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This study was commissioned by, and completed with the guidance of, the Presidential Climate Commission

Support South Africa's Presidential Climate Commission building consensus on key policy recommendations for just transition pathways to net zero

Modelling results

Cambridge Econometrics

June 2024, last updated: Oct 2023

This publication was funded by the European Union. Its contents are the sole responsibility of Cambridge Econometrics and do not necessarily reflect the views of the European Union.'

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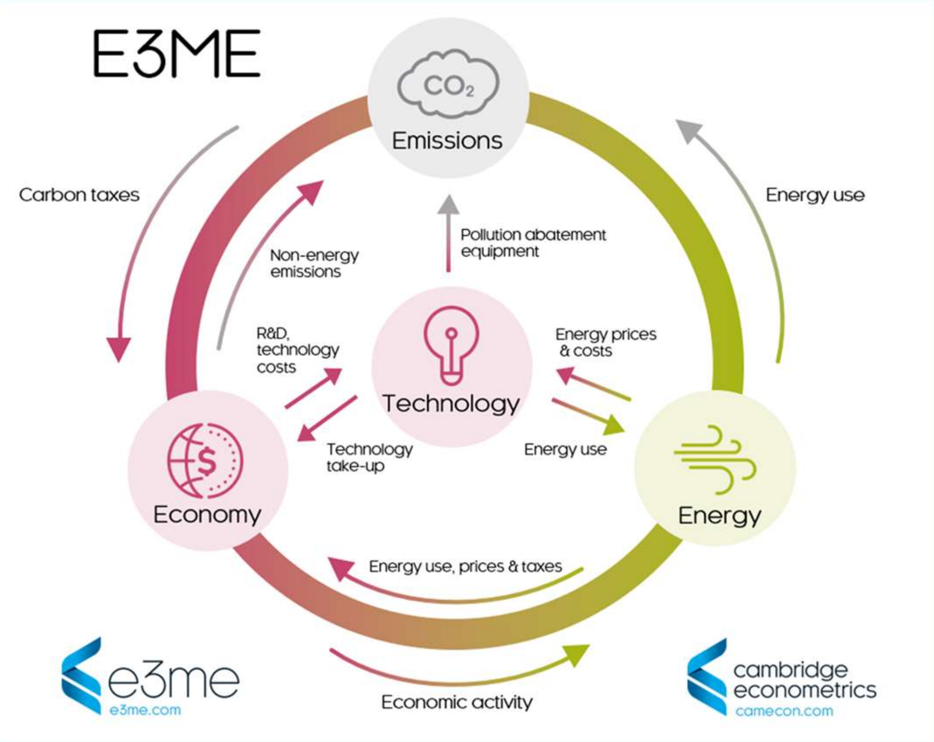
E3ME modelling

The goal is to capture socio-economic and energy implications of global developments × South Africa climate developments



We use **E3ME**, a non-equilibrium macroeconomic simulation model with E3 / IAM type representation of energy use and environmental impacts

- Simulation model, demand-led with supply constraints, non-equilibrium
- Multi-regional model (71 world regions), but different economic, labour, energy system characteristics and different behavioural parameters estimated on historical data
- 42 industry sectors within those regions, with own behavioural equations, 27 consumption categories
- Consumption and investment demand is converted into sectoral output with statistical converters and input-output matrices
- The model is frequently used for policy assessment internationally, see notes

Notes: The model was developed and is maintained by Cambridge Econometrics.

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Scenario design
Scenarios capture the interaction of global climate developments x South Africa climate developments

Scenario definitions

E3ME, being a multi-regional model, can simulate global x South Africa interactions, considering multiple policies and both global and local (to South Africa) measures.

BAU-BAU	Business-as-usual scenario for South Africa and the rest of the world. Energy system development follows current trends (calibrated to IEA STEPS) carbon taxes are minimal, there are no carbon border adjustment (CBA) measures, there is no Just Transition funding available for South Africa.
NZ-BAU	Decarbonisation / 1.5°C compatible pathway for South Africa, assuming energy system plans somewhat more ambitious than IRP, carbon taxation and revenue recycling of carbon tax revenues, in tandem with international Just Transition funding from partnership countries and from MDBs.
BAU-1.5°C	Business-as-usual scenario for South Africa as in BAU-BAU scenario, but 1.5°C compatible pathway in rest of the world, including energy efficiency improvements, deployment of renewables as well as global carbon taxes. South Africa faces an export penalty on goods with high embedded carbon content from other countries.
NZ-1.5°C	A combination of NZ-BAU and BAU-1.5°C. Both South Africa and the RoW aim for a 1.5°C compatible pathway, bringing in carbon taxes, energy system developments as well as international Just Transition funding for South Africa.

Notes: IRP – Integrated Resources Plan; MDB – Multilateral Development Bank

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Scenario design

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Scenario definitions

E3ME, being a multi-regional model, can simulate global x South Africa interactions, considering multiple policies and both global and local (to South Africa) measures.

South Africa goal	Global developments	Energy system development	Carbon tax levels (SA)	Export penalty on high carbon goods	Revenue recycling	International Just Transition funding
Climate pathway assumption for South Africa, either BAU (continued trends) or 1.5°C compatible.	Global climate pathway assumption, i.e., what happens outside of SA. Either BAU (continued trends) or 1.5°C compatible.	How the energy system will develop in South Africa. This either follows current trends or a pathway more ambitious than the current IRP.	Carbon tax on heavy industry and power generation in South Africa, with prices compatible to 1.5°C.	Whether exports from SA are penalised based on their embedded carbon content. Only relevant if global assumption is 1.5°C pathway.	If carbon taxes are collected in SA, how they are used. Carbon taxes are generally recycled towards energy efficiency and subsidizing household electricity price.	It is assumed that international Just Transition (JT) funding is conditional on SA aiming for a 1.5°C goal. JT funding is assumed to be spent on power generation transformation, and investment into sectors such as vehicles and H2.

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Scenario design – International funding

International funding is assumed to be a combination of IPG offer and MDB financing following JET IP

Scenario definitions

International Just Transition funding	Detailed assumptions
It is assumed that international Just Transition (JT) funding is conditional on SA aiming for a 1.5°C goal. JT funding is assumed to be spent on power generation transformation, and investment into sectors such as vehicles and H2.	JT funding is assumed as follows: • We assume that the IPG offer of US$8.5 billion is spent over 4 years, i.e., leading to an annual spending of US$2.1 from IPG source • We further assume that this is matched by an equal amount from MDB sources, i.e., leading to an overall annual amount of US$4.2 • These assumptions are mostly in line with the South Africa's JET IP document (pp124-125) • Further, based on the JET IP, we assume that about 70% of the available amount is spent on financing the transition in the power sector • While the rest (30%) is spent on further 'green' measures: these include improving municipal capacity, hydrogen production and investment in the vehicles sector

Notes: JT – Just Transition; IPG – International Partners Group

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Scenario design

Scenarios capture the interaction of global climate developments x South Africa climate developments

Scenarios

E3ME, being a multi-regional model, can simulate global x South Africa interactions, considering multiple policies and both global and local (to South Africa) measures

	Energy system development	Carbon tax levels (SA)	South Africa goal	Global developments	Export penalty on high carbon goods	Revenue recycling	International Just Transition funding
BAU-BAU	BAU	No	No	3+ °C	No	No	No
NZ-BAU	IRP+	Yes, 1.5°C	1.5°C compatible pathway	3+ °C	No	Yes, energy efficiency, residential electricity subsidies	Yes, annual 8.5 bn USD from JTP and MBDs
BAU-1.5°C	BAU	No	No	1.5°C	Yes	No	No
NZ-1.5°C	IRP+	Yes, 1.5°C	1.5°C compatible pathway	1.5°C	No	Yes, energy efficiency, residential electricity subsidies	Yes, annual 8.5 bn USD from JTP and MBDs

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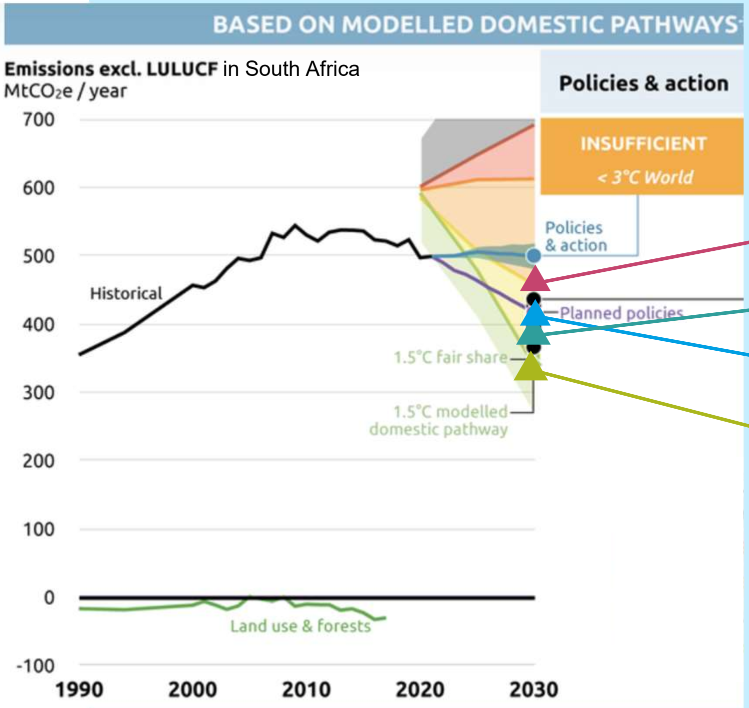
Key indicators by 2030

Apart from BAU-BAU, all scenarios achieve the NDC target, but other than NZ-1.5°C they fail to achieve the 1.5°C fair share

Scenarios[1,2]



