ELECTRONIC SUPPLEMENTARY MATERIAL

MEDEAS: a new modeling framework integrating global biophysical and socioeconomic constraints

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1. WIOD sector classification

Supplementary Table 1: WIOD sector classification used in MEDEAS model

Sectors			
1	Agriculture, Hunting, Forestry and Fishing	**18**	Construction
2	Mining and Quarrying	**19**	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail sail of fuel
3	Food, Beverages and Tobacco	**20**	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
4	Textiles and Textile Products	**21**	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household goods
5	Leather, Leather and Footwear	**22**	Hotels and Restaurants
6	Wood and Products of Wood and Corks	**23**	Inland Transport
7	Pulp, Paper, Printing and Publishing	**24**	Water Transport
8	Coke, Refined Petroleum and Nuclear fuel	**25**	Air Transport
9	Chemicals and Chemical Products	**26**	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
10	Rubber and Plastics	**27**	Post and Telecommunications
11	Other Non-Metallic Mineral	**28**	Financial Intermediation
12	Basic Metals and Fabricated Metal	**29**	Real Estate Activities
13	Machinery, Nec	**30**	Renting of M&Eq and Other Business Activities
14	Electrical and Optical Equipment	**31**	Public Admin and Defence; Compulsory Social Security
15	Transport Equipment	**32**	Education
16	Manufacturing , Nec.; Recycling	**33**	Health and Social Work
17	Electricity, Gas and Water supply	**34**	Other Community, Social and Personal Services
		35	Private Households with Employed Persons

Source: Own compilation on the basis of WIOD[1].

2. Input uncertainty ranges for the uncertainty analysis

Supplementary Table 2 below shows the uncertainty ranges taken for 72 inputs of the BAU scenario cases in order to perform the sensitivity analysis. Wide uncertainty ranges have been taken in order to test the stability and robustness of the obtained results in the 4 scenario cases. ±20% random uniform distributions with reference to the BAU scenario specification have been taken by default, while for those inputs and assumptions which we think are more affected by critical uncertainties, a more broad range of ±50% or even /2-x2 (i.e., half and double) have been considered. The latter is the case for the techno-sustainable potential of renewables[2–9], future efficiency improvements[10–12], sensitivity to scarcity[13–17] and inland and households transportation[7,12,18].

More information about stability and robustness of the MEDEAS models can be found in the following references[19,20].

Supplementary Table 2: Input uncertainty ranges for the uncertainty analysis performed on the 4 scenario cases. UD: Random uniform distribution.

