Complex system of systems simulation for energy transition

OS-C Transition tool

NAFEMS NRC France '22

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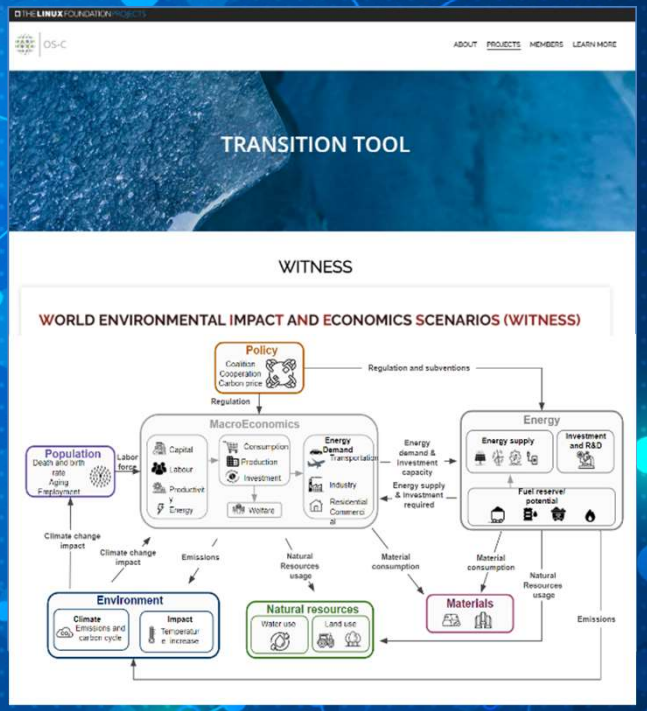
...and all the SoSTrades project team



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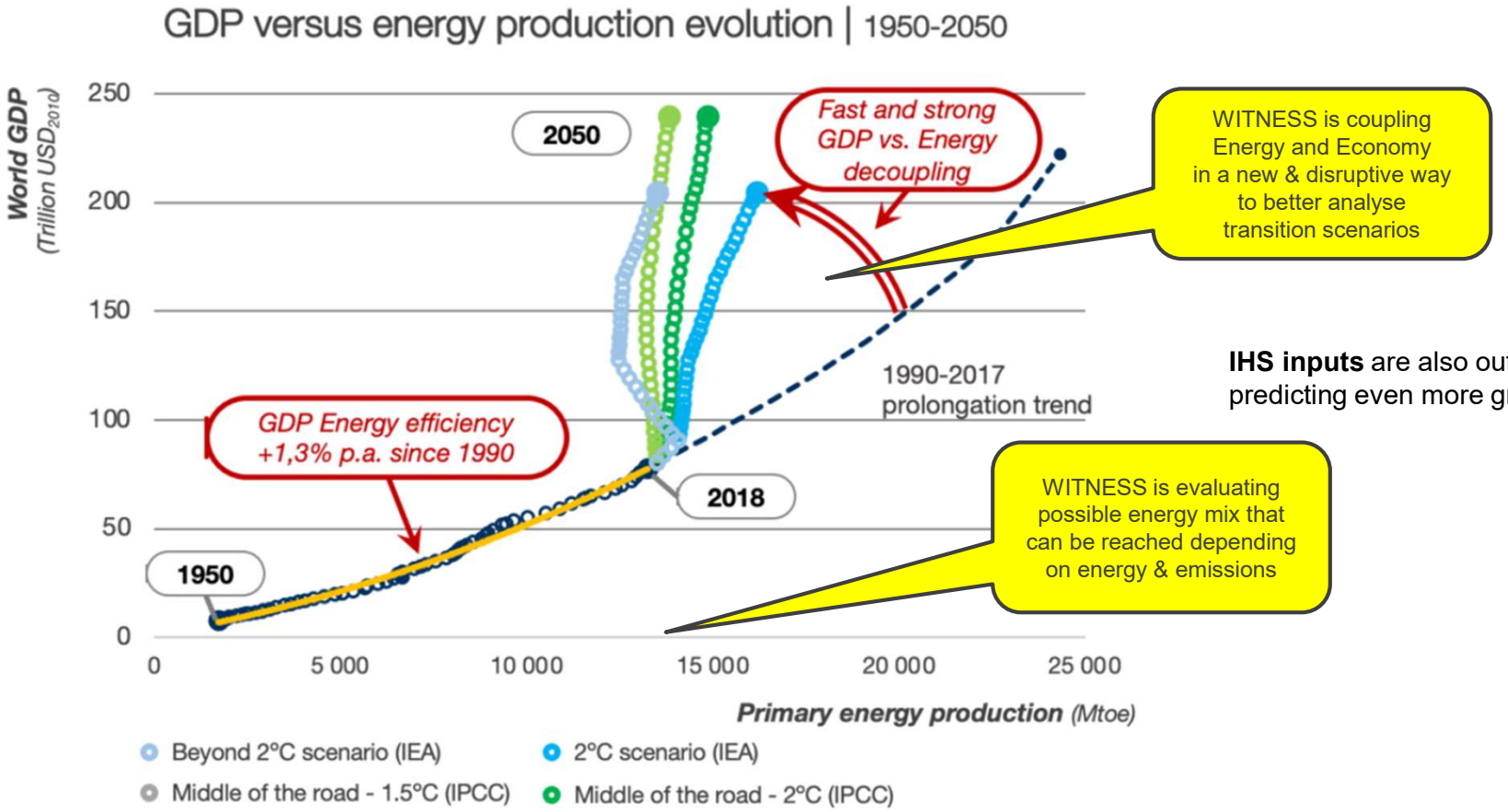
WITNESS