SA-World	GDP SA, 2030	Emp SA, 2030	Emission SA, 2030	Climate outcome (global)
	difference from BAU-BAU %	*difference from BAU-BAU %*	*total $MtCO_2$*	
BAU-BAU	-	-	**471 $MtCO_2$ / yr**	over 3°C
NZ-BAU	+8.6%	+1.5%	**376 $MtCO_2$ / yr**	over 3°C
BAU-1.5°C	-4.2%	-0.5%	**401 $MtCO_2$ / yr**	1.5°C
NZ-1.5°C	+2.4%	+0.7%	**313 $MtCO_2$ / yr**	1.5°C
NDC target			**350–420 $MtCO_2e$**	
1.5°C fair share			**340 $MtCO_2e$**	1.5°C

Notes: 1 – preliminary E3ME modelling results; 2 - CAT, https://climateactiontracker.org/countries/south-africa/

Key indicators

Decarbonization has a positive impact on the South African economy, regardless of global developments

Key results

	South Africa goal	Global developments	GDP SA 2030	GDP SA 2040	Emp SA 2030	Emp SA 2040	CO_2 SA 2030	CO_2 SA 2040
BAU-BAU	NDC goal	3+ degree						
NZ-BAU	1.5°C compatible pathway	3+ degree	+8.6%	+7.5%	+1.5%	+2.1%	-20.0%	-53.3%
BAU-1.5°C	NDC goal	1.5°C degree	-4.2%	-3.9%	-0.5%	-0.2%	-14.8%	-28.9%
NZ-1.5°C	1.5°C compatible pathway	1.5°C degree	+2.4%	+0.9%	+0.7%	+1.3%	-33.6%	-73.7%

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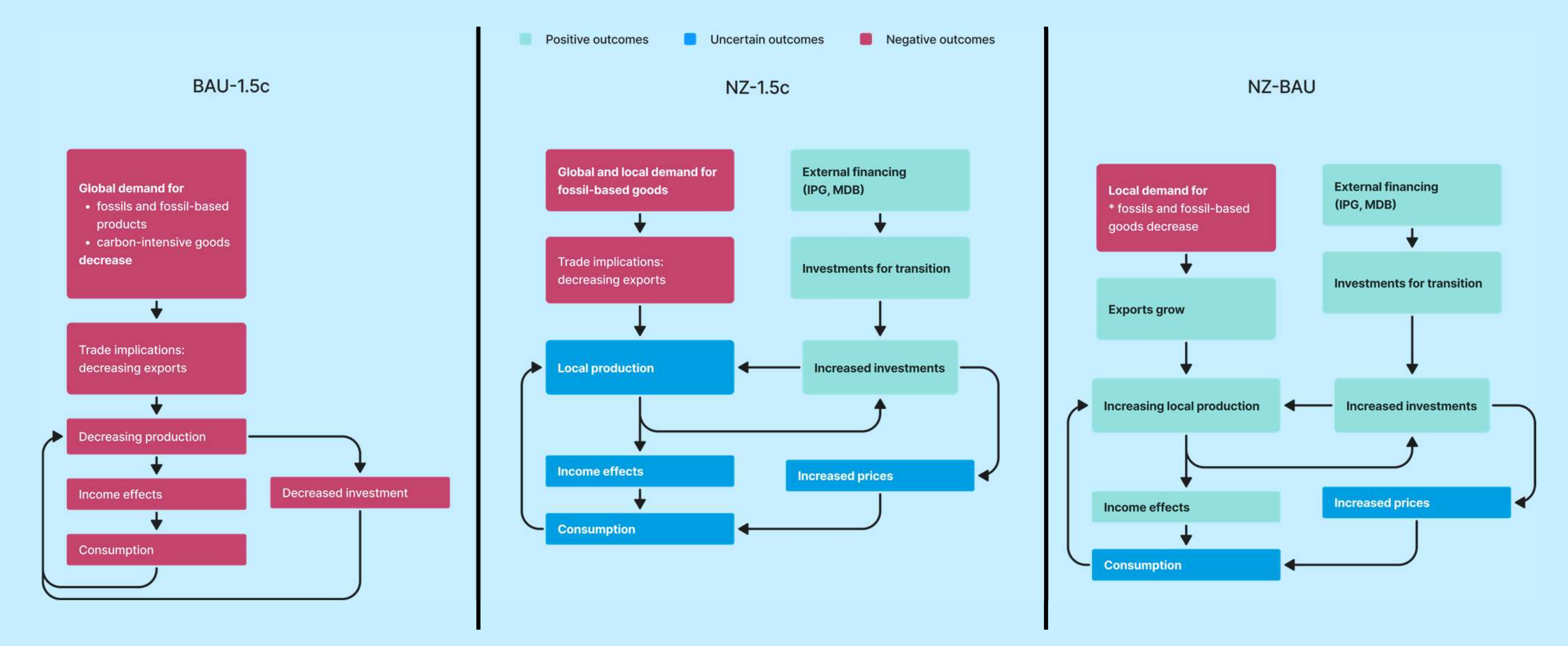
Economic results – overview of impact channels

RoW action has implications through trade channels, in SA-NZ cases investments for transition balances this effect

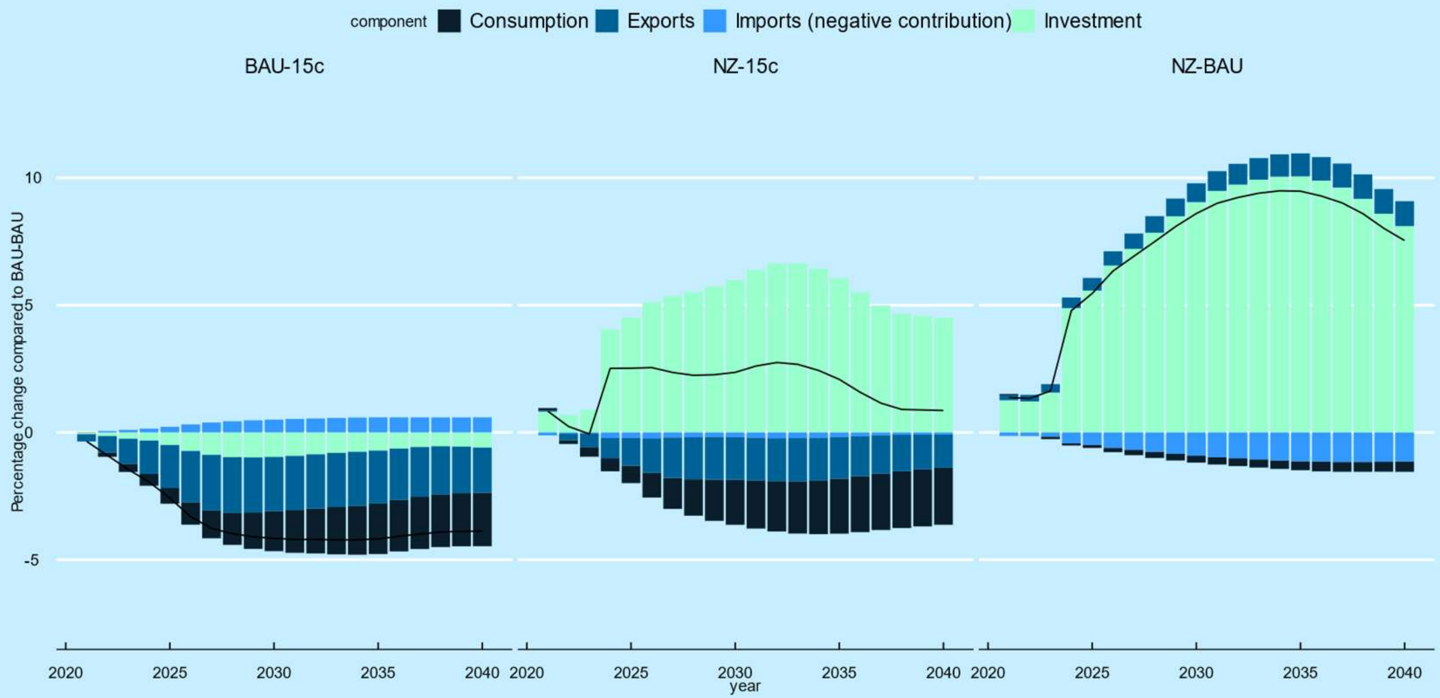
GDP



Economic results – excluding climate damages

If RoW goes for 1.5°C, SA loses exports, even more if SA does not decarbonise itself; investment in the transition can offset losses

