RICE-MED: a Regional Integrated assessment modeling of Climate and the Economy for the Mediterranean Basin

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Scan for the WP

Motivation. Climate change in the Mediterranean Basin

Sixth Assessment Report IPCC 2022 - Cross-Chapter Paper 4

CCP4 **Mediterranean Region**

Sharing and co-production of knowledge can support climate adaptation practices and enhance sustainability in the Mediterranean region (medium to high confidence).

***Currently incomplete knowledge of climate impacts and risks in the southern and eastern part of the basin hinders the implementation of adaptation measures**, creating a need for implementable plans with enhanced and cooperative research and monitoring capacities between the north, south and southeast countries (high agreement).*

(Source: CCP4.4 - IPCC AR6 - 2022)

The RICE-MED model. An overview.

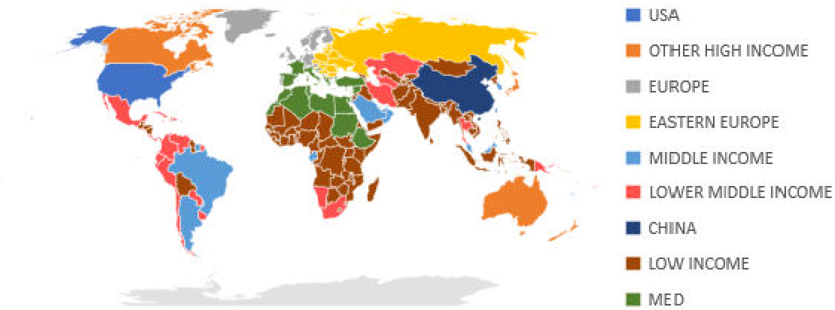
- ***Update to 2015*** the the Regional Climate and Economy model ***RICE-99*** [Nordhaus and Boyer, 2000], in which all world economies relies on ***energy produced with fossil fuels*** and there is no international trade.
- ***RICE-MED:*** spatial granularity of RICE-99 is improved focusing on the ***Mediterranean countries***.
- RICE- 99 ***Initialization*** process formalized ***analytically***.
- New figures on the ***social cost of carbon*** in BAU, Social Optimimum and Temperature Limit scenarios.
- *Golosov et al. [2014]* ***damage function***, with direct link with CO2 concentration .
- ***RICE-MED-U***: ***uncertainty*** associated to climate-induced catastrophic event *[Castelnuovo et al., 2003]*.
- ***RICE-MED-A***: exercise on ***agriculture*** *[Roson and Sartori, 2016]*.

The RICE-MED model. An overview.

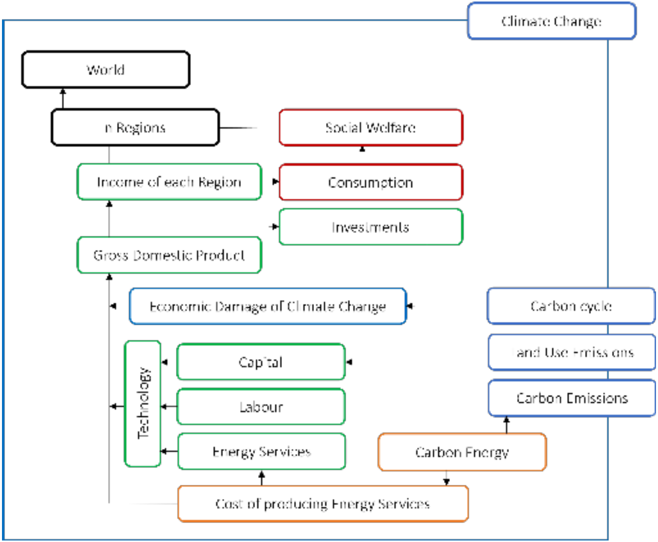
A regional model in which *Mediterranean nations* are considered at country level, allowing the identification of the economic damage of climate change at a finer spatial level, while other countries in the world are grouped in macro-regions.

The model. An overview.

