Connecting the Transition towards Renewable Energy with Wellbeing

Arup (2019)

A Computable General Equilibrium Analysis of Spain

11th Energy Research Talks, Disentis, 28th January 2026

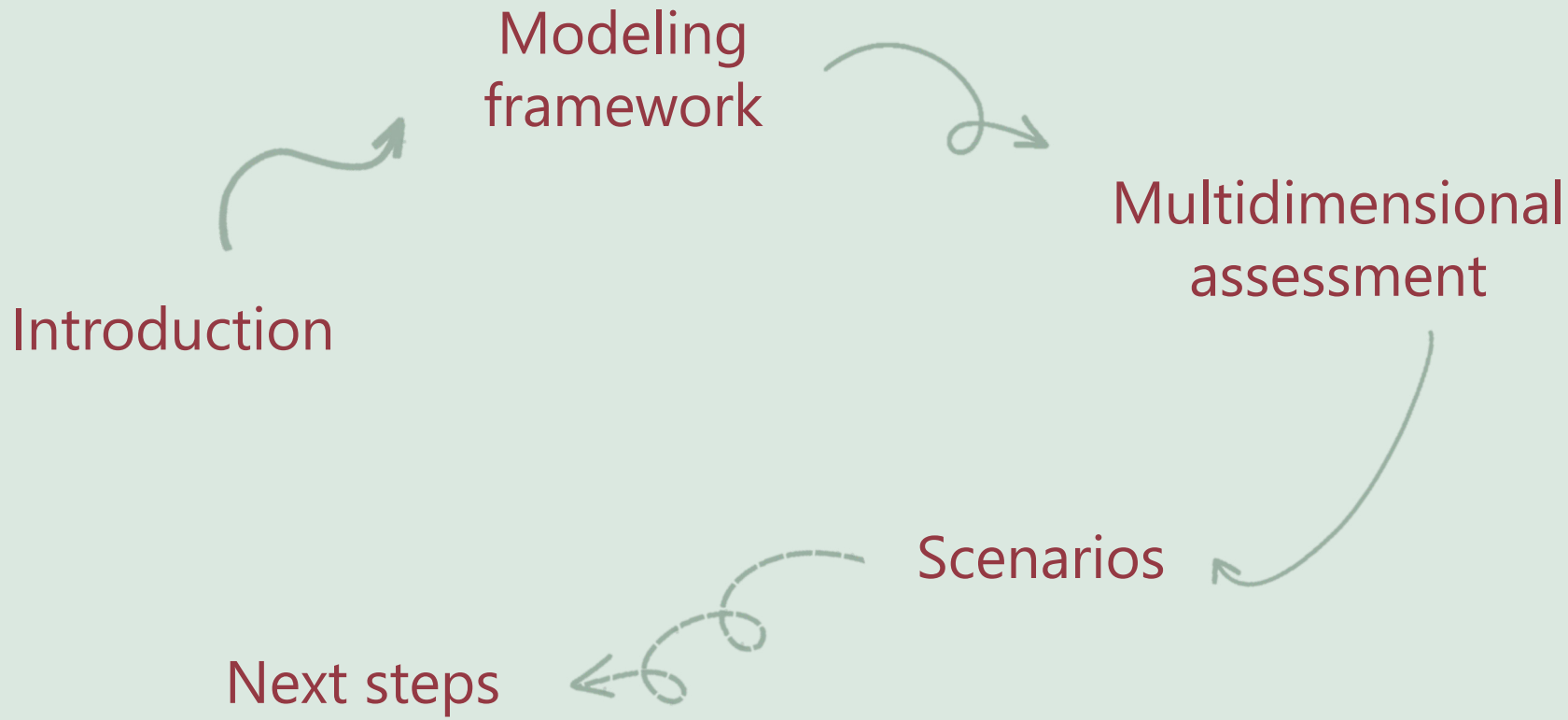
University of Basel

sweet swiss energy research for the energy transition
reFuel.ch

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Federal Office of Energy SFOE

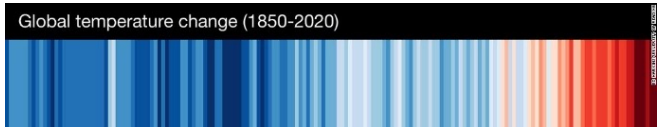
Gianna Angermayr, PhD Student in Sustainability Research