GDP

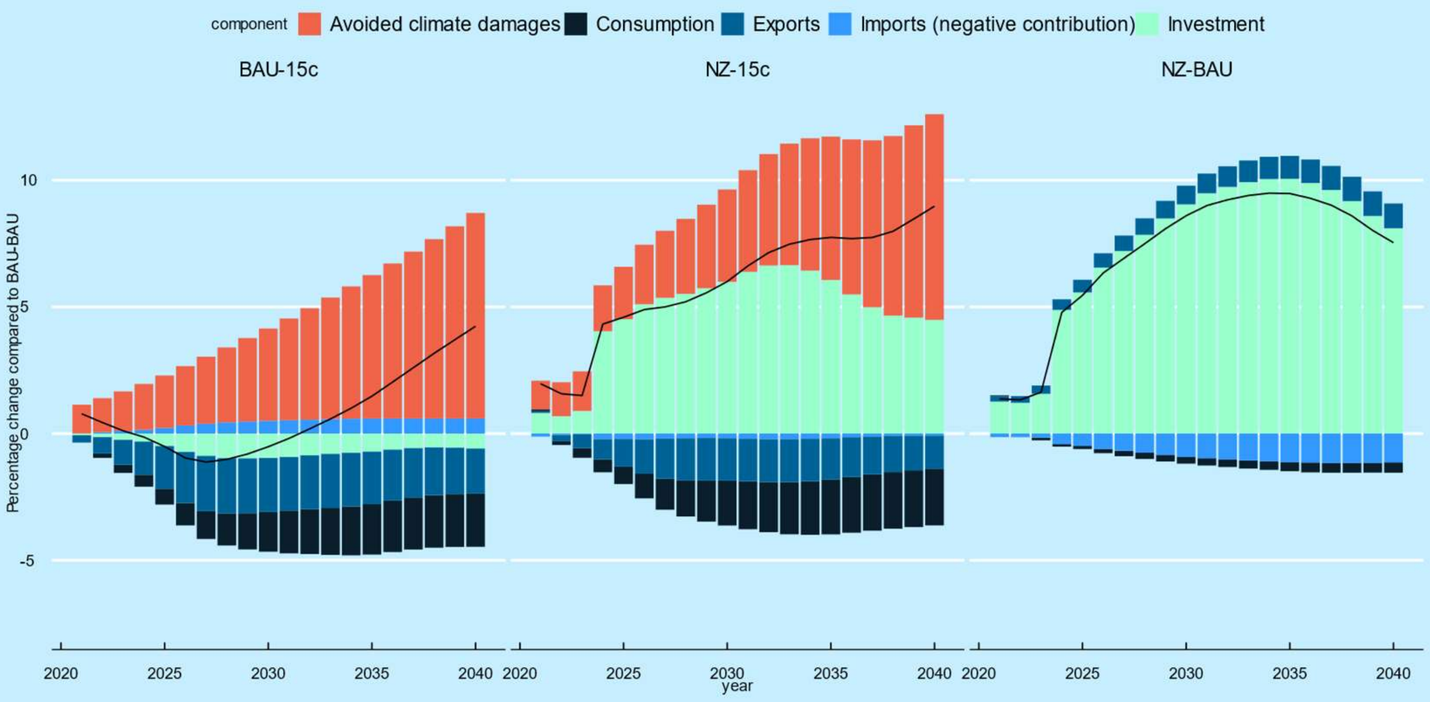


- Loss of exports drive the scenario results if the rest of the world decarbonises
- Investments – necessary for the transition – balance negative impacts in NZ-1.5°C scenario
- Consumption follows export losses, but is further decreased because of price increases (due to investment magnitudes)
- These results do not yet consider climate damages

Economic results – including climate damages

If we consider the economic impact of climate damages decarbonisation has more positive economic impacts

GDP w/ climate damages



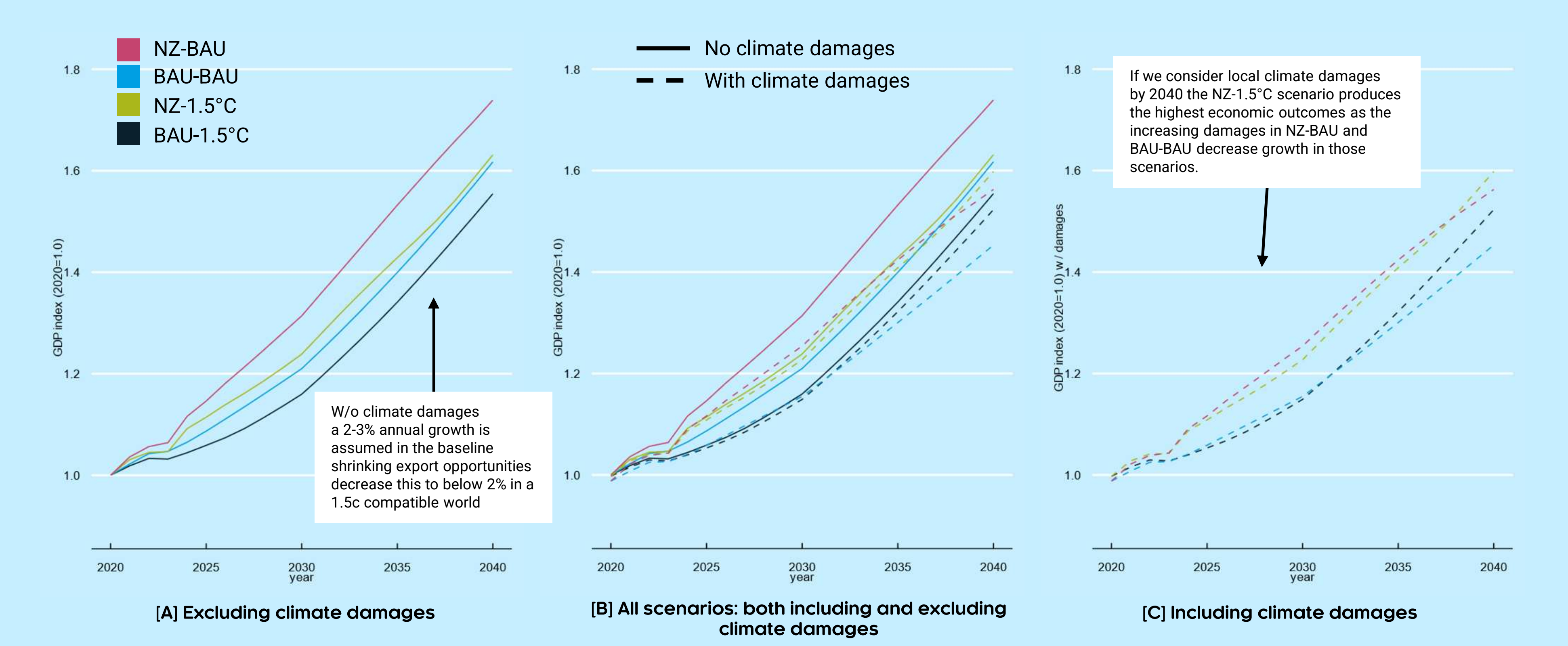
- Incorporating the effect of climate damages substantially increases returns in a 1.5°C world
- Figures still display outcomes compared to a BAU-BAU case, with a global warming outcome of over 3°C (by 2100); avoided climate damages are indicative, calculated based on Burke, Hsiang and Miguel (2015)
- Climate damages take local productivity decrease into account, they do not account for extreme whether events (e.g., droughts, floods) and interaction effects (i.e., climate damages in one jurisdiction might lead to losses in another)

Source: Burke, M., Hsiang, S.M., Miguel, E., 2015. Global non-linear effect of temperature on economic production. Nature 527, 235–239. https://doi.org/10.1038/nature15725

Economic results

Results need to be viewed in the context of economic growth in the baseline: 2-3% annual long-term growth

GDP index (2020=1.0)



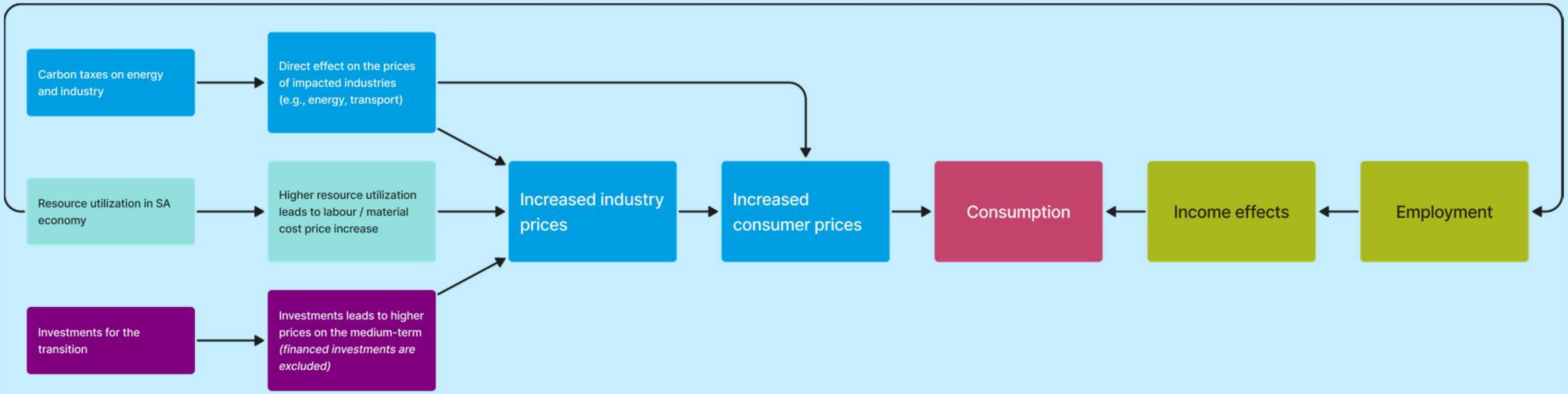
Note: indicative local climate damages are calculated based on Burke, M., Hsiang, S.M., Miguel, E., 2015. Global non-linear effect of temperature on economic production. Nature 527, 235–239. https://doi.org/10.1038/nature15725

Economic results

Transition investments and carbon pricing lead to price increases, that trickle through to the economy