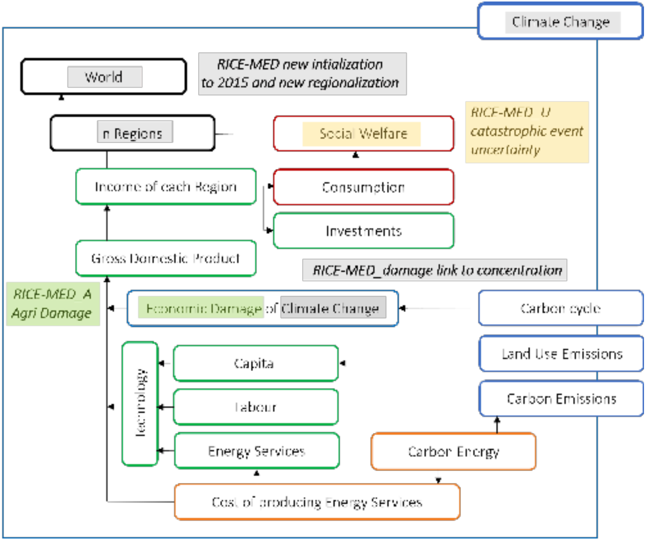
A regional model in which Mediterranean nations are considered at country level, allowing the identification of the economic damage of climate change at a finer spatial level, while other countries in the world are grouped in *macro-regions*.



The RICE-MED model. An overview.



The RICE-MED model. Novelties: RICE-MED, RICE-MED-U and RICE-MED-Agri.



The RICE-MED model: analytical framework.

The ***GDP of the economy*** $Y_j(t)$ is obtained as follows:

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

$$\text{where} \quad ES_j(t) = \zeta_j(t) E_j(t) \quad : \quad \textit{energy production function}, \tag{2}$$

the fossil fuels' (or carbon-energy) sector is included in the model as follows:

$$\begin{aligned} \textit{overall cost of producing energy services}: &\quad c_j^E(t) ES_j(t) \\ \textit{regional unitary cost of energy}: &\quad c_j^E(t) = q(t) + Markup_j^E \\ \textit{global wholesale price of energy}: &\quad q(t) = \xi_1 + \xi_2 \left(\frac{CumC(t)}{CumC^*}\right)^{\xi_3} \\ \textit{regional markup on energy costs}: &\quad Markup_j{}^E \end{aligned}$$

The ***regional output net of environmental damage*** $Q_j(t)$ is defined as:

$$Q_j(t) = \Omega_j(t) Y_j(t) = Y_j(t) - D_j(M_{AT}(t)) Y_j(t) \tag{3}$$

$$\textit{with} \quad \Omega_j(t) = 1 - D_j(M_{AT}(t)) = exp\left(-\theta_j \left(M_{AT}(t) - \bar{M}_{AT}\right)\right). \tag{4}$$

The RICE-MED-U model. Dealing with uncertainty [Castelnuovo et al., 2003].

The society is not able to identify the global temperature level at which the catastrophic event may occur, but is aware of that.

It assign two different levels of utility, one before the event (BC) and the other after (AC), duly weighted for a survival probability $SP(t)$ (in BC) and a catastrophe probability $(1 - SP(t))$, in AC. In BC a utility loss defined by the share b is introduced.

The RICE-MED welfare maximization problem is revised as follows:

$$\max_{c_j(t)} \quad W_j = \sum_t U\left[c_j(t), L_j(t)\right] R(t) \tag{5}$$

$$\text{with} \quad U\left[c_j(t), L_j(t), SP(t)\right] = SP(t)\, U\left[c_j(t), L_j(t)\right]_{BC} + \left[1 - SP(t)\right] U\left[c_j(t), L_j(t)\right]_{AC} \tag{6}$$

$$\text{and} \quad U\left[c_j(t), L_j(t)\right]_{AC} = (1 - b)\, U\left[c_j(t), L_j(t)\right]_{BC}, \tag{7}$$

The RICE-MED-U model. Dealing with uncertainty [Castelnuovo et al., 2003].

