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Summary

The goal of this work is to improve the spatial representation of the Regional Dynamic Integrated model of Climate and the Economy (RICE), in its '99 version, focusing on the Mediterranean countries, while also updating the calibration to the base year 2015. We evaluate the impact of climate damages and temperature changes in several scenarios, drawing comparisons across regions. Thanks to the theoretical structure of the model, which considers energy as an explicit input factor, we examine macroeconomic and energy indicators across regions. We find that a general slow down in economic growth is needed to decrease emissions and keep temperature change within 2°C by the end of this century. Our results are embedded in a framework showing the costs of delaying the energy transition. Our figures relies on fossil-fuel inputs and exogenous energy saving improvements.

Keywords: IAMs, climate change, social cost of carbon, emissions, temperature, energy, Mediterranean region, Mediterranean countries

JEL classification: Q54, H23, R13

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Balancing Climate Policies and Economic Development in the Mediterranean Countries

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Abstract

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1 Introduction

Climate change is a phenomenon triggered by a combination of natural occurrences and human behaviours. While it is recognised as a world issue, it is also important to acknowledge that its consequences are characterised by spatial heterogeneity (Ganti et al., 2023).

Emissions tend to rise with industrial development (Mardani et al., 2019), and it is now evident that some countries will incur more severe damage from climate change than others. Among these, the Mediterranean area is extremely exposed and vulnerable to climate warming (Ali et al., 2022). The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) includes a specific focus on the Mediterranean region (Ali et al., 2022). Furthermore, Seager et al. (2019) observe that all the regions sharing this *climate type* are experiencing dry periods, and this trend is expected to persist in the long run. Accordingly, Kutiel (2019) shows that the Mediterranean climate is characterised by a critical degree of spatial and temporal variability, taking into account atmospheric pressure, temperature and precipitation levels.

In such a context, our work contributes to the literature on the Integrated Assessment Models (IAMs), extending the Regional Integrated model of Climate and the Economy (RICE) introduced by Nordhaus and Boyer (2000), RICE-99, to include the Mediterranean regions. For this reason, we define this new version as RICE-MED.

We study the evolution of economic and climate variables under three scenarios. The first one is Business As Usual (BAU), in which there are no active policy measures against the effects of global warming and associated climate damage. The second one is Social Optimum (OPT), where climate damage is internalised and the optimal Social Cost of Carbon (SCC) is computed. The final scenario is Temperature Limit (TL), under which temperature is constrained to not exceed 2°C by the end of the century.

In term of regionalisation, the RICE-99 model divides the world into aggregates, namely the US, China, Europe, Other High-Income countries (OHI), Europe, Russia and Eastern Europe (EE), Middle Income countries (MI), Lower Middle Income countries (LMI) and Low Income countries (LI). We extend its original structure by considering twenty countries belonging to the Mediterranean area at a national spatial level.[1]

We also provide an analytical formulation of the RICE-99 model initialisation process to simplify future extensions of our work (Appendix C)[2].

As a further step, we use the new regional disaggregation, to qualitatively discuss regional climate and economic impacts. Our overarching motivation is to understand how climate policies should be designed to meet current climate goals, such as limiting temperature increase to 2°C above pre-industrial levels by the end of the century, including regional considerations. .

Finally, the structure of the RICE-MED model facilitates insights into the role of energy as a

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[1] Specifically we refer to: Albania, Algeria, Croatia, Cyprus, Egypt, Ethiopia, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Montenegro, Morocco, Spain, Sudan, Syria, Tunisia, and Turkey. See Table 2 for details.

[2] In Nordhaus and Boyer (2000) the conditions defining this process were mostly presented descriptively by the authors. In our view, an analytical formalisation can improve the understanding of the model and facilitate the replication process, as well as possible future extensions of it.

production factor, serving as a key element in modelling economies in a more realistic way. The results can inform and guide policy makers in the Mediterranean countries to design coherent mitigation policies. Our aim is to answer two broad research questions: (i) what are the economic and climate impacts on the Mediterranean regions under optimistic and pessimistic scenarios? (ii) and what are the effects in an increase of temperature on production and energy consumption?

In the following sections we review the previous literature (subsection 1.1), and introduce the macroeconomic modeling framework (section 2). The calibration task is presented in section 3 and numerical results are discussed in section 4. Section 5 concludes. Appendix reports include: a variables list, equations, analytical description of model initialisation conditions, tables summarising calibration and model outcomes, which are also presented in figures.

1.1 Review of the literature

We provide an overview of the most relevant literature in the field of IAMs characterised by a multi-regional framework, most of which originate from the perspective of the seminal work developed by Nordhaus and Yang (1996).

In terms of climate change and related economic impacts, some of the most comprehensive studies include,Kelly et al. (1999), Nikas et al. (2019), Weyant (2020) as well as the review work of Yang et al. (2016). Regarding the SCC, among others, we find Moore et al. (2017), Wang et al. (2019), Tol (2023) and Rennert et al. (2022), discussing its estimates across different models and its changes over time.

On the side of the *RICE-type* models (Nordhaus and Yang, 1996; Nordhaus and Boyer, 2000), the latest calibrated version is provided by Nordhaus and Yang (2021) and Yang (2022).[3]

The RICE version by Nordhaus and Boyer (2000), known as RICE-99, consists of a revised Cobb-Douglas production function with three inputs, namely capital, labour and carbon-energy, and a further production layer related to the energy sector, fully dependent on fossil fuel inputs. On the regional structure side, the world is divided into eight regions, grouped on the basis of economic/political similarities.

Bosello and Moretto (1999) carried out an exercise aimed at investigating the impact of uncertain future catastrophic climate events using different IAMs, including RICE-96 by Nordhaus and Yang (1996). Buonanno et al. (2001) developed ETC-RICE, extending the RICE framework with endogenous environmental technical change, and then Castelnuovo et al. (2003) introduced uncertainty into this structure, based on the approach of Bosello and Moretto (1999), creating

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[3] In the same time period in which RICE-96 was released, the MERGE model developed by Manne et al. (1995) and the FUND by Tol (1996) were also published. In the case of MERGE, we still have a regional structure, but with respect to RICE-96, its focus is on the management of climate change proposals and its Constant Elasticity of Substitution production function is composed of three inputs, namely capital, labor and energy, while in RICE-96 energy was not included in the production function. As far as the FUND model is concerned, one of its main characteristics is the "possibility to link scenarios for economy and population which are perturbed by climate change and greenhouse gas emission reduction policy". Specifically, policy variables are energy and carbon efficiency improvement, and sequestering carbon dioxide in forests (Tol, 1997). Again, the analytical structure is different, but since its release it has been recognised as one of the closest to the RICE model in terms of approach.

the ETC-U-RICE model. A further extension of the RICE-96 was that of Castelnuovo et al. (2005) embedding two different drivers of technological change, namely research and development and learning-by-doing, while Bosello (2010) focused on adaptation, mitigation and green R&D in the framework of Buonanno et al. (2001). A recent application at country level of this model can be found in Tamaki et al. (2019).

The RICE-99 structure was further extended by Galeotti and Carraro (2004), implementing different specifications of exogenous and endogenous induced technical change, which we find then, among others, in Bosetti et al. (2006c) and Bosetti et al. (2006a). Von Below and Persson (2008) provided an updated calibration of a revised version of RICE-99, while also including uncertainty. Other extensions are Nordhaus (2009), who released the RICE-2009 with a module dedicated to sea level rise,[4] while De Bruin (2014) developed the AD-RICE-99 model, where adaptation is considered as a policy variable. Schumacher (2018) discusses the aggregation dilemma using RICE-99 focusing on the effect of regional disaggregation on SCC, stating that country-level models would provide higher levels of SCC compared to fully aggregated frameworks, such as the case of the DICE-2013R model (Nordhaus, 2014). It is worth acknowledging that, according to our current review, apart from the work of Von Below and Persson (2008), all other extensions of the RICE model have focused on revising some parts of its analytical structure. To the best of our knowledge no further updates of the original model initialisation have been developed so far. This is where one of our contributions fits in, together with the analytical formulation of the model initialisation, the new regionalization and the updated calibration to the base year 2015. On the other hand, we have to acknowledge that the WITCH (World Induced Technical Change Hybrid) model developed by Bosetti et al. (2006b) can be considered, in our opinion, both an analytical and numerical evolution of the RICE-99 framework.

A new version of RICE was presented in Nordhaus (2010) (RICE-2010, hereafter). This new structure, focusing on abatement actions, is still characterised by a Cobb Douglas production function but with only two inputs, capital and labour, and the world is divided into 12 regions.[5] Recent contributions in the field of *RICE-type* models are the RICE 50+ model by Gazzotti (2022), and RICE-2020 provided by Nordhaus and Yang (2021) and discussed by Yang (2022). The first paper relies on an extension of the Dynamic Integrated Climate and Economy (DICE) model,[6] which is then regionalised in more than fifty regions and Europe is disaggregated at country level. The RICE-2020 model is, in turn, characterised by a high degree of flexibility in

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[4] We were not able to recover the detailed structure of the model from the web pages provided in the publications, but the description and references in the paper suggest that this version is largely based on the RICE-99 framework.

[5] In what follows we list some of the works related to this updated version. We start with Skoufias et al. (2011), who develop scenarios to assess long-term climate change impacts on poverty. Dennig et al. (2015) focus on the impacts of climate change on the poor and inequality, which in turn is extended by Budolfson et al. (2017) discussing discounting and catastrophes. Li et al. (2017) analyse predictions of historical responsibilities for carbon mitigation, while Adler et al. (2017) revise the analytical structure designing the social welfare function under the a prioritarian perspective and no time discount. Finally, in the RICE-2011 model of Nordhaus (2011) we find a detailed analysis of the SCC..

[6] Specifically the framework of DICE-2016R2 (Nordhaus, 2018). This choice allows the authors to introduce empirically estimated climate impact functions at the country level (Gazzotti, 2022).

regional breakdowns (16, 12 and 6 regions) to allow for comparison with the previous versions of RICE (Nordhaus, 2010). It is presented as a climate externality model and designed with the aim of obtaining solutions concerning pressing policy issues in the climate change area (Yang, 2022).[7]

Moving to our regional focus, the Mediterranean basin has been studied over the years from a macroeconomic and environmental perspective using various models. In what follows we report on the most relevant ones for our work.