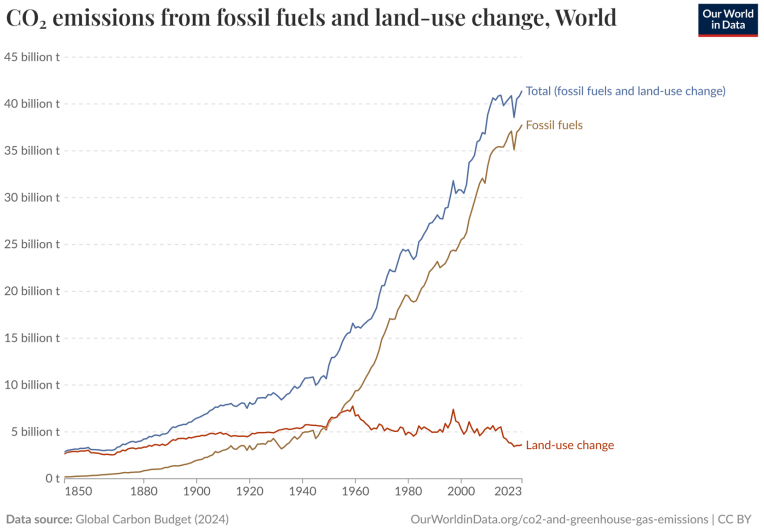
Agenda


Introduction
Modeling framework
Multidimensional assessment
Scenarios
Next steps

Introduction | Current state of the world

- **Global change** is affecting the earth (Lee et al., 2024)
  - Increasing temperatures
  - More frequent extreme weather events
  - Biodiversity loss
  - Ocean acidification
  - etc.
- Mainly related to historical **greenhouse gas emissions** that contribute to climate change (Millward-Hopkins et al., 2020)
- Energy system as one of the largest contributors to total emissions (Mauger, 2023)
  - **Energy system**: "all components related to the production, conversion, delivery, and use of energy" (Pachauri & Meyer, 2014)





CO_2 emissions by source (Our World in Data, 2024)


Inundaciones en Valencia, Octubre 2024 (Semana, 2025)