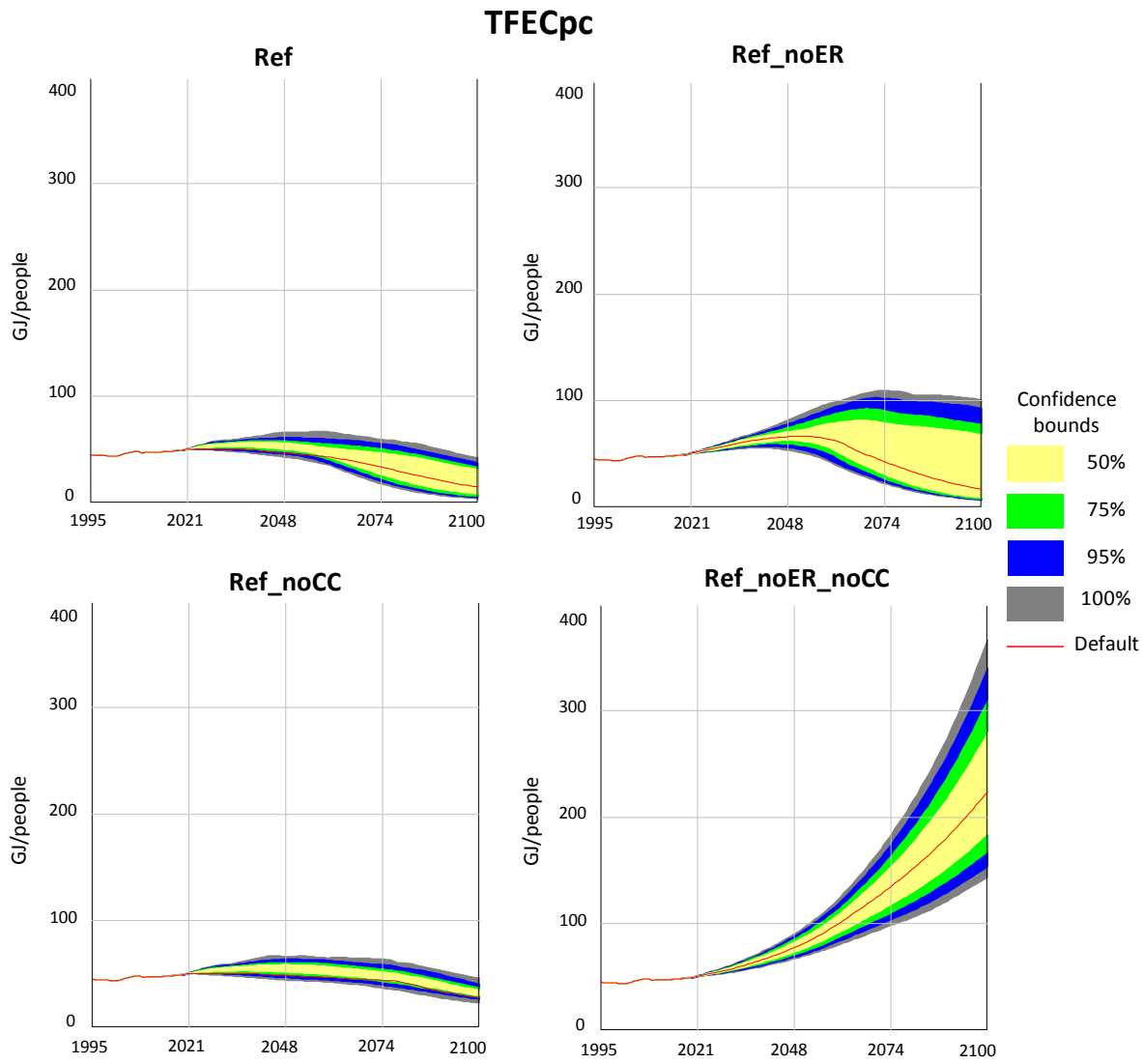
Scenario inputs&assumptions	**Input uncertainty ranges (with reference to BAU scenario specification)**	
Population (2015-2100)	±20% (UD) wrt to population growth in SSP2	
Expected GDPpc growth (2015-2100)	±25% (UD) (1.5%/yr is the 1979-2014 average, and 2.5%/yr corresponds with the 2015-2100 average for the SSP2)	
Target labor share	±20% (UD) wrt to the 2050 target taking into account that in the historic period it had a variability of ±5%	
Efficiency improvements (Final energy intensity)		
Minimum final energy intensity vs initial	/2;+50% (UD)	
% of change over the historic maximun variation of final energy intensities	±50% (UD)	
Sensitivity to scarcity	/2;+50% (UD)	
Energy scarcity forgetting factor	/2;+50% (UD)	
Inland and households transport ±50% (UD) to each target share of vehicle and fuel Oil dependence target per aggregated category in 2100:		
4-wheel vehicles	1%-67% starting in 2020-2050 (UD) with target year in 2051-2100 (UD)	
2-wheel vehicles	0%-50% starting in 2020-2050 (UD) with target year in 2051-2100 (UD)	
Heavy vehicles	61%-87% starting in 2020-2050 (UD) with target year in 2051-2100 (UD)	
Bus	31%-77% starting in 2020-2050 (UD) with target year in 2051-2100 (UD)	
Recycling rates of minerals (19 minerals)	0%-5% (UD) annual recycling rate improvement starting in 2020-2050	
Nuclear capacity	Capacity growth between 0-5%/year (UD) to start between the year 2020 and 2050 (UD).	
***Non-renewable energies depletion curves**		
Oil	0-25% (UD) to the URR and maximum extraction level	
Natural gas	0-25% (UD) to the URR and maximum extraction level	
Coal	0-25% (UD) to the URR and maximum extraction level	
Uranium	0-25% (UD) to the URR and maximum extraction level	
GHG emissions from other gases than CO_2 and CH_4 from fossil fuel combustion	50% prob. RCP6.0 50% prob. RCP8.5	
***Climate Change impacts**	50% prob. damage function calibrated to +1.75°C and 1% GDPpc losses 50% prob. damage function calibrated to +1.75°C and 3% GDPpc losses	
Renewables		
	Annual capacity growth (2015-2100)	***Techno-sustainable potential**
All technologies for electricity generation	±20% (UD)	/2-x2 (UD)
All technologies for heat generation	±20% (UD)	/2-x2 (UD)