The JRC-PESETA model[8] dates back 2009 and focuses on the creation of an interdisciplinary and regional Computable General Equilibrium (CGE) model to assess the physical and economic impacts induced by climate change in the EU in the 21st century with a bottom-up or sectoral approach, discussing the effects on agriculture, river basin floods, coastal systems, tourism, and human health.[9] The ENVISAGE model developed by the World Bank[10] is used by Galeotti and Roson (2011) to asses the economic impact of climate change in Italy and in the Mediterranean area, while Aaheim et al. (2012) study the impacts and adaptation to climate change in the EU using the GRACE model.[11] Paroussos et al. (2013) design four alternative macroeconomic scenarios for the southern and eastern Mediterranean using the GEM-E3 model framework,[12] thus accounting for the environment and energy systems in the analysis of governmental and economic development issues of the area.[13] Finally Bosello and Standardi (2018) present a regional version of the ICES model[14] to economically assess climate change impacts on the European Mediterranean countries, with a finer spatial resolution compared to that offered by standard CGE models.

Compared to Gazzotti (2022), our novelties are mainly linked to the decision to adopt the RICE-99 framework, which includes explicit energy input. By choosing such a version, our RICE-MED model is able to explicitly account for the carbon-energy factor in the production function. In

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[7] This version allows for different cooperative (efficient) solutions and non-cooperative (inefficient) Cournot-Nash equilibrium. In addition it is able to identify optimal solutions under exogenous policy constraints (Yang, 2022).

[8] Specifically, PESETA stands for "Projection of Economic Impacts of Climate Change in Sectors of the European Union Based on Bottom-up Analysis". Among others, publications related to the first stage of the project are Ciscar et al. (2009) and Ciscar et al. (2011). For the sake of brevity we do not list other related publications which can be found in the PESETA projects webpage.

[9] This model is considered the first regionally-focused, quantitative, integrated assessment of the effects of climate change on vulnerable aspects of the European economy and its overall welfare. The EU countries are grouped in 5 regions, namely Southern Europe, Central Europe South, Central Europe North, British Isles and Northern Europe (Ciscar et al., 2009).

[10] The Environmental Impact and Sustainability Applied General Equilibrium model is a standard recursive dynamic multi-sector multi-region CGE model with an emissions and climate module. Also in this case, it directly links economic activities to changes in global mean temperature, incorporating a feedback loop that links changes in temperature to impacts on economic variables such as agricultural yields or damage created by sea level rise (Source: Technical reference guide for ENVISAGE model)

[11] Global Responses to Anthropogenic Changes in the Environment (GRACE model Webpage)

[12] The GEM-E3 model is characterised by a multi-regional and multi-sectoral approach. Under a recursive dynamic CGE framework, it provides insights at the macroeconomic level and related interactions with the environment and the energy system. Further details are available at the GEM-E3 model webpage.

[13] See also specific focus on south Mediterranean provided in (Paroussos et al., 2015).

[14] The ICES model is based on the structure of the GTAP-E model developed by Burniaux and Truong (2002) (ICES model webpage).

addition to that, the original initialisation approach accounts for the disaggregation of the energy sector of each region included in the model. To the best of our knowledge, this is the first updated calibration adopting the original RICE-99 framework. Thanks to such a process, the initial level of capital stock, total factor productivity, output elasticity with respect to energy input and the markup on energy costs are calibrated simultaneously. With respect to Nordhaus and Yang (2021) and Yang (2022), we include the energy factor in the production function of the model. Compared to Von Below and Persson (2008), who consider capital stock as an exogenous variable for instance, we also provide an analytical formalisation of this process. Finally, compared to Paroussos et al. (2013) and Bosello and Standardi (2018), our representation of the Mediterranean countries is more complete. Thus, our contribution is twofold : (i) we provide a new formal analytical calibration of the RICE-99 model to facilitate future replication and improvements, and, (ii) we improve the granularity of the regional representation, including the Mediterranean countries.

2 The Model

In our new regionalisation, the world is divided into eight regions plus the countries of the Mediterranean area. In what follows, we briefly recall the structure of the model, while also highlighting our novel contributions at the analytical level.[15]

Regions maximise the social-welfare function W subject to economic and geophysical constraints. Every economic system produces an *all-inclusive* commodity $Q_j\left(t\right)$, to be allocated either for consumption or investment, with a specific level of technology $A_j\left(t\right)$, employing three production factors, namely capital $K_j\left(t\right)$, labour $L_j\left(t\right)$ and carbon-energy $ES_j\left(t\right)$, also seen as the energy services provided for the production of $Q\left(t\right)$.[16] Population growth and technological change are assumed to be exogenous, while the labour market is characterised by full-employment. The respective dynamics are described by Eq. (B.1) and Eq. (B.2).

The welfare optimisation problem considers each region j such that:

$$\max_{c_j(t)} W_j = \sum_t U\left[c_j\left(t\right), L_j\left(t\right)\right] R\left(t\right) \tag{1}$$

where the control is $c_j\left(t\right)$, per capita consumption, $R\left(t\right)$ is the pure time preference discount factor, as well as the social time preference across different generations, as per Eq. (B.7), and $U\left[c_j\left(t\right), L_j\left(t\right)\right]$ is the utility function characterising the society of agents of each economy, which

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[15] The regionalisation of the model is described in Table 2 in Appendix D. The list of all the variables is provided in Table 1 Appendix A while the model equations are listed in Appendix B.

[16] The framework of Nordhaus and Boyer (2000) is characterised by the absence of international trade across regions, except for the exchange of carbon emissions permits. Regions are organised in emissions' trading blocks. Each trading block is characterised by its own level of carbon tax. In line with the RICE-99 framework, each region is a trading block and within it the emissions permits market is cleared. Furthermore, the world is then assumed to be a unique trading block, so that the *where-efficiency* condition (see Nordhaus and Boyer (2000)) is satisfied, thus emissions reductions allocation is performed in a cost minimising way and a common carbon tax across regions is identified.

takes the functional form described by Eq. (B.6). The society is willing to reduce the wealth of high-consumption generations in favour of low-consumption ones,[17] therefore the utility function becomes:

$$U\left[c_j\left(t\right),L_j\left(t\right)\right]=L_j\left(t\right)log\left[c_j\left(t\right)\right]. \tag{2}$$

Since the model assumes a one-sector closed economy, the optimisation problem is subject to the following budget constraint:[18]

$$Q_j\left(t\right)=C_j\left(t\right)+I_j\left(t\right) \tag{4}$$

where $C_j\left(t\right)$ is the aggregate consumption of the $j-th$ region and $I_j\left(t\right)$ are the investments, while $Q_j\left(t\right)$ is the regional aggregate GDP. The latter is represented on the side of production as:[19]

$$Q_j\left(t\right)=\Omega_j\left(t\right)\left[A_j\left(t\right)K_j\left(t\right)^{\gamma}L_j\left(t\right)^{1-\beta_j-\gamma}ES_j\left(t\right)^{\beta_j}-c_j^E\left(t\right)ES_j\left(t\right)\right], \tag{5}$$

incorporating the environmental damage caused by the usage of carbon energy, with coefficient $\Omega_j\left(t\right)$, revised following Golosov et al. (2014), that is:

$$\Omega_j\left(t\right)=1-D_j\left(M_{AT}\left(t\right)\right)=exp\left(-\theta_j\left(M_{AT}\left(t\right)-\bar{M}_{AT}\right)\right). \tag{6}$$

Eq. (6) depends on the damage function $D_j\left(M_{AT}\left(t\right)\right)$, which in turn is affected by $M_{AT}\left(t\right)$ and $\bar{M}_{AT}$, that are respectively, the stock of carbon concentration in the atmosphere (AT) and the corresponding pre-industrial level.[20] Following Golosov et al. (2014), in our formulation damage is proportional to atmospheric concentrations, rather than temperatures. The parameter θ_j allows for incorporating the region specific damage cost, where the higher θ_j is, the more extensive the negative impact of a changing climate is on the economy.

Back to Eq. (5), let us recall that the term $c_j^E\left(t\right)ES_j\left(t\right)$ is the cost of producing carbon-energy, which is subtracted from the overall output produced by the economy. The production function of carbon-energy, Eq. (B.11) in Appendix B, is a function of $\varsigma_j\left(t\right)$, which is the exogenous level of carbon-augmenting technology[21] and carbon services $E_j\left(t\right)$.

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[17] In Eq. (B.6) the parameter α is assumed to tend to 1. This parameter represents the societal valuation of different consumption levels.

[18] Let us recall from above that regions are allowed to trade only carbon emissions permits $\Pi_j\left(t\right)$, thus the budget constraint on regional expenditures is:

$$Q_j\left(t\right)+\tau_j\left(t\right)\left[\Pi_j\left(t\right)-E_j\left(t\right)\right]=C_j\left(t\right)+I_j\left(t\right) \tag{3}$$

where $\tau_j\left(t\right)$ represents the price of each permit (and the carbon tax as well), while $\Pi_j\left(t\right)$ is the number of carbon emissions allowances allocated to region j and $E_j\left(t\right)$ the carbon emissions. The term $\tau_j\left(t\right)\left[\Pi_j\left(t\right)-E_j\left(t\right)\right]$ represents the net revenues a region receives from trading emissions permits. Eq. (4) yields combining eq. (3) with the following assumptions: i) the world is a unique trading block, thus all the region are subject to the same carbon tax ii) for any positive value of the carbon tax, the emissions permits market is cleared.

[19] The Cobb-Douglas function is characterised by constant-returns-to-scale.

[20] The term $M_{AT}\left(t\right)-\bar{M}_{AT}$ is always positive, since the stock of carbon concentration in the atmosphere AT has been constantly increasing overtime with respect to the pre-industrial level. Further detail can be found, among others, in Hofmann et al. (2009).