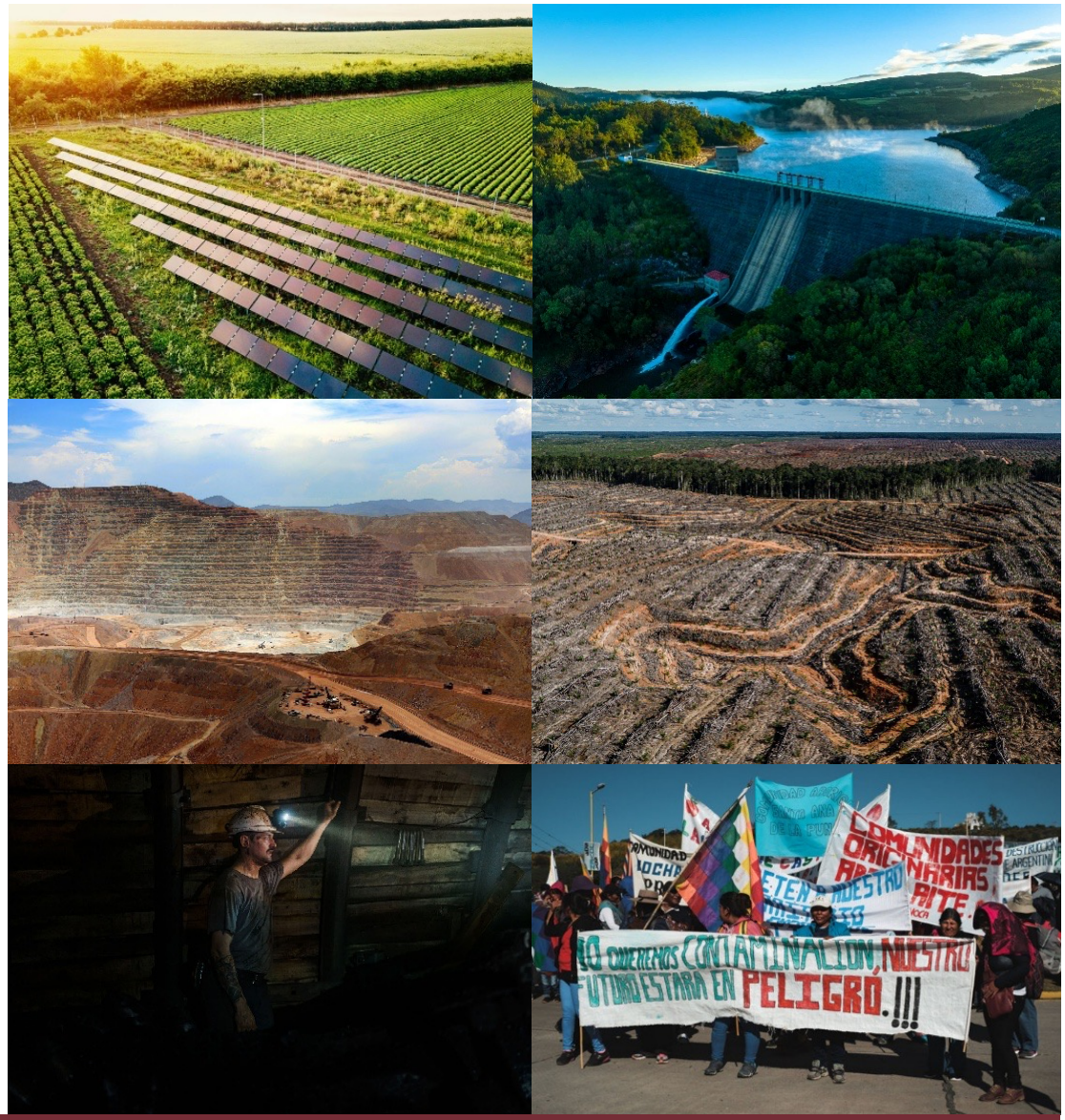
Motivation | Trade-offs

The **fourth energy transition** shifting from fossil fuels to renewable energy has been portrayed as a promising strategy to **decarbonize** the economy and to increase **energy security**

Boston (2022); Carley and Konisky (2020); Mauger (2023)

However, the use of renewable energy sources does not come without **trade-offs**

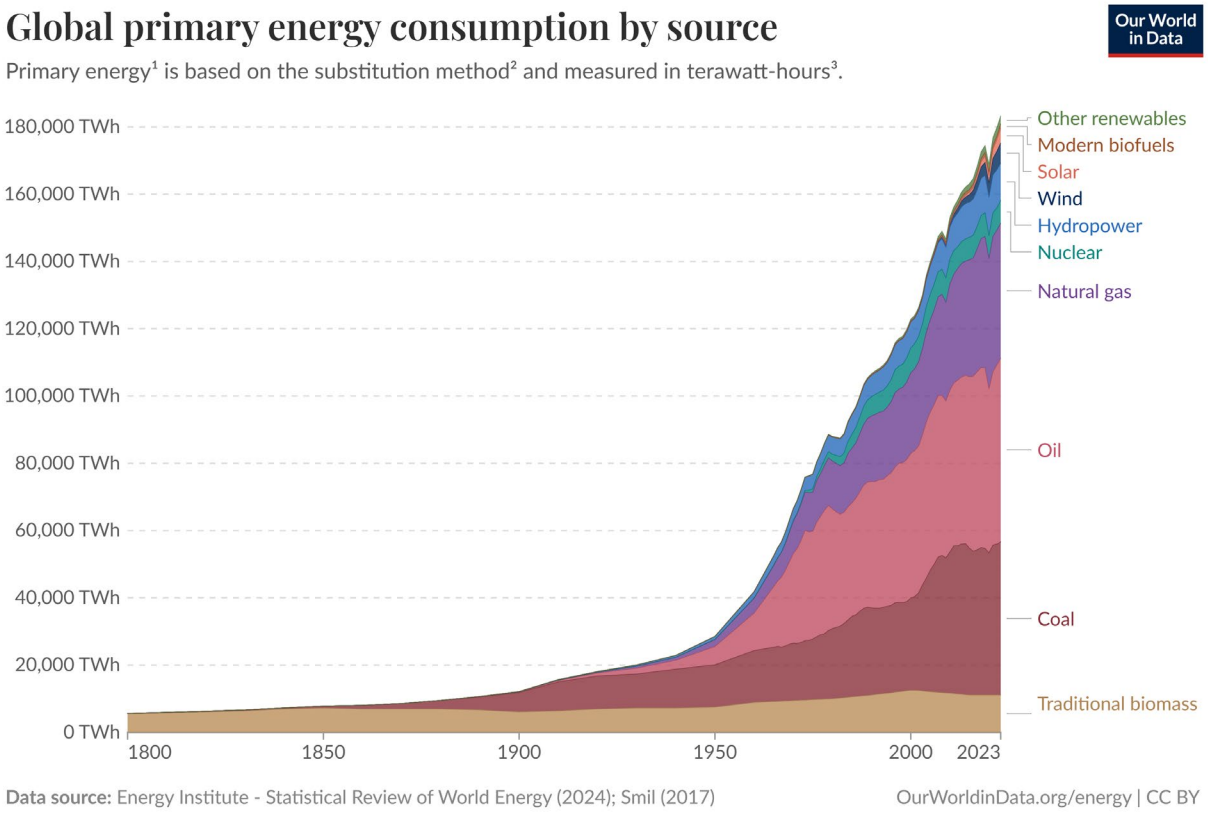
Parrique (2019); Li et al. (2023); Carley and Konisky (2020); Jenkins et al. (2016)



Motivation | The Great Acceleration

An effective decarbonization strategy must incorporate both **production- and consumption-based policies** to address inequalities and resource overconsumption, especially given the lack of absolute decoupling between economic growth and resource use