Price impacts captured in the modelling

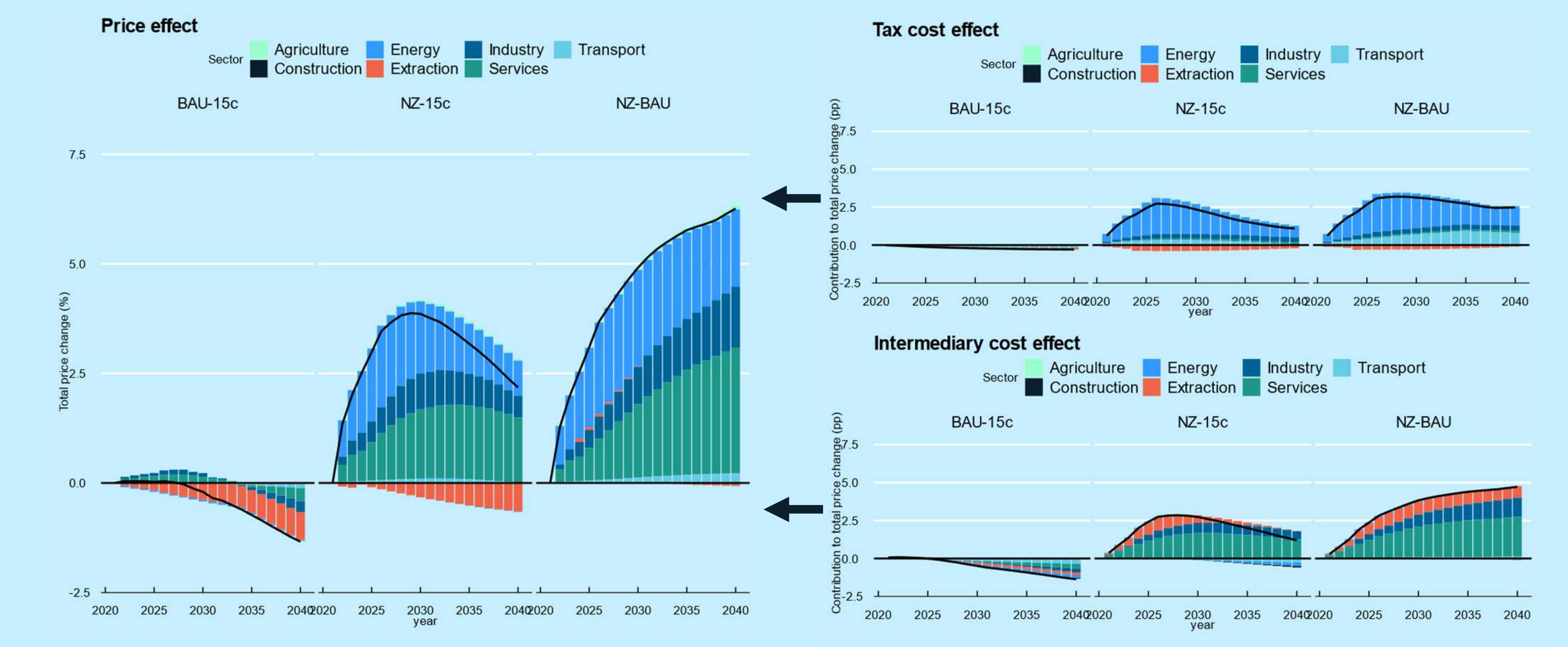
While the magnitude of price impacts is limited price pressures appear in most of the economy both because of generally higher utilization and because of increased energy prices, which are used in all industries. While price increases cause somewhat decreasing consumption this is offset by increasing employment and consecutive income effects that cause consumption to increase.



Economic results

Transition investments and carbon pricing lead to price increases, that trickle through to the economy

Price level difference (%*) compared to BAU-BAU

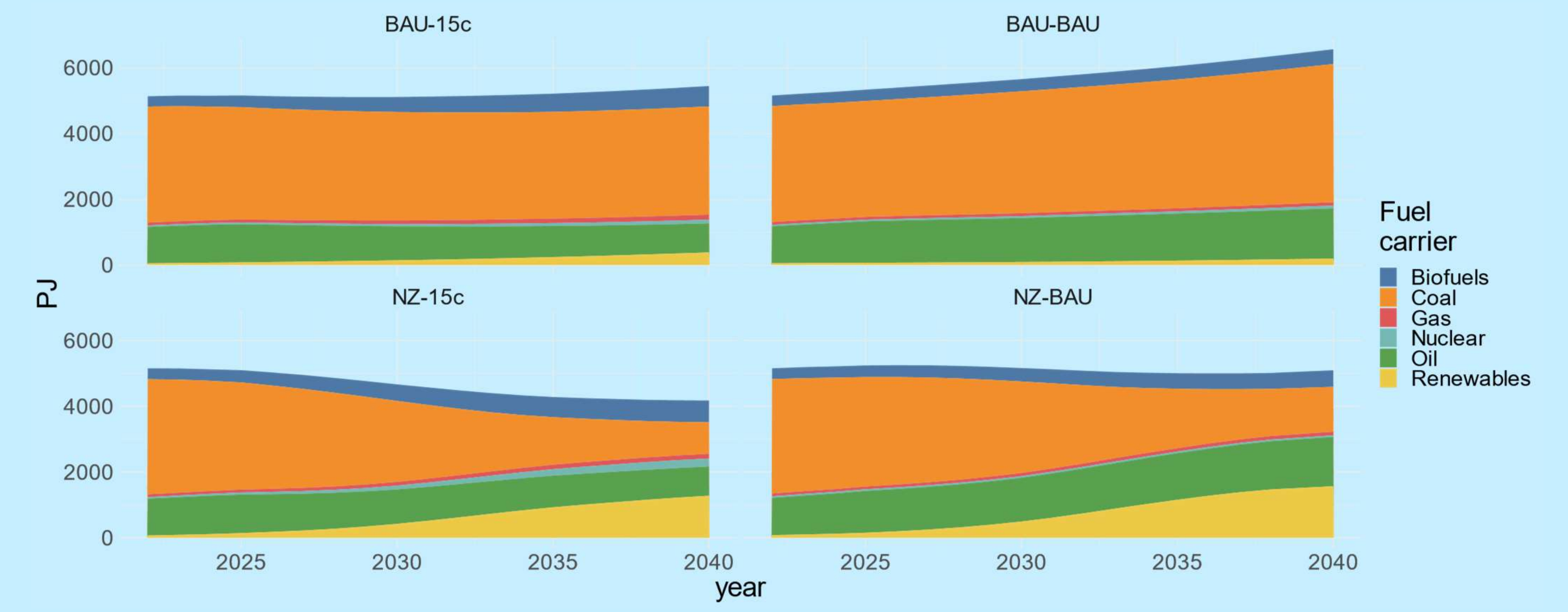


Note: * 0.1 translates to 10% increase | Price effect in total is composed of cost change of intermediary inputs (excl. labour), tax cost change and labour cost change (not pictured here)

Energy results – primary energy

Other than BAU-BAU, energy intensity decreases. NZ in SA scenarios consider substantial energy efficiency improvements. Coal is still in the mix by 2040 in all cases, yet in varying degrees.

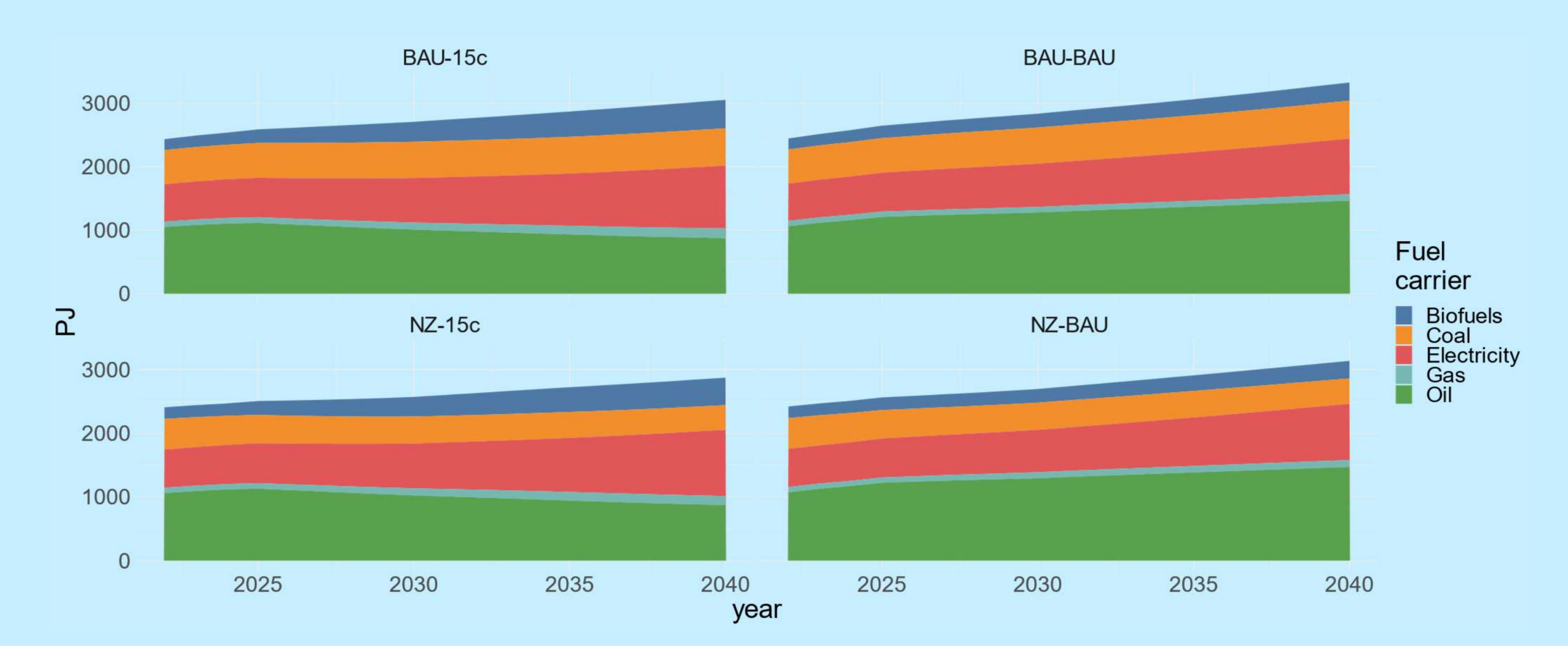
Primary energy demand



Energy results – final energy

NZ in SA scenarios imply a substantial reduction of coal use, while global 1.5°C achievement decreases oil use.

