2022), IMF (2022) and NGFS (2021). Under this worst-case scenario, it is assumed that carbon prices will be reaching the level of EUR 200 per ton of CO2 emitted by 2030. All other aspects of the simulation design, such as the trajectory of the shocks, the assumptions surrounding the fiscal rule and the parameterisation of the model are unchanged from the baseline scenario.

As expected, results indicate that under this worst-case scenario, fluctuations in macroeconomic variables are expected to be considerably stronger. Energy prices are expected to increase



Figure 7: Macroeconomic responses to baseline and -case carbon scenarios

by slightly more than 20% by 2030, significantly decreasing brown energy demand. The increases in energy costs are, on the one hand, expected to lead to an increase in marginal cost leading to an even bigger drop in exports when compared to the baseline scenario. Moreover, stronger negative income and wealth effects are expected to compress private consumption considerably more, with non-energy private consumption falling by around 2.5%. The asymmetric effects of energy cost increases on private non-energy consumption are even more pronounced under this scenario, with the fall in non-Ricardian consumption reaching almost 4.5% within the window under consideration, almost double the fall registered by Ricardian households. As in the baseline scenario, these results are partly driven by the higher consumer inflation experienced by non-Ricardians, reaching a peak of almost 0.5pp and eroding the purchasing power of their disposable income.

As expected, following the considerably stronger carbon price increases assumed under this scenario, the share of renewable energy in the electricity mix is projected to increase by 2.5pp, more than double the increase expected under the baseline scenario. This, together with the



Figure 8: Sectoral responses to to baseline and worst-case carbon scenarios

drop in overall energy consumption is expected to contribute to a drop in green house gasses emitted by the energy sector of more than 8%.

Different paths: In the next exercise I explore how results would change in case the adjustment path of the carbon prices is not linear. In particular, I simulate two additional scenarios. The first scenario assumes a delay in the price hike of carbon prices and mimics a postponement in the cuts of global emsission quotas. In the second scenario, I assume that the increase of carbon prices is front-loaded and mimics an overly-aggressive cut in carbon quotas in the first years of the shock. Both scenarios assume that carbon prices still reach the baseline level of EUR 135 per ton by 2030 but with significantly different paths. All other assumptions surrounding the baseline scenario are once again unchanged.

Compared to the linear path, the front-loaded scenario brings about a stronger fall in output for most of the period under consideration. This is driven by stronger cuts in private consumption and immediate and more pronounced falls in exports. The latter are driven by more abrupt increases in marginal costs of production driven by the steeper increase in energy prices over the short run. Apart from hurting Malta's international competitiveness more in the shortrun, the front-loaded path of carbon price increases also transmits itself in considerably stronger consumption inflation in the short run. Indeed, the impact on the year-on-year consumer inflation is expected to peak immediately in the first year of the simulation, reaching a maximum increase of more than 0.3pp when compared to steady-state.

The share of renewables in electrical energy is expected to increase at substantial rates right at the onset of the simulations, reaching the peak adoption registered in the baseline scenario already by 2029, that is four years before the baseline. Emissions are expected to fall considerably more across the whole period under consideration. This is driven by both a higher adoption rate of renewable electrical energy as well as by the steeper drop in overall energy demand that is consistent with this scenario. By 2034, the reduction of green house gasses is expected to be slightly larger than that consistent with the baseline scenario.





On the contrary, the back-loaded scenario simulates a postponement of the increase in EU



Figure 10: Sectoral responses to different carbon paths

carbon prices and mimics a delay in the capping of carbon quotas that reflects itself into lower carbon price increases in the short run. Under this scenario, carbon prices remain virtually unchanged till 2026, followed by a steep increase in carbon prices between 2027 and 2030 reaching the same level of EUR 135 per ton of CO2 by 2030.