The survivor probability is a function of the endogenous temperature variation:

$$SP(t) = \exp\left[-HR(t)\right] \tag{8}$$

through the $HR(t)$ is the hazard rate function $HR(t)$:

$$HR(t) = \begin{cases} HR(t-1) + \left[\varphi_0 + \varphi_1 T(\dot{t})\right] \eta \left[\max\left(0; T(t) - T_0\right)\right]^{\eta-1} & \text{if} \quad T(\dot{t})>0, \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

$$\text{and} \quad T(\dot{t}) = \frac{\Delta T(t)}{T(t-1)}, \quad \text{with} \quad \frac{\partial HR(t)}{\partial T(t)} > 0. \tag{10}$$

Policy insights.

- The ***effect of increasing societal awareness of the impact of a potential climate-related disaster*** is found in all model results: ***better performance in temperature increase at the end of the century.***
- This demonstrates the importance of ***society correctly recognising and valuing*** a survivor probability determined by the temperature change and the potential loss of utility associated with the disaster.

The RICE-MED-Agri model. Impact on agriculture.

- ***The damage function mapping climate change impact on the economy of each region is calibrated considering the share of the agricultural sector on the overall GDP,*** relying again on the analysis of Roson and Sartori [2016].
- ***As an example, for Italy,*** the parameter $\theta_{j=ITA}$, representing the region specific climate damage cost, is $= 1.74708E - 06$, while $\theta^{A}_{j=ITA} = 6.5807E - 05$: the higher is θ, the more is the negative impact of a changing climate on the economy.

Policy insights.

- ***Understanding the impact of climate change on agriculture is critical to the design of government policies*** aimed at identifying effective approaches and technologies in this changing environment to ensure the ***safety of the entire food supply chain*** and mitigate associated risks.

The RICE-MED model. The scenarios

- *BAU - Business as Usual*. It assumes no change in climate-related policies. This scenario represents the cost implications of unmitigated climate damage.

- **OPT - Social Optimum**. The social welfare function is maximized under the economic (regional) and climate (global) constraints, identifying the optimal pathways of consumption, production and emissions reduction in each point in time. Such paths allow the identification of the optimal carbon tax to achieve such benchmarks.

- **TL - Temperature Limit**: The OPT scenario runs under an additional constraint that limits the temperature increase below 2°C.

→ *Time horizon*: 2015-2305 (time step: 10 years).

→ *Time range of results*: 2015-2105

Outcomes of the RICE-MED model

Model initialization [Nordhaus and Boyer, 2000].

For each country i***, with*** $i \in j - th$ ***region,***

→ $A_i(0)$, the total factor productivity $A_i(0)$,

→ $K_i(0)$, the capital stock,

→ $\beta_i(0)$, the elasticity of output respect to the energy input,

→ $Markup_i^E(0)$, the markup on the wholesale price of energy,

are calibrated so that at the base year the GDP, industrial emissions and the interest rate ***match respective historical observations.***

Emissions of country i $E_i^d(0)$ are a function of the consumption of the ***carbon energy input, or energy source,*** s ***(coal, oil, gas ...)***, $X_{s,i}(0)$, and the emissions per unit of consumption for the energy source s, γ_s.

$$E_i^d(0) = \sum_s X_{s,i}(0)\,\gamma_s = \sum_s \omega_{s,i}(0)\left[\frac{P_{s,i}(0)}{P_{s,i}(0) + \tau_j(0)\,\gamma_s}\right]^{\eta_s} \gamma_s \tag{11}$$