Final energy demand

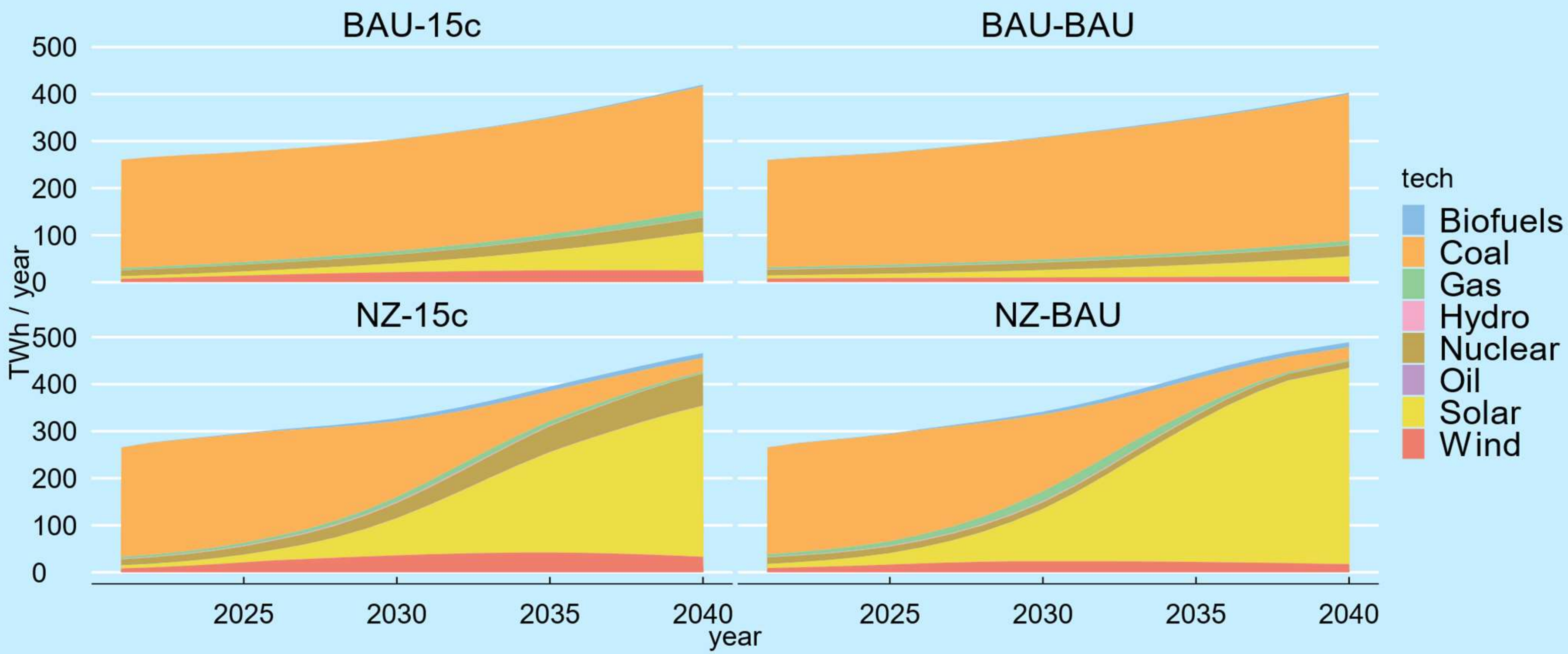


Energy results

The power-generation mix shifts away from coal in the NZ cases, role of solar and wind is dominant, however, the lower energy demand also means a somewhat slower transition (NZ-1.5°C vs NZ-BAU)

ToC

Power generation

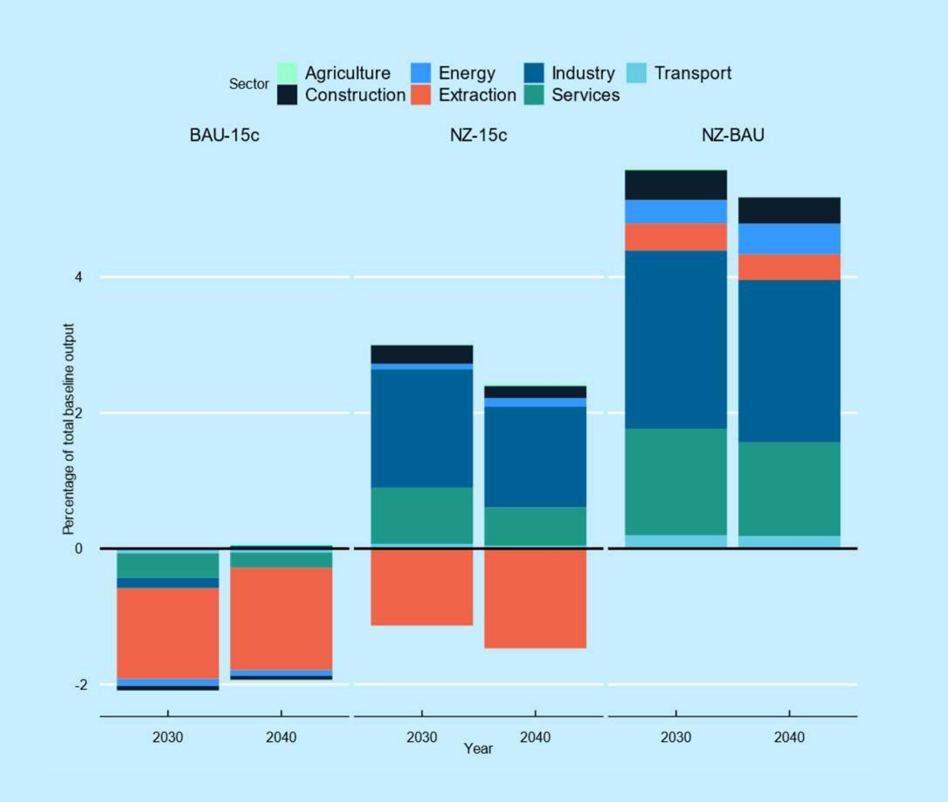


Sectoral results

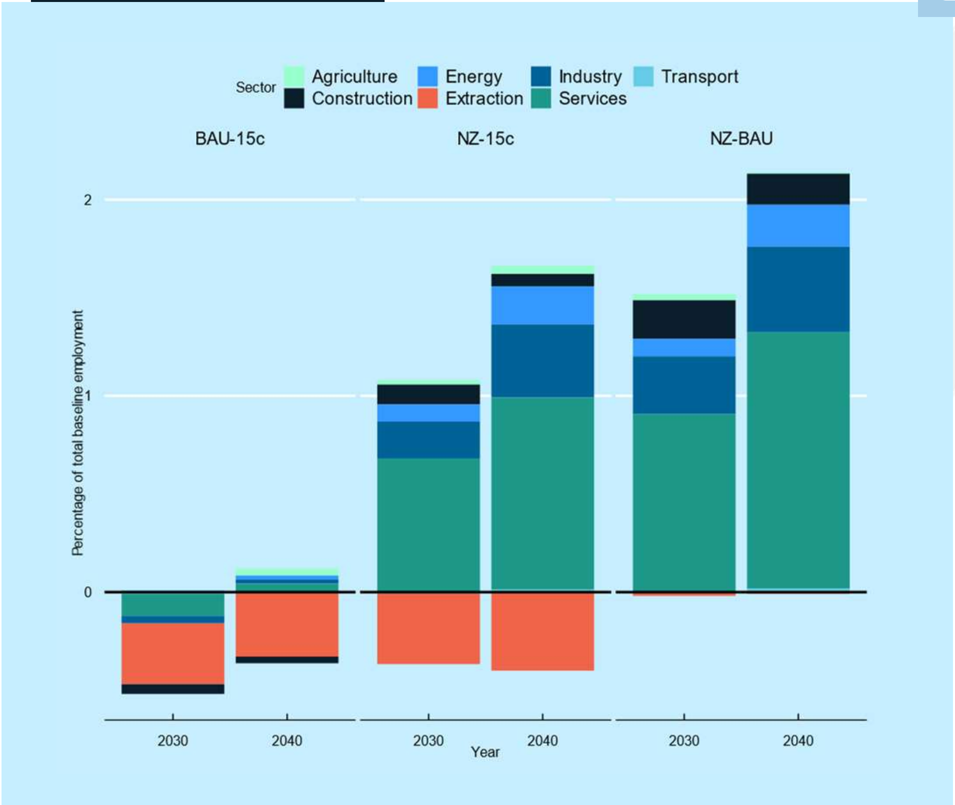
Loss of exports (1.5°C) leads to output and sectoral losses in extraction, but NZ investments induces gains industry/energy/construction, this outweighs losses by 2040

ToC

Sectoral output



Sectoral employment



Sectoral results

Several sectors can gain from a net-zero transition in SA, but the distribution of impacts is dependent on global developments as well

Output (by 2040)

Extraction decreases in all cases, where globally the world works towards a 1.5°C pathway. Output in the **energy and constructions** sectors is driven by two main factors: first, global action initially leads to decreased economic activity, due to this we see a decrease in both sectors in BAU-1.5°C. However, if the transition process itself can lead to a boost of the economy, with a particular impact on these sectors: that's what we see in NZ-1.5°C. Other sectors, such as **industry, services and transport** follow suit, mainly driven by income and indirect effects. In **industry** particularly supplier sectors that are important for green industries, such as **electronics, mechanical engineering** drive the growth.

scenario	Agriculture	Construction	Energy	Extraction	Industry	Services	Transport
BAU-1.5°C	1%	-1%	-3%	-25%	0%	0%	-2%
NZ-1.5°C	1%	4%	4%	-24%	5%	1%	1%
NZ-BAU	0%	8%	14%	6%	7%	3%	5%

Note: % difference, compared to BAU-BAU.

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Sectoral results

Several sectors can gain from a NZ transition in SA, but the distribution of impacts is dependent on global developments as well

Employment (by 2040)

Employment generally follows economic activity trends. It drops in the **extraction** sector in both cases where a global 1.5°C pathway is followed. It increases, however, in **construction and energy**, when decarbonization is happening in SA (NZ-1.5°C and NZ-BAU). Industry employment is also increasing more than its output, meaning that the overall GVA share of the industry output is growing in the simulation. This is a result of higher average wages in the simulation due to **higher resource utilization** in the economy and eventually **decreasing unemployment.**

scenario	Agriculture	Construction	Energy	Extraction	Industry	Services	Transport
BAU-1.5°C	1%	-1%	2%	-17%	0%	0%	0%
NZ-1.5°C	1%	1%	14%	-21%	2%	2%	0%
NZ-BAU	0%	2%	15%	-1%	3%	2%	0%

Note: % difference, compared to BAU-BAU.