Despite the lack of carbon price increases in the first three years of the shock, economic agents foresee the increase in prices that will start to materialise by 2027 and start cutting back slightly on both energy and non-energy consumption. The drop in domestic output leads to a more significant drop in both headline and core inflation when compared to the baseline scenario. Lower domestic demand leads to downward pressures on real wages and employment in the domestic sector. This translates into lower price pressures (through lower wages) to the tradable sector. Contrary to the baseline scenario, energy prices are almost constant in the short run, implying that the downward pressures from wages (and rental rate of brown capital) lead to a reduction in export prices leading to an increase in exports. This leads to an increase in labour demand in the tradable sector that almost compensates for the drop in domestic employment demand.

As energy prices start increasing after the third year, the direct upward pressures emanating from energy inputs start to outweigh the downward pressures in real wages and rental rates of brown capital leading to an increase in marginal costs of both domestic-targeted and foreigntargeted sectors. As a result, headline and core consumption inflation increase considerably, with peak increases exceeding those registered in the front-loaded and baseline scenarios by 2030. These inflationary pressures lead to drops in exports and employment that are more in line with both baseline and front-loaded scenarios.

With regards to environmental targets, pre-emptive measures by economic agents push for an increased use of renewable sources even before the increases in brown electricity and fuel prices start to materialise. Nonetheless, the share of renewables in electrical energy is expected to increase at a slower rate in the first three years of the simulation when compared to the baseline scenario. The adoption of green energy is expected to increase as soon as carbon prices start to rise such that the share of green energy in the electricity mix is expected to reach that consistent with the baseline by 2034. This implies that delaying the increases in carbon prices will result in reaching the maximum adoption rate of renewable electricity almost two years after the baseline scenario. Emissions are expected to fall considerably between 2029 and 2030 although these are expected to remain slightly above the levels reached in the baseline scenario across the period under consideration.

All in all, the differences between the three scenarios are mainly expected to consist of differences in the dynamics of macroeconomic and sectoral variables during the transition period. Undoubtedly these transitional differences can have very important policy implications, mostly related to inflation dynamics. In this regards, the baseline scenario consistent with an orderly and gradual transition, has a very smooth inflation response, limiting adverse effects of mitigation policies on price stability. Both front-loaded, and even more so, the back-loaded scenarios have considerable peaks in inflation dynamics that substantially exceed those found in the baseline thereby risking to create more meaningful trade-offs with the monetary policy mandate of the monetary authority. On the other hand, while consistent with a considerable spike in inflation between 2028 and 2031, the back-loaded scenario also seems to be conducive to lower drops in private consumption of both types of households across the period under consideration. In this light, the back-loaded scenario might at face value appear to be consistent with acceptable transitional and very low distributional costs associated with carbon mitigation measures. However, this conclusion rests on the fact that up till now the simulation design has intentionally abstracted from issues related to the recycling of the fiscal proceedings that accrue from these policies.

In fact, the largest differences between the three scenarios is evident in the fiscal position of the government by the end of the period under consideration. While the model foresees an improvement in the government debt to GDP ratio under all three timing scenarios, the extent of this improvement, and consequently the extent of fiscal space available for government to mitigate the transitional costs or else to further contribute in incentivising the demand for clean energy, varies considerably between a drop of 4.5pp in the front-loaded scenario and 1pp in the back-loaded scenario. In this light, while the latter scenario looks like having the lowest costs in terms of economic activity, a more holistic evaluation of the different timing options needs to include the study of the implications of different government revenue recycling options.

Moreover, despite the baseline calibration for carbon price paths is theoretically consistent with the Paris Agreement of limiting global warming to $1.5^{\circ}C$, the resulting drops in emissions and the projected increase in the use of renewable energy, falls short of the reductions sought after by the EU's Green Deal and Fit-for-55 programmes.²⁹ Moreover, under the Draft National Energy & Climate Plan covering 2021 and 2030, Malta has bound itself to increase its share of renewables in total energy by 3pp.³⁰ Under the simulation scenarios taken in consideration up till now, the share of renewables in total energy is estimated to increase between 0.5pp and 1.1pp (under the worst-case scenario), which correspond to 1pp and 2.5pp when the share is expressed in terms of electrical energy. Therefore even when considering the worst-case scenario of EUR 200 per ton of CO2, these simulations indicate that if policies were to exclusively focus on increments in carbon prices, Malta is projected to miss on its environmental targets.