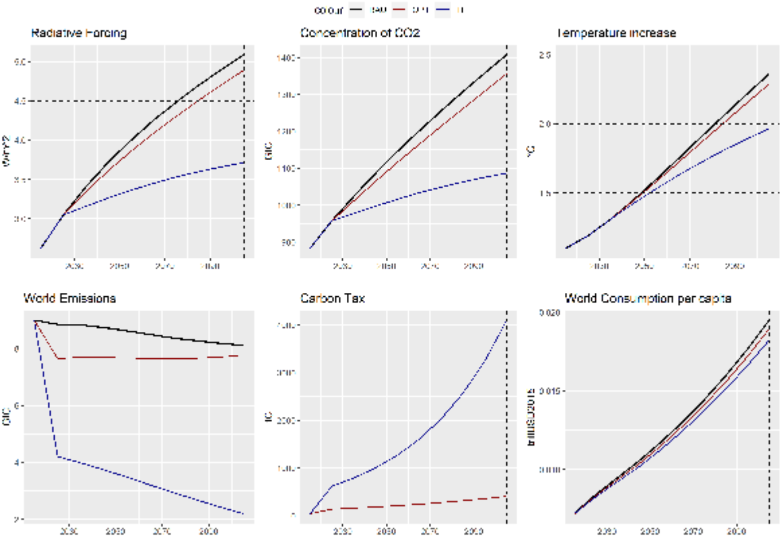
- $\omega_{s,i}(0)$ is the consumption of energy source s in the first period,
- $P_{s,i}(0)$ is its the price at the same time
- η_s is the price elasticity of demand for carbon energy source s.

Model initialization [Nordhaus and Boyer, 2000]: analytical resuolution.

The unknown values of $A_i(0)$, $K_i(0)$, $\beta_i(0)$ and $Markup_i^E$ yields from the resolution of this system of equations, representing all the assumptions previously mentioned.

$$\begin{cases} Q_i(0) = A_i(0)K_i(0)^{\gamma}L_i(0)^{1-\beta_i-\gamma}E_i(0)^{\beta_i} - c_i^E(0)E_i(0); \\ \\ E_i(0) = \frac{1}{\zeta_i(0)}\left\{\left[c_i^E(0) + \frac{h(0)}{\zeta_i(0)} + \frac{\tau_j(0)}{\zeta_i(0)}\right]\frac{1}{\beta_i(0)A_i(0)K_i(0)^{\gamma}L_i(0)^{1-\beta_i-\gamma}}\right\}^{\frac{1}{\beta_i-1}}; \\ \\ (1+r_i)^{10} = \frac{\partial Q_i(0)}{\partial K_i(0)} + \frac{\partial K_i(1)}{\partial K_i(0)}; \\ \\ \underbrace{E_i(0,\tau=0) - E_i(0,\tau=50) =}_{Change \quad in \quad emissions} \underbrace{E_i^d(0,\tau=0) - E_i^d(0,\tau=50)}_{Disaggregated \quad Energy \quad Model}. \end{cases} \tag{12}$$

Global results: scenarios overview



Global results: climate variables

RICE-MED: Temperature increase and carbon tax

Variables / Scenario	2015	2025	2035	2055	2105	Average
Temperature increase (°C from 1900)						
Business as Usual	1.10	1.19	1.31	1.60	2.36	
Optimal	1.10	1.19	1.31	1.58	2.29	
Temperature limit ≤ 2.0	1.10	1.19	1.31	1.53	1.96	
Carbon Tax (USD/tC)						
Optimal	38.94	133.87	157.29	209.45	406.42	231.32
Temperature limit ≤ 2.0	39.76	617.36	788.72	1268.63	4104.60	1728.41

Global results: the effect of introducing uncertainty

RICE-MED-U: the survivor probability and catastrophic event probability

Variable / Scenario	2015	2025	2035	2055	2105
RMU0.30-BAU	0.999 (0.001)	0.998 (0.002)	0.997 (0.003)	0.990 (0.010)	0.938 (0.062)
RMU0.50-BAU	0.999 (0.001)	0.998 (0.002)	0.997 (0.003)	0.991 (0.009)	0.942 (0.058)
RMU0.70-BAU	0.999 (0.001)	0.998 (0.002)	0.997 (0.003)	0.991 (0.009)	0.942 (0.054)
RMU0.30-OPT	0.999 (0.001)	0.998 (0.002)	0.997 (0.003)	0.991 (0.009)	0.942 (0.058)
RMU0.50-OPT	0.999 (0.001)	0.998 (0.002)	0.997 (0.003)	0.991 (0.009)	0.946 (0.054)
RMU0.70-OPT	0.999 (0.001)	0.998 (0.002)	0.997 (0.003)	0.991 (0.009)	0.949 (0.051)
RMU0.30-TL $\leq$2.0	0.999 (0.001)	0.998 (0.002)	0.997 (0.003)	0.991 (0.009)	0.955 (0.045)
RMU0.50-TL $\leq$2.0	0.999 (0.001)	0.998 (0.002)	0.997 (0.003)	0.991 (0.009)	0.956 (0.044)
RMU0.70-TL $\leq$2.0	0.999 (0.001)	0.998 (0.002)	0.997 (0.003)	0.991 (0.009)	0.956 (0.044)

Text in blue brackets refers to the probability of a catastrophic event.
RMU*b*-Scenario: where *b* is the share sizing the utility loss. The higher is *b* the wider is the utility loss.

