Long-term growth impact of climate change and policies: the Advanced Climate Change Long-term (ACCL) scenario building model

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Overview of the ACCL model

- **Global level projection tool, 30 countries / regions, with results at the global and country / regional level**
- **Focusing on climate change damage and the impact of policies impacting energy prices (e.g. carbon taxes) on GDP and its supply-side components**
- **Simulation horizon: 2060 and 2100**
- **5 different types of energy inputs according to their CO_2 emitting properties (coal, oil, natural gas, dirty electricity, clean electricity)**
- **Supply-side approach (potential growth)**
- **Full calibration possible at each stage, with estimated or literature-based default parameters**
- **User-friendly, free-access projection tool**
  http://www.longtermproductivity.com/

Economic literature on the assessment of climate change impacts

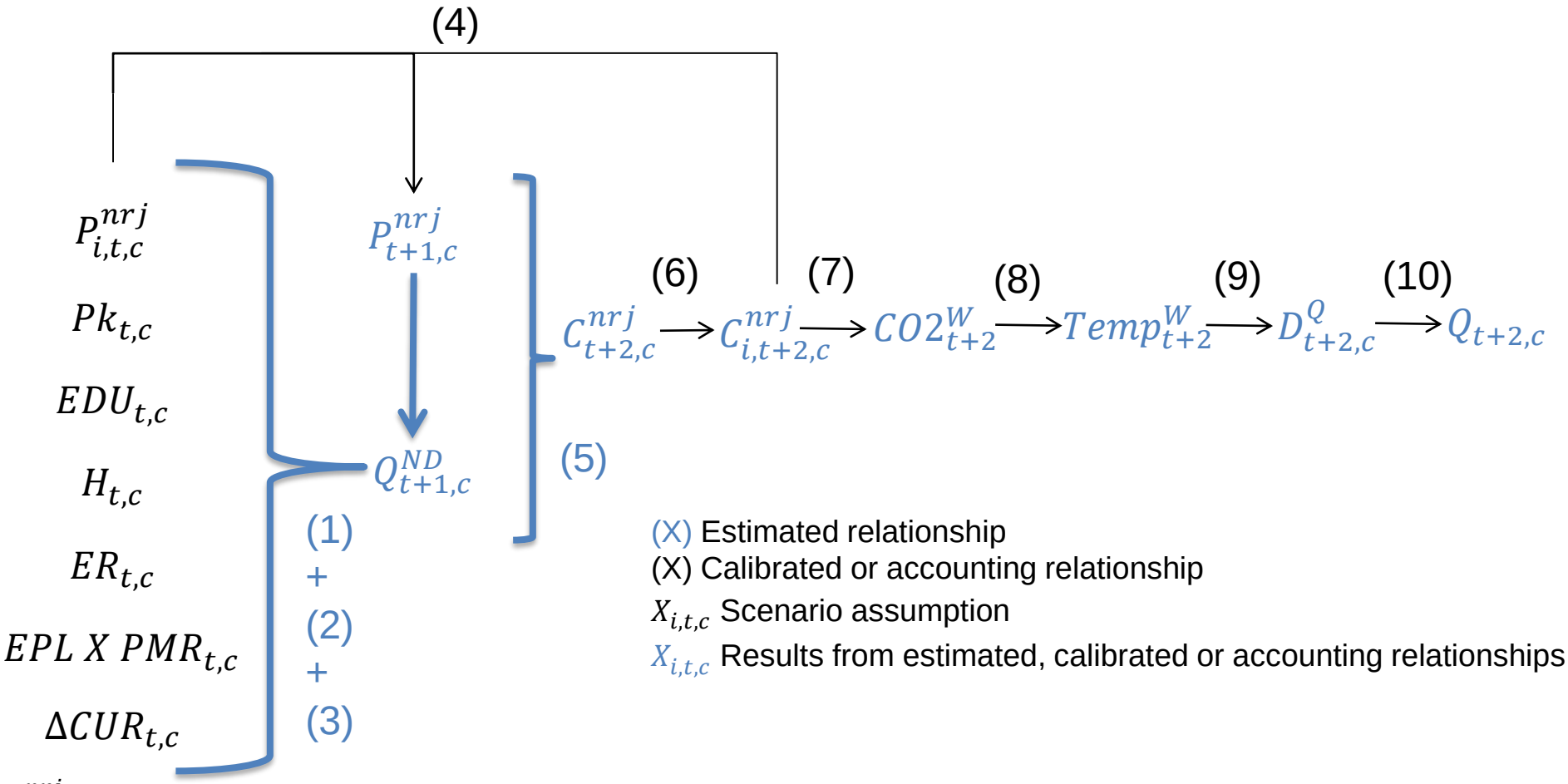
- **Integrated Assessment models (IAM)**
  - DICE (Nordhaus, 1991 ; 2018)
  - Simple, normative and transparent
  - Pyndick's criticism (2017)

- **Computable General Equilibrium (CGE)**
  - ENV-linkages (OECD, 2014)
  - Large, many dimensions, positive approach
  - Criticized for lack of transparency

- **Advanced Climate Change Long-term model (ACCL)**
  - Endogenous TFP and GDP effects of climate change and policies
  - User can change all the parameters
  - Totally transparent

Contents

1. Projections: overall scheme



(X) Estimated relationship
(X) Calibrated or accounting relationship
$X_{i,t,c}$ Scenario assumption
$X_{i,t,c}$ Results from estimated, calibrated or accounting relationships

$P^{nrj}_{i,t,c}$: Relative Energy price for energy i, year t and country c
$Pk_{t,c}$: Relative investment price
$EDU_{t,c}$: Average years of education
$H_{t,c}$: Average hours worked per employee
$ER_{t,c}$: Employment rate
$EPL\ X\ PMR_{t,c}$: Regulation index
$\Delta CUR_{t,c}$: Change in Capacity utilization rates

$Q_{t,c}$: Gross Domestic Product in volume and PPP 2010
$Q^{ND}_{t,c}$: No Damage GDP
$C^{nrj}_{t,c}$: Energy Final Consumption
$CO2^{W}_{t}$: World CO_2 emission
$Temp^{W}_{t}$: Increase in world temperature from pre-industrial era
$D^{Q}_{t,c}$: Damage to GDP from global warming in country c

1. Projections: overall scheme

Table 1: Series used in the scenario tool

Scenario hypotheses	Results from estimated, calibrated or accounting relationships
$P_{i,t,c}^{nrj}$: Relative energy prices	$Q_{t,c}$: GDP in volume and PPP 2010
$Pk_{c,t}$: Relative investment price	$C_{t,c}^{NRJ}$: Energy Final Consumption
$EDU_{t,c}$: Average years of education	$CO2_t$: World CO_2 emissions
$H_{t,c}$: Average hours worked per employee	$Temp_t$: Increase in world temperatures from pre-industrial era
$ER_{t,c}$: Employment rate	$D_{t,c}^{Q}$: Damage to GDP from global warming in country c
$(EPL \times PMR)_{t,c}$: Regulation index	
$\Delta CUR_{t,c}$: Change in Capacity utilization rates	
User can change all the parameters	