4.2.3 Recycling proceeds from carbon pricing

In this respect, to better understand both the true costs of the transition to a more carbon neutral economy as well as to better understand where Malta stands in reaching its climaterelated targets, I repeat the baseline simulation above using different assumptions with regards to how carbon tax proceeds are used by government.

Recycling through transfers: As a first exercise, I assume that Government utilises all proceeds gained from taxing brown energy sources to increase lump-sum transfers. In this exercise

 $^{^{29}}$ Current emissions are estimated to have to fall by 25% so as to abide by the 55% drop in emissions when compared to 1990 levels foreseen in the EU Green Deal (IMF, 2022).

 $^{^{30}}$ The Green Deal foresees an EU-wide increase in the total share of renewable sources of 42.5% by 2030, implying a 20pp increase in the share of renewables. Malta's Draft National Energy & Climate Plan 2021-2030 foresees a less ambitious increase of 3 pp.

I explore two options, one in which transfers are increased symmetrically between the two types of households, and another one in which non-Ricardian households gain the most of the transfer increments.³¹ All results up till now have indicated that carbon taxes disproportionally affect the purchasing power of poor (proxied by the non-Ricardian) households who apart from having to rely exclusively on labour income to finance their consumption, also experience stronger negative real income effects, when compared to their Ricardian counterparts, due to higher consumption inflation. In this light, Government might wish to partially address this by distributing a larger share of the carbon revenues to hand-to-mouth households. Results for these policy experiments are found in figures 11 and 12.

Figure 11: Macroeconomic responses under debt-neutral policies - Transfer adjustments



Given their non-distortionary nature, both symmetric and targeted lump-sum transfers are consistent with limited macroeconomic impacts. There are however interesting sectoral results that merit some discussion. Depleting the fiscal space generated with the carbon policy by $\overline{}^{31}$ In the latter scenario, I assume that each non-Ricardian household receives twice the transfers that are

44

extended to a Ricardian household.



Figure 12: Sectoral responses under debt-neutral policies - Transfer adjustments

increasing transfers leads to negative wealth effects that reinforce the drops in private nonenergy consumption of Ricardian households, especially in the first year of the simulation. This reinforces the negative demand effects that further strengthens the short-term drops in both overall and core consumption inflation. This leads to a steeper fall in real wages in the short-run which in turn leads to an even more pronounced fall in the non-Ricardian private consumption. In other words, the falls in labour income received by non-Ricardians outweigh the extra nonlabour income received through transfers. The steeper fall in real wages experienced in the first year of the simulation leads to some short-lived negative pressures on real marginal costs which translate in some upward pressures in real exports.

These effects are however quite short-lived. From the second year of the simulation onwards, as the amount of transfers injected in the economy starts to increase (in line with the increase in fiscal space available to the government) the drop in labour income received by hand-to-mouth households starts to be outweighed considerably by the increase in transfer income leading to significant upward pressures in private consumption of these type of households. Under symmetric transfers the increase in transfer income is never enough to fully compensate non-Ricardian households for the drop in their real disposable income which follows the de-carbonisation policy. The more targeted approach of focusing most of the transfer increments on the poorer household types, is more successful at almost fully insulating non-Ricardian households from increments in energy prices brought about by the climate mitigation policies. In fact by the end of the simulation horizon, non-energy consumption of poor households are almost back to their steady-state. On aggregate, the upward pressure on non-Ricardian private consumption outweighs the drops in Ricardian private consumption leading to some upward demand-side pressures. This leads to some upward pressure in real wages starting from 2026 onwards that (despite propping up further the real income of non-Ricardians) lead to some further upward pressure on core inflation. Moreover, these inflationary pressures lead to a deeper drop in exports when compared to the baseline scenario, in turn leading to a somewhat more pronounced fall in overall GDP by the end of the simulation exercise.