Boston (2022); Engler et al. (2024); García Vaquero et al. (2021)



ReFuel.ch | Consortium

- The goal is to develop **robust consumption and supply paths** for sustainable fuels and platform chemicals (SFPC) that align with Switzerland's long-term climate policy objectives
  - Renewable electricity
  - Storage products (methanol, hydrogen, sustainable aviation fuels (SAF), ammonia, etc.)
- Involved in working package 2 focused on the **international** social, economic and policy assessment of possible pathways
- **Task 2.4**. Identify and quantify socio-economic impacts on selected exporting countries to formulate the basics of an import strategy
  - **CGE analysis for Spain**

The majority of SFPCs are expected to be **imported** (approximately **90% by 2050**)

Goals

- Integrating a broad **set of social, economic and ecological indicators**.
- Consider (among others) **resource scarcity** (local availability of water, biomass, land, production materials) and **societal and political transformations**.

ReFuel.ch Full Proposal (2022, pp. 44-45)

Spain | An ambitious decarbonization strategy

Because it can

- Great renewable energy potential (sunshine, winds) (Gobierno de España, 2020; Sarasa & Turner, 2021)

Because it needs to

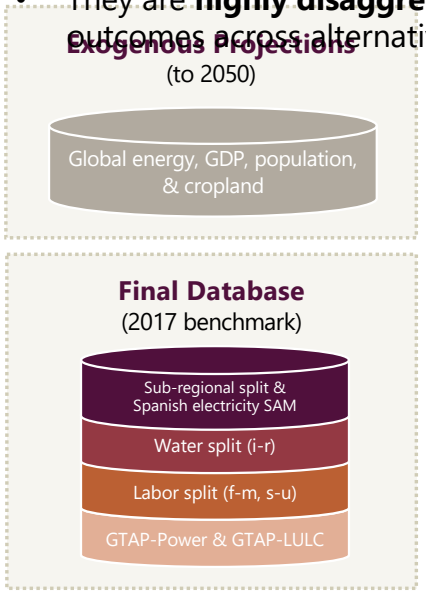
- Vulnerability to climate change impacts (high temperatures, strong rainfalls and prolonged droughts) (Instituto para la Transición Justa, 2022)
- Reducing energy dependency and guaranteeing energy security (Gobierno de España, 2020)

Because it wants

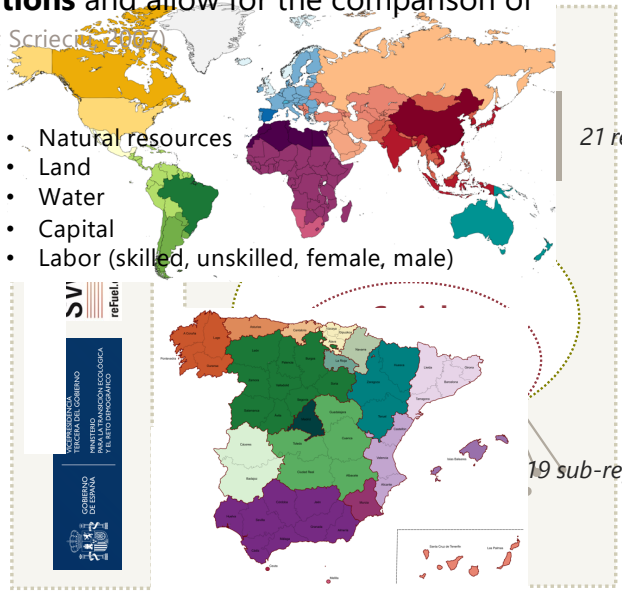
- Aspiration to be a European forerunner (Gobierno de España, 2024)
- «Powerhouse of Europe» (already the third-largest renewable energy exporter in the EU) (Peña-Ramos et al., 2021; AJOT, 2022; Montel, 2025)

Overview of the modeling framework

- **CGEs are widely used** in energy and climate policy analysis (Li et al., 2024; Hafner et al., 2020)
- They are **highly disaggregated** and can depict detailed economy-wide **intersectoral interactions** and allow for the comparison of outcomes across alternative scenarios (An et al., 2023; Böhringer and Löschel, 2005; Campagnolo et al., 2018; Scrieciu, 2007)