2. Main relations

- **Production function and capital stock**
  - **Cobb-Douglas production function**

    $Q_{c,t} = TFP_{c,t}.K_{c,t-1}^{\alpha}.\left(N_{c,t}.H_{c,t}\right)^{1-\alpha}$
  - **Endogenized Capital Stock**

    $\Delta k_{c,t-1} = \Delta pq_{c,t} + \Delta q_{c,t} - \Delta pk_{c,t}$

    Hypothesis of the stability of the ratio of capital to GDP in value
  - **With**:

    $Q_{c,t}$: Gross Domestic Product

    $TFP_{c,t}$: Total Factor Productivity

    $K_{c,t}$: Capital stock

    $N_{c,t}$: Number of employees

    $H_{c,t}$: Average hours worked per employee

    Pq: GDP price

    Pk: Investment price

    x: = Log(X)

    c: Country index

2. Main relations

- **Total factor productivity (TFP)**
  - **(1) Long-run Regression of the Log of TFP**

$$tfp_{c,t} = \alpha_1.[pnrj - pq]_{c,t-1} + \alpha_2.[pk - pq]_{c,t-1} + 0.05.EDU_{c,t-1} + \alpha_3.ER_{c,t-1} + \mathrm{FE_c} + \alpha_t.I_{T,t} + Cte + \varepsilon_{c,t}$$

With $\alpha_1 = -0.023$; $\alpha_2 = -0.37$; $\alpha_3 = -0.40$

  - **(3) Regression of the Country Fixed Effects on Average Regulations**

$$FE_c = \beta.(EPL \times PMR)_{t,c} + Cte + \varepsilon_c$$

With $\beta = -0.108$

  - **With**:

$TFP_{c,t}$:	Total Factor Productivity	$ER_{t,c}$:	Employment rate
$Pnrj_{c,t}$:	Energy relative price	FE_c:	Country Fixed Effects
$Pq_{c,t}$:	GDP price	$I_{T,t}$:	Time breaks
$Pk_{c,t}$:	Investment relative price	$(EPL \times PMR)_{t,c}$:	Regulation index
$EDU_{t,c}$:	Average years of education	*x = Log(X)*	

2. Main relations

➢ Energy consumption and prices

- **(4) Global energy price**

$$P_{t,c}^{nrj} = \sum_i P_{i,t,c}^{nrj} \times \frac{C_{i,t,c}^{nrj}}{C_{t,c}^{nrj}}$$

With:

$P_{t,c}^{nrj}$: Relative price of energy

$C_{i,t,c}^{nrj}$: Consumption of energy

$Q_{c,t}$: Gross Domestic Product

- **(5) Regression of the Log Energy Final Consumption on GDP and energy price**

$$tfc_{c,t}^{nrj} = \eta_1 . q_{c,t-1} + \eta_2 . pnrj_{c,t-1} + Cte + \varepsilon_c$$

With: $tfc_{c,t}^{nrj}$: Log energy final consumption

With: $\eta_1 = 0.96$; $\eta_2 = -0.67$

- **(6) Decomposition of energy final consumption by energy types** based on substitution elasticity by energy types and energy prices hypotheses:

⇒ Coal, oil, natural gas, CO_2 emitting electricity and non-CO_2 emitting electricity

⇒ Baseline substitution elasticities from Stern (2009) and Papageorgiou et al. (2017)

2. Main relations

➢ CO_2, temperature and damage

- **(7) Emissions at the global level**

$$CO_{2t}^{W} = \sum_{i,c} C_{i,t,c}^{nrj} \times \gamma_i$$

With γ_i coefficient of CO_2 emission per energy *i* (Default emission factors from the Covenant of Mayors for Climate and Energy report, 2017)

- **(7') From emission to CO_2 stock through permanent inventory method**

$$StockCO_{2t} = (1 - \rho_1).StockCO_{2t-1} + (1 - \rho_2).CO_{2t} - \rho_3$$

With: $\rho_1 = 0$; $\rho_2 = 0$; $\rho_3 = \frac{1}{3} CO_{22016}^{W}$

With:

CO_{2t}^{W}:	Global CO_2 emission
$C_{i,t,c}^{nrj}$:	Total final consumption of energy
γ_i:	Coefficient of CO_2 emission per energy *i*
$StockCO_{2t}$:	Global stock of CO_2

2. Main relations

➢ CO_2, temperature and damages

- **(8) From CO_2 stock to temperature increase compared to pre-industrial era**

  $Temp_t = \lambda_1 . StockCO_{2t}$ With: $StockCO_{2t}$: Global stock of CO_2

  With $\lambda_1 = 0.0008$ derived from the Representative Concentration Pathway (RCP) of the Intergovernmental Panel on Climate Change (IPCC, 2014)

- **(9) Global GDP losses from temperature increase**

  $D_t^Q = \theta_1 . Temp_t + \theta_2 . Temp_t^2$

  With $\theta_1 = 0.38$; $\theta_2 = -0.48$ derived from Nordhaus' review (2017)

  With: $Temp_t$: Increase in global temperature from pre-industrial area

  D_t^Q: Damage to GDP from global warming

- **(9') Local GDP losses decomposition** based on OECD (2015), taking into account changes in crop yields, loss of land and capital due to sea level rise, changes in fisheries catches, capital damage from hurricanes, labour productivity changes and changes in healthcare expenditures from diseases and heat stress, changes in tourism flows, and changes in energy demand for cooling and heating Hypothesis of no tipping points

3. Scenarios for the future

- **4 scenarios**

  Hypothesis of no tipping points

  - **Business As Usual (BAU)**
    - Energy prices relative to GDP price are stable
  - **Decrease of Renewable (clean) Energy relative Price scenario (DREP)**
    - Clean electricity price relative to GDP price decreases by 2% per year x 0.4 over 2017-2060 and x 0.2 over 2017-2100
    - CO_2 emitting energy prices relative to GDP price are stable
  - **Low Carbon Taxation scenario (LCT)**
    - CO_2 emitting energy prices relative to GDP price increase by 1% per year x 1.5 over 2017-2060 and x 2.3 over 2017-2100
    - Non CO_2 emitting energy prices relative to GDP price are stable
  - **High Carbon Taxation scenario (HCT)**
    - CO_2 emitting energy prices relative to GDP price increase by 3% per year x 3.6 over 2017-2060 and x 11.6 over 2017-2100
    - Non CO_2 emitting energy prices relative to GDP price are stable