Turning now to the specific differences between the symmetrical and targeted lump-sum transfers, one can note that with the exception of results for non-Ricardian non-energy private consumption, there are no major differences in the impulse responses. As expected, lowering the proportion of transfers shared with Ricardian households induces further negative income effects which further push down private consumption for the richer type of households. This leads to slightly lower aggregate private consumption when compared to the symmetric case which further pushes down on overall real output, implying that on aggregate, while effectively minimising the impacts on non-Ricardian households, targeted transfers have an even greater destabilising effect on long term economic growth. Moreover, recycling carbon-related revenues through an increase in lump-sum transfers has no effect on Malta's environmental targets.

Recycling through green capital subsidies The next experiment assumes that government utilises all proceeds gained from the increase in carbon prices to finance an increase in the subsidies to the returns of green capital. This exercise is performed under two scenarios. In the first scenario I assume that Government policy with regards to land allocated to the installation of green capital is left unchanged at baseline levels. In another instance I assume that Government increases the allocation of land that is earmarked for the installation of green capital. This distinction is quite important for Malta due to the strict development policies that limit the effective new space to be used for green capital installations. In this light, the second scenario simulates a simultaneous increase in green capital subsidies and a gradual expansion of the land parcels that are already earmarked by local authorities for development by 10% by 2030.



Figure 13: Macroeconomic responses under debt-neutral policies - Green capital subsidies

Green capital subsidies - fixed land Green capital subsidies - increasing land Baseline

The gradual increase in green capital subsidies leads to a rise in the net returns to green capital, leading to a considerable increase in the optimal green capital allocation chosen by households, (who are the ultimate owners of all private capital in the economy). Households are incentivised to allocate a larger proportion of their disposable income into green investment. The significant increase in green investment and consequently in green capital stock leads to a rise in the production of green electricity. This in turn leads to a fall in the prices of green electricity and put some downward pressures on the increase in overall energy prices fuelled by the increase in carbon prices. The drop in energy prices, also brought about by an increase in the share of renewable electricity in the total energy mix, partially outweighs some of the increase in cost pressures brought about by the increase in brown energy prices. This leads to some upward pressures on exports as Malta's international competitiveness is slightly improved.

The increase in the production of green electricity leads to an increase in the total net profits of green electricity producers. Moreover, despite the high import content of green capital and the



Figure 14: Sectoral responses under debt-neutral policies - Green capital subsidies

low labour share in green electricity production, the increased demand for green capital goods leads to positive demand side effects on employment. Both scenarios studied in this section show that recycling carbon revenues by subsidising green capital is able to completely outweigh the negative employment effects that are consistent with the baseline decarbonisation scenario, with employment levels expected to exceed their steady-state levels in the long-run. This implies that a decarbonisation policy made up of increases in carbon taxes and in green capital subsidies can actually lead to sightly positive employment effects even in a small economy such as Malta, which is required to import all the green capital stock to sustain the increase in green energy demand leading to relatively small demand-side effects.

Despite leading to increases in the relative return of green investment when compared to conventional capital, the rise in green capital subsidies also leads to upward pressures on private conventional investment which is foreseen to fall be less than in the baseline scenario. On the other hand, despite the positive demand and supply-side effects of increasing green subsidies, Ricardian household private non-energy consumption falls to a larger extent when compared to the baseline scenario. This is driven by general equilibrium effects that lead households to reduce their private consumption so as to finance the lower drops in private conventional investment and more importantly the considerable increase in green investment. The positive effects on the demand for labour inputs driven by the increase in green subsidies also lead to subdued increases in labour income streams that partially outweigh the negative effects driven by the higher carbon prices. This leads to a slightly lower drop in non-Ricardian private consumption when compared to the baseline scenario. Nonetheless, the positive distributional element of green subsidies is considerably lower than what was esitmated in the event of a full recycling of carbon revenues through increments in both targeted and symmetric lump-sum transfers. In fact, private nonenergy consumption of hand-to-mouth households is still projected to fall by more than 1% when compared to steady-state, in line line with the falls foreseen for the Ricardians. All-in-all, the strategy of recycling cabon revenues by boosting green capital subsidies leads to a drastic cut in overall economic costs associated with a decarbonisation policy that rests solely on an increase in carbon prices. Indeed, when compared to the baseline, the two scenarios presented in this section are consistent with a much more contained drop in real GDP, ranging between 0.4% and 0.2%.