Scenario inputs&assumptions	Input uncertainty ranges (with reference to BAU scenario specification)	
Conventional bioenergy	-	/2-x2 (UD)
2nd generation bioenergy cropland	±20% (UD)	/2-x2 (UD)
3rd generation bioenergy cropland	±20% (UD) starting in 2025-2050 (UD)	
Residues bioenergy	±20% (UD) starting in 2025-2050 (UD)	/2-x2 (UD)
Marginal lands bioenergy	±20% (UD) starting in 2025-2050 (UD)	±20% (UD)

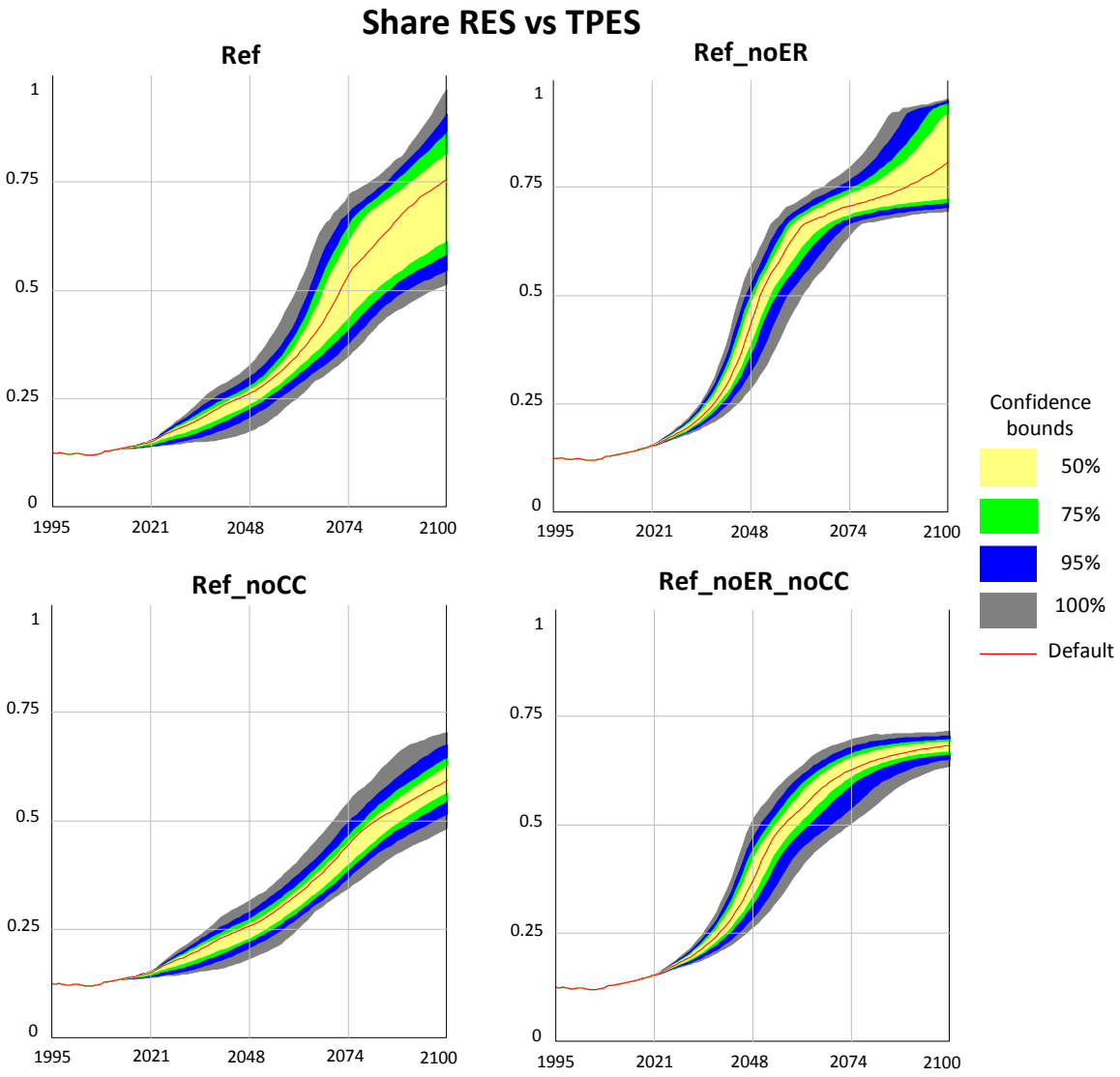
3. Outputs from the uncertainty analysis