3. Scenarios for the future

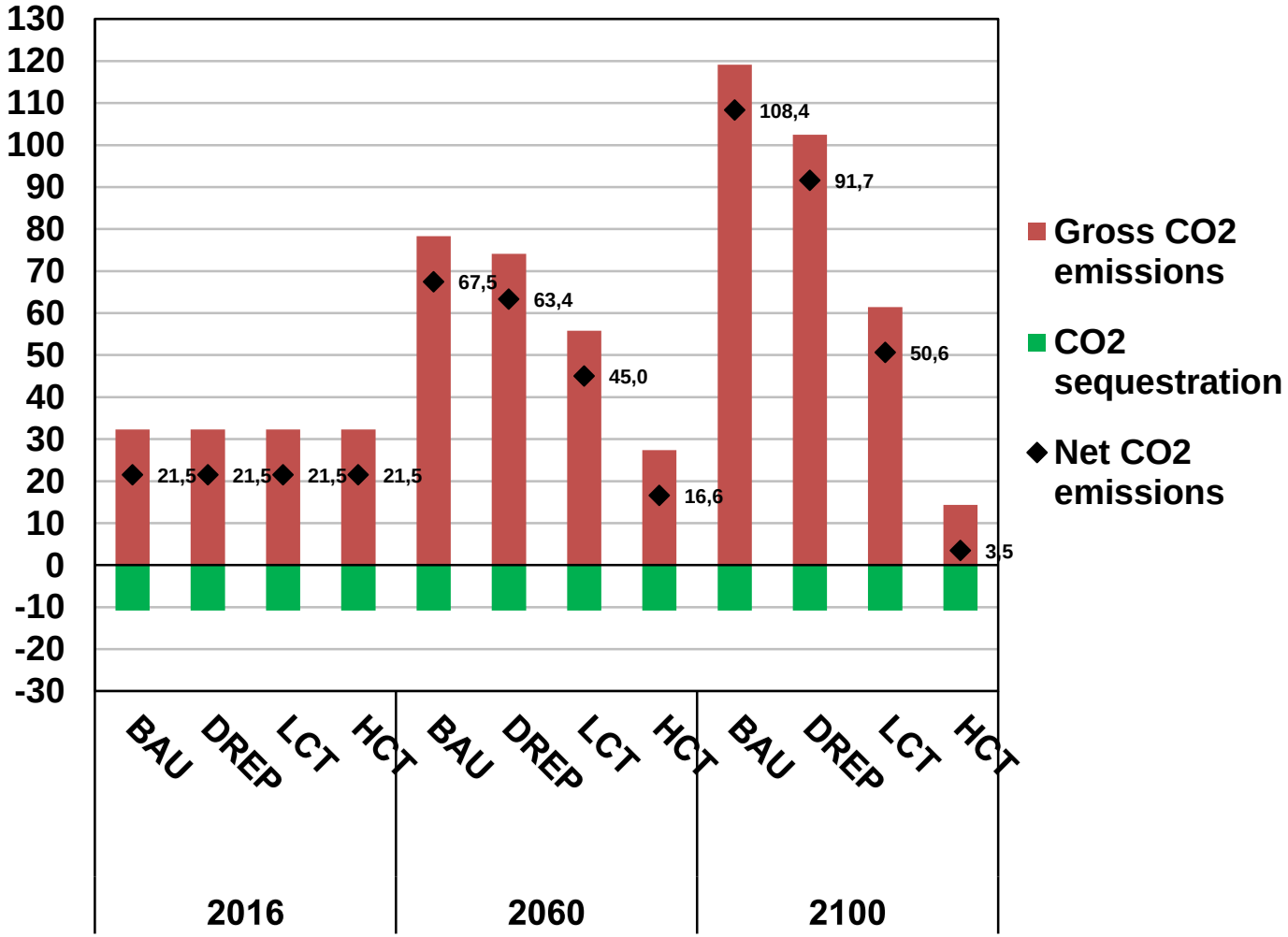
- **Impacts on GDP level (in %)**

  - **BAU**
    - Climate damage

  - **LCT, HCT and DREP**
    - Net impact =
      BAU climate damage
      - Avoided climate damage
      + GDP losses from climate policies

3. Scenarios for the future

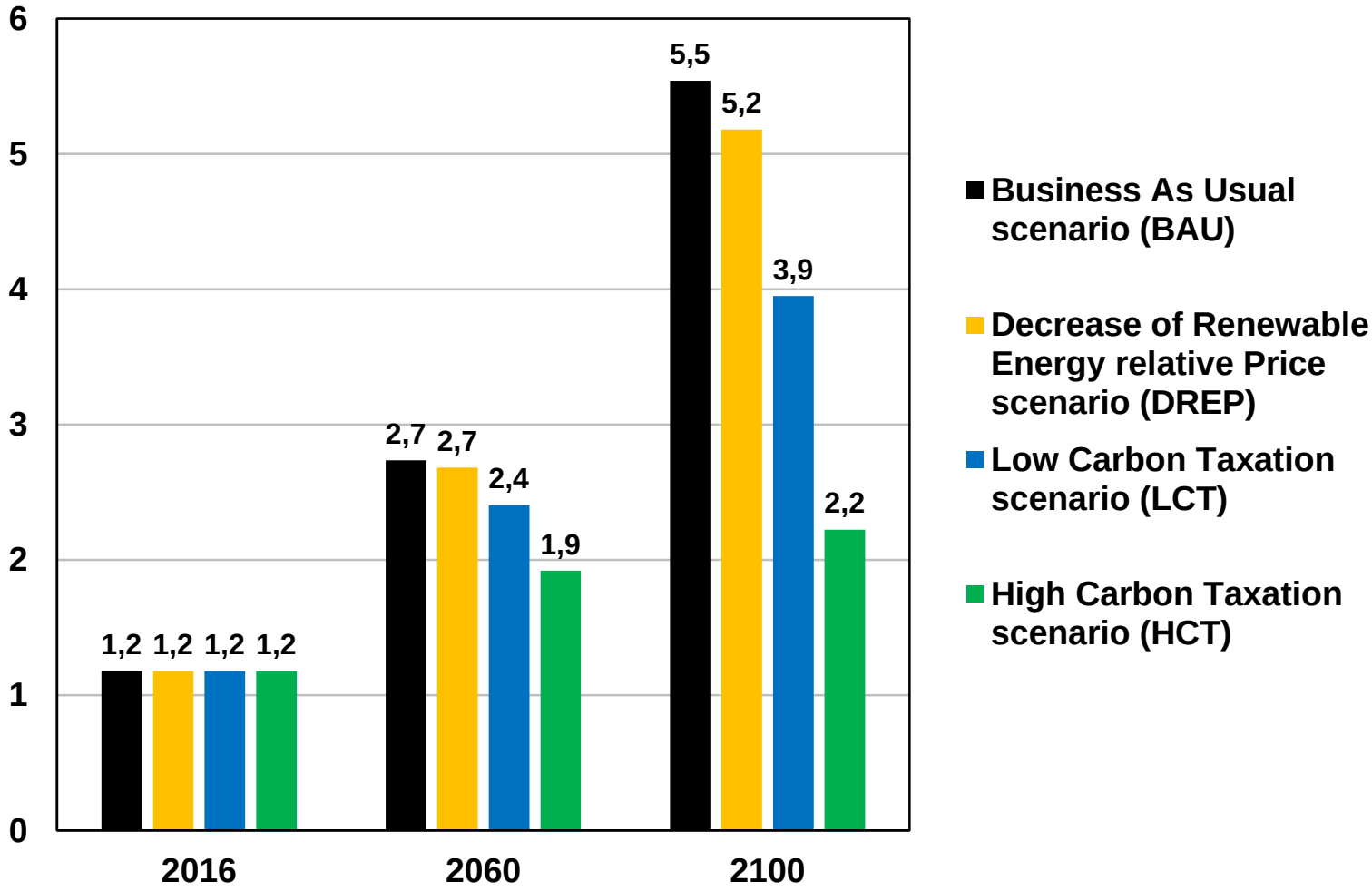
- Global CO_2 emissions per year (in giga tonnes of CO_2)