Data



Scenarios **Geographical coverage** **Assessment**

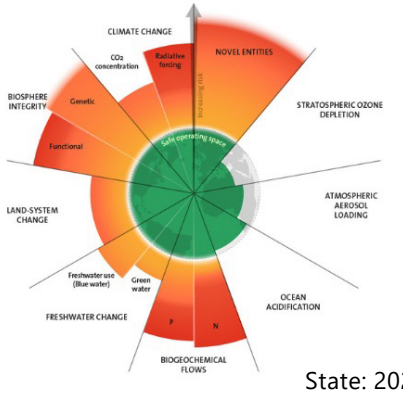
*GTAP: Global Trade Analysis Project

Indicator Framework Development

Beyond-GDP Literature

Theoretical foundations

Derive **important** wellbeing & sustainability dimensions



State: 2023

9 Planetary Boundaries

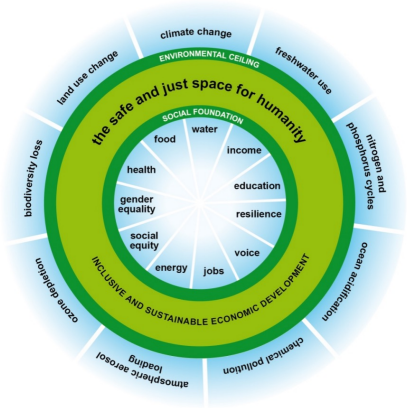
A Safe Operating Space for Humanity

(Rockström et al., 2009)

And many others…

- Ends-Means Framework
- Provisioning Systems
- Subjective Wellbeing
- Welfare Economics

- Needs Theories
- Capability approach
- Ecological approaches
- etc.



11 Dimensions of the Doughnut Economics

A "Safe and Just Space" Framework

(Raworth, 2012)

Indicator Framework Development

Beyond GDP Literature

Theoretical foundations

Derive **important** wellbeing & sustainability dimensions

Planetary boundaries, Doughnut economics, Ends-means framework, Provisioning systems, Subjective wellbeing, Welfare economics, Needs theories, Capability approach, Ecological approaches, etc.

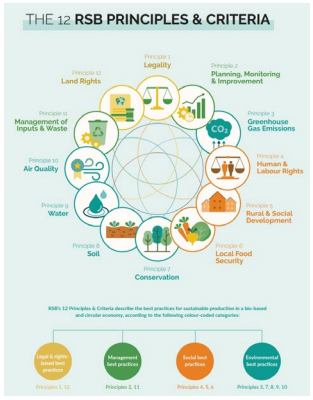
"What is measured tends to be done"

BLI, EF, GDI, GEI, GII, HDI, GPI, MPI, SDGs, etc.

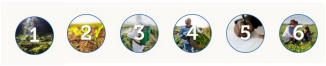
What are existing indicators in the literature?

What are specific measures related to the energy system?

Derive **relevant** wellbeing & sustainability indicators

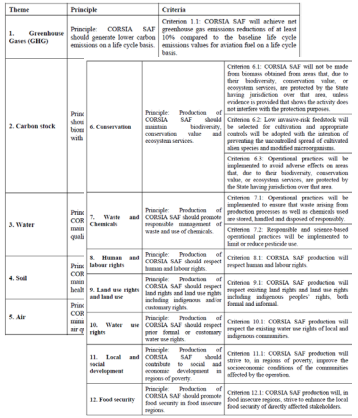


RSB principles & criteria, Roundtable on Sustainable Biomaterials (RSB), 2023



1. Protection of land with high biodiversity value or high carbon stock
2. Environmentally responsible production to protect soil, water and air
3. Safe working conditions
4. Compliance with human and labour rights and responsible community relations
5. Compliance with land rights, laws and international treaties
6. Good management practices and continuous improvement

ISCC principles, International Sustainability & Carbon Certification (ISCC), 2022 & 2024