n=1000 Monte Carlo simulations were performed using the software Vensim. The Supplementary Figures 1 to 6 depict the results of the uncertainty analysis for a selection of outputs: Total final Energy Consumption per capita (SF1), share of renewable energy sources vs Total Primary Energy Supply (SF2), Gross Domestic Product per capita (SF3), total greenhouse gas emissions (SF4), temperature change (SF5) and CO2eq intensity of final energy (SF6). The red solid line represents the 4 scenario cases reported in the main paper (*Ref, Ref_noRE, Ref_noCC, Ref_noRE_noCC*). In general, it is noteworthy that a good level of stability and robustness is obtained for the 4 scenario cases despite the wide input and assumptions uncertainty ranges considered. Population is the same for all the scenarios given that it is an exogenous input. A certain asymmetry is found in those scenarios with limited energy availability, due to the fact that the uncertainty input range for the URR and the maximum extraction level is assymetrical in order to accout for the possibility that higher fossil and nuclear endowments might be available in the future.

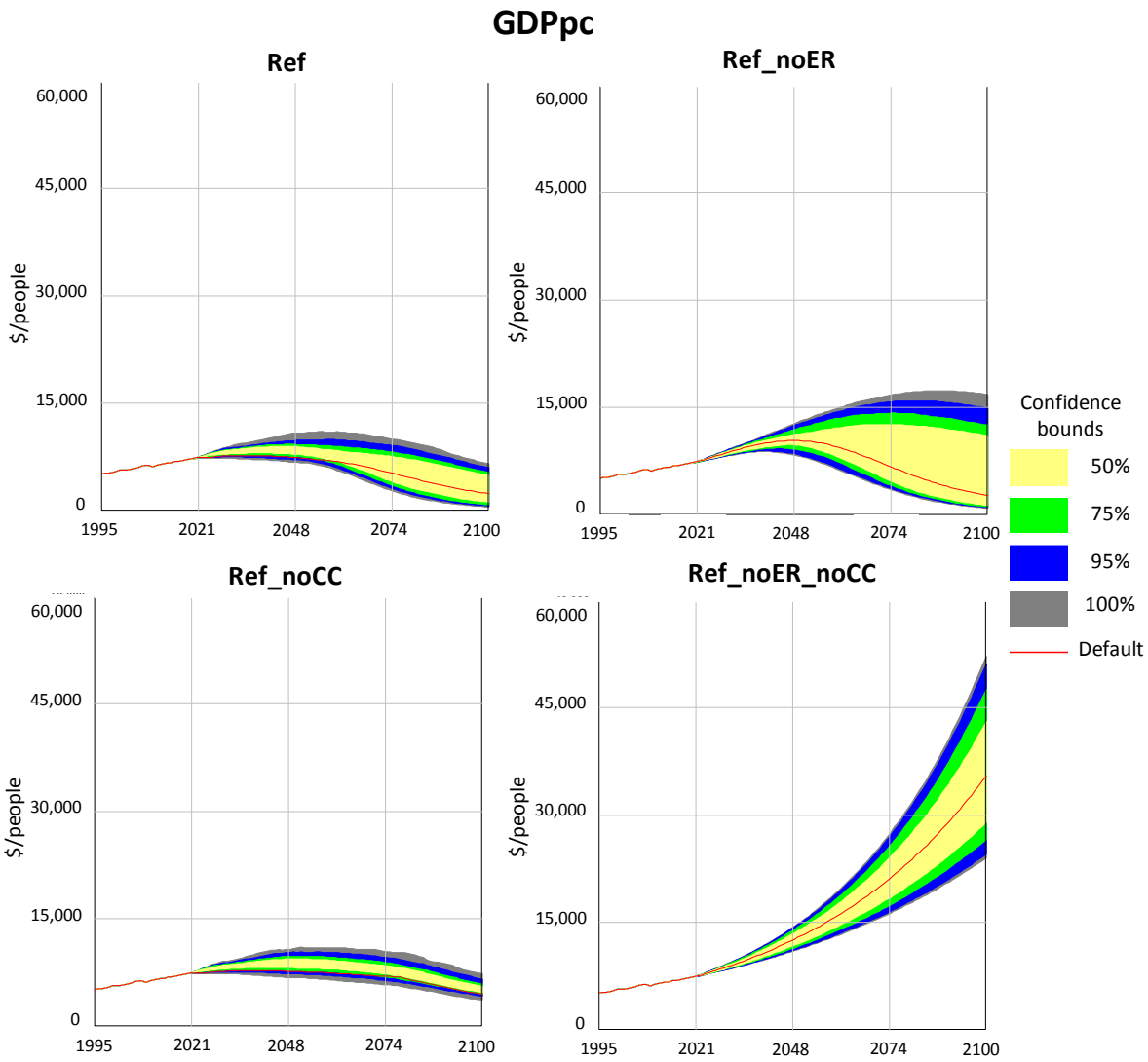
The uncertainty input shared in the 4 scenario cases for population is also depicted in SF7.



