Open Source for Climate

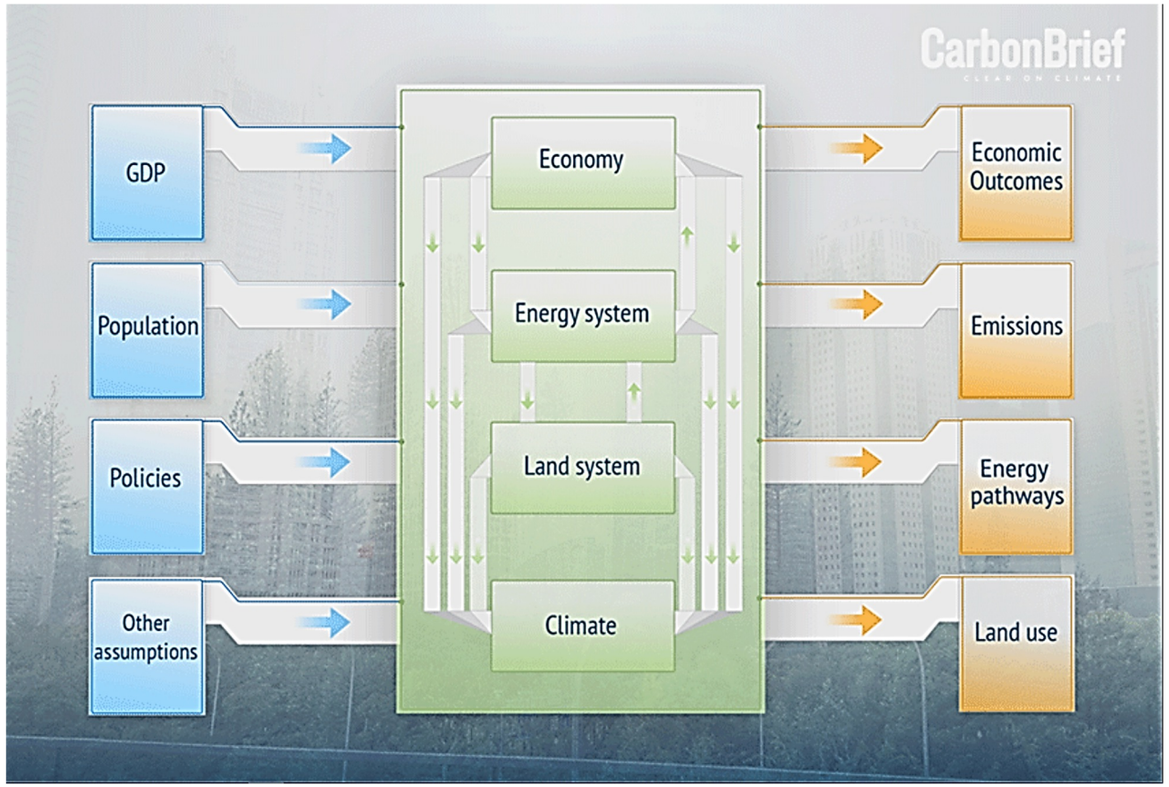
“What If …?” Exploring Economic & Climate Scenarios with the WITNESS Integrated Assessment Model

LF Open Source Summit
April 17th 2024

Michael Tiemann
OS-Climate Project Lead
mtiemann@os-climate.org

OS-C Transition risk tool development is proudly sponsored by Capgemini

Integrated Assessment Modeling (Nordhaus 1992)