The "Green growth" envisaged in IHS, IEA and IPCC GDP…
… is probably overly optimistic



WITNESS is coupling Energy and Economy in a new & disruptive way to better analyse transition scenarios

IHS inputs are also out of range predicting even more growth

WITNESS is evaluating possible energy mix that can be reached depending on energy & emissions

Source [Carbon4]

…but Energy-Economy coupling is a tough story !

Linux Foundation Open Source for Climate (OS-Climate or OS-C)

Applying the community-based open-source approach that has enabled breakthroughs in Life Sciences & Tech to solve data & analytics challenges required for investment to achieve Paris Climate Accord goals

OPEN SOURCE COMMUNITY

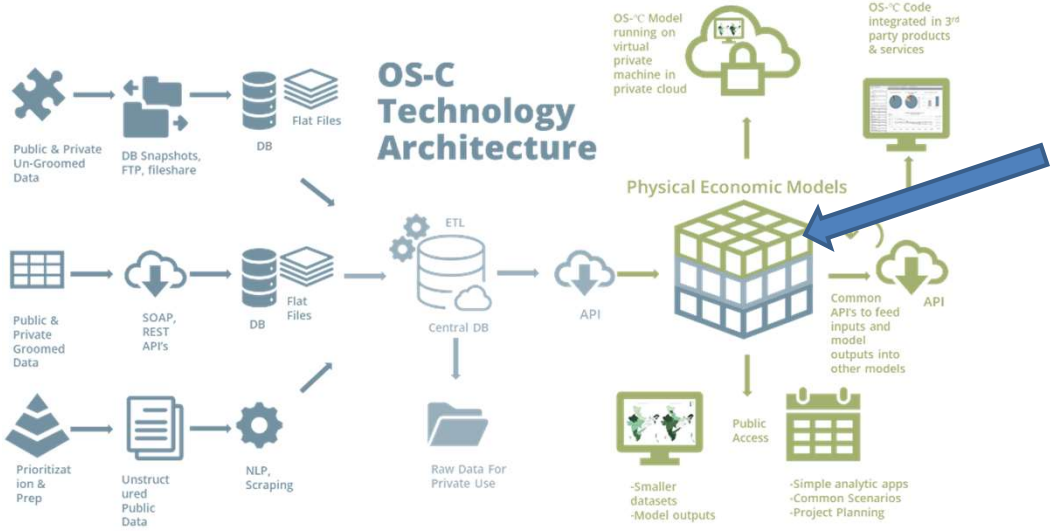
- Governance, licensing, and collaboration structures enabling stakeholders to share cost, intellectual property, and effort.
- Joint projects for new data, modelling, standards, and supporting technology

COMMONS

- Curated library of public and private sources, for both transition and physical risk/opportunity
- More accurate corporate historical and forward-looking climate & ESG metrics as a public good

GLOBAL DATA ANALYTIC TOOLS

- Integrate climate-related risk and opportunity into decisions by investors, financial institutions, regulators, etc.
- Top-down and bottom-up modelling
- Scenario analysis tools
- Alignment tools