[21] The term $\varsigma_j\left(t\right)$ can also be interpreted as the ratio between carbon-energy $ES_j\left(t\right)$ and carbon services provided by fossil fuel inputs $E_j\left(t\right)$. The higher the ratio, the higher the carbon-energy generated per unit of fossil fuels inputs and the lower the emissions of CO2 produced in such a process.

3 Calibration and Scenarios

The reference year is 2015. The model runs for more than thirty periods in order to include climate change inertia and future climate impacts with a time step (Δt) of 10 years.[22] The model is initialised using the parameters described in Table 3. Subsequently, a set of equations is solved, assuring matching with the empirical observations in the base year. For each region j this process involves the simultaneous calibration of initial total factor productivity $A_j(0)$, initial capital stock $K_j(0)$, output elasticity with respect to energy input β_j and the markup on energy costs $Markup_j$. The whole calibration has been fine-tuned to replicate regional GDP and industrial emissions. Appendix C provides the analytical details, while outcomes are summarised in Appendix D.1, Table 4.

Like the original RICE-99 version, population dynamics are exogenous. Yet, in the RICE-MED model it has been updated following the IIASA-SSP2 scenario. Regional population follows a logistic-type formulation as described in Appendix B.1. [23]

The carbon cycle and the climate dynamics' parameters have been updated following Nordhaus and Sztorc (2013) and Folini et al. (2021). Furthermore, the exogenous radiative forcings for the year 2015 have been calibrated to match the latest IIASA RCP-4.5 projections.

Following Golosov et al. (2014), the RICE-MED model directly links atmospheric concentrations and the damage function, as a proxy for the increase in atmospheric temperature. Previous damage estimates are quite mixed, and the economic loss in terms of output varies in the range of a few percentage points to ten or even more [24] Including such a direct link between CO2 concentration and damage, has the prerogative to consider micro-founded estimates for damages.[25] Moreover, to exploit the regional structure of the RICE-MED model, we calibrate and incorporate the region specific damage cost θ_j in Eq. (6), following the work of Roson and Sartori (2016).[26]

As already mentioned in the introduction, we consider three scenarios, briefly described below:

- *Business as Usual (BAU).* This assumes no change in climate-related policies. This scenario represents the cost effects of unmitigated climate damages. [27]

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[22] The model runs until 2305. The time step is in line with the current climate change scientific literature. The effects of a small increase in the atmospheric CO2 concentration on temperature are exhibited after several years. For this reason, such a time lag is identified in about 10 years (Pindyck, 2022).

[23] The population growth rate matches the IIASA 2050 projections. Source of data SSP Database (Shared Socioeconomic Pathways) - Version 2.0.

[24] See Howard and Sterner (2017); Tol (2018); Van Der Wijst et al. (2023).

[25] However, recent works highlight that IAMs models tend to underestimate the impact of climate change on economic damages (Kalkuhl and Wenz, 2020; Roson and Sartori, 2016; Burke et al., 2015), especially due to the uncertainty surrounding the effects of temperature rise (Pindyck, 2022).

[26] The regional damage cost parameter θ_j is listed in Table 5 . This is calibrated on the basis of the following equation: $\theta_j = -\frac{\log\left(1-D_j(M_{AT}(t))\right)}{M_{AT}(t)-\bar{M}_{AT}}$, where $D_j\left(M_{AT}(t)\right)$ represents the impact on the GDP of each country of an atmospheric temperature increase equal to 3°C according to Roson and Sartori (2016), while $M_{AT}(t)$ is the value of the atmospheric CO2 concentration associated with a temperature increase of 3°C.

[27] According a recent study of the International Monetary Fund (link to access here), by June 2022 only 46 countries (24%) of the 195 in the world, are implementing schemes aimed at pricing emissions, i.e. carbon taxes and/or emissions trading schemes (ETS). This reflects a situation in which 76% of the world's countries have yet

- *Social Optimum (OPT).* The social welfare function is maximised under economic and climate constraints, identifying the optimal pathways of emissions reduction at each point in time. Marginal costs and benefits are equalised, balancing climate damage and mitigation efforts.
- *Temperature Limit (TL).* The social welfare function is maximised under an additional constraint that limits the temperature increase to below 2°C. This scenario is the one closest to the Paris' agreement target and evaluates the economic viability of a stringent climate policy.

The outcomes of the scenario analysis are discussed in the following section, where we first will present figures of climate variables and the Social Costs of Carbon across scenarios. Then, we delve into the findings for some key variables, such as GDP, energy intensity, investments, emission intensity and energy services. Subsequently, we narrow our focus to the Mediterranean countries, providing a set of results in that specific context.

4 Results

In Appendix D.2, Tables 6 and 7 report some key variables such as temperature, concentration, radiative forcing and the SCC across scenarios.

The model runs start in 2015 and the SCC is close to USD 40/tC [USD 11/tCO2] in both the OPT and TL scenarios. By 2035, the SCC jumps to USD 157/tC [USD 43 /tCO2] in the OPT scenario, while it goes up to almost USD 800/tC [USD 217 /tCO2] in the TL scenario, almost five times higher than the OPT scenario in the same year. This result reflects the need for an aggressive climate policy to keep the temperature below 2°C in this context.

The BAU scenario in Table 8 shows variations in average annual GDP growth rates for the macro regions,which range between 2.8% in LI and 0.74% in the OHI by 2055.[28] By the middle of the century, EUROPE shows values below 1%, while the USA average rate is close to 1%. CHINA and EE have growth rates slightly above 2%. These trajectories suggest that some mature economies might experience slower growth due to external factors such as aging populations and market saturation. In contrast, emerging economies like CHINA and EE could sustain higher growth rates due to ongoing development and industrialisation. Furthermore, these outcomes might also stem from a slowdown in capital stock accumulation, attributed to diminished investment and decreased energy utilisation. This is in line with the expected trends towards sustainable development and energy efficiency improvements, which might lead to reduced energy consumption.

We now look at the level of energy intensity growth rate e.g., the ratio of energy services to the level of GDP, across different macro-groups and scenarios, as reported in Table 9. The data

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to implement any kind of policy to reduce emissions. On average, we can say that the world is behaving as in the BAU scenario.

[28] More specifically, the figure for 2035 represents the average annual GDP growth rate relative to 2015, while the figure for 2055 refers to 2035 as the base year and the one for 2105 to 2055.

suggest that more ambitious climate policies and technological advancements (as in the TL<2°C scenario) could lead to substantial improvements in energy efficiency, especially in high-income countries.

This discussion provides insightful observations on how these regions are managing energy consumption relative to output growth. The USA, CHINA and EE exhibit the smallest variations in the BAU by 2035, underlying stability in the ratio of energy services to their outputs, as a result of energy improvements. In contrast, LI, LMI and EUROPE show a stronger decrease in the BAU, which becomes even more marked when climate policies are implemented. Concerning EUROPE's energy intensity growth rate, it might reflect its commitment to climate targets and the effort of transitioning to a more sustainable economy. The aggregates MI and OHI experience the highest fluctuations across scenarios, highlighting the effort needed especially to comply with stringent climate policies.

In Table 10, investment, emission intensity and energy services are discussed across scenarios. The OPT and TL scenarios show a greater slowdown in the growth rate than the BAU scenario. This is quite straightforward, as the introduction of the damage function and a limit on the temperature increase impose constraints that slow investments. The heterogeneity in responses across the macro-regions is noteworthy. CHINA leads with investment rates above 2%, suggesting a resilient economy even under stringent environmental scenarios. EE, LI and LMI show figures above 1%, indicating a heterogeneous level of resilience and adaptability to the imposed constraints. MI have average rates slightly below 1%, while the developed countries are characterised by rates below 1%, mainly due to a significant impact of environmental commitments on their more mature economies. Regarding emission intensity, developed regions, particularly OHI and MI, perform best. This could be due to their ability to produce more energy per unit of fossil fuel input or more stringent environmental regulations. The TL scenario shows a maximum reduction of about 1% per year in emission intensity. LI and EUROPE follow closely, with reductions of less than 1% per year, on average. The USA ranks just below the group average, showing modest progress in emissions reduction. The worst performers are EE and CHINA, with the latter showing minimal variations close to zero in the OPT scenario.

Finally, Table 11 provides an overview of average changes in GDP reductions for the macro-regions[29]. The USA and CHINA show a relatively small loss in the OPT scenario compared to the BAU, and a larger loss in the TL scenario. EE and EUROPE are characterised by loss in the OPT case, while the stricter TL scenario induces a small gain with respect to the BAU. The intuition behind such a result is that stricter environmental policies could lead to positive economic gains. On the contrary, LI and LMI experience the largest losses in both scenarios compared to the BAU one, reflecting the vulnerability of less developed economies to environmental policy changes. Finally, MI and OHI face moderate losses in the OPT and TL scenarios.

In a context where regions and countries rely solely on energy improvements and economic growth, without modelling explicitly investment in renewables or disruptive technologies, Table

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[29] Figures in Table 11 yield from figures in Table 8, which are then compared across scenarios.

8, 9 and 10 underscore the complexities and regional imbalances in pursuing economic growth and environmental sustainability targets. The heterogeneous responses in the OPT and TL scenarios with respect to the BAU, reflect the different regional capacities and priorities in addressing climate change while inducing economic development.

Let us now analyse the outcomes for the Mediterranean countries in Tables 12 and 13. These countries are divided into 4 groups based on geographical proximity. Group 1 (G1) includes Albania, Croatia, Greece and Montenegro; group 2 (G2) contains Cyprus, Israel, Lebanon, Syria and Turkey; group 3 (G3) includes Algeria, Egypt, Ethiopia, Libya, Morocco, Sudan and Tunisia; and group 4 (G4) contains France, Italy, Malta and Spain. The growth rate of the first group varies between 2%-3% for Albania and Croatia, falls for Montenegro and drops to a minimum of half a point for Greece. G2 rates vary between 1.5%-3%. Israel, Lebanon and Turkey have less variability between scenarios. G3 is the group that suffers the most from economic slowdown, going from growth rates of 5% to average rates of around 1.5%. The comparison between OPT and TL shows a virtuous case in Ethiopia, and the two worst performers being Libya and Tunisia. Finally, the countries belonging to G4 are those with the lower growth rates, on average, varying from 1.65% for France to 0.5% in the case of Spain.