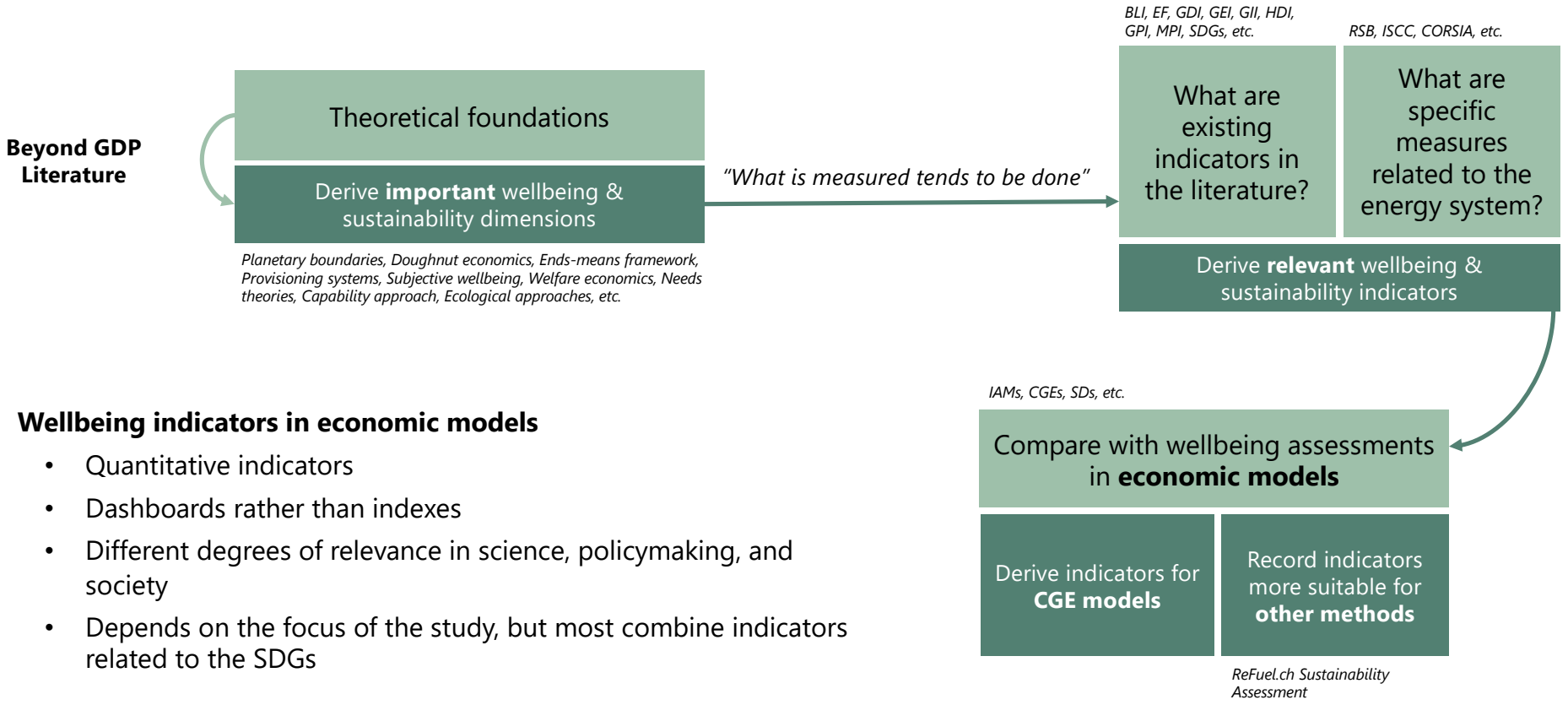


CORSIA sustainability principles, International Civil Aviation Organization (ICAO), 2021

Fig. 2. Sustainability criteria (outer circle) and related *impact categories* (inner circle).

Green hydrogen production: Integrating environmental and social criteria to ensure sustainability, Blohm & Dettner, 2023