WITNESS

SOS TRADES

Visit www.os-climate.org for more information

SoSTrades/WITNESS online

SoSTrades/WITNESS on OS-C GitHub

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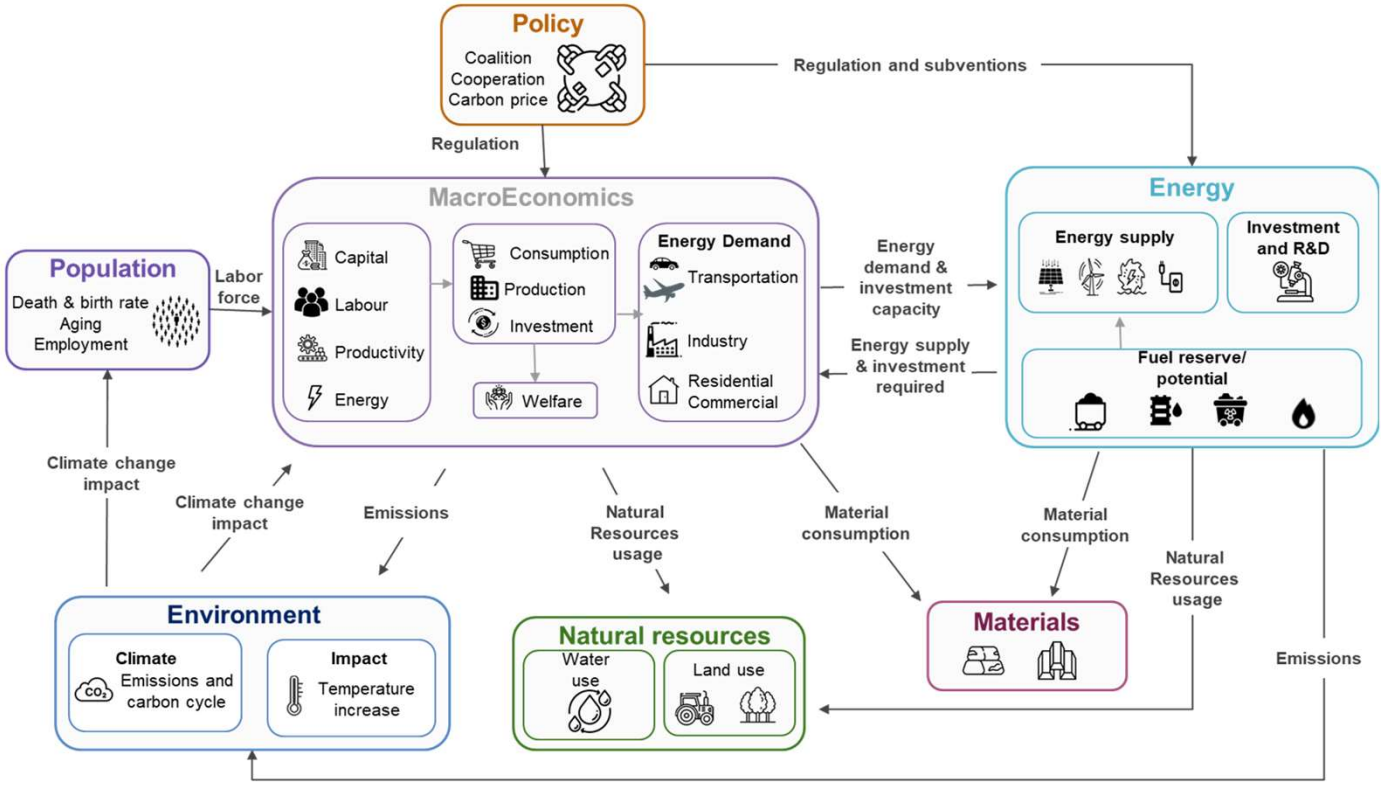
World environmental ImpacT aNd Economics ScenarioS

A complex system of systems approach to transition simulation

Transparent & collaborative assessment of energy transition paths at global / macro level



Explore by simulation potential energy transition paths, identify mostly influential transition drivers
Jointly agree on a trajectory envelope, engage a critical mass of actors to make it happen (self-fulfilling prophecy)
Estimate risk by measuring delta between planned trajectory and worse ones