Global results: the effect of introducing uncertainty

- As the ***temperature*** continues to ***rise*** over time, the ***probability of facing a disaster highers*** too;
- such proportion is ***mitigated by the scenarios stringency*** and the in the ***size of the utility loss (i.e*** b ***highers)*** associated to the consequences of the disaster.
- ***As we get closer to the end of the century, changes across scenarios become apparent***: the more environmentally binding the policy scenario becomes, the smaller the positive variation in the disaster probability overtime.

Global results: the effect of uncertainty introduction

RICE-MED vs RICE-MED U

Variables / Scenario	2015	2025	2035	2055	2105	
Temperature increase (°C from 1900)						
RM-Optimal	1.10	1.19	1.31	1.58	2.29	
RMU0.30-Optimal	1.10	1.19	1.31	1.56	2.18	
RMU0.50-Optimal	1.10	1.19	1.31	1.55	2.12	
RMU0.70-Optimal	1.10	1.19	1.31	1.55	2.12	
RM-Temperature limit ≤2.0	1.10	1.19	1.31	1.53	1.96	
RMU0.30-Temperature limit ≤2.0	1.10	1.19	1.31	1.53	1.95	
RMU0.50-Temperature limit ≤2.0	1.10	1.19	1.31	1.52	1.94	
RMU0.70-Temperature limit ≤2.0	1.10	1.19	1.31	1.52	1.94	
Carbon Tax (USD/tC)						*Average*
RM-Optimal	38.94	133.87	157.29	209.45	406.42	231.32
RMU0.30-Optimal	39.02	263.98	299.85	369.79	558.07	371.31
RMU0.50-Optimal	39.30	373.37	423.50	521.68	783.04	521.45
RMU0.70-Optimal	39.40	486.09	551.38	680.90	1031.71	681.66
RM-Temperature limit ≤2.0	39.76	617.36	788.72	1268.63	4104.60	1728.41
RMU0.30-Temperature limit ≤2.0	39.76	714.03	885,57	1348.86	3961.38	1752.02
RMU0.50-Temperature limit ≤2.0	39.76	782.20	788.72	1268.63	3890.40	1778.67
RMU0.70-Temperature limit ≤2.0	39.76	853.29	1028.28	1479.04	3838.53	1814.11

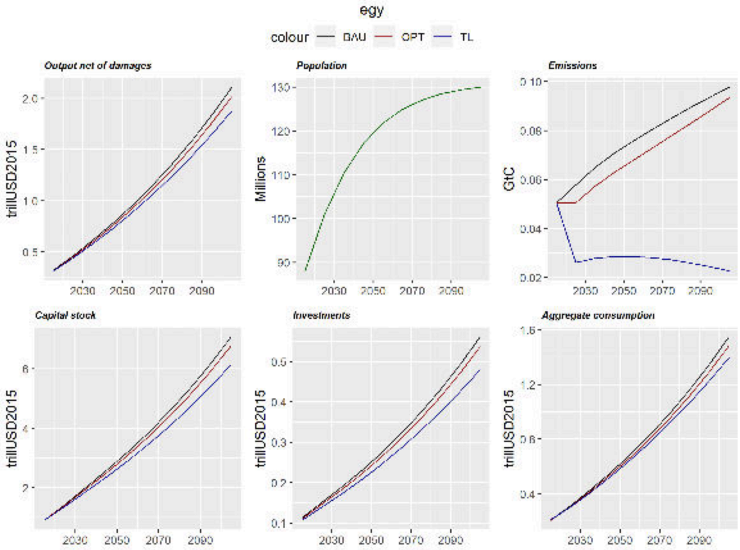
Social Rate of Time Preference (SRTP) is 1.5%. RM: RICE-MED. RMUb: RICE-MED-U model with $b = \{0.3, 0.50\}$.