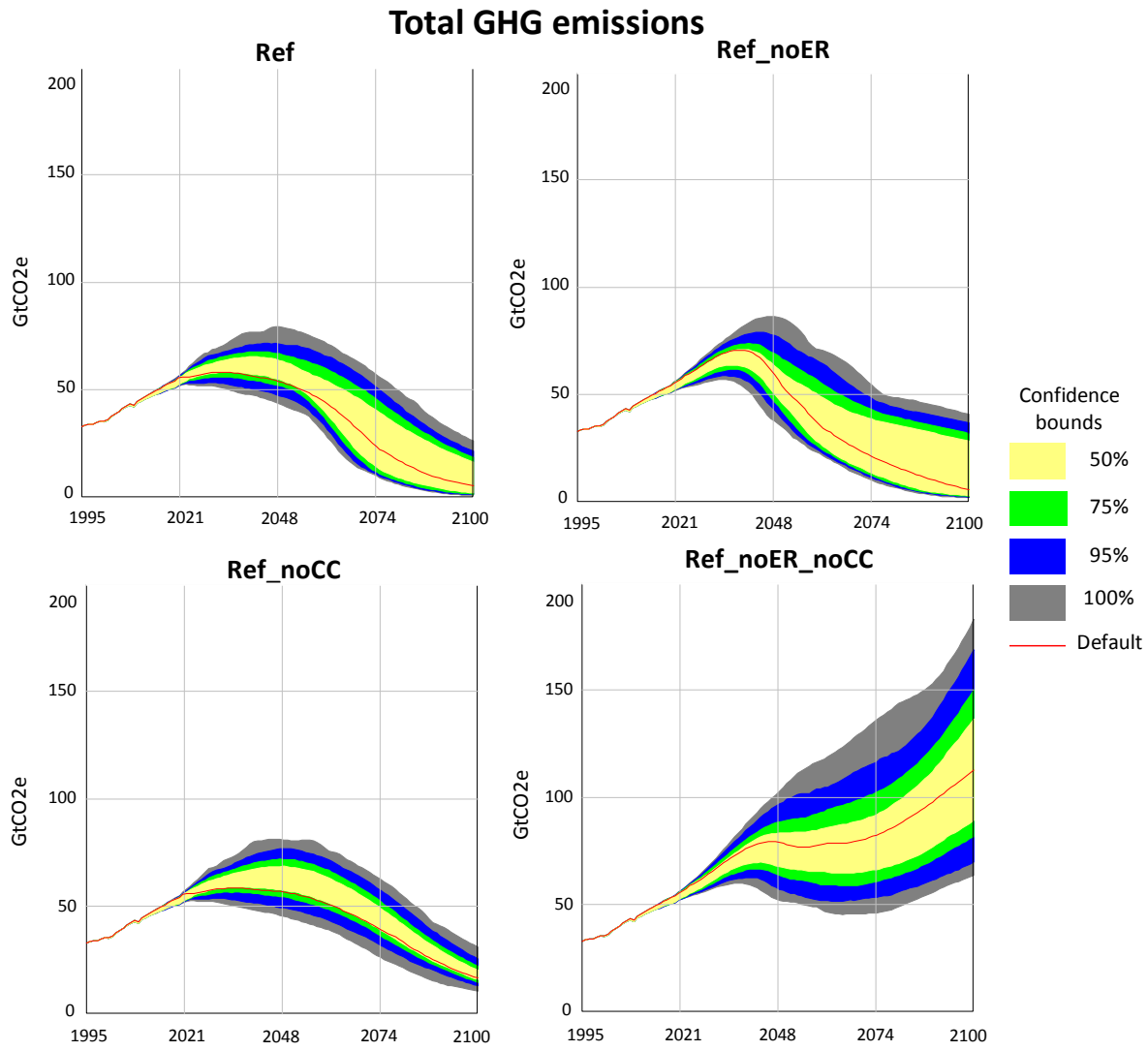
Supplementary Figure 1: Probability distribution of the Total Final Energy Consumption per capita (TFECpc) for the four scenario cases. Shaded areas depict the uncertainty ranges (whole range, 5–95%, 25–75%), the red line ("Default") represents the output for each scenarios case reported in the main text: Ref, Ref_noRE, Ref_noCC, Ref_noRE_noCC.