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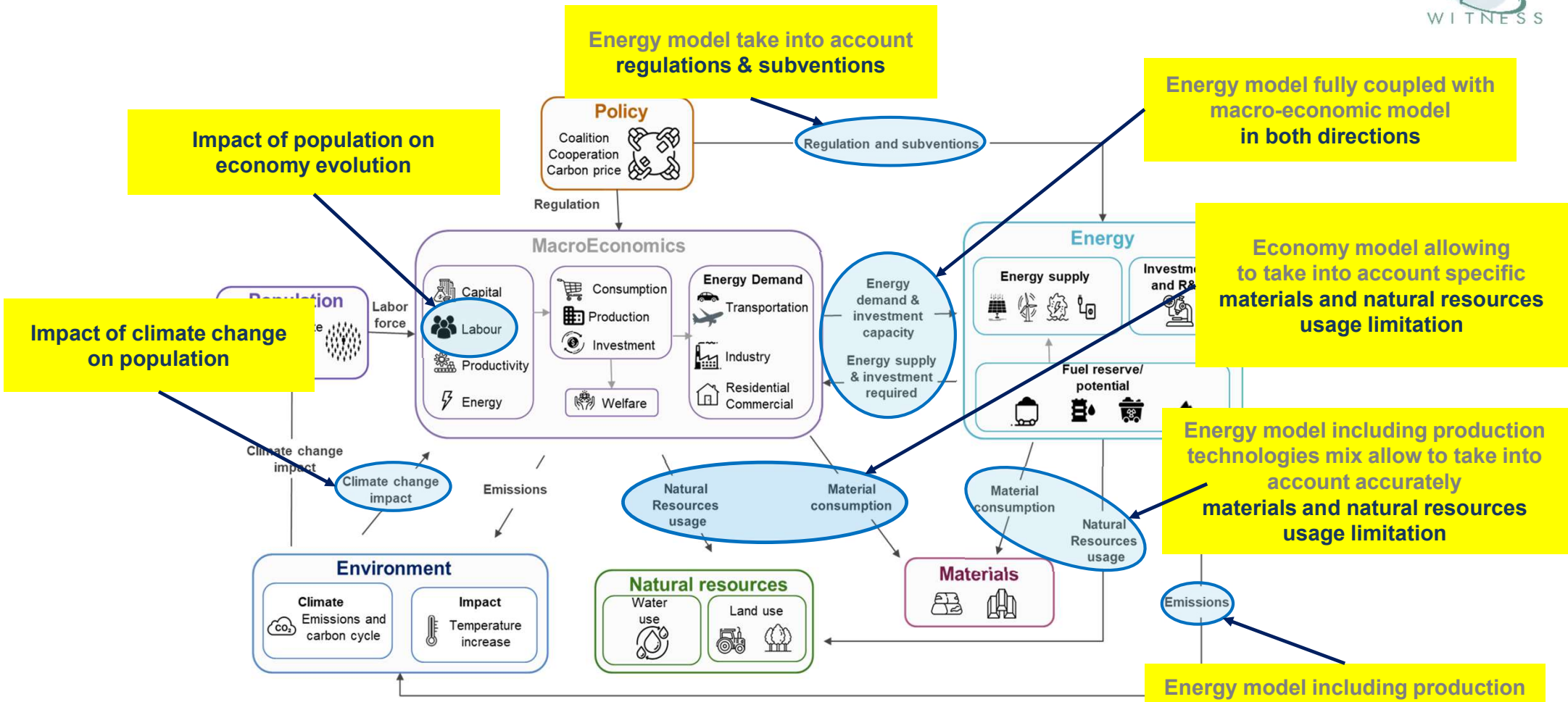
WITNESS key couplings



Key coupling assumptions in WITNESS

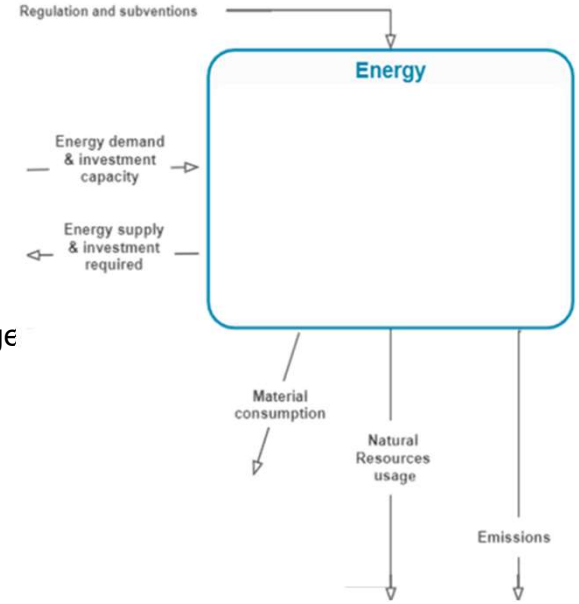
"Labour without energy is a corpse; capital without energy is a sculpture." Steve Keen