As expected, an incremental increase in the land earmarked for the installation of green capital, raises the overall effectiveness of increases in green capital subsidies. The increase in land available for the development of green projects crowds in green investment leading to more pronounced falls in the price of green electricity, leading to further drops in overall energy prices when compared to the fixed land scenario. This first leads to more pronounced positive demandside effects due to the increase in green investment, while also helping to slightly further improve international competitiveness in the medium rum. Under the increased land scenario, overall private consumption is on the other hand expected to be marginally lower, due to a slightly more negative non-energy private consumption of non-Ricardians.

Differences in the results between the fixed-land and increasing-land scenarios are even more prominent when looking at environmental results. First, it is important to note that under both these scenarios, recycling carbon revenues by raising green capital revenues has a very beneficial effect on the environmental targets of the Maltese government. Indeed, the increase in green investment and the subsequent increase in the demand for green electricity leads to a considerable rise in the share of renewables in total electrical energy. As the share of green electricity increases green house gasses are expected to fall by almost double the percentages foreseen for the baseline scenario. Increasing the land earmarked for green capital installation reinforces these effects. Under the increasing-land policy, the share of renewables in electrical energy is expected to increase by almost 10 percentage points by 2034, translating into an increase of 4.5pp in the renewables-to-total energy ratio. This is considerably higher than the 7pp increase in the renewables-to-electric energy ratio that is foreseen under the fixed-land scenario and translating to 3.3pp increase in the renewables-to-total energy ratio. On the other hand, this implies that under both recycling scenarios considered in this exercise, Malta is projected to exceed its targeted increase in renewable sources.³²

5 Conclusion

This paper documents a new extension to the Central Bank of Malta's DSGE model. The model combines a detailed fiscal block as in Rapa (2017) with a new multi-sectoral energy block. The model seeks to capture the peculiarities of Malta's energy generation, with electricity depending on a single LNG-fired complex, with a sizeable proportion of all electricity demand being imported directly through the Malta-Sicily interconnector. Apart from being used in the production process, energy is directly demanded by households for consumption purposes. Energy production is divided in several stages. At a first stage, energy is composed of electrical and fuel-based energy. Electrical energy which is produced by the energy sector is a combination of grid energy (which is in turn a combination of energy produced locally by burning LNG, and energy imported through the Malta-Sicily interconnector) and electricity produced through renewable sources.

The model, contrary to most others in this class, seeks to capture the economy's dependency on fossil fuel both for electricity generation and transport purposes, and also seeks to directly capture the asymmetric effects that energy prices have on poorer households by allowing for household-type dependent preferences for energy within the private consumption bundle.

Policy simulations show that a decarbonisation policy based solely on carbon price hikes is likely to be mildly inflationary in the medium run, and consistently contractionary with respect to economic activity. Energy price increases resulting from these policies are expected to contribute to asymetric effects across household types with "poorer" households expected to experience

 $^{^{32}}$ When analysing these effects, it is important to point out that renewable electricity is not the only way in which Government aims to increase the share of renewables in the total energy mix. The definition of renewable energy includes the use of biofuels in total fuel consumption, the installation of heat pumps and similar initiatives. In this respect, the simulations shown in these exercises abstract from these additional measures and focus solely on the production of renewable electricity through the installation of solar panels or wind turbines. This assumption is required in view of the model's setup but is also warranted by the fact that within its National Energy and Climate Plan, authorities are expecting to achieve most of the renewable gains through the installation of solar power.

consumption inflation which is twice as high as that experienced by their Ricardian counterparts. This, together with falls in labour income, is expected to lead to considerable asymmetric effects in terms of private consumption dynamics. Despite their non-trivial economic costs, policies based exclusively on carbon price hikes are expected to be consistent with small gains in terms of the increase in the share of renewable energy use and with relatively contained cuts in green house gas emissions. Recycling carbon revenues through increasing lump-sum transfers is very effective at reducing these asymmetric effects across households but at the cost of some further loss in overall economic activity and with little-to-no gain in environmental targets. Utilising carbon revenues by boosting government subsidies on green capital is very effective at increasing the use of renewable energy sources beyond the Maltese Government commitments for 2030 and are very effective at cutting back on green house gas emissions albeit at the cost of being less effective at boosting consumption levels of non-Ricardian households. Finally, both back and front loading of carbon price increases are consistently found to lead to more volatile inflation dynamics, when compared to gradual and linear implementation of carbon price hikes.