Focusing on the energy services input in Table 13, we show that all Mediterranean countries are characterised by a slowdown in the use of energy in the TL scenario. This is mainly due to the fact that all countries are diminishing the use of fossil-fuel inputs, either by reducing the growth rate or by substituting other inputs, i.e capital and labour, or by taking advantage of technological improvements that can reduce emissions per unit of output (as will become clearer in the following analysis of emission intensity per country). If the overall result is a reduction in the use of energy services, there are large differences between countries, depending on their characteristics. In detail, the average reduction in G1 is around 30%, with a range of around 1/7 for Montenegro to 1/5 for Albania. In Croatia, energy services in the TL scenario are about half of those in the other two scenarios. Greece shows a reduction of around one third. All countries in G2 experience a sharp slowdown in energy services under the TL scenario in the first period (2015-2025), with a partial recovery in the intermediate period (2055) and then a downward adjustment in the final period, to align with the temperature constraint. Group G3 shows an average reduction of 25%, with small variations for Ethiopia and Morocco, larger for Algeria and Tunisia (around 30%) and in line with the average value for Egypt, and Libya. The G4, made up of the most developed countries in the Mediterranean area, shows an average reduction of about 30%, with Spain and France decreasing at a rate of 25%, while Italy is characterised by a more pronounced decrease, reducing its use of energy services input by about 50% .

5 Conclusions

This study extends the RICE-99 model to increase its spatial granularity, focusing on the countries belonging to the Mediterranean region. A more in depth analysis of this area is crucial as this territory is expected to suffer extensively from climate change damage.

In this new and updated framework, the social cost of carbon under the Social Optimum and the Temperature Limit scenarios shows a steep increase by 2035, especially in the more environmentally binding scenario. This result highlights the need for stringent climate policies in order to keep the temperature increase below 2°C by the end of this century.

Then, as a first step, we performed a macro-region analysis. A comparison across scenarios shows heterogeneity in the variations in average annual GDP growth rates, across the different macro-regions. Mature economies like EUROPE and the USA are projected to experience slower growth, while countries like CHINA might maintain higher growth rates. Investment rates, emission intensity, and energy services across scenarios reveal that environmental policies, in particular the stringent one, could lead to significant reductions in emission intensity and changes in energy consumption patterns. Developed regions are expected to perform better in reducing emissions intensity due to their technological advances and compliance with environmental regulations.

The analysis of Mediterranean countries further underscores the regional differences in response to climate policies. While all these countries show a reduction in energy services in the Temperature Limit scenario, the extent varies, reflecting diverse national characteristics and capacities for mitigation. Developed Mediterranean countries are projected to see a more significant decrease in energy services usage, aligning with their commitments to climate targets and sustainable economic transition.

To conclude, the results reflect the complex interplay between environmental policy, economic growth, and energy consumption. Aggressive climate policy is necessary for keeping the global temperature rise below the 2°C target, but comes with varying economic impacts and burdens across different regions and countries. While our study provides valuable insights into the potential impacts of climate change and policies on global economies and regional ones, with a focus on the Mediterranean countries, it is crucial to acknowledge its limitations in terms of the assumptions made, the exclusion of certain factors, and the inherent uncertainties in long-term projections. Although our work aims to increase the spatial representation of regions with a focus on the Mediterranean, the whole model is quite sensitive to the parameters used for its initialisation, the utilitarian welfare function and the discount rate. This stems from our choice to adhere to the formal initialisation process of the original version of the model. Therefore, the results should be interpreted with caution, also considering the uncertainties arising from the complexity of the observed system. In addition, as our model does not explicitly account for investment in renewable energy or disruptive technologies, which may significantly influence future energy paths in all countries, we could observe an overestimation of future energy use and economic growth; therefore, our future research will include the impact of adaptation measures and the effect of clean technologies, such as renewable energy and carbon capture and sequestration.

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A Appendix - Variables list

Table 1: List and description of all the variables in the model.

Variable	*Description*
t	Time, where $\Delta t = 10$ and $t = 1, 2...10$
j	Region
i	Country
s	Energy source
$L_j\left(t\right)$	Population and labour stock (million people)
g_j^L	Population growth rate, rate per Δt
$C_j\left(t\right)$	Aggregate consumption (trillion USD2015)
$c_j\left(t\right)$	Per capita consumption (trillion USD2015)
$A_j\left(t\right)$	Technological change (Hicks-neutral)
$g_j^A\left(t\right)$	Technological change growth rate
δ_j^A	Constant rate of decline of $g_j^A\left(t\right)$
α	Social valuation of different levels of consumption
$\rho\left(t\right)$	Pure rate of time preference
g^ρ	Growth rate of $\rho(t)$, rate per Δt
$\prod j\left(t\right)$	Carbon emissions permits
$I_j\left(t\right)$	Investments (trillion USD2015)
$K_j\left(t\right)$	Capital (trillion USD2015)
δ_K	Capital depreciation rate
$ES_j\left(t\right)$	Carbon-energy / energy services
γ	Elasticity of output respect to capital
β_j	Elasticity of output respect to the energy services
$1 - \beta_j - \gamma$	Elasticity of output respect to labour
δ_K	Capital stock annual depreciation rate
$c_j^E\left(t\right)$	Cost per unit of carbon-energy
$q\left(t\right)$	Wholesale price of carbon-energy exclusive of the Hotelling rent

Variable	*Description*
$Markup_j^E$	Mark up on energy costs, capturing regional differences in transportation, distribution costs and national energy taxes (thousand USD2015 per tC)
$\varsigma_j(t)$	Level of carbon-augmenting technology / Ratio of carbon to carbon-energy
$g_j^z(t)$	Growth rate of the carbon-augmenting technology, rate per Δt
δ_j^Z	Constant rate of decline of $g_j^z(t)$
$E_j(t)$	Carbon-energy inputs / carbon services, measured as CO2 emissions (GtC)
$E(t)$	World use of carbon-energy in period t / Sum of carbon-energy across regions
$\Omega_j(t)$	Damage coefficient
$D_j(S_t)$	Damage function
θ_J	Climate change damage parameter
θ_J^A	Climate change damage parameter related to the agricultural sector
π_j	Share of agricultural sector production on the overall GDP of the $j-th$ region
$M_{AT}(t)$	End - of - period of carbon in the atmosphere (AT) (GtC)
$\bar{M}_{AT}$	Pre-industrial atmospheric carbon dioxide (CO2) concentration (GtC)
$M_{UP}(t)$	Mass of carbon in the upper reservoir (biosphere and upper oceans) / Atmospheric concentration of CO2 in billions of Carbon (GtC)
$M_{LO}(t)$	Mass of carbon in the lower oceans (GtC)
$\phi_{i,j}$	Per-period transfer rate from reservoir i to reservoir j, with $i,j = AT, UP, LO$
$ET(t)$	Global CO2 emissions including those arising from land use changing (Gtc).
$LU_j(t)$	Land-use carbon emissions (GtC)
$CumC(t)$	Cumulative consumption of carbon-energy at the end of period t (GtC)

Variable	*Description*
$CumC^*$	Parameter representing the inflection point beyond which the marginal cost of carbon-energy begins to rise sharply(GtC)
ξ_i	Parameters related to $q\left(t\right)$ path overtime, where $i = 1, 2, 3$
$F\left(t\right)$	Radiative forcing (increase in radiative forcing since 1990 in watts per square meter $\left(W/m^2\right)$)
$\mathcal{O}\left(t\right)$	Forcings of other GHGs (CFCs, CH4, N20 and ozone) and aerosols
$T\left(t\right)$	Increase in the globally and seasonally averaged temperature in the atmosphere and at the upper level of the ocean since 1900 (°C)
λ	Feedback parameter
σ_i	Transfer coefficients reflecting the rates of flow and the thermal capacities of the different sinks, with $i = 1, 2, 3$

B Appendix - Equations in the model

Population dynamics

$$L_j\left(t+1\right)=L_j\left(t\right)\left(\frac{L_j\left(T\right)}{L_j\left(t\right)}\right)^{g_j^L} \tag{B.1}$$

Technological change dynamics

$$A_j\left(t+1\right)=A_j\left(t\right)e^{g_j^A\left(t\right)} \tag{B.2}$$

Technological change growth rate

$$g_j^A\left(t\right)=g_j^A\left(0\right)e^{\left(-\delta_j^A t\right)} \tag{B.3}$$

Social welfare

$$W_j\left(t\right)=\sum_t U\left[c_j\left(t\right),L_j\left(t\right)\right]R\left(t\right) \tag{B.4}$$

Per capita consumption

$$c_j\left(t\right)=\frac{C_j\left(t\right)}{L_j\left(t\right)} \tag{B.5}$$

Utility function

$$U\left[c_j\left(t\right),L_j\left(t\right)\right]=L_j\left(t\right)\frac{c_j\left(t\right)^{1-\alpha}-1}{1-\alpha} \tag{B.6}$$

Pure time preference discount factor

$$R\left(t\right)=\prod_{\nu=0}^{t}\left[1+\rho\left(\nu\right)\right]^{-10} \tag{B.7}$$

Pure rate of time preference

$$\rho\left(t\right)=\rho\left(0\right)exp\left(-g^{\rho}t\right) \tag{B.8}$$

Production function

$$Q_j\left(t\right)=\Omega_j\left(t\right)\left[A_j\left(t\right)K_j\left(t\right)^{\gamma}L_j\left(t\right)^{1-\beta_j-\gamma}ES_j\left(t\right)^{\beta_j}-c_j^E\left(t\right)ES_j\left(t\right)\right] \tag{B.9}$$

Capital stock dynamics

$$K_j\left(t\right)=K_j\left(t-1\right)\left(1-\delta_K\right)^{\Delta t}+\Delta t I_j\left(t-1\right) \tag{B.10}$$

Energy services production function

$$ES_j\left(t\right)=\varsigma_j\left(t\right)E_j\left(t\right) \tag{B.11}$$

Technological change in the energy production

$$\varsigma_j\left(t\right)=\varsigma_j\left(0\right)exp\left(\int_0^t g_j^z\left(t\right)dt\right) \tag{B.12}$$