3. Scenarios for the future

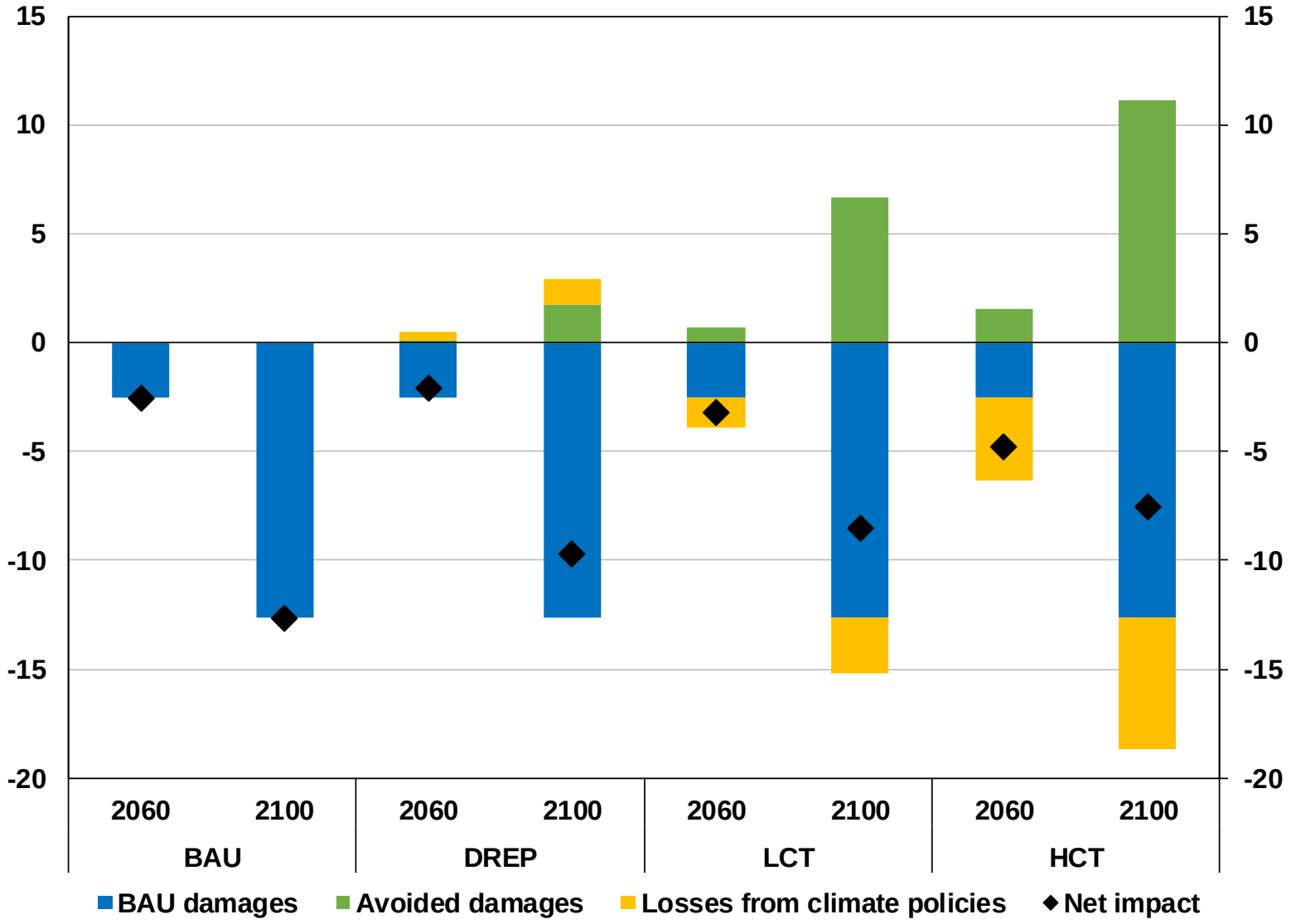
- **Global change in temperature (in °C)**