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Sectoral results

Several sectors can gain from a net-zero transition in SA, but the distribution of impacts is dependent on global developments as well

Prices (by 2040)

Prices reflect both investments, increasing resource utilization and slightly increasing tax burdens. In the **energy** sector, prices substantially increase due to carbon pricing and new investments. However, the price increase is much smaller in the NZ-1.5°C case as technology prices are decreasing globally due to strong renewable deployment across the world. In the **extraction** sector prices drop as demand, especially export demand falls. While in **industry and services** decarbonization results in both higher energy prices which channel into sectoral prices and increasing resource utilization (i.e., higher employment, higher wages) which again results is some increases.

scenario	Agriculture	Construction	Energy	Extraction	Industry	Services	Transport
BAU-1.5°C	-1%	0%	1%	-9%	-1%	-1%	-2%
NZ-1.5°C	3%	0%	40%	-9%	2%	3%	0%
NZ-BAU	6%	0%	74%	-1%	6%	6%	5%

Note: % difference, compared to BAU-BAU.

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Summary

South Africa would gain from decarbonising its economy, even if global action is less than what's needed to keep global warming within 1.5°C

1. **The scenarios results support the idea that decarbonisation comes with both gains and losses**

   Our results show that investments related to the transition can create new jobs and add to economic activity, therefore boosting employment and economic growth

2. **Just transition investments and financial support are likely to be necessary to mitigate losses**

   Investments associated with the JTP and MBD financing are important instruments to mitigated losses and support growth

3. **The transition brings sectoral transformation and requires labour mobility**

   While the net effects on employment and economic activity might be zero or even positive, the process itself implies significant labour mobility across sectors. This needs to be supported by policies to facilitate that mobility and reskilling.

4. **South Africa should have an interest in limiting climate damages**

   Already by 2040 expected climate damages substantially impact productivity, and extreme weather events would impact infrastructure even further with adverse impacts mostly falling on vulnerable groups with limited means for adaptation. A global 1.5°C pathway can mean over 5% of GDP avoided losses.

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Next steps

Potential new research directions stemming from this work

This modelling exercise has aimed to provide an overview of the interactions between global climate action and mitigation ambition in South Africa, focusing on the macroeconomics and sectoral outcomes; while we hope that the results and the interpretation can provide some insights there are various questions and areas that need to be addressed with rigorous analysis, below we provide some points on these, noting that we have collected ideas from various stakeholders, but this is still far from a comprehensive list:

a. Modelling of emerging 'green industries' and new industrial opportunities

While our modelling considers some trade implications it is unable to fully capture the opportunities and challenges of new 'green' industries. Products of these industries are expected to be globally demanded and as such they can provide ample opportunities for economic progress, including battery production, sustainable building materials, waste processing, carbon capture and storage, etc.

b. Modelling and understanding distributional impacts

It is understood that the "Just Transition" has many dimensions: we need to have a just transition in a global sense, i.e., making sure that countries are not left behind, but we also need to ensure a just transition in a national sense, enabling the most vulnerable groups to benefit from the transition. Therefore, analysis on the within country distributional effects of both climate damages and transition would be beneficial.

c. Skills and competencies forecast and labour market transformation

The low-carbon transition will require a flexible labour force and mobility between sectors as well as upskilling and reskilling of the existing workforce. In addition to a pre-existing unemployment problem this means that South Africa should be able to understand the expected labour, skill and competency opportunities and needs of the future. There are examples of doing this, e.g., in Europe the CEDEFOP skills forecast aims to fill the gap.

d. Understanding the strategies and roles of key players

While this analysis has taken a macro-level view to the low-carbon transition even in this context it is inevitable to talk about the strategy and role of key firms in the South African economy strongly linked to the current energy structure such as SASOL and ESKOM. In the case of these companies we believe that detailed, micro level analysis is required to understand the organization opportunities and challenges.

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Ioannis Gutzianas, economist

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Modelling has been carried out by Cambridge Econometrics using the E3ME global macroeconometric model. Work has been carried out in co-operation with the Presidential Climate Commission of South Africa, under the project "Support to the EU's Bilateral Relations with Strategic Partners on Climate-Related Policies and Investment (SPIPA II)", with reference to the contract "Modelling of key sectors' decarbonization pathways RSA01".

Last updated: 04/10/2023

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Change log

Release date	Changes
10/03/2023	• Added Appendix • Added slide 6, detailed explanation of assumptions on external financing • Modelling mechanics for the treatment of energy efficiency investments has changed, we have removed an effect where energy efficiency investments caused labour-intensity to drop in industry sectors; while we still believe that there is a potential labour-capital substitution in industrial sectors, as are represented in the model by default, we believe that this linkage might not be fully relevant in the case of energy efficiency investments, as the investments here do not lead to higher labour productivity, but lead to higher energy-productivity; this also has implications for prices, i.e., energy efficiency investments are not considered “price increasing” investments as they are paid for by revenue recycling and external financing; this has led us to update results on slides 7-10, 12-14, 16-22 • Added slide 24, discussing future research directions • Added slides 11 and 15 explaining impact channels that are captured in the scenarios • Slides 16 and 17 were updated to sufficiently capture changes in final and primary energy demand • Minor changes to formatting and text across the slides

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Appendix

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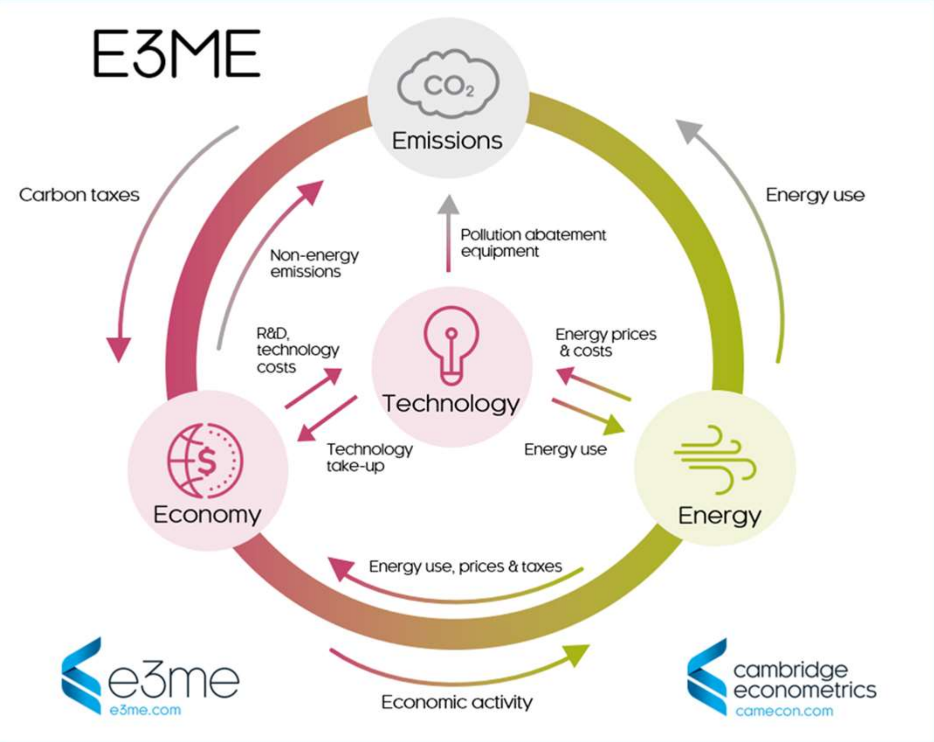
E3ME modelling

The goal is to capture socio-economic and energy implications of global developments × South Africa climate developments



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- The model is frequently used for policy assessment internationally, see notes

Notes: The model was developed and is maintained by Cambridge Econometrics. **Further information can be found at** https://E3ME.com

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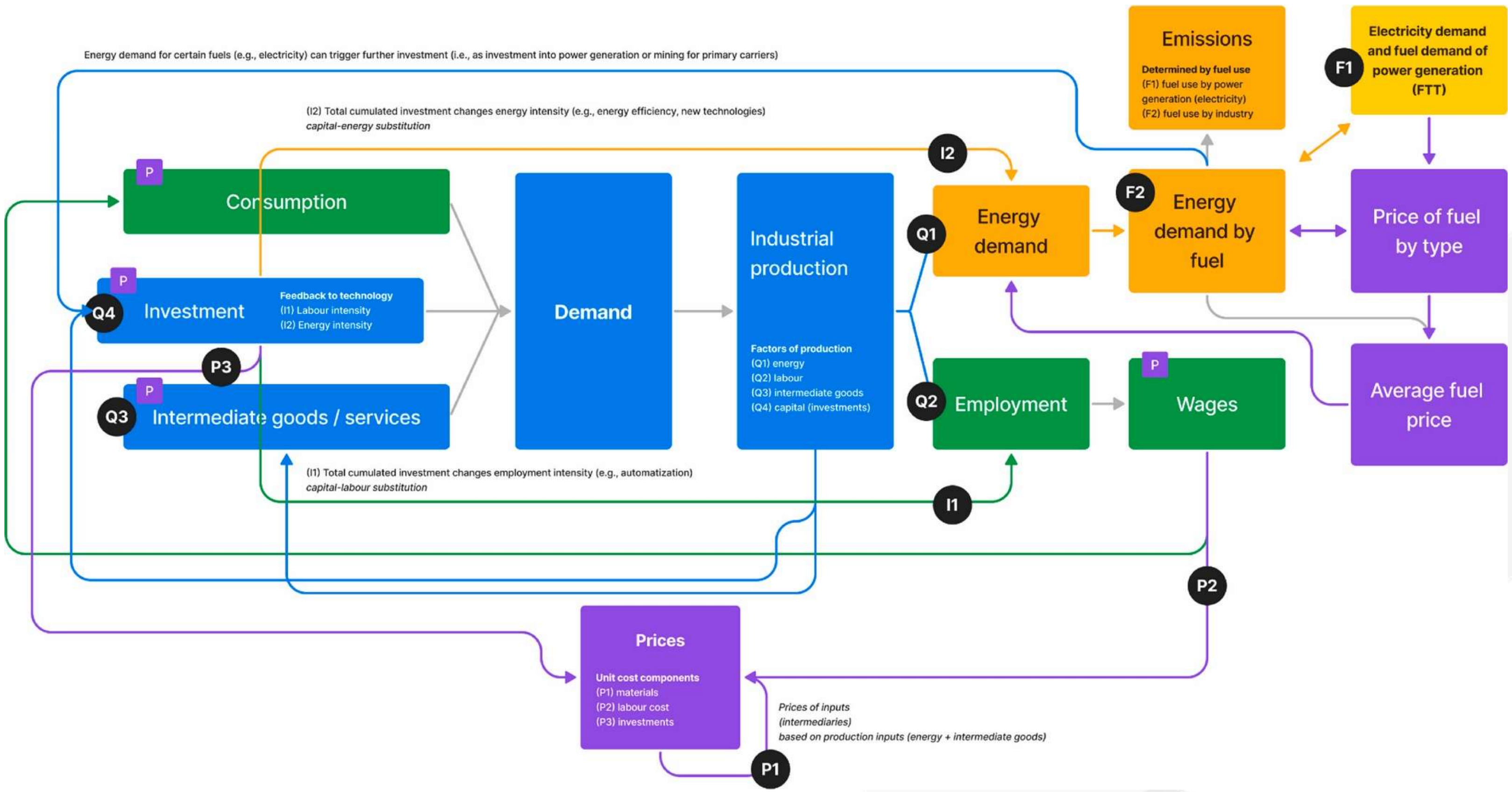
E3ME modelling