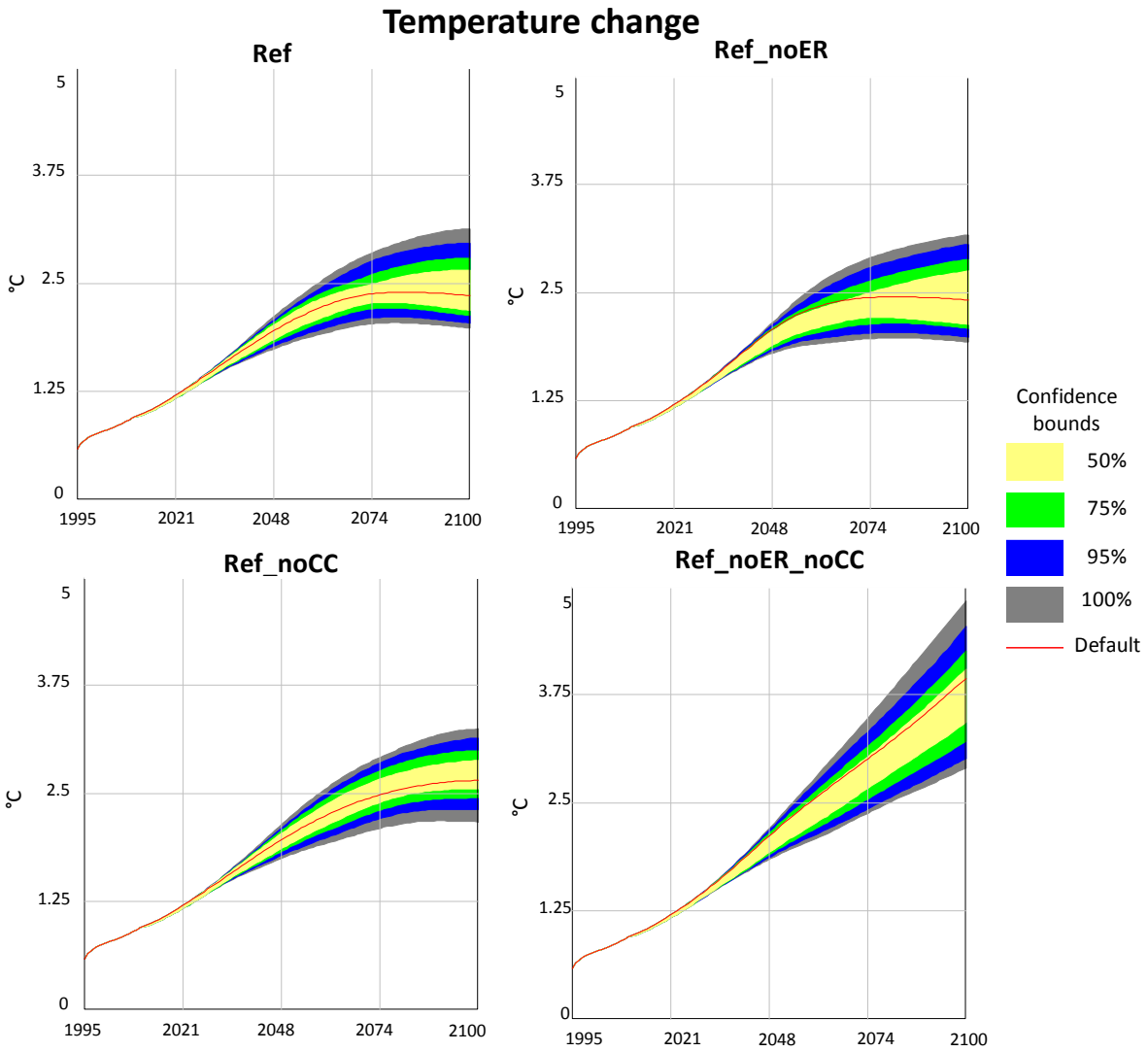
Supplementary Figure 2: Probability distribution of the share of renewable energy sources (RES) over Total Primary Energy Supply (TPES) for the four scenario cases. Shaded areas depict the uncertainty ranges (whole range, 5–95%, 25–75%), the red line ("Default") represents the output for each scenarios case reported in the main text: Ref, Ref_noRE, Ref_noCC, Ref_noRE_noCC.