  With respect to pre-industrial era



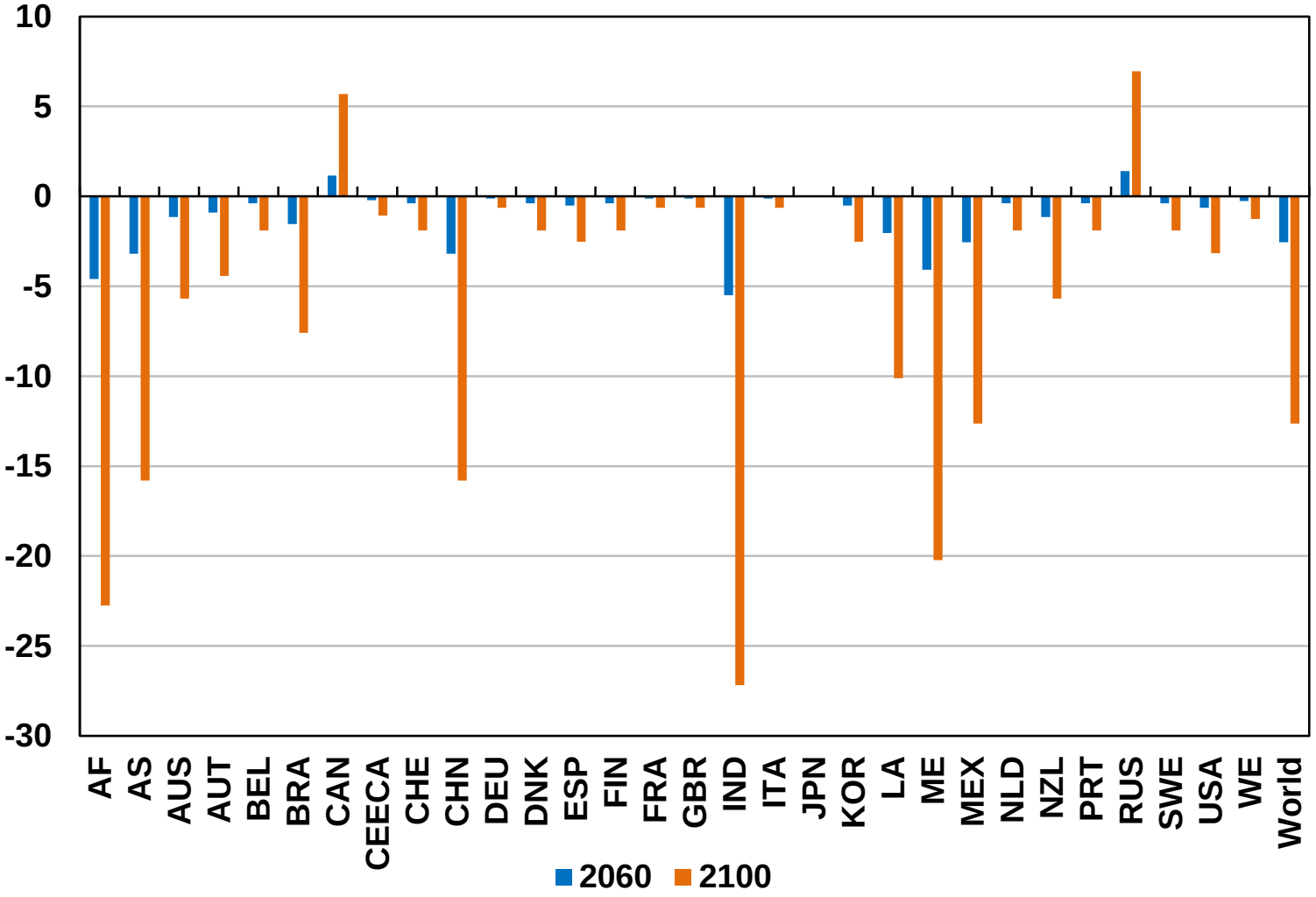
3. Scenarios for the future

➢ Impacts on Global GDP level (in % of GDP)



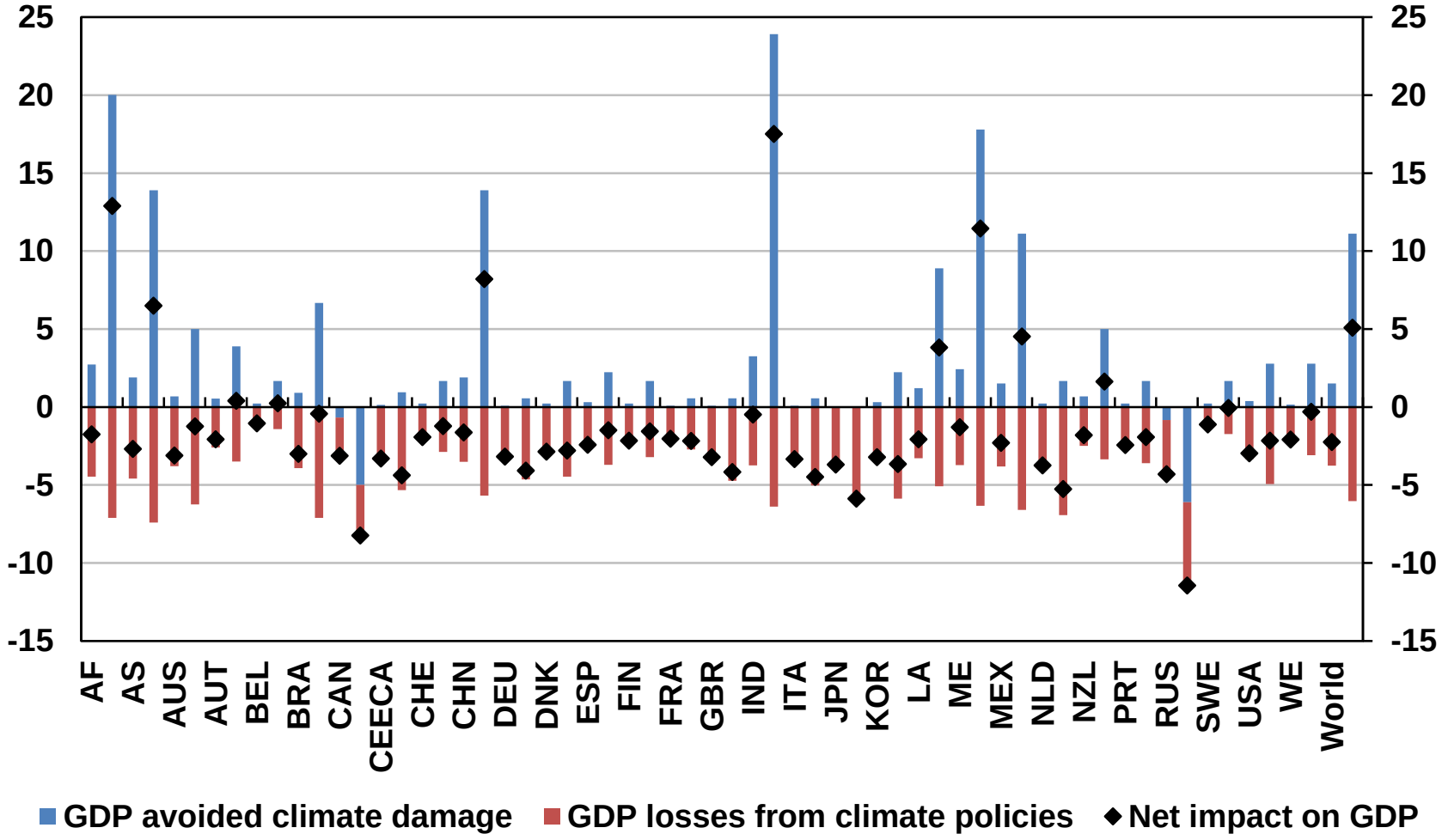
3. Scenarios for the future

- **Business As Usual scenario (BAU)**
  Country / region warming damage on GDP (in % of GDP)



3. Scenarios for the future

- **High Carbon Tax scenario (HCT)**
  Consequences on GDP (in % of GDP) compared to BAU scenario
  For each country, first bar:2060, second bar: 2100



4. Take aways

- **Major damage in case of BAU scenario**
  With wide dispersion in damage across countries / regions
- **Climate policies both generate GDP losses and avoid damage**
- **Two tragedies appear**
  - **The « Tragedy of the horizon »** – At the global level
    In the medium term: GDP losses from climate policies > Avoided damage
    In the very long term: favorable net impact of climate policies
    => Need to discount appropriately long-term horizon damages
  - **The Tragedy of Free-Riding** – for each country / region
    Losses from its own climate policy > Avoided damage from this own policy
    => Need for international coordination
- **Unequal exposure to warming damage**
  - For some countries (Can. Rus.), even a possible supply-side gain (extension of arable land)
  - For numerous developed countries, negative impact of climate policies
    Would not be the case in a longer horizon (2200)
  - For some other countries / regions (Afr., Asia, LA), huge damage