High-level / non-comprehensive overview of E3ME's structure



Adapted from: Kiss-Dobronyi, B., Chitiga-Mabugu, M., Lewney, R., & Mbona, N. (2023). Interactions between recovery and energy policy in South Africa. Energy Strategy Reviews, 50, 101187. https://doi.org/10.1016/j.esr.2023.101187

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Appendix

E3ME
Macroeconometric simulation model

Detailed Coverage
- 70 regions (all EU member states, several individual economies)
- 70/44 economic sectors and 42/28 consumption categories
- 23 fuel users of 12 fuels

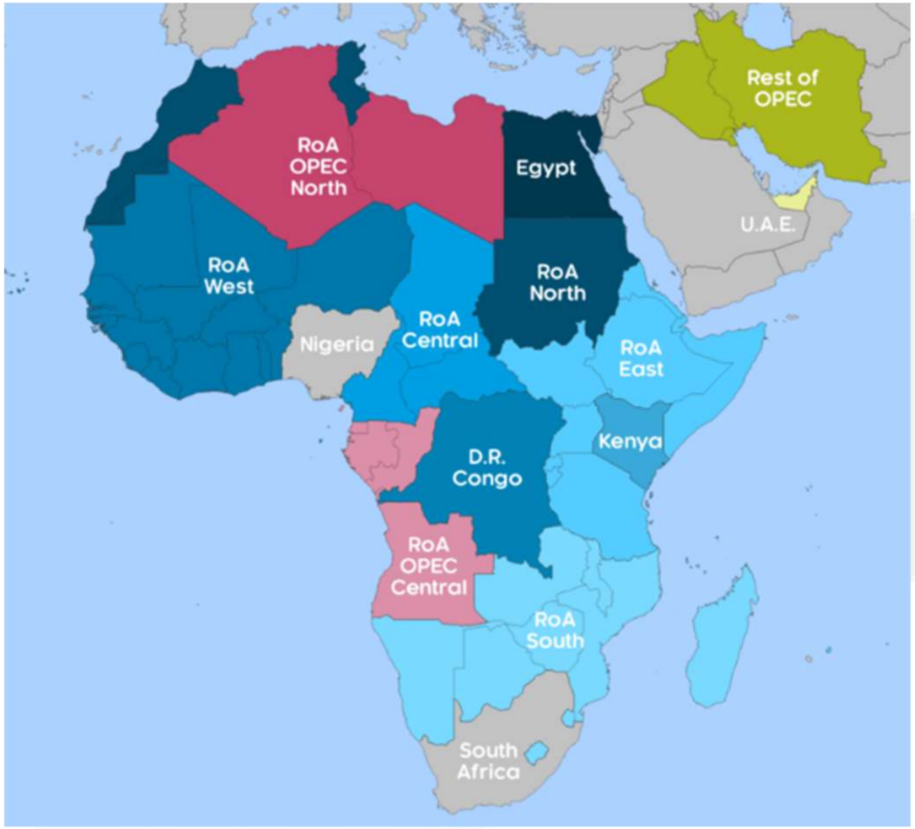
Comprehensive
- whole energy, environment and economic system
- two way feedbacks between each module
- many policy instruments

Modular
- E3: Energy, Environment, Economy and materials
- FTT: power generation
- In development: transport, heating, steel and agriculture

Highly Empirical
- 1970-2018 database
- 28 econometric equation sets
- validated relationships
- econometrics allows for short- medium and long term analysis

Consistent
- based on system of national accounting
- input-output tables
- bilateral trade

Forward Looking
- annual projections to 2050 (2100)
- behavioural equations with effects from previous outcomes
- ex-ante scenario analysis (ex-post is also feasible)



E3ME regional coverage of the African continent

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Notes: The model was developed and is maintained by Cambridge Econometrics. **Further information can be found at https://E3ME.com**

E3ME modelling
Set of estimated econometric equations

Energy	Economic	Labour	Price	Trade	Materials
Aggregate energy demand	Aggregate consumer demand	Employment demand	Industry prices	Internal import (EU)	…
Coal	Disaggregate consumer demand	Wages	Export prices	External import (EU)	
Oil	Investment demand	Participation rate	Import prices	Bilateral trade	
Gas	Investments in dwellings	Hours worked			
Electricity*	Normal output				
	Residual incomes				

Notes: The model was developed and is maintained by Cambridge Econometrics. **Further information can be found at https://E3ME.com**

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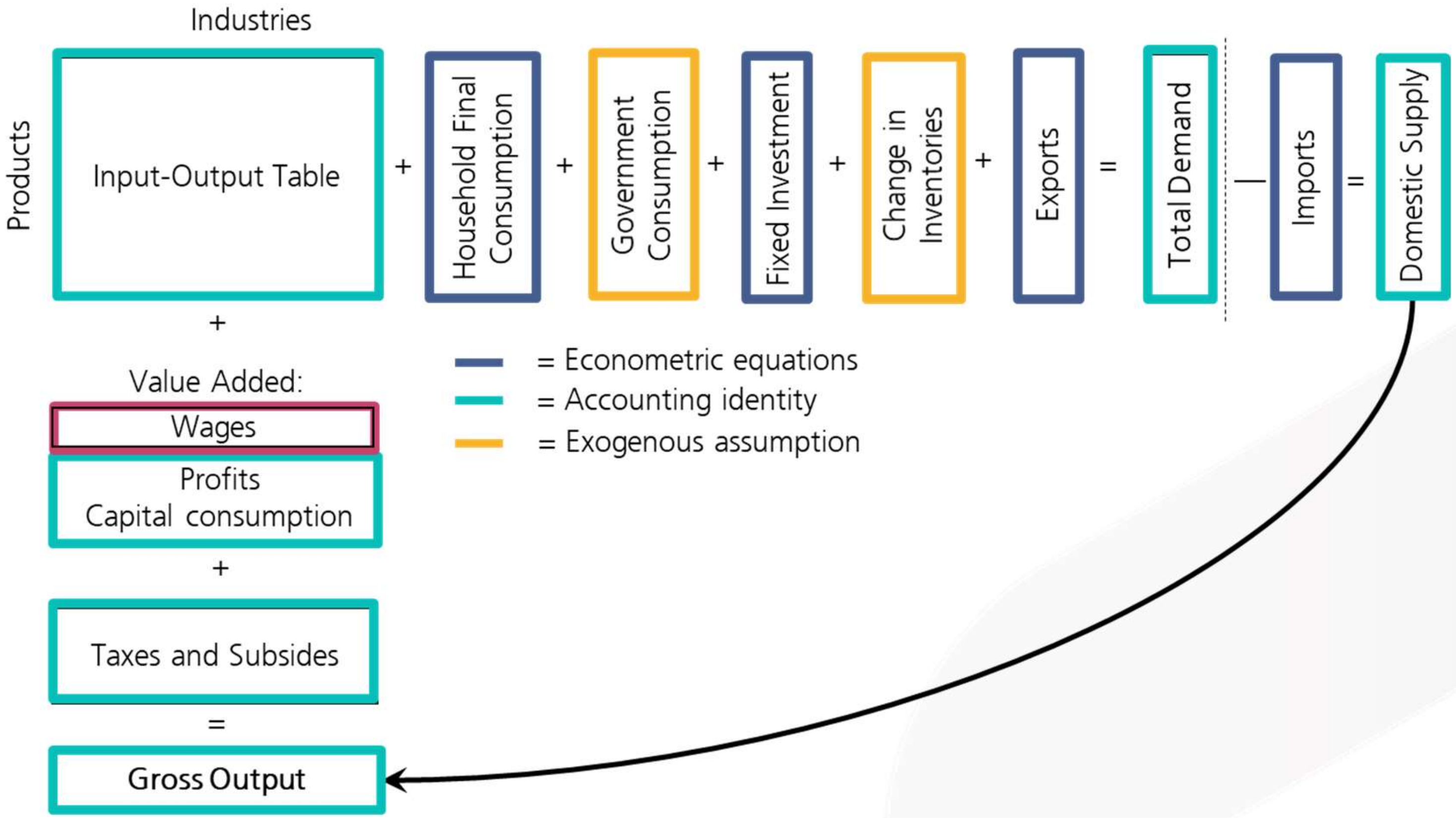
E3ME modelling
Core input-output structure



Notes: The model was developed and is maintained by Cambridge Econometrics. **Further information can be found at https://E3ME.com**

E3ME modelling
International trade and econometric approach

International trade

- Four step approach (*two-tier Armington*):

1. For each country, **total imports are estimated** using equations based on time-series national accounts data. Import volumes are determined primarily by domestic activity rates and relative prices.
2. Separate **bilateral equations for import shares** are then estimated for each destination region, sector and origin region.
3. Bilateral imports are then **scaled** so that they sum to the total estimated at the first stage.
4. Finally, export volumes are determined by **inverting** the flows of imports.