Growth rate of technological change in the energy production

$$g_j^z\left(t\right)=g_j^z\left(0\right)exp\left(-\delta_j^Z t\right) \tag{B.13}$$

Cost per unit of carbon-energy

$$c_j^E\left(t\right)=q\left(t\right)+Markup_j^E \tag{B.14}$$

Wholesale supply price of carbon-energy

$$q\left(t\right)=\xi_1+\xi_2\left(\frac{CumC\left(t\right)}{CumC^*}\right)^{\xi_3} \tag{B.15}$$

Cumulative consumption of carbon-energy

$$CumC\left(t\right)=CumC\left(t-1\right)+\Delta t E\left(t\right) \tag{B.16}$$

World use of carbon-energy

$$E\left(t\right)=\sum_{j=1}^{n}E_j\left(t\right) \tag{B.17}$$

Global CO2 emissions comprehensive of land use emissions

$$ET(t) = \sum_{j=1}^{n} \left(E_j(t) + LU_j(t)\right) \tag{B.18}$$

Damage coefficient

$$\Omega_j(t) = 1 - D_j\left(M_{AT}(t)\right) = exp\left(-\theta_j\left(M_{AT}(t) - \bar{M}_{AT}\right)\right) \tag{B.19}$$

End-of-period mass of carbon in the atmosphere (AT)

$$M_{AT}(t) = \Delta t ET(t-1) + \phi_{11} M_{AT}(t-1) + \phi_{21} M_{UP}(t-1) \tag{B.20}$$

Mass of carbon in the upper reservoir (UP)

$$M_{UP}(t) = \phi_{12} M_{AT}(t-1) + \phi_{22} M_{UP}(t-1) + \phi_{32} M_{LO}(t-1) \tag{B.21}$$

Mass of carbon in the lower oceans (LO)

$$M_{LO}(t) = \phi_{23} M_{UP}(t-1) + \phi_{33} M_{LO}(t-1) \tag{B.22}$$

Radiative forcing

$$F(t) = \eta\left\{log\left[\frac{M_{AT}(t)}{\bar{M}_{AT}}\right]\frac{1}{log(2)}\right\} + \mathcal{O}(t) \tag{B.23}$$

Increase in temperature in atmosphere and upper level

$$T(t) = T(t-1) + \sigma_1\left\{F(t) - \lambda T(t-1) - \sigma_2\left[T(t-1) - T_{LO}(t-1)\right]\right\} \tag{B.24}$$

Increase in temperature in the deep oceans

$$T_{LO}(t) = T_{LO}(t-1) + \sigma_3\left\{T(t-1) - T_{LO}(t-1)\right\} \tag{B.25}$$

C Appendix - Initial conditions

In the base year (i.e. 2015 in our model, $t = 0$), for each region j the initial values of total factor productivity $A_j(0)$, initial capital stock $K_j(0)$, output elasticity with respect to energy input β_j and markup on the energy costs $Markup_j$ are calibrated so that the model matches certain specific conditions. Specifically, the first two refers to the matching with empirical observations of the GDP and industrial emissions respectively. On the side of the interest rates on capital, the third condition requires the matching of their historical target values with capital net marginal products. Finally, the impact of a constraint on carbon emission is introduced considering the effect of a carbon tax in a *disaggregated energy model*. Therefore, the required initial values are identified simultaneously as a solution of a four-equations system.

In what follows we will provide an overview for each analytical aspect together with the final formulation of the system.

The production side. In equation (B.9) the term $c_j^E(t)\,ES_j(t)$ represents the cost of producing carbon-energy and the related production function is described by Eq (B.11), where $\zeta_j(t)$ is the level of carbon-augmenting technology, that is the capacity of society to squeeze out more energy services per unit of carbon inputs. At time $t = 0$, this value is set to be equal to 1, so that $ES_j(0) = E_j(0)$.

Concerning the cost per unit of carbon-energy $c_j^E(t)$, it yields from the sum of two terms: $q(t)$, the wholesale price of carbon energy, exclusive of the Hotelling rent $h(t)$, equalised across regions, and $Markup_j$ representing spatial heterogeneity on the side of transportation, distribution costs and national taxation in each energy market. As mentioned above, at time $t = 0$, the latter is identified so that the model satisfies specific conditions, while $q(0)$ is in line with the original RICE-99 framework.

Under this framework, the production function described by Eq. (5) becomes:

$$\begin{aligned} Q_j(0) &= A_j(0)\,K_j(0)^{\gamma}\,L_j(0)^{1-\beta_j-\gamma}\,ES_j(0)^{\beta_j} - c_j^E(0)\,E_J(0), \qquad \text{(C.1)} \\ &\text{with} ES_j(0) = E_j(0), \end{aligned}$$

where labour $L_j(0)$, $Q_j(0)$ and $E_j(0)$ are set equal to their historical values at the base year.[30]

The capital market. The interest rate on capital at the base year must equal its net marginal product, which yields from the sum of the contribution of capital with respect to the output and to the capital next period's stock. To this end, we first define r as the targeted value matching the historical level of the interest rate and the condition is then:

$$(1+r)^{10} = \frac{\partial Q_j(0)}{\partial K_j(0)} + \frac{\partial K_j(1)}{\partial K_j(0)}, \qquad \text{(C.2)}$$

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[30] Specifically, the initial values of labor (i.e. population) and output are taken from the World Bank, whereas carbon-energy, expressed in CO2 emissions terms, from the Enerdata database.

where the the first element in the RHS is the contribution of capital to output, while the second is the one with respect to the next period's capital stock, with capital stock dynamics presented in Eq. (B.10).

The industrial emission. The third condition requires matching with the industrial emissions historical value. To this end, we need to account for the carbon-energy market, in which following condition must hold:

$$\beta_j \Lambda_j(t)\, ES_j(t)^{\beta_j-1} = c_j^E(t) + \frac{h(t)}{\zeta_j(t)} + \frac{\tau(t)}{\zeta_j(t)}, \tag{C.3}$$

with $\Lambda_j(t) = \Omega_j(t)\, A_j(t)\, K_j(t)^{\gamma}\, L_j(t)^{1-\beta_j-\gamma}$. The LHS of (C.3) is the marginal productivity of carbon-energy and the RHS its market price, seen as the sum of the cost of producing carbon-energy $c_j^E(t)$, the Hotelling rent $h(t)$, representing the effect of current extraction of carbon fuels on future extraction costs, and $\tau(t)$ the carbon tax. Since the carbon tax and the Hotelling rent are applied only to the carbon content of carbon-energy, they are adjusted by the ratio of carbon to carbon-energy $\zeta_j(t)$ (Nordhaus and Boyer, 2000). By substituting Eq. (B.11) in (C.3) we obtain the level of emissions:

$$E_j(t) = \left\{ \left[c_j^E(t) + \frac{h(t)}{\zeta_j(t)} + \frac{\tau(t)}{\zeta_j(t)} \right] \frac{1}{\beta_j \Lambda_j(t)} \right\}^{\frac{1}{\beta_j-1}}. \tag{C.4}$$

At the base year the Hotelling rent $h(0)$ and the carbon tax $\tau(0)$ are assumed to be nil while, as already mentioned above, $\zeta_j(0) = 1$, $L_j(0)$ and $E_j(0)$ are equal to their historical values and $\Omega_j(0) = 1$, leading to the following functional form of previous Eq. (C.4):

$$E_j(0) = \left[\frac{c_j^E(0)}{\beta_j \Lambda_j(0)} \right]^{\frac{1}{\beta_j-1}}. \tag{C.5}$$

The disaggregated energy model. The carbon emissions of each region j, $E_j(0)$, are determined by the sum of consumption of each energy source s (i.e. natural gas, oil, coal and electricity generated by fossil fuels) $X_{j,s}(0)$, weighted by its corresponding carbon coefficient $\gamma_{j,s}$. Accordingly, this is defined as:

$$E_j(0) = \sum_s X_{j,s}(0)\, \gamma_{j,s} \tag{C.6}$$

Each carbon coefficient $\gamma_{j,s}$ is computed as the ratio of the industrial carbon emissions from a particular fossil fuel s over its industrial consumption.[31] Data are sourced from the Enerdata repository.

The demand of each fossil fuel $X_{j,s}(0)$ is defined as:

$$X_{j,s}(0) = \omega_{j,s}(0) \left[\frac{P_{j,s}(0)}{P_{j,s}(0) + \tau(0) \gamma_{j,s}} \right]^{\eta_j}, \tag{C.7}$$

where $\omega_{j,s}(0)$ is the consumption of energy source s in the base year, $P_{j,s}(0)$ is the price of the energy source s and η_j is the price elasticity of demand for the energy source s.[32] Both consumption and prices information are sourced by Enerdata (2022), whereas the distribution of electricity generation by fossil fuels, used to compute the corresponding consumption of electricity, is available at the International Energy Agency (IEA) website.[33] To deal with missing data, aggregation to the regional case is performed by selecting the subset of countries for which information is available.[34]

Once the equations are calibrated with real values, the disaggregated energy model is run under two different scenarios, following Nordhaus and Boyer (2000). In the first case, the carbon tax entering into Eq. (C.7)is set to be 0, i.e. $\tau(0) = 0$, which leads to the emission value $E_j(0, \tau = 0)$. In the second case, the carbon tax is assumed to be equal to USD 50 per metric ton of Carbon, i.e. $\tau(0) = 50$, which leads to the corresponding $E_j(0, \tau = 50)$. Finally, the difference between the two resulting values, i.e. $E_j(0, \tau = 0) - E_j(0, \tau = 50)$, is set to be equal to the same imposition applied to Eq. (C.4), so that the last constraint of the initial condition system is identified.

The initial calibration system. The four above constraints are required to provide the initial calibration of the model, on the basis of which it is possible to determine the initial values of the unknown $A_j(0)$, $K_j(0)$, β_j and $Markup_j$. This is done analytically by solving the following system of equations:

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[31] For electricity, the corresponding value is calculated as the sum of the carbon coefficients of individual fossil fuels weighted by their share in electricity generation.