  => Need for international solidarity

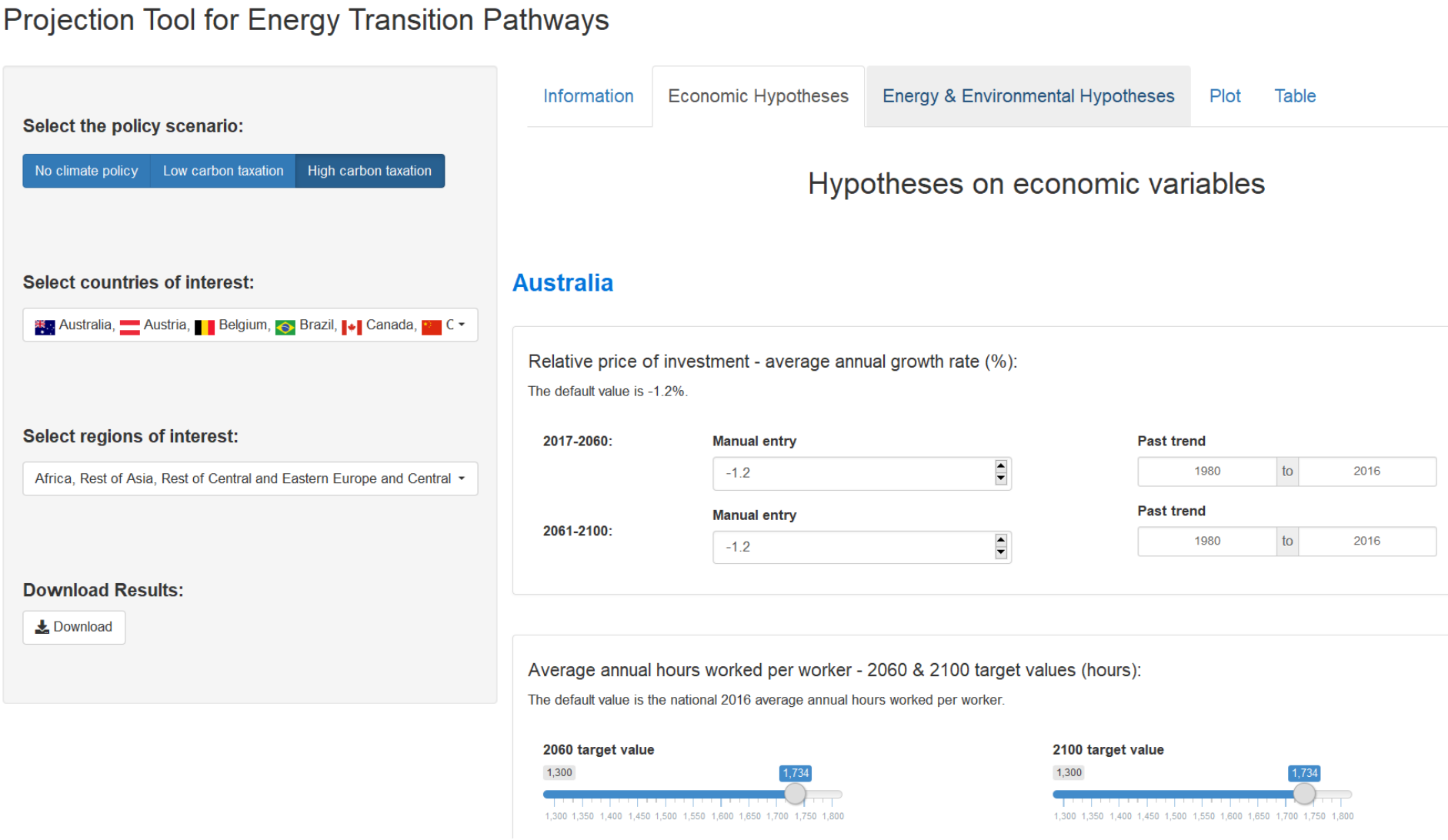
Appendices

A1. Screenshots of the projection tool

A2. Estimation results

A3. Calibration parameters

A1. Screenshots of the projection tool



A1. Screenshots of the projection tool

Parameters

These parameters are identical for all countries.

Elasticity of GDP to the capital stock:

α

Total factor productivity equation:

$$ln(tfp_{i,t}) = \beta_1 + \beta_2 ln(P^{NRJ}_{i,t-1}) + \beta_3 ln(P^{GFCF}_{i,t-1}) + \beta_4 EDU_{i,t-1} + \beta_5 ER_{i,t-1} + \theta_{1985} t_{1985} + \theta_{2012} t_{2012} + \delta_i$$

β_1

1.969871

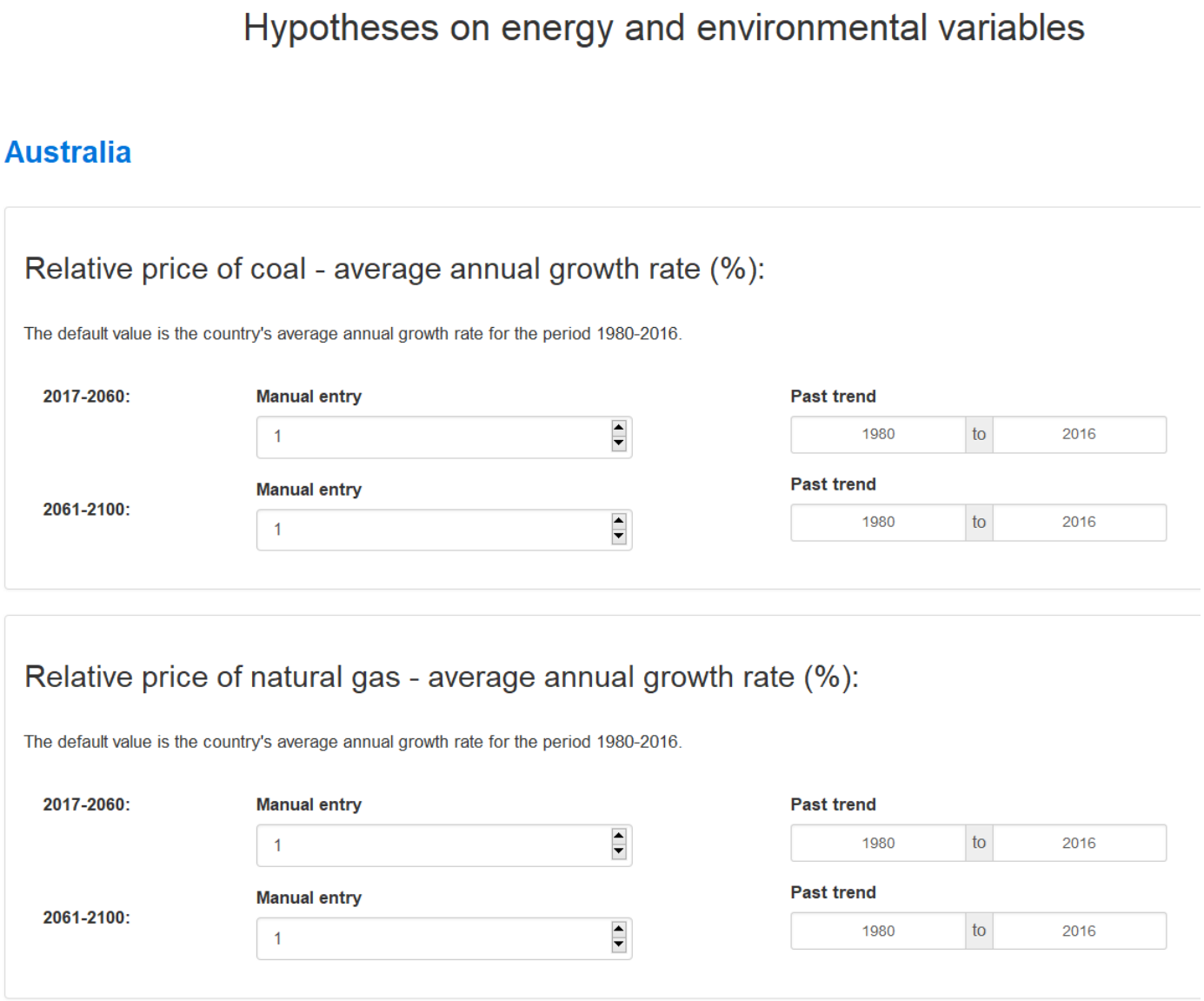
β_2

β_5

-0.4014866

θ_{1985}

A1. Screenshots of the projection tool



A1. Screenshots of the projection tool

Parameters

These parameters are identical for all countries.