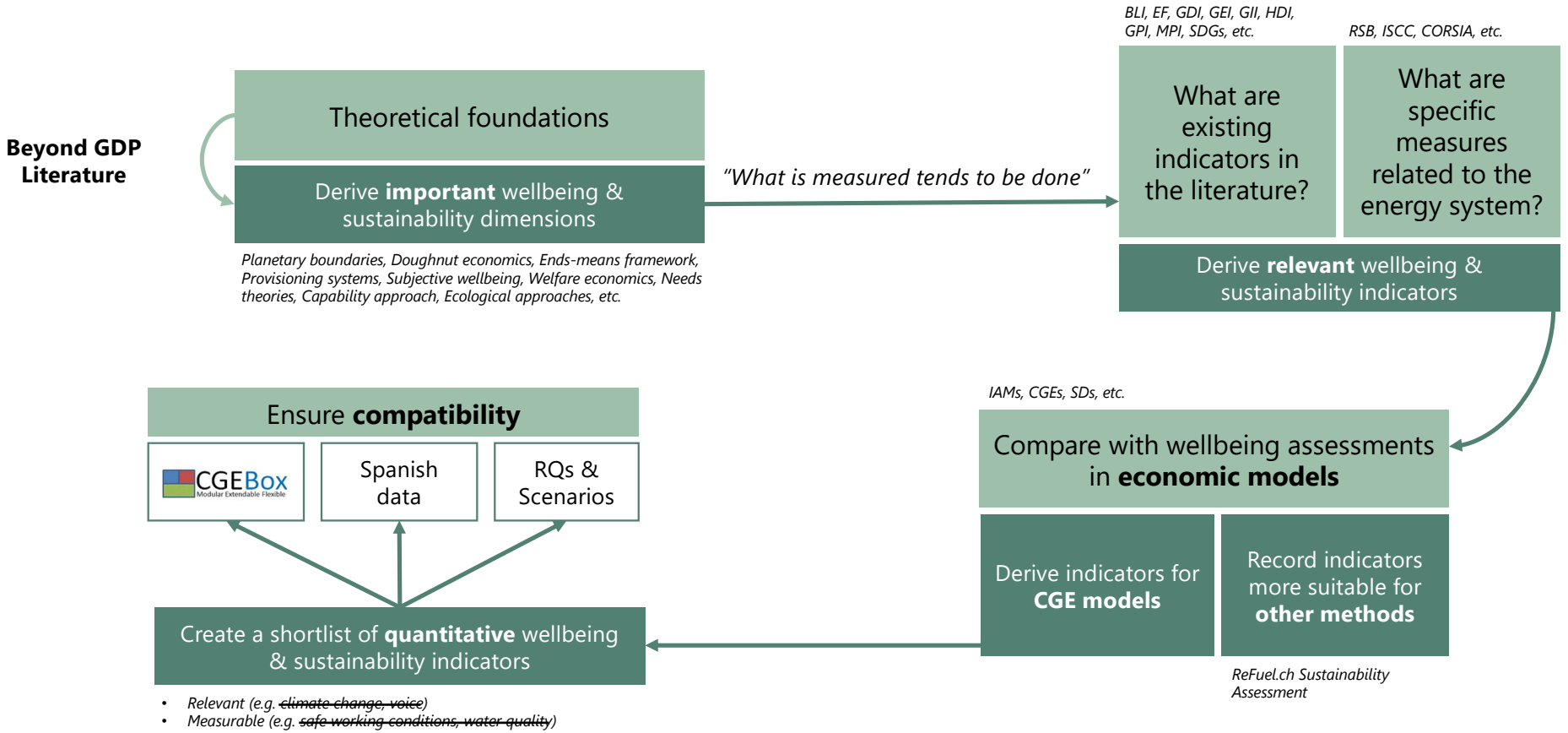
Indicator Framework Development



Wellbeing indicators in economic models

- Quantitative indicators
- Dashboards rather than indexes
- Different degrees of relevance in science, policymaking, and society
- Depends on the focus of the study, but most combine indicators related to the SDGs

Indicator Framework Development



Indicator Framework |

3 pillars
12 dimensions
38 indicators

Pillars	Dimension	Indicators
Environmental indicators	**Water use**	Irrigation water-use Water supply
	Land use	Share of crop area on total managed land area Share of pasture area on total managed land area Share of solar area on total land area Share of unmanaged land on total land area Share of unmanaged forest area on total land area
	Energy use	Share of renewable electricity in total final electricity consumption Share of fossil fuel energy in total final energy consumption (Final) energy intensity Total energy consumption
	Material use	Material footprint intensity Material footprint per capita
	GHG emissions	Total GHG emissions per year Total GHG emissions per capita Emissions intensity
Social indicators	**Food security**	Consumer-based food price index Average food consumption per capita Share of food expenditure in total income Share of food imported in total food consumed
	Energy security	Consumer-based energy price index Share of spending on electricity Share of spending on energy Share of electricity imported in total electricity consumed Share of energy imported in total energy consumed Share of electricity exported of total electricity produced Share of energy exported of total energy produced
	Gender equality	(Unadjusted) gender pay gap for skilled and unskilled labor Share of female labor in the renewable energy sectoral employment
	Health	Air pollution intensity
Economic indicators	**Income**	Real GDP Income per capita
	Employment	Regional wage differences for labor Labor participation rate
	Macro economy	Consumer Price Index (CPI) Trade balance-to-GDP ratio Fiscal balance-to-GDP ratio Share of total government spending on essential services

Scenario co-design | Qualitative data collection

●○○○

Preliminary deskwork

Derive **policy-relevant & literature-based** scenario options

●●○○

Semi-structured expert interviews

Explore the **socio-political feasibility & desirability** of Spain's decarbonization pathways in light of their trade-offs