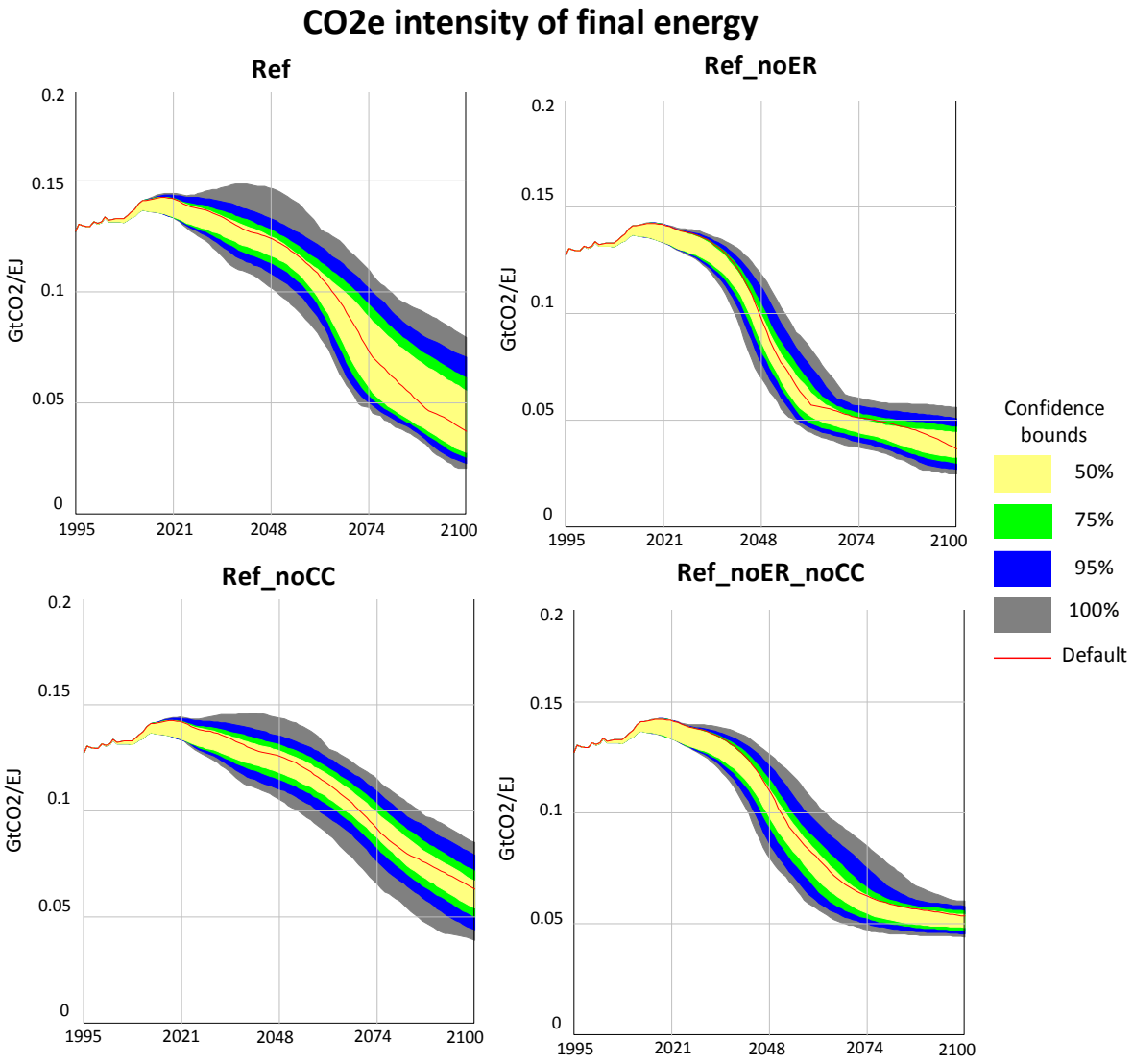
Supplementary Figure 3: Probability distribution of the Gross Domestic Product per capita (GDPpc) for the four scenario cases. Shaded areas depict the uncertainty ranges (whole range, 5–95%, 25–75%), the red line ("Default") represents the output for each scenarios case reported in the main text: Ref, Ref_noRE, Ref_noCC, Ref_noRE_noCC.