Interfuel substitution elasticities:

The default values are estimated from David Stern's meta-analysis (2009) and Papageorgiou (2017).

Coal to natural gas

1.441

Coal to oil

1.067

Coal to electricity

1

Natural gas to oil

2.029

Natural gas to electricity

1.5

Oil to electricity

1

"CO2 emitting" electricity to "non CO2 emitting" electricity

2

A1. Screenshots of the projection tool

Stock of cumulative CO2 emission (tCO2):

The default value is equal to the 2016 World CO2 emissions.

$$StockCO2_t^W = (1 - \rho_1) StockCO2_{t-1}^W + (1 - \rho_2) CO2_t^W - \rho_3$$

ρ_1

0

ρ_2

0

ρ_3

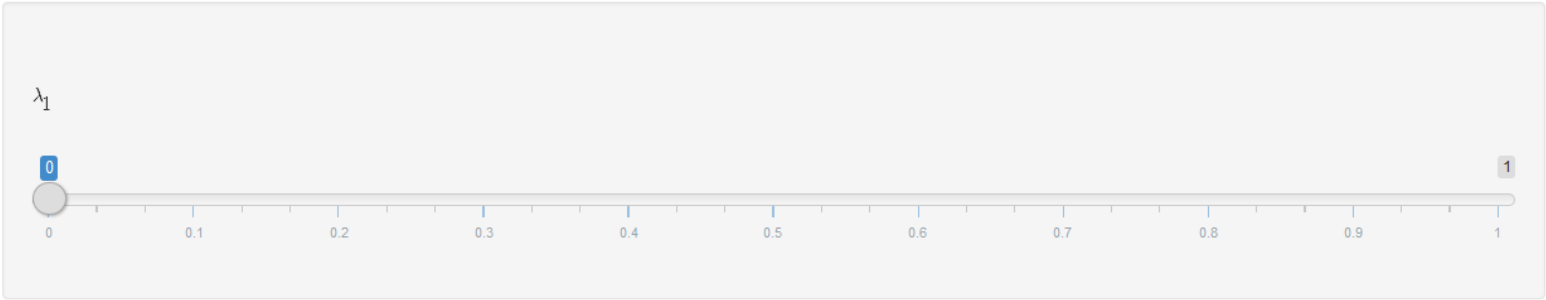
10771406713

A1. Screenshots of the projection tool

Relationship between temperatures (degree Celsius relative to 1850-1900) and cumulative total CO2 emissions (GtCO2):

Default values derived from the Representative Concentration Pathway (RCP) of the Intergovernmental Panel on Climate Change (IPCC, 2014).

$$Temp^W = \lambda_1 \sum StockCO2_t^W$$

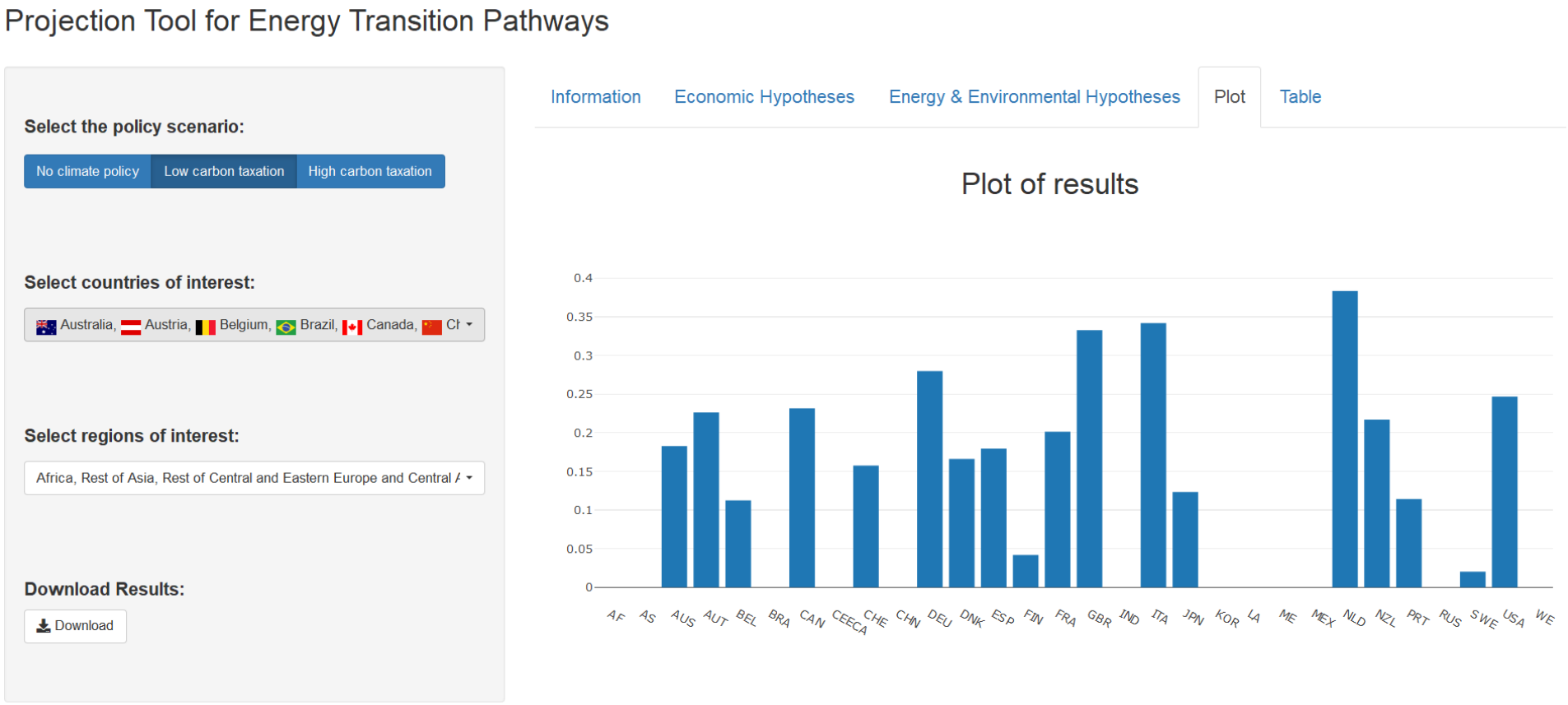


Global climate change damages (% of GDP):