The model documented in this paper is designed to help in assessing a number of energy and climate related policy-relevant questions. Going forward the model can be used to answer questions related to policy-induced changes in the energy mix of Malta. For instance, the disaggregation of the energy sector within MEDSEA-NRG allows to study the impact of increasing Malta's reliance on imported electricity through the installation of additional interconnector capacity. Moreover, given the detailed fiscal sector embedded within it, MEDSEA-NRG could also be used to understand the macroeconomic and environmental implications of the government strategy of insulating local energy prices from foreign dynamics through the use of systematic subsidies across all fossil-based energy types.

Going forward, the model can also be extended in a number of dimensions. Most notably, the current setup of a small-open economy is unable to account for spillovers of carbon-pricing strategies that are enacted at European or global levels. In this respect, work is underway to extend this version of the model with a parsimonious external block with energy features. Moreover, in its current state, MEDSEA-NRG does not account for any externalities related to the greenhouse gasses and is also unable to account for emission abatement efforts that could be undertaken by economic agents.

References

- Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous (2012), "The environment and directed technical change." *American economic review*, 102, 131–166.
- Bartocci, Anna, Alessandro Notarpietro, and Massimiliano Pisani (2022), ""green" fiscal policy measures and non-standard monetary policy in the euro area." Bank of Italy Temi di Discussione (Working Paper) No, 1377.
- Bodenstein, Martin, Luca Guerrieri, and Christopher J Gust (2013), "Oil shocks and the zero bound on nominal interest rates." *Journal of International Money and Finance*, 32, 941–967.
- Coenen, Günter, Romanos Priftis, and Matija Lozej (2023), "Macroeconomic effects of carbon transition policies: An assessment based on the ecb's new area-wide model with a disaggregated energy sector."
- Darmanin, Jude (2021), "The inflation experience of low income households." Central Bank of Malta Policy Note.
- Doojav, Gan-Ochir and Undral Batmunkh (2018), "Monetary and macroprudential policy in a commodity exporting economy: A structural model analysis." *Central Bank Review*, 18, 107 – 128.
- Forni, Lorenzo, Andrea Gerali, and Massimiliano Pisani (2010), "The macroeconomics of fiscal consolidations in euro area countries." *Journal of Economic Dynamics and Control*, 34, 1791– 1812.
- Gatt, William, Noel Rapa, and Luca Brugnolini (2020), "MEDSEA-FIN A DSGE model of the Maltese economy with housing and financial frictions." CBM Working Papers WP/04/2020, Central Bank of Malta, URL https://ideas.repec.org/p/mlt/wpaper/0420.html.
- Giovannini, Massimo, Stefan Hohberger, Robert Kollmann, Marco Ratto, Werner Roeger, and Lukas Vogel (2019), "Euro area and us external adjustment: The role of commodity prices and emerging market shocks." Journal of International Money and Finance, 94, 183–205, URL https://www.sciencedirect.com/science/article/pii/S0261560619300579.
- IEA (2022), "World energy outlook 2022." Technical report, International Energy Agency.
- IMF (2022), World Economic Outlook: Countering the Cost-of-Living Crisis,, chapter 3. International Monetary Fund.

Kanzig, D (2022), "The unequal economic consequences of carbon pricing. available at ssrn."