●●●○

Develop storylines

Come up with **qualitative scenarios** describing the different pathways

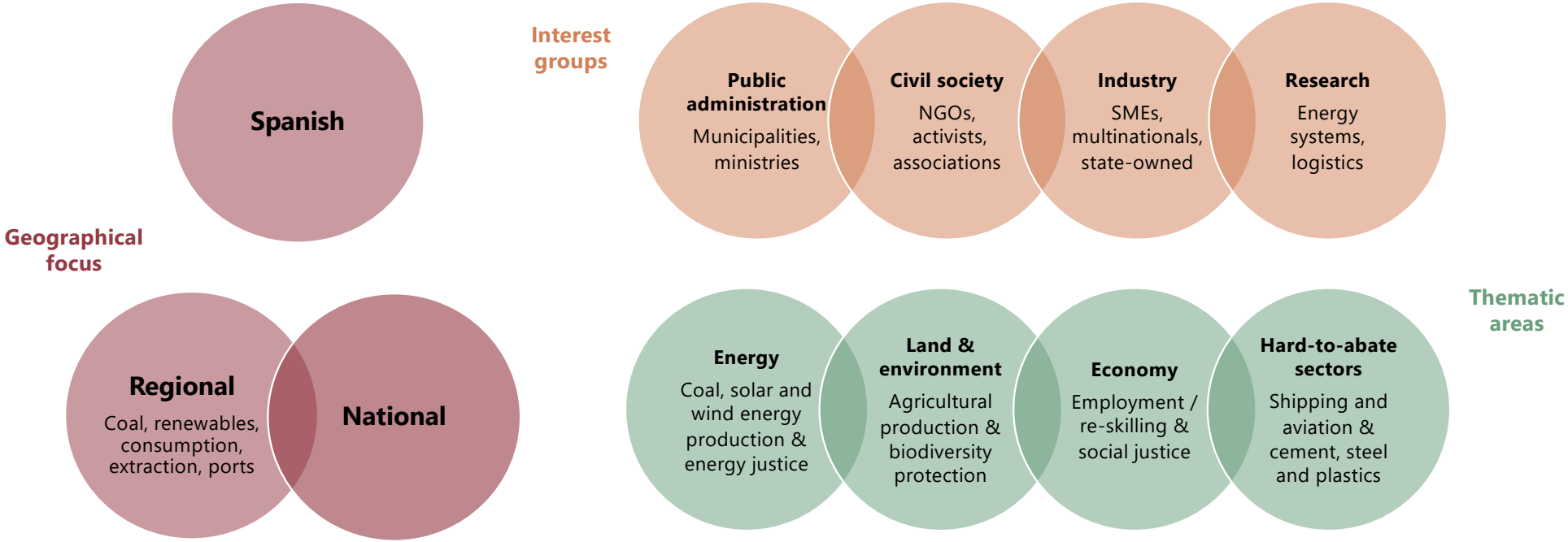
●●●●

Stakeholder workshop

Co-design **numerical decarbonization scenarios** for CGE modeling in Spain

Purposeful sampling | Heterogeneous stakeholders for different perspectives

Following Okoli & Pawlowski (2004), develop a Knowledge Resource Nomination Worksheet to categorize experts before identifying them



Spanish targets | Legal framework

Strategic Framework for Energy and Climate

(Gobierno de España, 2020, 2021, 2023)

Law 7/2021 on Climate Change and Energy Transition

32% reduction	39.5% reduction	48%	81%	2030
Greenhouse gas emissions (1990)	Primary energy consumption (energy efficiency)	RE* in final energy use	RE* in electricity generation	

Climate neutrality	2050
90% reduction in total GHG emissions (1990)	100% Renewable electricity

National Integrated Energy and Climate Plan (PNIEC)

Roadmap for 2021-2030 to achieve the legally-binding targets

Decarbonization	Energy efficiency	Energy security	Internal energy market	Research, innovation & competitiveness

Just Transition Strategy (JTS)

Mitigate direct negative impacts of the transition on people, territories and the environment

*RE: renewable energy

How to reach the targets? | Preliminary deskwork

●○○○

●●●○ Storylines	●●◔● Assumptions	●●●● Scenarios
Baseline	Global dynamics: GDP & population, energy Spanish dynamics: resource limitations (water, land)	**BAU**
Technology-based	BAU + technological innovation, energy efficiency, electrification, renewables expansion	**TB**
Demand-side	BAU + consumption shifts towards renewables, sufficiency in energy & carbon-intensive consumption	**DS**
Combined	BAU + TB + DS	**AE** *All efforts*
Powerhouse	AE + export-oriented reFuel.ch	**PH**

Trade-offs

Land use
Water use
Energy use
Material use
GHG emissions
Food security
Energy security
Health
Gender equality
Income
Employment
Macro economy

Next steps | Spring 2026

- Calibrate the global model
- Define the Spanish scenarios numerically
- Conduct the stakeholder mapping
  - **In case you have contacts or know people or organizations in Spain to include in the study, let me kindly know! ☺**

Contact details: gianna.angermayr@unibas.ch

Acknowledgments

The research published in this presentation was carried out with the support of the Swiss Federal Office of Energy as part of

sweet swiss energy research for the energy transition
reFuel.ch

reFuel.ch - Renewable Fuels and Chemicals for Switzerland

reFuel.ch is a consortium sponsored by the Swiss Federal Office of Energy's SWEET programme and is hosted by Empa.

The authors bear sole responsibility for the conclusions and the results presented.

Empa Materials Science and Technology · zhaw · PSI · Universität Basel · ETH zürich · EPFL · nw Fachhochschule Nordwestschweiz · Scuola universitaria professionale della Svizzera italiana SUPSI · Università della Svizzera italiana · CASALE

Thank you

for your attention

Any questions or feedback?

Gianna Angermayr, PhD Student in Sustainability Research, University of Basel