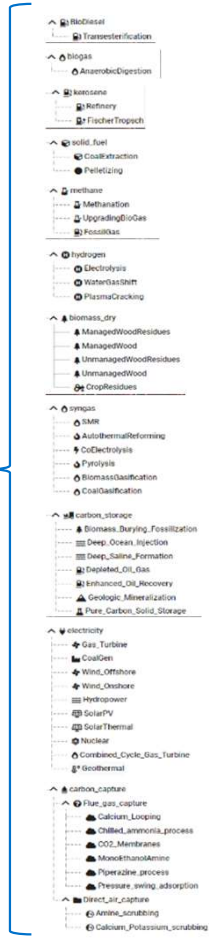
- **Gross Domestic Product depends on capital, labour and net energy output**
  - **usable capital** : capital need to be fed with energy, for it to be able to produce output
  - **maximum usable energy of capital** : not able to absorb more energy that it is built for
  - **productivity factor of capital** : representing loss of productivity if minimum number of labour is not available
- **Need to have a population model to properly create world scenarios** (as in World3 model)
  - **labour** : GDP depends on evolving population age distribution
  - **population** : impacted by climate change damage (extreme weather conditions, sea level rise, etc…)
  - **amount of food available** : evolves with climate change impact on productivity of agriculture and land usage
- **Access to net energy production to properly feed production function**
  - production **technologies** : needed to model their resources impact and their interdependencies in the global energy production mix
  - production **interdependencies** : to solve **net** energy production computation.
  - production **investments** in energy sector : linked to overall GDP for global investment capability depending on economy evolutions
- **Earth is a finite system with many resources limits reflected in the framework**
  - **resources** consumption: they are tracked wherever used (e.g. energy, economy, agriculture…), and pitched against reserve estimations

capital : all assets, for instance factories, buildings, machines and so on…
labour : employed population, changes depending on age distribution and population evolution.
net energy output: usable energy, removing from raw production, energy used to produce energy itself

Evolutive coupling approach in a massive # of models

- 40+ energy production technologies & more by the day
  need to be able to add easily new energy production technologies
- Changing interactions between energy production technologies
  e.g. produced electricity used to produce hydrogen by electrolysis
- Time dependant dynamic evolution
  depending on economy, learning curve, amortization… and impacted by climate damage
- Resources and materials limitations / constraints
  some limitations potentially limiting several technologies over time
- Various modeling & coupling strategies needed
  e.g. analytic & stochastic, continuous & discrete, categories, game theory…