[32] Following the original RICE-99 model, we assign a regional specific η_j equal to -0.7 for the United States, Europe, Australia,New Zealand, Canada, Japan and those countries in the Mediterranean belonging to the EU, whereas a value of -0.84 is assigned to the remaining regions.

[33] See the IEA page dedicated to electricity.

[34] Specifically, regional consumption of energy as well as industrial carbon emissions are given by the sum of the corresponding country-level data, whereas energy prices are taken as weighted mean at country level, taking GDP values as weights.

$$\begin{cases} Q_j\left(0\right) = \Omega_j\left(0\right)\left[A_j\left(0\right)K_j\left(0\right)^{\gamma}L_j\left(0\right)^{1-\beta_j-\gamma}ES_j\left(0\right)^{\beta_j} - c_j^E\left(0\right)E_j\left(0\right)\right] \\ E_j\left(0\right) = \left\{\frac{q(0)+Markup_j}{\beta_j\Omega_j(0)A_j(0)K_j(0)^{\gamma}L_j(0)^{1-\beta_j-\gamma}}\right\}^{\frac{1}{\beta_j-1}} \\ \left(1+r\right)^{10} = \frac{\partial Q_j(0)}{\partial K_j(0)} + \frac{\partial K_j(1)}{\partial K_j(0)} \\ \underbrace{E_j\left(0,\tau=0\right) - E_j\left(0,\tau=50\right)}_{\text{Computed as in Eq.}C.4} = \underbrace{E_j\left(0,\tau=0\right) - E_j\left(0,\tau=50\right)}_{\text{Disaggregated energy model}} \end{cases} \tag{C.8}$$

A last remark should be made with respect to the last constraint. That is, industrial carbon emissions need to be calculated under two scenarios: a first one where no carbon tax exists, i.e. $\tau\left(0\right) = 0$, and a second one where $\tau\left(0\right) = 50$. Accordingly, on the left hand side of the last equation, this is done following (C.5) (i.e. the industrial emission function), while on the right hand side, the same change is calculated following Eq. (C.6)(i.e. via the disaggregated energy model).

D Appendix - Tables

Table 2: Regional structure of the model.

Code	Description	Type[35]
USA	USA	Country
China	People's Republic of China	Country
Europe	Europe (Austria, Belgium, Switzerland, Germany, Denmark, Finland, UK, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden)	Region
OHI	Other High-Income countries (Aruba, Australia, Bahamas, Canada, Guam, Hong Kong, Japan, New Zealand, Virgin Islands, Singapore)	Region
EE	Russia and Eastern Europe countries (Bulgaria, Bosnia Herzegovina, Belarus, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Moldova, Republic of Macedonia, Poland, Romania, Russia, Serbia, Slovakia, Slovenia, Ukraine)	Region
MI	Middle Income countries (United Arab Emirates, Argentina, Bahrain, Brazil, Barbados, Brunei Darussalam, Gabon, Kuwait, Saint Lucia, Macao, Martinique, Malaysia, New Caledonia, Oman, Puerto Rico, French Polynesia, Reunion, Qatar, Saudi Arabia, Suriname, Trinidad and Tobago)	Region
LMI	Lower Middle Income countries (Belize, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Fiji, Micronesia, Guadeloupe, Grenada, French Guiana, Iran, Jamaica, Kazakhstan, Mexico, Mauritius, Namibia, Panama, Perù, Papua New Guinea, Paraguay, El Salvador, Thailand, Turkmenistan, Tonga, Uruguay, Saint Vincent and Grenadines, Venezuela, Vanuatu, South Africa)	Region
LI	Low Income countries (Afghanistan, Angola, Armenia, Azerbaijan, Burundi, Benin, Burkina Faso, Bangladesh, Bolivia, Bhutan, Botswana, Central African Republic, Cote d'Ivoire, Cameroon, Congo (Kinshasa), Congo(Brazzaville), Comoros, Cape Verde, Djibuti, Georgia, Ghana, Guinea, Gambia, Guinea-Bissau, Equatorial Guinea, Guatemala, Guyana, Honduras, Haiti, Indonesia, India, Iraq, Jordan, Kenya, Kyrgyzstan, Cambodia, Lao PDR, Liberia, Sri Lanka, Lesotho, Madagascar, Maldives, Mali, Myanmar, Mongolia, Mozambique, Mauritania, Malawi, Niger, Nigeria, Nicaragua, Nepal, Pakistan, Philippines, North Korea, Rwanda, Senegal, Solomon Islands, Sierra Leone, Somalia, Sao Tome and Principe, Swaziland, Chad, Togo, Tajikistan, Tanzania, Uganda, Uzbekistan, Vientnam, Yemen, Zambia, Zimbabwe, Samoa)	Region

Table 2: Regional structure of the model.

Code	Description	Type[35]
Mediterranean countries		
ALB	Albania	Country
DZA	Algeria	Country
HRV	Croatia	Country
CYP	Cyprus	Country
EGY	Egypt	Country
ETH	Ethiopia	Country
FRA	France	Country
GRC	Greece	Country
ISR	Israel	Country
ITA	Italy	Country
LBN	Lebanon	Country
LYB	Libya	Country
MLT	Malta	Country
MNE	Montenegro	Country
MAR	Morocco	Country
ESP	Spain	Country
SDN	Sudan	Country
SYR	Syria	Country
TUN	Tunisia	Country
TUR	Turkey	Country

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[35] We define as region, the aggregation of economies of different countries

D.1 Calibration

Table 3: Parameters (Nordhaus and Boyer, 2000).

Parameter	Value
γ	0.3
$\rho(0)$	0.015
g^{ρ}	0
r	0.05
δ_K	0.1
$CumC^*$	6000 (GtC)
ξ_1	113
ξ_2	700
ξ_3	4
ϕ_{11}	0.88
ϕ_{12}	0.12
ϕ_{21}	0.196
ϕ_{22}	0.797
ϕ_{23}	0.007
ϕ_{32}	0.001465
ϕ_{33}	0.9985
η	3.6813
σ_1	0.1005
σ_2	0.088
σ_3	0.025
λ	1.47252
$\bar{M}_{AT}$	581 (GtC)
$M_{AT}(0)$	883.3599 (GtC)
$M_{UP}(0)$	460 (GtC)
$M_{LO}(0)$	1740 (GtC)

Table 4: Initial conditions.

Region j	$Q_j\,(0)$	$L_j\,(0)$	$E_j\,(0)$	$K_j\,(0)$	$A_j\,(0)$	$\beta_j(0)$	$Markup_j\,(0)$
USA	18.238	321	1.298	49.089	0.131	0.042	507.181
China	11	1379.86	2.744	31.018	0.038	0.055	127.430
Europe	11	234.053	0.47	27.858	0.097	0.017	283.587
OHI	8.159	204.47	0.592	21.288	0.085	0.012	20
EE	3	311.126	0.7	7.542	0.036	0.037	42.153
MI	4.264	339.04	0.591	11.291	0.043	0.027	84.010
LMI	4	541.586	0.667	11.309	0.034	0.042	165.317
LI	6	3463.487	1.166	17.252	0.013	0.04	117.720
Mediterranean Countries							
ALB	0.011	2.881	0.001	0.029	0.0187	0.023	147.255
DZA	0.166	39.728	0.038	0.488	0.042	0.124	502.643
HRV	0.05	4.203	0.005	0.139	0.059	0.074	595.426
CYP	0.02	1.16	0.002	0.035	0.041	0.02	50
EGY	0.329	92.44	0.058	0.903	0.024	0.061	252.982
ETH	0.065	100.84	0.003	0.169	0.005	0.008	60.711
FRA	2.438	66.55	0.085	6.352	0.08	0.011	196.558
GRC	0.196	10.821	0.017	0.546	0.078	0.075	817.167
ISR	0.3	8.38	0.017	0.97	0.076	0.016	165.548
ITA	1.836	61	0.088	4.441	0.084	0.047	807.304
LBN	0.05	6.534	0.007	0.133	0.03	0.01	-100
LYB	0.028	6.41	0.014	0.084	0.046486	0.144	165.548
MLT	0.011	0.445	0.00041	0.02499	0.051	0.004	-50
MNE	0.004	0.622	0.0006	0.0085	0.02	0.03	-5
MAR	0.101	34.66	0.016	0.1	0.02	0.01	-100
ESP	1.195	46.44	0.068	3.167	0.071	0.028	384.091
SDN	0.052	38.903	0.005	0.20	0.0083	0.036	165.548
SYR	0.016	17.99	0.007	0.03	0.012	0.09	165.550
TUN	0.046	11.18	0.008	0.138	0.049	0.139	813.771
TUR	0.864	78.53	0.093	2.264	0.036	0.017	-48.49

(GDP and capital stock are expressed in trillions of USD, while labour in millions and emissions in GtC.)

Table 5: Total (θ_j) damage parameters.

Regions	Parameter θ_j
USA	1.55281E-06
China	1.0432E-05
Europe	-1.16633E-05
OHI	8.75422E-05
EE	-1.01069E-05
MI	3.82824E-05
LMI	4.37687E-05
LI	7.68147E-05
ALB	2.48498E-05
DZA	3.79714E-05
HRV	1.76457E-06
CYP	4.57677E-05
EGY	3.79714E-05
ETH	5.81472E-05
FRA	-2.90483E-06
GRC	1.31805E-05
ISR	2.17705E-05
ITA	1.74708E-06
LBN	1.31805E-05
LYB	2.17705E-05
MLT	6.5693E-05
MNE	3.08377E-05
MAR	3.6762E-05
ESP	7.49581E-06
SDN	5.81472E-05
SYR	5.81472E-05
TUN	3.08377E-05
TUR	8.08234E-06

D.2 Results

Table 6: Increase in the global mean temperature, concentration and radiative forcing

Year	△Temperature (wrt 1900)			Concentration (GTC)			Radiative forcing (W/m^2)		
Scenarios	*BAU*	*OPT*	*TL<2°C*	*BAU*	*OPT*	*TL<2°C*	*BAU*	*OPT*	*TL<2°C*
2015	1.10	1.10	1.10	883.36	883.36	883.36	2.63	2.63	2.63
2025	1.19	1.19	1.19	957.52	957.52	957.52	3.05	3.05	3.05
2035	1.31	1.31	1.31	1024.28	1012.22	977.78	3.41	3.35	3.16
2055	1.60	1.58	1.53	1145.98	1115.88	1016.30	4.00	3.86	3.36
2105	2.36	2.29	1.96	1407.96	1356.82	1086.99	5.09	4.89	3.71

Table 7: Social Cost of Carbon (USD/tC)

Year / Scenarios	*OPT*	*TL<2°C*
2015	38.94	39.76
2025	133.87	617.36
2035	157.29	788.72
2055	209.45	1268.63
2105	406.42	4104.60
Average 2105	231.32	1728.41
Average 2305	806.23	53724.93

Table 8: Average yearly GDP growth rate of the macro regions.