Regional results

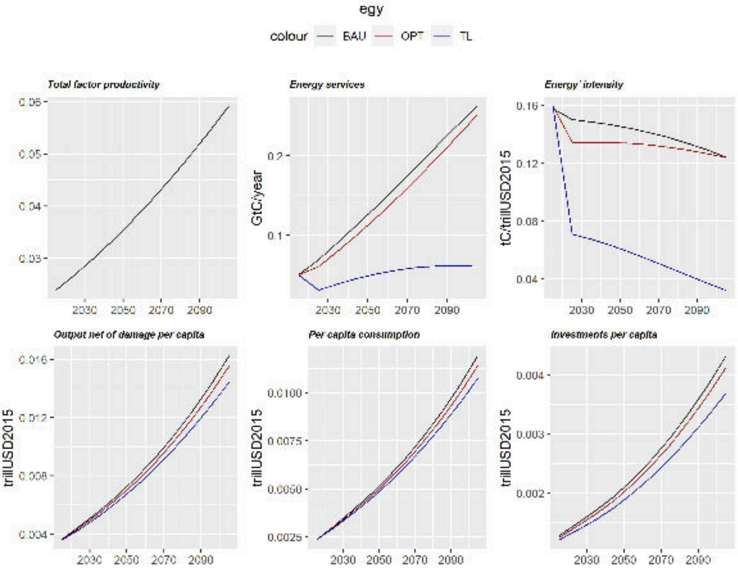
Outline

1. Model outcomes at regional level
2. Regional economic damage
3. Climate change economic damage and the agricultural sector

Regional results



Regional results



Average changes in GDP reductions between scenarios for MED countries

Average loss across scenarios			*Group average loss*		*Group variance*	
	BAUvsOPT	*BAUvsTL*	*BAUvsOPT*	*BAUvsTL*	*BAUvsOPT*	*BAUvsTL*
ALB	0.13%	0.29%	0.09%	0.33%	0.07%	0.08%
HRV	0.01%	0.27%				
MNE	0.16%	0.45%				
GRC	0.05%	0.32%				
CYP	0.23%	0.40%	0.19%	0.55%	0.17%	0.58%
ISR	0.10%	0.19%				
LBN	0.08%	0.24%				
SYR	0.46%	1.58%				
TUR	0.06%	0.32%				
DZA	0.25%	1.08%	0.27%	0.90%	0.06%	0.63%
EGY	0.24%	0.75%				
ETH	0.35%	0.31%				
LBY	0.24%	2.21%				
MAR	0.27%	0.46%				
SDN	0.35%	0.61%				
TUN	0.19%	0.86%				
FRA	-0.01%	0.06%	0.07%	0.15%	0.13%	0.062%
ITA	0.01%	0.17%				
MLT	0.27%	0.21%				
ESP	0.03%	0.17%				

Average reduction across scenarios by type of variable in regions

	Energy services		Emissions intensity	
	BAUvsOPT	*BAUvsTL*	*BAUvsOPT*	*BAUvsTL*
USA	0.31%	4.80%	0.22%	3.42%
CHINA	0.45%	6.19%	0.25%	3.47%
EE	0.40%	6.40%	0.34%	3.85%
EUROPE	0.35%	4.94%	0.30%	3.84%
LI	1.00%	8.11%	0.31%	4.06%
LMI	0.74%	6.86%	0.29%	3.92%
MI	0.85%	6.73%	0.40%	4.21%
OHI	0.79%	5.42%	0.43%	4.22%