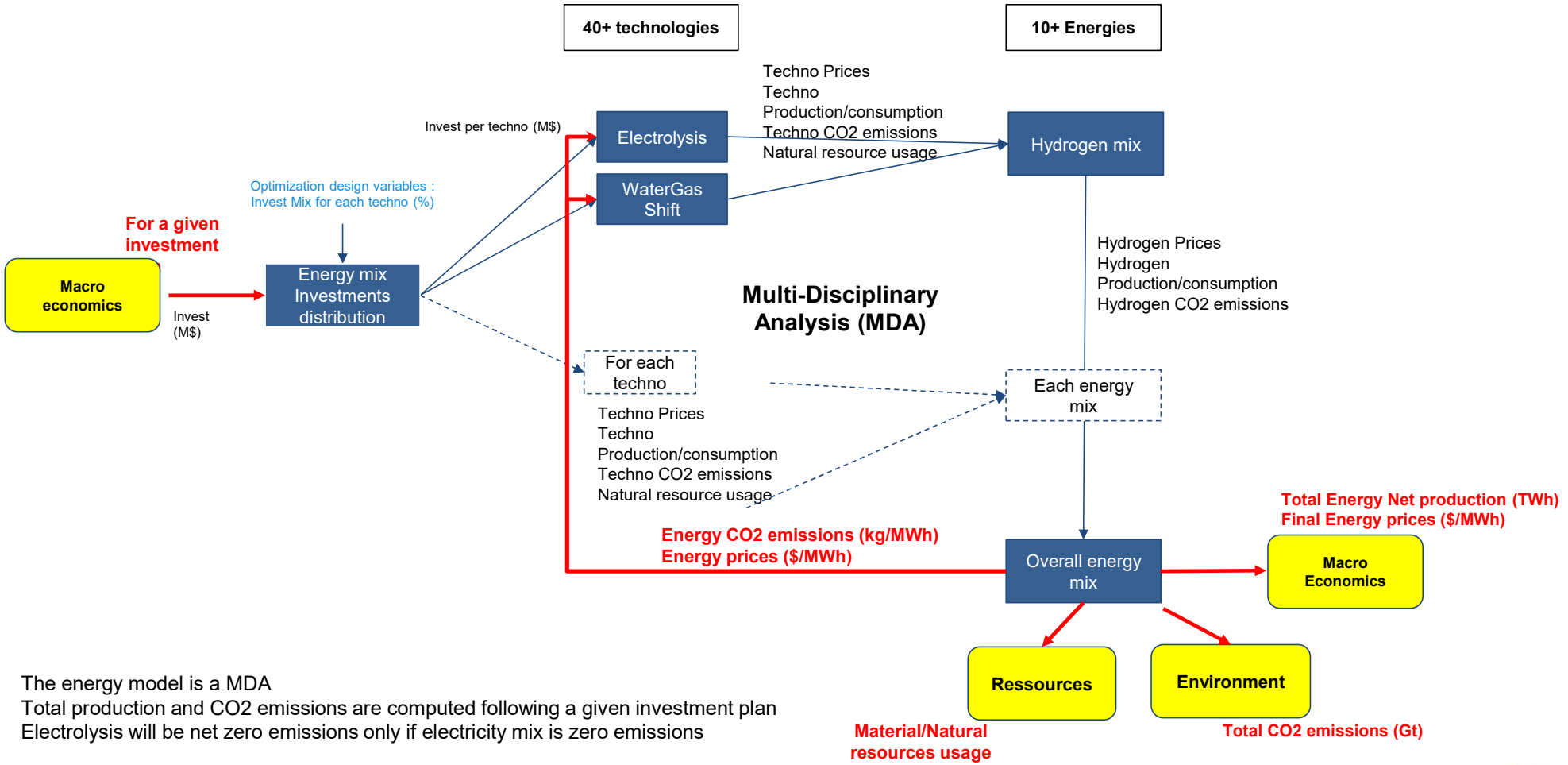


Objective	*maximize* **welfare** and *minimize* **CO2 emissions**
Design Variables	**technologies investments mixes** *(from 2020 to 2100)*
Constraints	*(from 2020 to 2100)*: total energy production > energy lower bound net energies production > energies demand liquid fuel + H2 prod + H2 liquid production > % total production solid fuel + electricity + biomass production > % total production hydropower production < hydropower production in 2020 H2 liquid production > %H2 total production available land > land demand (for forest, agriculture,...)

MDO
65 disciplines
4240 design variables
265383 variables
1200 constraints

MDA
63 disciplines
25064 coupling variables
262715 variables

Zooming on energy system as an example



- ➔ The energy model is a MDA
- ➔ Total production and CO2 emissions are computed following a given investment plan
- ➔ Electrolysis will be net zero emissions only if electricity mix is zero emissions

A glimpse of WITNESS numerical analysis optimization

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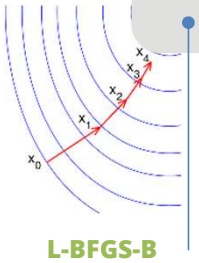
Adjoint based gradient computation

1 function evaluation
1 adjoint system
instead of
241 functions evaluations per iteration