	Year / Scenarios	*BAU*	*OPT*	*TL<2°C*
USA	2015 - 2035	1.90%	1.89%	1.80%
	2035 - 2055	1.11%	1.10%	1.05%
	2055 - 2105	0.87%	0.87%	0.80%
CHINA	2015 - 2035	3.30%	3.25%	2.96%
	2035 - 2055	2.19%	2.19%	2.15%
	2055 - 2105	2.21%	2.20%	2.11%
EE	2015 - 2035	2.75%	2.76%	2.51%
	2035 - 2055	2.07%	2.08%	2.03%
	2055 - 2105	2.34%	2.36%	2.27%
EUROPE	2015 - 2035	1.44%	1.47%	1.42%
	2035 - 2055	0.80%	0.80%	0.76%
	2055 - 2105	0.68%	0.69%	0.65%
LI	2015 - 2035	4.59%	4.32%	4.07%
	2035 - 2055	2.84%	2.75%	2.72%
	2055 - 2105	2.43%	2.32%	2.27%
LMI	2015 - 2035	3.62%	3.48%	3.26%
	2035 - 2055	2.07%	2.02%	1.97%
	2055 - 2105	1.47%	1.43%	1.37%
MI	2015 - 2035	3.04%	2.93%	2.76%
	2035 - 2055	1.74%	1.70%	1.66%
	2055 - 2105	1.06%	1.02%	0.99%
OHI	2015 - 2035	1.24%	1.06%	0.98%
	2035 - 2055	0.74%	0.66%	0.66%
	2055 - 2105	0.80%	0.72%	0.74%

Table 9: Energy Intensity growth rate macro regions.

	Year / Scenarios	*BAU*	*OPT*	*TL<2°C*
USA	2035	-0.24%	-0.61%	-2.42%
	2055	-0.15%	-0.10%	-0.75%
	2105	-0.24%	-0.15%	-0.88%
CHINA	2035	-0.21%	-0.80%	-3.04%
	2055	-0.01%	0.19%	-0.18%
	2105	-0.15%	0.00%	-0.63%
EE	2035	-0.29%	-1.07%	-3.43%
	2055	-0.03%	0.22%	-0.24%
	2105	-0.23%	-0.04%	-0.72%
EUROPE	2035	-0.36%	-0.86%	-2.92%
	2055	-0.22%	-0.14%	-0.88%
	2105	-0.31%	-0.19%	-0.93%
LI	2035	-0.42%	-1.08%	-3.34%
	2055	-0.21%	-0.03%	-0.75%
	2105	-0.37%	-0.19%	-0.96%
LMI	2035	-0.37%	-0.97%	-3.17%
	2055	-0.18%	-0.03%	-0.71%
	2105	-0.31%	-0.14%	-0.89%
MI	2035	-0.59%	-1.35%	-3.59%
	2055	-0.34%	-0.18%	-1.00%
	2105	-0.47%	-0.28%	-1.03%
OHI	2035	-0.77%	-1.68%	-3.89%
	2055	-0.42%	-0.19%	-1.03%
	2105	-0.52%	-0.27%	-1.01%

Table 10: Investment, Emission Intensity, Energy Services growth rate macro regions.

	Year	Investment			Emission Intensity			Energy Services		
	Scenarios	*BAU*	*OPT*	*TL<2°C*	*BAU*	*OPT*	*TL<2°C*	*BAU*	*OPT*	*TL<2°C*
USA	2035	0.53%	0.45%	0.26%	-0.24%	-0.61%	-2.42%	1.56%	1.05%	-1.49%
	2055	0.46%	0.46%	0.41%	-0.15%	-0.10%	-0.75%	0.93%	0.98%	0.14%
	2105	0.53%	0.54%	0.47%	-0.24%	-0.15%	-0.88%	0.53%	0.66%	-0.43%
CHINA	2035	2.49%	2.43%	2.28%	-0.21%	-0.80%	-3.04%	2.96%	1.93%	-1.87%
	2055	2.32%	2.32%	2.27%	-0.01%	0.19%	-0.18%	2.18%	2.46%	1.89%
	2105	2.45%	2.46%	2.33%	-0.15%	0.00%	-0.63%	1.89%	2.20%	0.82%
EE	2035	1.98%	1.93%	1.75%	-0.29%	-1.07%	-3.43%	2.30%	1.09%	-2.64%
	2055	1.66%	1.68%	1.63%	-0.03%	0.22%	-0.24%	2.03%	2.39%	1.69%
	2105	1.75%	1.78%	1.68%	-0.23%	-0.04%	-0.72%	1.84%	2.27%	0.72%
EUROPE	2035	0.58%	0.50%	0.30%	-0.36%	-0.86%	-2.92%	0.98%	0.35%	-2.32%
	2055	0.55%	0.56%	0.53%	-0.22%	-0.14%	-0.88%	0.55%	0.64%	-0.25%
	2105	0.62%	0.64%	0.61%	-0.31%	-0.19%	-0.93%	0.26%	0.44%	-0.58%
LI	2035	1.69%	1.61%	1.48%	-0.42%	-1.08%	-3.34%	3.79%	2.31%	-1.99%
	2055	1.47%	1.41%	1.39%	-0.21%	-0.03%	-0.75%	2.52%	2.70%	1.57%
	2105	1.74%	1.67%	1.63%	-0.37%	-0.19%	-0.96%	1.61%	1.91%	0.23%
LMI	2035	1.49%	1.42%	1.26%	-0.37%	-0.97%	-3.17%	2.97% v	1.83%	-1.99%
	2055	1.10%	1.07%	1.03%	-0.18%	-0.03%	-0.71%	1.81%	1.97%	0.99%
	2105	1.69%	1.65%	1.58%	-0.31%	-0.14%	-0.89%	0.94%	1.18%	-0.13%
MI	2035	1.03%	0.95%	0.79%	-0.59%	-1.35%	-3.59%	2.09%	0.79%	-2.81%
	2055	0.80%	0.77%	0.75%	-0.34%	-0.18%	-1.00%	1.28%	1.45%	0.33%
	2105	1.16%	1.13%	1.10%	-0.47%	-0.28%	-1.03%	0.33%	0.61%	-0.55%
OHI	2035	0.62%	0.56%	0.43%	-0.77%	-1.68%	-3.89%	0.27%	-0.98%	-3.67%
	2055	0.63%	0.56%	0.58%	-0.42%	-0.19%	-1.03%	0.26%	0.44%	-0.50%
	2105	0.68%	0.61%	0.64%	-0.52%	-0.27%	-1.01%	0.07%	0.35%	-0.64%

Table 11: Average GDP loss of the macro regions. Comparison across scenarios

	BAUvsOPT	BAUvsTL
USA	0.01%	0.23%
CHINA	0.07%	0.49%
EE	-0.04%	0.35%
EUROPE	-0.05%	0.08%
LI	0.46%	0.79%
LMI	0.23%	0.56%
MI	0.19%	0.43%
OHI	0.34%	0.38%

Table 12: Average yearly GDP growth rate for the MED regions.

		Year /Scenarios	*BAU*	*OPT*	*TL<2°C*
G1	alb	2015 - 2035	3.03%	2.96%	2.86%
		2035 - 2055	1.91%	1.88%	1.85%
		2055 - 2105	1.97%	1.94%	1.90%
	hrv	2015 - 2035	3.08%	3.07%	2.93%
		2035 - 2055	2.20%	2.19%	2.15%
		2055 - 2105	2.50%	2.50%	2.41%
	mne	2015 - 2035	2.83%	2.72%	2.49%
		2035 - 2055	1.90%	1.87%	1.85%
		2055 - 2105	1.58%	1.55%	1.51%
	grc	2015 - 2035	1.08%	1.05%	0.94%
		2035 - 2055	0.55%	0.53%	0.47%
		2055 - 2105	0.56%	0.55%	0.46%
G2	cyp	2015 - 2035	3.31%	3.18%	3.05%
		2035 - 2055	1.65%	1.60%	1.58%
		2055 - 2105	1.36%	1.31%	1.30%
	isr	2015 - 2035	2.21%	2.17%	2.11%
		2035 - 2055	1.90%	1.87%	1.84%
		2055 - 2105	1.56%	1.53%	1.52%
	lbn	2015 - 2035	2.77%	2.70%	2.58%
		2035 - 2055	1.80%	1.79%	1.76%
		2055 - 2105	1.58%	1.58%	1.57%