The default values are derived from Nordhaus' review (2017).

$$D_t^{GDP} = \eta_1 Temp_t + \eta_2 Temp_t^2$$

A1. Screenshots of the projection tool



A2. Estimation results

Table 1: Long-run Regression of the Log Total Factor Productivity

	(1) 1980 2017	(2) Different breaks	(3) Without break	(4) With ER and hrs constrained	(5) Without ER	(6) Without country FE	(7) With education not constrained
Log Relative Price of Energy (t-1)	-0.023*	-0.027*	0.083***	-0.025*	-0.009	-0.263***	-0.088***
	(0.011)	(0.012)	(0.011)	(0.012)	(0.011)	(0.025)	(0.010)
Log Relative Price of Investment (t-1)	-0.370***	-0.394***	-0.970***	-0.519***	-0.392***	0.762***	-0.222***
	(0.041)	(0.041)	(0.029)	(0.043)	(0.042)	(0.073)	(0.034)
Education (t-1) (constrained)	0.050	0.050	0.050	0.050	0.050	0.050	-0.057***
	(.)	(.)	(.)	(.)	(.)	(.)	(0.006)
Employment Rate (t-1)	-0.401***	-0.393***	-0.008	-0.500		-1.088***	-0.489***
	(0.073)	(0.074)	(0.086)	(.)		(0.083)	(0.060)
Log Average Hours Worked (t-1)				-0.500			
				(.)			
Break in 1985	0.007***				0.006***	0.017***	0.014***
	(0.000)				(0.000)	(0.001)	(0.001)
Break in 1987		0.007***		0.005***			
		(0.000)		(0.000)			
Break in 2011		-0.009***					
		(0.002)					
Break in 2012	-0.011***			-0.009**	-0.009**	-0.014	-0.015***
	(0.003)			(0.003)	(0.003)	(0.007)	(0.002)
Country FE	Yes	Yes	Yes	Yes	Yes	No	Yes
Observations	672	672	672	672	672	672	672
R^2							0.9622
Adjusted R^2							0.9608

Standard errors in parentheses
All regressions are weighted by countries' Gross Domestic Product
Constant included but not reported
ER: Employment Rate
hrs: average hours worked
Country FE: Country Fixed Effects (with respect to the United States)
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A2. Estimation results

Table 2: Regression of the Country Fixed Effects on Average Regulations

	(1) Country FE on EPL and PMR	(2) Country FE on EPL and PMR	(3) Country FE on EPL and ETCR	(4) Country FE on EPL and ETCR
EPL_ID × PMR_BTI	-0.108*			
	(0.042)			
EPL_IDTC × PMR_BTI		-0.130*		
		(0.055)		
EPL_ID × ETCR_ABPO			-0.009	
			(0.007)	
EPL_ID × ETCR_EB				-0.010
				(0.007)
Observations	18	18	18	18
R^2	0.2902	0.2605	0.0890	0.1006
Adjusted R^2	0.2459	0.2143	0.0320	0.0444

Standard errors in parentheses

Average regulations computed for the time period 1998-2013

Constant included but not reported

Country FE: Country Fixed Effects (With respect to the United States)

EPL: Employment Protection Legislation

ETCR: Energy, Transport and Communication Regulations

PMR: Product Market Regulations

EPL_ID: EPL (individual dismissals), EPL_IDTC: EPL (individual dismissals temporary contracts)

ETCR_EB: ETCR (entry barriers), ETCR_ABPO: ETCR (all but public ownership)

PMR_BTI: PMR (barriers to trade and investment)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A2. Estimation results

Table 3: Regression of the Log Energy Final Consumption

	(1) 1980-2015	(2) With trend	(3) With unitary GDP elasticity	(4) With unitary GDP elasticity, with trend
Log Gross Domestic Product (t-1)	0.965***	0.979***	1.000	1.000
	(0.009)	(0.009)	(.)	(.)
Log Relative Price of Energy (t-1)	-0.670***	-0.544***	-0.681***	-0.543***
	(0.058)	(0.057)	(0.058)	(0.057)
Trend		-0.009***		-0.010***
		(0.001)		(0.001)
Observations	636	636	636	636
R^2	0.9481	0.9534		
Adjusted R^2	0.9480	0.9532		

Standard errors in parentheses

Constant included but not reported

GDP: Gross Domestic Product

country FE: country Fixed Effects (with respect to the United States)

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A3. Calibration parameters

Table 2: Default Values of the Scenario Hypotheses

	Developed countries	Emerging countries or regions
$P_{i,t,c}^{nrj}$	Depends on the scenario choice	
$Pk_{c,t}$	-1.2%	
$EDU_{t,c}$	Convergence towards the Australian' 2016 level in 2060 (the country of our panel with the highest level of education)	
$H_{t,c}$	The national 2016 average annual hours worked per worker	No change
$ER_{t,c}$	The national 2016 employment rate	No change
$EPL_{t,c}$	The national 2016 Employment Protection Legislation index value	No change
$PMR_{t,c}$	The national 2016 Product Market Regulations index value	No change

A3. Calibration parameters

Table 3: Interfuel substitution elasticities

Energy Types		*CO_2-emitting*				*Non-CO_2-emitting*
		Coal	**Oil**	**Natural Gas**	**Electricity – CO_2-emitting inputs**	**Electricity – non-CO_2-emitting inputs**
CO_2-emitting	**Coal**		1	1.5	1	1
	Oil	1		2	1	1
	Natural Gas	1.5	2		1.5	1.5
	Electricity – CO_2-emitting inputs	1	1	1.5		2
Non-CO_2-emitting	**Electricity – non-CO_2-emitting inputs**	1	1	1.5	2	

A3. Calibration parameters

Table 4: coefficient of CO_2 emissions per energy type

Energy types	**Default emission factors** (tCO_2-eq/MWh)
Coal	0.359
Oil (heating oil, gasoline, diesel)	0.307
Natural Gas	0.240
Electricity – CO_2 emitting energy	0.321
Electricity – non-CO_2 emitting energy	0.017

Source : computations from the default emission factors of the Covenant of Mayors for Climate and Energy report, 2017

A3. Calibration parameters

Table 5: Damages from selected climate change impacts, central projection

GDP % compared to baseline

Region	Country or Sub-region	Damages
Africa		-3.6
Asia		-2.5
	China	-2.5
	India	-4.3
	Japan	0.0
	South Korea	-0.4
Central and Eastern Europe and Central Asia		-0.17
	Russia	1.1
Latin America		-1.6
	Brazil	-1.2
	Mexico	-2.0
Middle East		-3.2
North America		-0.4
	Canada	0.9
	United States	-0.5
Oceania		-0.9
	Australia	-0.9
	New-Zealand	-0.9
Western Europe		-0.2
	France	-0.1
	Germany	-0.1
	Italy	-0.1
	Spain	-0.4
	United Kingdom	-0.1
	Other	-0.3

Source : computations from *OECD, 2015*