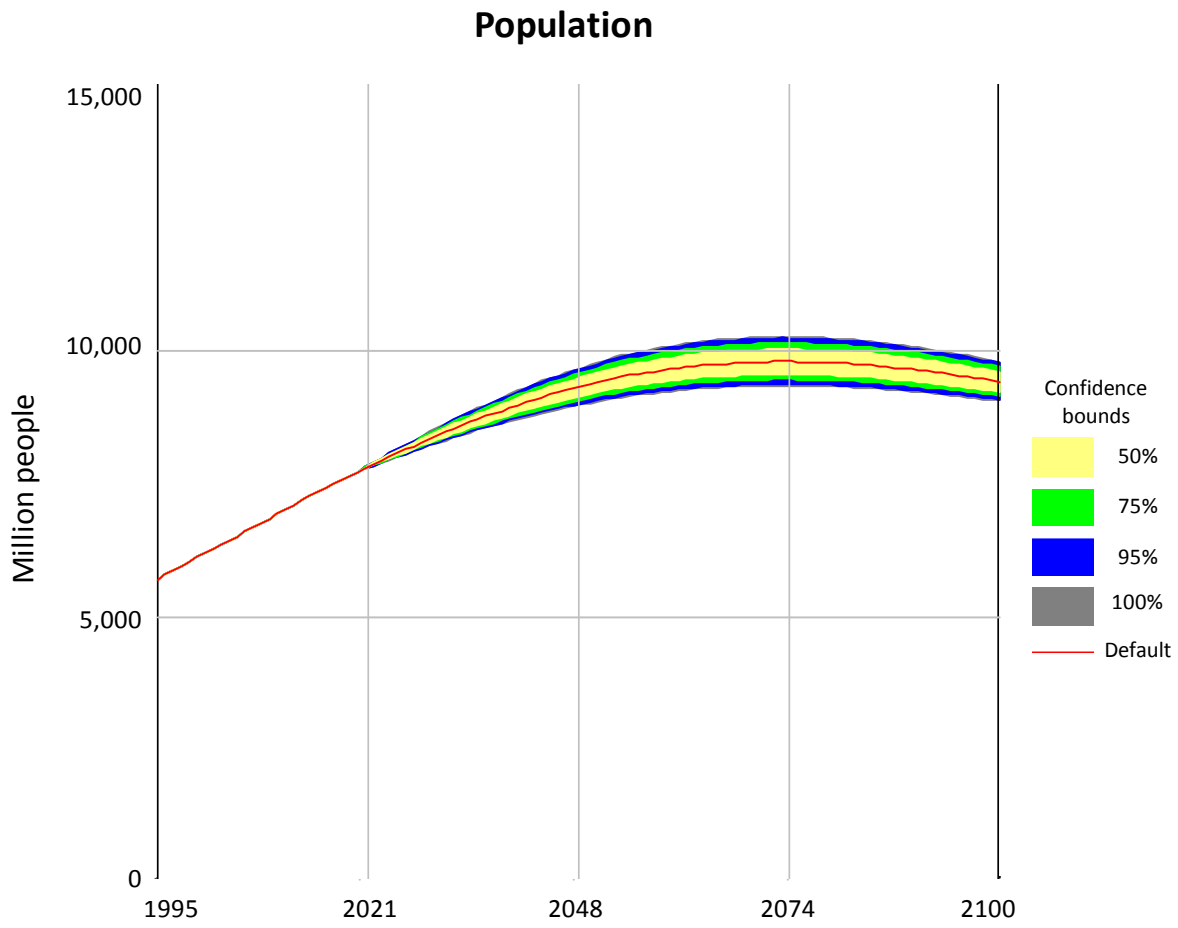
Supplementary Figure 4: Probability distribution of the total greenhouse gas (GHG) emissions for the four scenario cases. Shaded areas depict the uncertainty ranges (whole range, 5–95%, 25–75%), the red line ("Default") represents the output for each scenarios case reported in the main text: Ref, Ref_noRE, Ref_noCC, Ref_noRE_noCC.



Supplementary Figure 4: Probability distribution of the temperature change for the four scenario cases. Shaded areas depict the uncertainty ranges (whole range, 5–95%, 25–75%), the red line ("Default") represents the output for each scenarios case reported in the main text: Ref, Ref_noRE, Ref_noCC, Ref_noRE_noCC.



Supplementary Figure 4: Probability distribution of the CO2e for the four scenario cases. Shaded areas depict the uncertainty ranges (whole range, 5–95%, 25–75%), the red line ("Default") represents the output for each scenarios case reported in the main text: Ref, Ref_noRE, Ref_noCC, Ref_noRE_noCC.



Supplementary Figure 7: Probability input distribution for population for the four scenario cases. Shaded areas depict the uncertainty ranges (whole range, 5–95%, 25–75%), the red line ("Default") represents the input for all the scenarios cases reported in the main text: Ref, Ref_noRE, Ref_noCC, Ref_noRE_noCC.

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