- Lozej, Matija (2019), "Economic migration and business cycles in a small open economy with matching frictions." *Economic Modelling*, 81, 604–620.
- NGFS (2021), "Ngfs climate scenarios for central banks and supervisors." Technical report, Network for Greening the Financial System.
- Papageorgiou, Chris, Marianne Saam, and Patrick Schulte (2017), "Substitution between clean and dirty energy inputs: A macroeconomic perspective." *Review of Economics and Statistics*, 99, 281–290.
- Rapa, Noel (2016), "MEDSEA: A small open economy DSGE model for Malta." CBM Working Papers WP/05/2016, Central Bank of Malta.
- Rapa, Noel (2017), "Estimates of Fiscal Multipliers using MEDSEA." CBM Working Papers WP/04/2017, Central Bank of Malta.
- Ritchie, Hannah (2020), "Sector by sector: where do global greenhouse gas emissions come from?" *Our World in Data*. Https://ourworldindata.org/ghg-emissions-by-sector.
- Rotemberg, Julio J. (1982), "Monopolistic price adjustment and aggregate output." *The Review* of *Economic Studies*, 49, 517–531.
- Schmidt, Tobias S, Nicolas Schmid, and Sebastian Sewerin (2019), "Policy goals, partisanship and paradigmatic change in energy policy–analyzing parliamentary discourse in germany over 30 years." *Climate Policy*, 19, 771–786.
- Varga, Janos, Werner Roeger, and Jan in 't Veld (2021), "E-QUEST A Multi-Region Sectoral Dynamic General Equilibrium Model with Energy Model Description and Applications to Reach the EU Climate Targets." European Economy - Discussion Papers 2015 - 146, Directorate General Economic and Financial Affairs (DG ECFIN), European Commission, URL https://ideas.repec.org/p/euf/dispap/146.html.

A Main macroeconomic parameters

Table 1:	Steady-state	values
----------	--------------	--------

Domestic Private Demand	
Private consumption (C^P)	61
Total investment (I)	17.9
Exports (X)	98.2
Imports (M)	94.4
Fiscal Variables	
Public purchases (G)	6.6
Public investment (I^G)	3.4
Transfers to households (TR)	14.3
Wage bill $(N^G W)$	12.5
Total Expenditure	35.2
Debt (annualised)	60
Effective tax rates	
Labour (τ_l)	25
Rental rate of capital (τ_k)	11
Consumption (τ_c)	22

All ratios with the exception of effective tax rates are expressed in terms of GDP. Effective taxes are expressed as a % of its base.

Households	
Rate of time preference (β)	0.99
Inverse elasticity of labour supply (η)	2
Habit formation (χ)	0.6
Share of Type-I households (ω)	0.3
Substitution between private and public goods (ν)	NA^*
Bias towards private consumption (ϕ)	1
Intermediate firms	
Labour share in non-tradables (γ_N)	0.65
Labour share in domestically produced tradables (γ_{XD})	0.60
Productivity of public capital (γ_q)	0.1
Depreciation of public and private capital (δ)	0.04
Final good firms	
Quasi-share of imports in private consumption (α_{C^P})	0.51
Quasi-share of imports in public consumption (α_G)	0.63
Quasi-share of imports in private investment (α_{IP})	0.66
Quasi-share of imports in public investment (α_{I^G})	0.66
Quasi-share of imports in exports (α_{I^G})	0.49
Elast. of subst. between domestic and imported pri. cons. (η_{C^P})	1.1
Elast. of subst. between domestic and imported pub. purch. (η_G)	1.1
Elast. of subst. between domestic and imported pri. inv. (η_{I^P})	1.1
Elast. of subst. between domestic and imported pub. inv. (η_{I^G})	1.1

 Table 2: Parameters affecting Steady State Values

*In baseline model, results are not sensitive to ν since ϕ is set to 1.

 Table 3: Mark-ups and Nominal Rigidities

Nominal Rigidities	
Export prices adjustment costs (ψ_X)	58.3
Non-tradable prices adjustment costs (ψ_{NT})	20.4
Import prices adjustment costs (ψ_M)	58.3
Indexation of export prices (ι_X)	0.5
Indexation of non-tradable prices (ι_{NT})	0.5
Indexation of import prices (ι_M)	0.5
Wage Indexation (Hall parameter) (ι_W)	0.95
Elasticities of substitution (Implied markups)	
Tradable sector (ε_t^{XD})	6(1.2)
Non-tradable sector (ε_t^{NT})	3(1.5)
Imports sector (ε_t^M)	6(1.2)
Wages (ε_t^W)	4.3(1.3)
Exports (η_X)	4(1.33)