Average reduction in Energy Services between scenarios for MED countries

Average loss across scenarios			Group average loss		Group variance	
	BAUvsOPT	BAUvsTL	BAUvsOPT	BAUvsTL	BAUvsOPT	BAUvsTL
ALB	0.59%	6.61%	0.43%	5.29%	0.26%	1.50%
HRV	0.18%	4.18%				
MNE	0.71%	6.56%				
GRC	0.24%	3.80%				
CYP	0.95%	6.98%	0.87%	7.02%	0.29%	1.56%
ISR	0.52%	6.08%				
LBN	0.68%	5.48%				
SYR	1.26%	9.57%				
TUR	0.96%	6.98%				
DZA	0.56%	6.57%	0.95%	7.53%	0.56%	1.17%
EGY	0.69%	7.55%				
ETH	1.10%	8.66%				
LBY	0.97%	8.43%				
MAR	2.09%	8.28%				
SDN	0.83%	7.84%				
TUN	0.40%	5.40%				
FRA	0.44%	5.35%	0.47%	4.86%	0.28%	0.79%
ITA	0.21%	3.77%				
MLT	0.86%	5.53%				
ESP	0.37%	4.79%				

Regional results: regional economic damage induced by climate change

	Scenario	2015	2025	2035	2055	2105
Europe	Optimal	0.35	0.94	0.82	0.89	1.38
(Δ% to Baseline)	Temp Limit	0.35	0.94	0.12	-0.51	-1.41
LMI	Optimal	-1.31	-2.39	-2.19	-3.60	-4.86
(Δ% to Baseline)	Temp Limit	-1.31	-4.40	-5.48	-6.71	-9.54
Egypt	Optimal	-1.14	-2.14	-2.62	-3.23	-4.28
(Δ% to Baseline)	Temp Limit	-1.14	-4.67	-5.80	-7.21	-11.08
Sudan	Optimal	-1.74	-3.08	-3.70	-4.61	-6.37
(Δ% to Baseline)	Temp Limit	-1.74	-4.58	-5.63	-6.83	-9.51
Tunisia	Optimal	-0.93	- 1.80	-2.26	-2.80	-3.64
(Δ% to Baseline)	Temp Limit	-0.93	-4.87	-6.22	-8.00	-13.89

Difference in Output w.r.t. Business As Usual (%)

Regional results: climate change and the agriculture

Outline

- Agricultural damages changes over time
- Agricultural damages changes across scenarios
- The effect of uncertainty

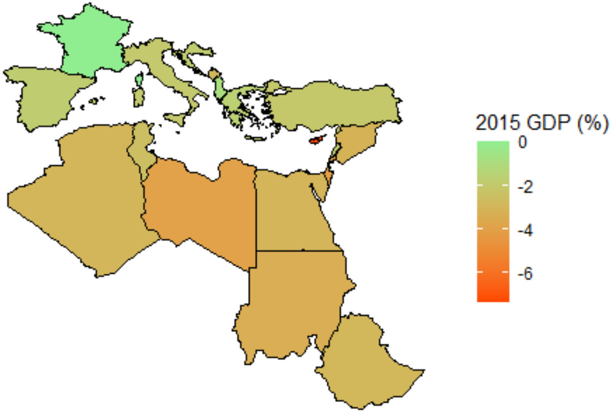
Regional results: climate change and the agriculture

	Scenario	2015	2025	2035	2055	2105
Italy (Δ% to Baseline)	Optimal	-0.05	0.20	-0.03	-0.16	-0.14
	Optimal-AGRI	-1.97	-3.40	-4.09	-5.20	-7.48
	Temp Limit	-0.05	-0.07	-1.04	-1.97	-4.09
	Temp Limit-AGRI	-1.97	-3.64	-4.70	-5.95	-8.77
Greece (Δ% to Baseline)	Optimal	-0.40	-0.53	-0.85	-1.16	-1.48
	Optimal-AGRI	-1.58	-2.75	-3.34	-4.26	-6.12
	Temp Limit	-0.40	-1.59	-2.76	-4.11	-7.71
	Temp Limit-AGRI	-1.58	-3.79	-4.98	-6.55	-10.70
Egypt (Δ% to Baseline)	Optimal	-1.14	-2.14	-2.62	-3.23	-4.28
	Optimal-AGRI	-3.03	-5.43	-6.41	-8.07	-11.48
	Temp Limit	-1.14	-4.67	-5.80	-7.21	-11.08
	Temp Limit-AGRI	-3.03	-8.00	-9.25	-11.02	-15.58
Tunisia (Δ% to Baseline)	Optimal	-0.93	- 1.80	-2.26	-2.80	-3.64
	Optimal-AGRI	-2.49	-4.63	-5.52	-6.96	-9.91
	Temp Limit	-0.93	-4.87	-6.22	-8.00	-13.89
	Temp Limit-AGRI	-2.49	-7.69	-9.14	-11.26	-17.90