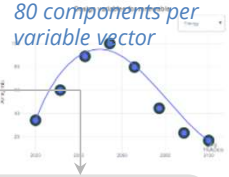
Optimization solver



L-BFGS-B

B-splines

8 poles per variable vector
instead of
80 components per variable vector



DesignVar

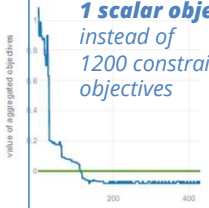
MDA Analysis

NewtonRaphson solver
~30 iterations
~8 minutes

WITNESS model

Lagrangian objective formulation

1 scalar objective
instead of
1200 constraints and 160 objectives



FuncManager

GEMSEO

key numbers

MDO
65 disciplines
4240 design variables
265383 variables
1200 constraints

MDA
63 disciplines
25064 coupling variables
262715 variables

MDO
65 disciplines
424 design variables
261567 variables
0 constraint

MDA
63 disciplines
25064 coupling variables
262715 variables

solved in ~10 hours

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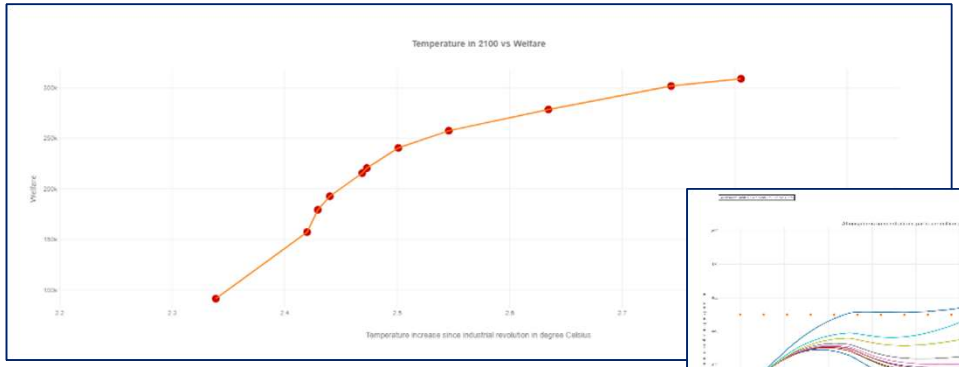
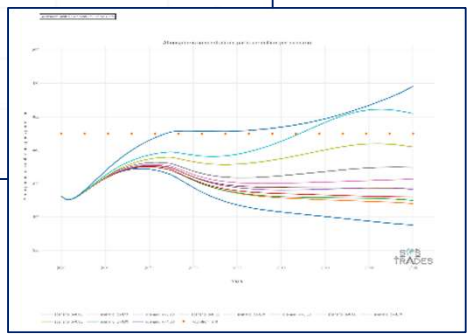
WITNESS allows building

Design space explorations
=> **pareto front** extracted from multi-scenario analysis,
understanding what are the **limiting factors** to progress towards an objective



Temperature vs Utility pareto

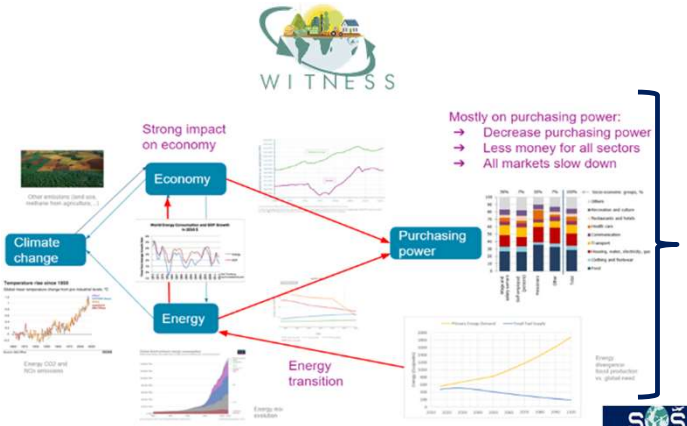


Atmospheric concentrations per scenario
(with Rockström limit)

Run in **multi-scenario** a current/preferred/planned scenario,
together with worst case ones (with pessimistic assumptions)
=> delta between current and worst cases used as a **risk metric**

Run **real-options value simulation** for possible trade choices
=> better **steer and value** investments

Open framework where various modules or scenarios can be explored, replaced or studied as alternates
=> exploration of new technologies potential,
identification of **game-changers / tipping points**
=> **risks and margins** determination, **hedging…**



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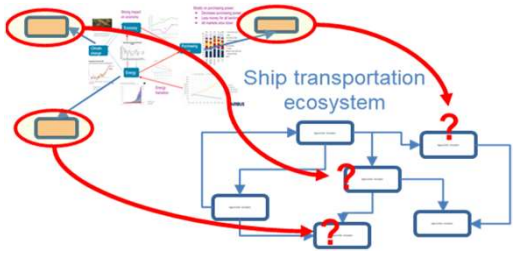
Same platform,
different set of modules…



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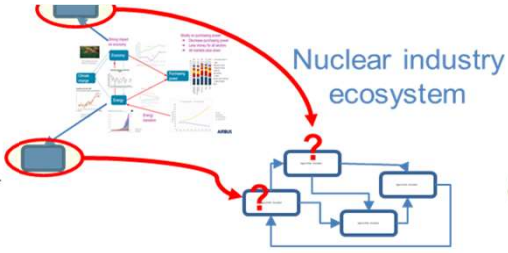