E3ME econometric specification

- Cointegration (long-run) and error-correction (short-run) methodology
- estimate using 2SLS method (IV)
- **Error correction term is a key variable:** ECM coefficient determines speed and type of return to equilibrium following an external shock to the system
- This makes E3ME suitable for both **short, medium and long term** analysis
- Special 'shrinkage' treatment for regions with limited time series data

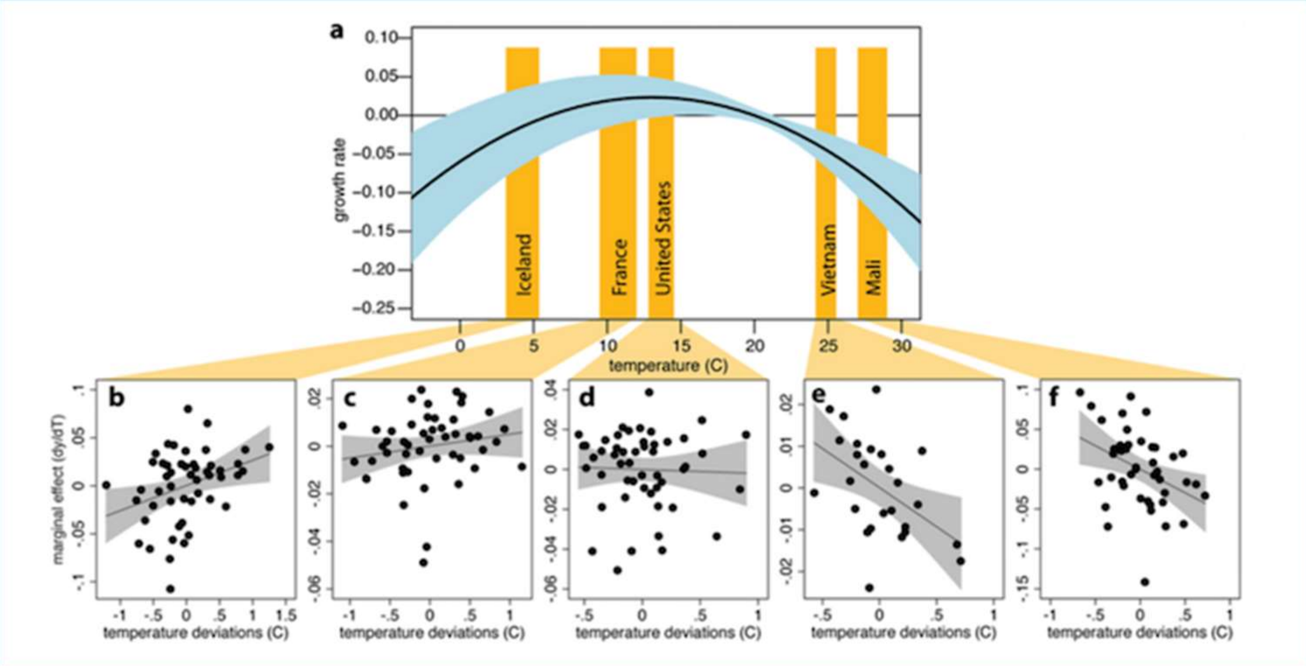
Notes: The model was developed and is maintained by Cambridge Econometrics. **Further information can be found at https://E3ME.com**

Funded by the European Union

Economic results – including climate damages

Climate damages on economic productivity are considered based on research by Burke et al. (2015)

Calculation of damages



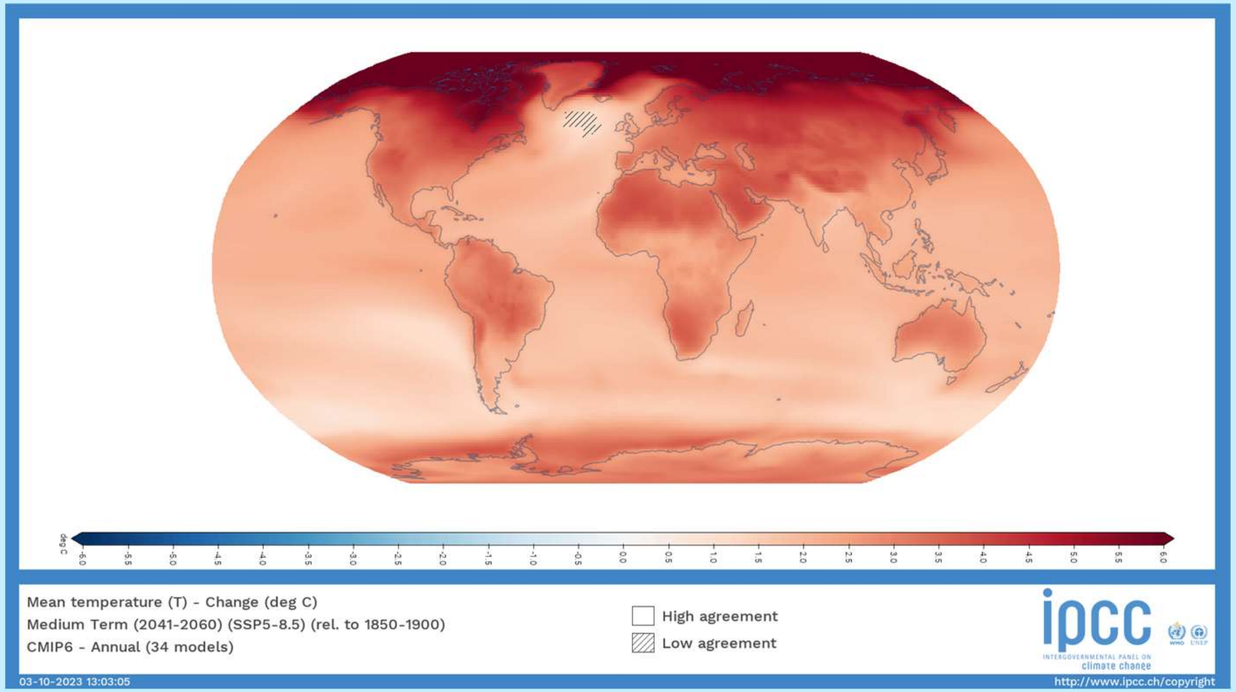
- We consider the impact of warming climate on economic output based on **Burke et al. (2015)**, in their paper the authors have econometrically estimated a relationship between temperature deviations and economic productivity based on historical data across all countries
- As the authors summarize: *"Looking across all countries in the world, we find that the effect of warming temperatures depends on what your average temperature was to start. The warmer your average temperature to start, the more negative the impacts of additional warming."*
- Climate damages projected by the authors are accessible here: https://web.stanford.edu/~mburke/climate/data.html
- We tailor these projections to get to the indicative impact presented earlier

Source: Burke, M., Hsiang, S.M., Miguel, E., 2015. Global non-linear effect of temperature on economic production. Nature 527, 235–239. https://doi.org/10.1038/nature15725

Economic results – including climate damages

Adjustment of projected damages

Calculation of damages



- Burke et al. in their paper calculate effects of warming scenario vs. a non-warming scenario, specifically, in their "climate change" scenario they calculate with an RCP8.5 scenario, which generally though to correspond to warming above 3°C; however, they consider a global mean warming not a region specific one
- Meanwhile, based on IPCC studies we expect that the actual pattern of warming is unlikely to be uniform, as in some regions are expected to see higher temperature change already in the medium term
- Therefore, we apply a scaling multiplicator based on the expected warming outcome of the scenario and the region's specific coefficient to the projections calculated by Burke et al.

$$d_{t,r} = \gamma_{t,r} \times \frac{\Delta\theta}{\Delta\bar{\theta}} \times \beta_r$$

- where $d_{t,r}$ is damages in year t and country r, γ is the damage calculate by Burke et al., β is the country specific scaling coefficient derived from IPCC projections, while $\frac{\Delta\theta}{\Delta\bar{\theta}}$ is the ratio between warming assumed by Burke et al. and our scenario

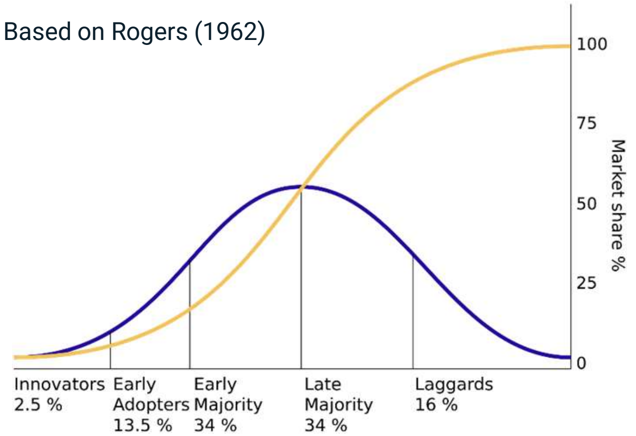
Source: IPCC WGI Interactive Atlas: Regional synthesis, https://interactive-atlas.ipcc.ch/regional-information/about

Appendix

FTT models
Diffusion model for new technologies

Why?

- **Bottom-up model**; econometric approach is lacking (1) small number of large capacity plants, (2) emerging new technologies (no historical evidence on take-up)
- "Best" method is question of purpose: Planning vs Forecasting
- Optimisation (planning) is not the best method, when the market and individual decisions are involved



FTT:Power

- J.-F. Mercure (Mercure 2012) developed the framework at the University of Cambridge
- **Technology diffusion** follows a *S-shaped curve*, but depends on existing technologies and their lifetime
- FTT:Power models new capacities from the perspective of **investor decisions**, where the distribution of **levelised cost (LCOE)** is the deciding factor
- Costs decrease in line with global investments (learning-by-doing) in renewables and move along supply-demand curves for fossil fuels
- Adaptation decisions have spill-over effects and influence further decisions, therefore scenarios often **path-dependent**

Source: Mercure, J.-F. (2012). FTT:Power: A global model of the power sector with induced technological change and natural resource depletion. Energy Policy, 48, 799–811. https://doi.org/10.1016/j.enpol.2012.06.025