 Table 4: Fiscal Policy

Fiscal Rule	
Sensitivity of instrument to debt target (ϕ_{q1})	± 1.5
Sensitivity of instrument to changes in debt (ϕ_{q2})	± 15
Sensitivity of instrument to changes in output (ϕ_{g3})	± 15
Monetary Policy Rule	
Sensitivity of interest rates to NFA (ρ_{ϕ})	0.0002

Energy specific parameters В

Table 5: Energy steady-state value	Table 5:	Energy	steady-st	ate	value
---	----------	--------	-----------	-----	-------

Table 5: Energy steady-state values		
Energy expenditure in GDP $\frac{P^E E}{GDP}$ Electrical energy in energy $\frac{E^E}{E}$ Grid electrical energy in energy $\frac{E^{EG}}{E}$ Local production of brown energy in energy $\frac{E^{EBL}}{E}$	7.5 44.2 41.0 29.3	$\iota_n = 0.05$ $\iota_e = 0.52$ $\iota_{ee} = 0.07$ $\iota_{eeb} = 0.26$
Energy in private consumption Share of NRG cons in priv cons $\frac{P^E E^C}{P^C C}$ Share of NRG cons in priv cons (Ricardian) $\frac{P^E E^{CR}}{P^{CR} CR}$ Share of NRG cons in priv cons (non-Ricardian) $\frac{P^E E^{CNR}}{P^{CNR} CNR}$	$6.0 \\ 5.0 \\ 11.5$	$\phi_{er} = 0.04$ $\phi_{enr} = 0.08$

Table 6:	Elasticity	of substitution	and adjustment costs
----------	------------	-----------------	----------------------

Energy in intermediate production	
Elast. of subst. between energy and value added bundle (domestic) (η_N)	0.25
Elast. of subst. between energy and value added bundle (exports) (η_N)	0.25
Energy bundle E_t	
Elast. of subst. between fuel and electrical energy (η_E)	1.5
Adjustment cost of fuel energy (Φ^E)	10
Adjustment cost of electrical energy (Φ^F)	10
Markup of electricity bundle (\mathcal{M}^E)	1
Adjustment costs of grid electricity prices (ψ^E)	0
$\frac{1}{2}$	0
Electrical energy bundle E^E	
Electrical charge value D_t	18
Liast. Of Subst. between green and grid (brown) electricity (η_{EE})	1.0
$Pomonumble electricity production F^{ER}$	
Share of land in parametels analysis and disting (x_t)	0.1
Share of labour in the conital labour min (γ_l)	0.1
Share of labour in the capital-labour mix (γ^{-1})	0.03
G · L J · · · · · J · J · DEG	
Grid electricity bundle E_t^{BO}	
Elast. of subst. between local and imported grid grid (brown) electricity (η_{EEG})	1
Markup of grid electricity bundle (\mathcal{M}^{LEG})	1.07
Adjustment costs of grid electricity prices (ψ^{EEGL})	0
Rat	
Local grid electricity production E_t^{EGL}	
Elast. of subst. between LNG and capital inputs in local grid electricity production (η_{EEGL})	0.5
Technology/efficiency parameter in local grid electricity production (γ_g)	0.29
Markup of local grid electricity bundle (\mathcal{M}^{EEGL})	1
Adjustment costs of local grid electricity prices (ψ^{EEGL})	0
Imported (interconnector) grid electricity production E_{\star}^{EGI}	
Markup of imported grid electricity (\mathcal{M}^{EEGI})	1.95
Adjustment costs of imported grid electricity prices (ψ^{EEGI})	0
	~
Private consumption bundle	
Elast of subst between private non-energy consumption and energy (Ricardian) (upp)	0.4
Flast of subst between private non-energy consumption and energy (non Bicardian) (ν_{ER})	0.4
(<i>upper</i>)	0.4
(νENR) Adjustment cost of energy in consumption (Ricardian) (Φ_{RR})	50
Adjustment cost of energy in consumption (non Ricardian) (ΨER)	50
Aujustment cost of energy in consumption (non-Alcardian) (Ψ_{ENR})	$_{00}$