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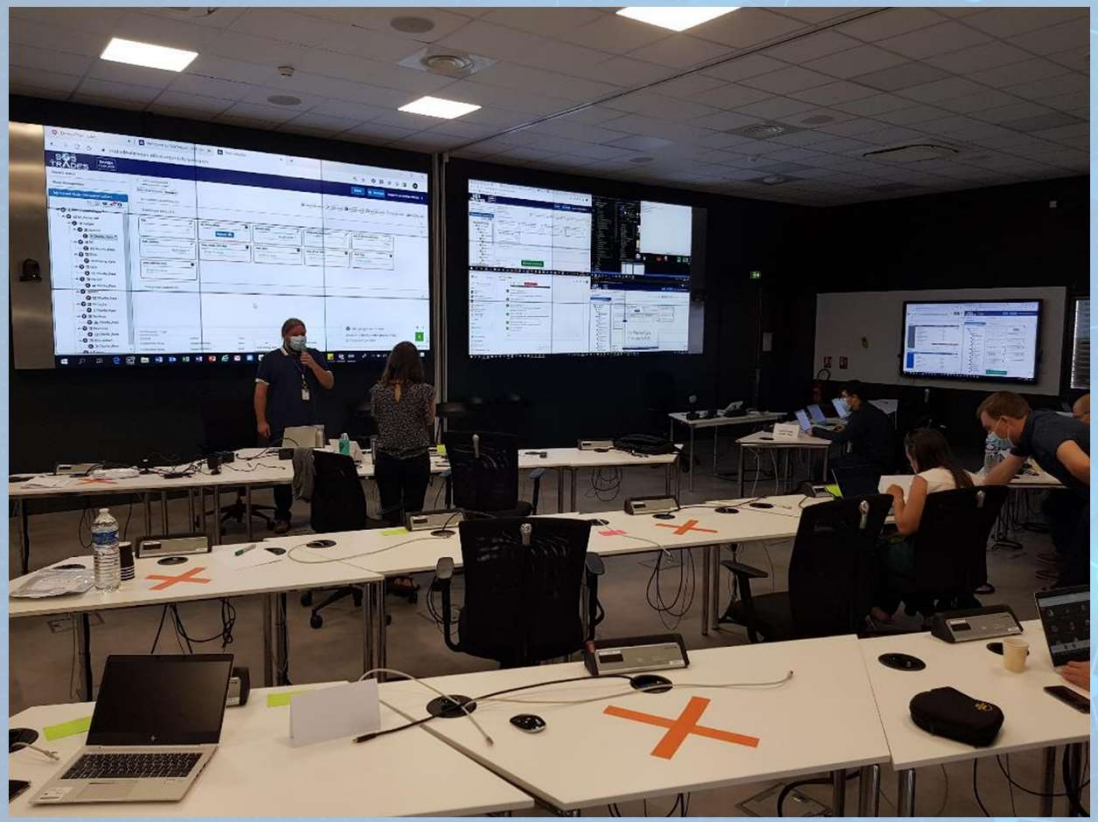
Demo



Link to the public platform
(you'll need a GitHub account)

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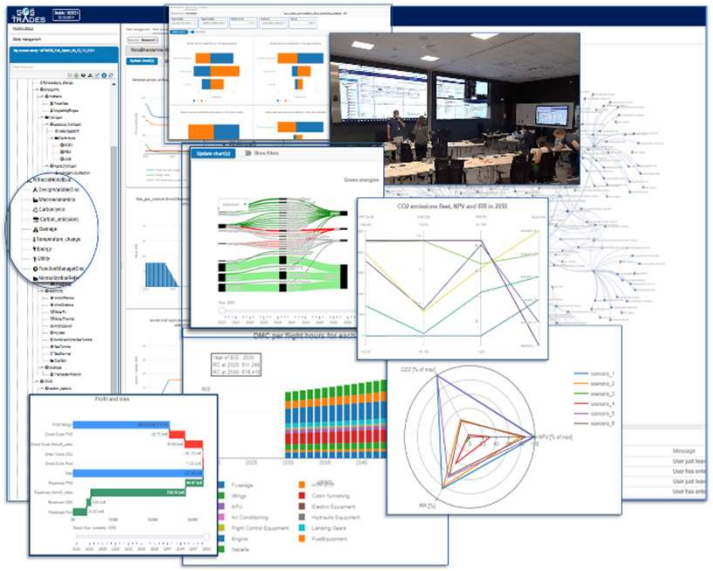
Thank you

- **Complex numerical simulation is successfully expanding from initial physics modeling area to ecosystems or business modeling**

- **Mix of new IT technology usage (cloud, containerization…) and breakthrough simulation assembly techniques, provide a significant step in ability to handle complex system of system simulation**



Interested in Learning More:

https://os-climate.org/transition-tool/
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