Difference in Output w.r.t. Business As Usual (%) - Comparison for damages in agriculture

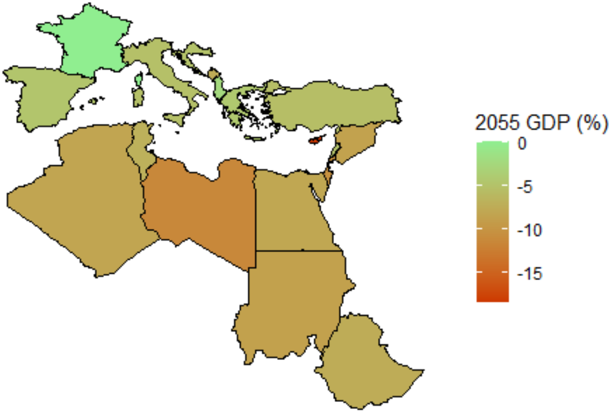
Regional results: climate change and the agriculture

RICE-MED - Percentage of output loss under the OPT Scenario (2015).



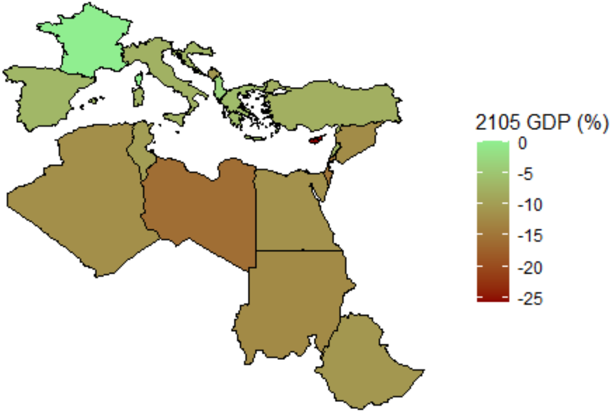
Regional results: climate change and the agriculture

RICE-MED - Percentage of output loss under the OPT Scenario (2055).



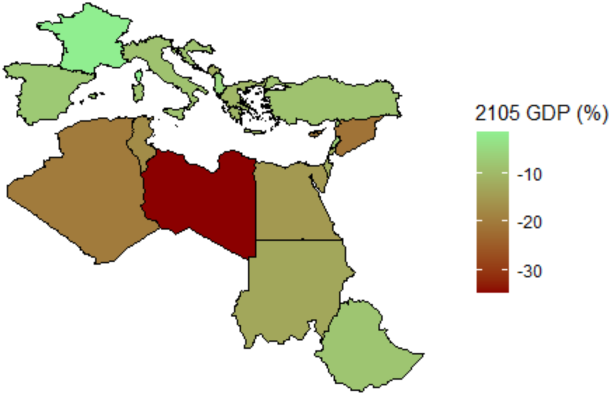
Regional results: climate change and the agriculture

RICE-MED - Percentage of output loss under the OPT Scenario (2105).



Regional results: climate change and the agriculture

RICE-MED-U0.30- Percentage of output loss under the TL Scenario (2105).



Conclusions

RICE-MED, an integrated assessment model for the Mediterranean basin: assessing the climate-economy-agriculture nexus

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The paper in brief.

- Updated calibration of the RICE-99 of Nordhaus and Boyer [2000] to year 2015.
- Analytical formalization of the model initialization process.
- New regionalization, with Mediterranean nations at country level.
- New damage function [Golosov et al., 2014].
- RICE-MED-U: Uncertainty [Castelnuovo et al., 2003].
- RICE-MED-AGRI: economic damages linked to climate change to the agricultural sector.

Scan here to read the working paper.

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Thank you for your time!

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