		Year /Scenarios	*BAU*	*OPT*	*TL<2°C*
	syr	2015 - 2035	6.96%	6.63%	5.84%
		2035 - 2055	2.79%	2.72%	2.61%
		2055 - 2105	2.24%	2.18%	1.96%
	tur	2015 - 2035	3.62%	3.57%	3.39%
		2035 - 2055	2.14%	2.13%	2.09%
		2055 - 2105	1.48%	1.48%	1.45%
G3	dza	2015 - 2035	4.40%	4.24%	3.76%
		2035 - 2055	2.66%	2.61%	2.49%
		2055 - 2105	1.79%	1.75%	1.52%
	egy	2015 - 2035	4.63%	4.49%	4.18%
		2035 - 2055	2.77%	2.72%	2.65%
		2055 - 2105	2.41%	2.36%	2.22%
	eth	2015 - 2035	5.38%	5.20%	5.19%
		2035 - 2055	3.23%	3.15%	3.16%
		2055 - 2105	2.60%	2.51%	2.55%
	lby	2015 - 2035	4.51%	4.27%	3.03%
		2035 - 2055	2.18%	2.17%	1.88%
		2055 - 2105	1.61%	1.62%	1.18%
	mar	2015 - 2035	7.63%	7.43%	7.24%
		2035 - 2055	1.58%	1.55%	1.54%
		2055 - 2105	1.36%	1.33%	1.34%
	sdn	2015 - 2035	4.55%	4.36%	4.18%
		2035 - 2055	3.11%	3.03%	3.01%
		2055 - 2105	2.45%	2.36%	2.32%
	tun	2015 - 2035	3.98%	3.86%	3.50%
		2035 - 2055	2.29%	2.25%	2.15%
		2055 - 2105	1.77%	1.73%	1.52%
G4	fra	2015 - 2035	1.65%	1.67%	1.64%
		2035 - 2055	1.00%	1.00%	0.97%
		2055 - 2105	0.81%	0.81%	0.79%
	ita	2015 - 2035	1.21%	1.22%	1.15%
		2035 - 2055	0.68%	0.68%	0.63%
		2055 - 2105	0.65%	0.66%	0.60%
	mlt	2015 - 2035	1.88%	1.74%	1.75%
		2035 - 2055	1.13%	1.06%	1.08%
		2055 - 2105	1.11%	1.04%	1.09%

	Year /Scenarios	*BAU*	*OPT*	*TL<2°C*
esp	2015 - 2035	1.58%	1.57%	1.50%
	2035 - 2055	0.90%	0.88%	0.84%
	2055 - 2105	0.54%	0.54%	0.50%

Table 13: Investment, Emission Intensity, Energy Services growth rate MED regions.

		Year	Investment			Emission Intensity			Energy Services		
		Scenarios	*BAU*	*OPT*	*TL<2°C*	*BAU*	*OPT*	*TL<2°C*	*BAU*	*OPT*	*TL<2°C*
G1	alb	2035	1.72%	1.63%	1.44%	-0.37%	-0.99%	-3.20%	2.43%	1.39%	-2.16%
		2055	1.76%	1.74%	1.71%	-0.19%	-0.04%	-0.72%	1.65%	1.82%	0.86%
		2105	1.86%	1.84%	1.80%	-0.34%	-0.18%	-0.94%	1.30%	1.58%	0.08%
	hrv	2035	2.01%	1.94%	1.76%	-0.08%	-0.34%	-1.87%	2.94%	2.52%	-0.03%
		2055	1.77%	1.78%	1.73%	-0.01%	0.07%	-0.13%	2.18%	2.29%	1.96%
		2105	1.89%	1.90%	1.77%	-0.07%	-0.01%	-0.48%	2.34%	2.47%	1.35%
	mne	2035	1.80%	1.74%	1.60%	-0.38%	-1.31%	-3.71%	2.24%	0.70%	-3.07%
		2055	1.37%	1.35%	1.33%	-0.04%	0.29%	-0.26%	1.85%	2.27%	1.49%
		2105	1.69%	1.67%	1.64%	-0.29%	-0.04%	-0.76%	1.07%	1.48%	0.18%
	grc	2035	0.68%	0.60%	0.40%	-0.18%	-0.45%	-2.01%	0.87%	0.51%	-1.44%
		2055	0.69%	0.68%	0.60%	-0.11%	-0.07%	-0.64%	0.43%	0.46%	-0.23%
		2105	0.72%	0.72%	0.59%	-0.17%	-0.10%	-0.78%	0.34%	0.43%	-0.50%
G2	cyp	2035	0.68%	0.61%	0.45%	-0.67%	-1.50%	-3.74%	2.19%	0.72%	-2.96%
		2055	0.95%	0.92%	0.91%	-0.38%	-0.20%	-1.03%	1.14%	1.34%	0.22%
		2105	1.15%	1.11%	1.11%	-0.52%	-0.30%	-1.04%	0.49%	0.81%	-0.42%
	isr	2035	1.19%	1.10%	0.90%	-0.45%	-1.07%	-3.26%	1.56%	0.63%	-2.52%
		2055	0.39%	0.38%	0.37%	-0.25%	-0.13%	-0.89%	1.55%	1.69%	0.62%
		2105	0.51%	0.49%	0.49%	-0.35%	-0.19%	-0.94%	0.94%	1.21%	-0.13%
	lbn	2035	2.24%	2.17%	1.95%	-1.55%	-2.90%	-4.54%	0.37%	-1.76%	-4.30%
		2055	1.35%	1.34%	1.33%	-0.69%	-0.14%	-0.97%	0.86%	1.59%	0.46%
		2105	1.87%	1.87%	1.87%	-0.86%	-0.46%	-1.08%	0.04%	0.76%	-0.36%
	syr	2035	0.78%	0.71%	0.54%	-0.39%	-1.00%	-3.23%	6.03%	4.30%	-1.16%
		2055	1.36%	1.33%	1.21%	-0.19%	-0.03%	-0.72%	2.50%	2.68%	1.52%
		2105	1.58%	1.55%	1.34%	-0.32%	-0.15%	-0.90%	1.57%	1.87%	0.18%
	tur	2035	1.46%	1.39%	1.20%	-0.97%	-2.10%	-4.18%	1.96%	-0.02%	-3.63%
		2055	1.17%	1.17%	1.14%	-0.44%	-0.09%	-0.89%	1.52%	2.00%	0.82%

		Scenarios	*BAU*	*OPT*	*TL<2°C*	*BAU*	*OPT*	*TL<2°C*	*BAU*	*OPT*	*TL<2°C*
		2105	1.49%	1.50%	1.48%	-0.61%	-0.30%	-1.01%	0.42%	0.96%	-0.29%
G3	dza	2035	1.84%	1.78%	1.61%	-0.21%	-0.56%	-2.39%	4.02%	3.21%	-0.43%
		2055	1.12%	1.10%	0.95%	-0.10%	-0.01%	-0.55%	2.51%	2.59%	1.67%
		2105	2.01%	1.99%	1.65%	-0.18%	-0.08%	-0.77%	1.44%	1.59%	0.16%
	egy	2035	1.68%	1.61%	1.44%	-0.29%	-0.79%	-2.88%	4.07%	3.00%	-1.11%
		2055	1.56%	1.53%	1.45%	-0.15%	-0.03%	-0.66%	2.54%	2.68%	1.64%
		2105	1.85%	1.82%	1.68%	-0.28%	-0.14%	-0.89%	1.80%	2.04%	0.34%
	eth	2035	1.45%	1.35%	1.19%	-0.50%	-1.27%	-3.56%	4.34%	2.61%	-2.07%
		2055	1.28%	1.23%	1.25%	-0.25%	-0.05%	-0.79%	2.82%	3.07%	1.87%
		2105	1.59%	1.52%	1.57%	-0.43%	-0.23%	-0.98%	1.62%	2.00%	0.32%
	lby	2035	1.06%	1.05%	0.86%	-0.50%	-1.18%	-3.39%	3.55%	2.09%	-2.41%
		2055	0.76%	0.78%	0.50%	-0.29%	-0.16%	-0.96%	1.76%	1.93%	0.57%
		2105	1.33%	1.40%	0.94%	-0.42%	-0.25%	-1.00%	0.85%	1.18%	-0.42%
	mar	2035	0.16%	0.09%	-0.04%	-1.59%	-2.93%	-4.55%	3.60%	0.14%	-3.89%
		2055	1.25%	1.23%	1.24%	-0.68%	-0.13%	-0.96%	0.68%	1.37%	0.29%
		2105	1.57%	1.54%	1.57%	-0.81%	-0.39%	-1.04%	-0.01%	0.68%	-0.40%
	sdn	2035	2.13%	2.07%	1.91%	-0.36%	-0.94%	-3.15%	3.87%	2.60%	-1.60%
		2055	1.32%	1.27%	1.24%	-0.18%	-0.03%	-0.71%	2.82%	2.99%	1.87%
		2105	1.70%	1.65%	1.60%	-0.33%	-0.17%	-0.93%	1.72%	2.00%	0.31%
	tun	2035	1.88%	1.81%	1.61%	-0.14%	-0.40%	-1.94%	3.72%	3.16%	0.21%
		2055	1.45%	1.43%	1.28%	-0.07%	-0.01%	-0.46%	2.18%	2.24%	1.49%
		2105	2.07%	2.06%	1.70%	-0.13%	-0.06%	-0.68%	1.52%	1.63%	0.32%
G4	fra	2035	0.62%	0.54%	0.34%	-0.44%	-1.03%	-3.18%	1.07%	0.30%	-2.58%
		2055	0.50%	0.51%	0.49%	-0.26%	-0.17%	-0.95%	0.69%	0.80%	-0.16%
		2105	0.59%	0.59%	0.58%	-0.37%	-0.21%	-0.97%	0.30%	0.51%	-0.56%
	ita	2035	0.68%	0.60%	0.39%	-0.18%	-0.44%	-1.98%	1.00%	0.66%	-1.29%
		2055	0.64%	0.64%	0.59%	-0.11%	-0.07%	-0.64%	0.56%	0.59%	-0.09%
		2105	0.67%	0.68%	0.60%	-0.17%	-0.10%	-0.77%	0.43%	0.52%	-0.41%
	mlt	2035	1.20%	1.12%	0.95%	-1.16%	-2.28%	-4.26%	0.28%	-1.34%	-4.00%
		2055	1.15%	1.09%	1.12%	-0.63%	-0.31%	-1.14%	0.36%	0.69%	-0.31%
		2105	1.20%	1.13%	1.19%	-0.73%	-0.42%	-1.09%	-0.02%	0.41%	-0.60%
	esp	2035	0.61%	0.53%	0.34%	-0.30%	-0.73%	-2.68%	1.18%	0.61%	-1.98%
		2055	0.32%	0.32%	0.29%	-0.18%	-0.12%	-0.82%	0.68%	0.75%	-0.12%
		2105	0.67%	0.67%	0.63%	-0.27%	-0.16%	-0.90%	0.20%	0.34%	-0.62%

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