Gross Domestic Product depends on capital, labor and net energy output

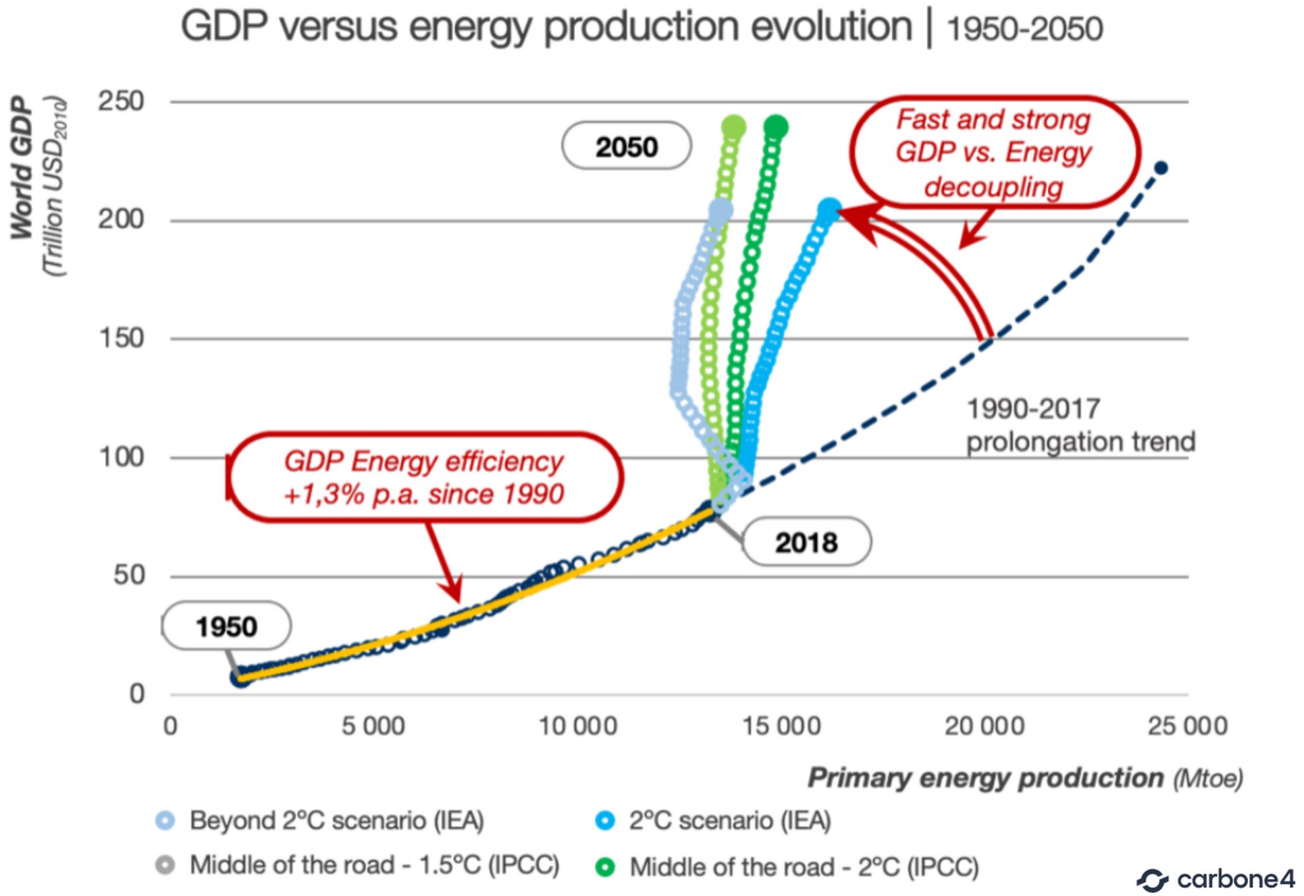
Need to have a population model to properly create world scenarios
(as in World3 model)

Access to net energy production to properly feed production function

Earth is a finite system with many resources limits reflected in the framework. If we want to limit CO2 emissions, we can set a price on carbon.

[DICE] is a model that attempts to use the tools of modern economics to determine an efficient strategy for coping with the threat of global warming.
https://ideas.repec.org/p/cwl/cwldpp/1009.html

Transition planning and Black Boxes—what are they thinking?



IHS, IEA and IPCC GDP assumptions are not reliable in the energy transition context
'Black box' discrepancies & doubtful assumptions do not favor actors' alignment…

A Public Right to Science

Global warming is a collective tragedy, and so its solutions, especially around information for adapting to the risks it portends, must be a public good. That is why governments must step up.

People have a fundamental right to science.

The climate science community needs to rapidly develop a publicly available alternative to paywalled [and gate-kept—Tiemann] climate information; failing to do so would be unjust and dangerous.

— Professor James Mankin

https://www.nytimes.com/2024/01/20/opinion/climate-risk-disasters-data.html

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 the 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

DATA MESH & COMMONS

Data infrastructure & data management for data federation that treats “data as code,” enabling better data coverage, comparability, interoperability, accuracy, and trustworthiness.

A growing resource of climate-related open data.

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

Visit www.os-climate.org for more information

Nobel Prizes, Open Source, and Economics (Historic)

Theory of Change: The (awesome) economics of open source

https://opensource.com/article/18/9/awesome-economics-open-source

By lowering barriers to innovation, open source is superior to proprietary software for enabling continued positive economic growth.

Cygnus 1989: Making free software affordable

Coase 1991: Theory of the Firm

Williamson 2009: Value of the Firm

Ostrom 2009: Community Governance

Image by: *© Marie-Lan Nguyen, Wikimedia Commons, CC BY 3.0*

Nobel Prizes, Open Source, and Economics (forward-looking)

“He who receives ideas from me, receives instruction himself without lessening mine; as he who lights his taper at mine receives light without darkening me. That ideas should freely spread from one to another over the globe, for the moral and mutual instruction of man, and improvement of his condition, seems to have been peculiarly and benevolently designed by nature […] incapable of confinement or exclusive appropriation” – Thomas Jefferson

Coase 1991: Theory of the Firm

Williamson 2009: Value of the Firm

Ostrom 2009: Community Governance

Nordhaus 2018: Integrated Assessment Modeling

Romer 2018: Knowledge as driver of long-term growth

“The more I learn about the open source community, the more I trust its members. The more I learn about proprietary software, the more I worry that objective truth might perish from the earth.” – Paul Romer

https://paulromer.net/jupyter-mathematica-and-the-future-of-the-research-paper/

Transition challenge: where we are today

Inconsistent reports

on climate & energy transition
risks / potential actions

Inconsistent opinions

on why reports reach different
conclusions

No consensual strategy to overcome transition

due to inability to build a constructive analysis of differences
as reports are in nature not reproductible, hard to audit,
and might incur many conscious/unconscious biases/errors

Inconsistent actions and policies

that ultimately fail to address transition efficiently
and make future highly unpredictable for anyone

The History of INTEROP, and the future of Climate Science

Mid-1970's: Dan Lynch managed the computing facility for the AI center at SRI; connecting to ARPAnet was "not 100% reliable". Lynch and others started sharing code and trying to work cross country, with Bolt, Beranek, and Newman (later BBN Technologies) in Boston, to debug some of the issues with TCP.

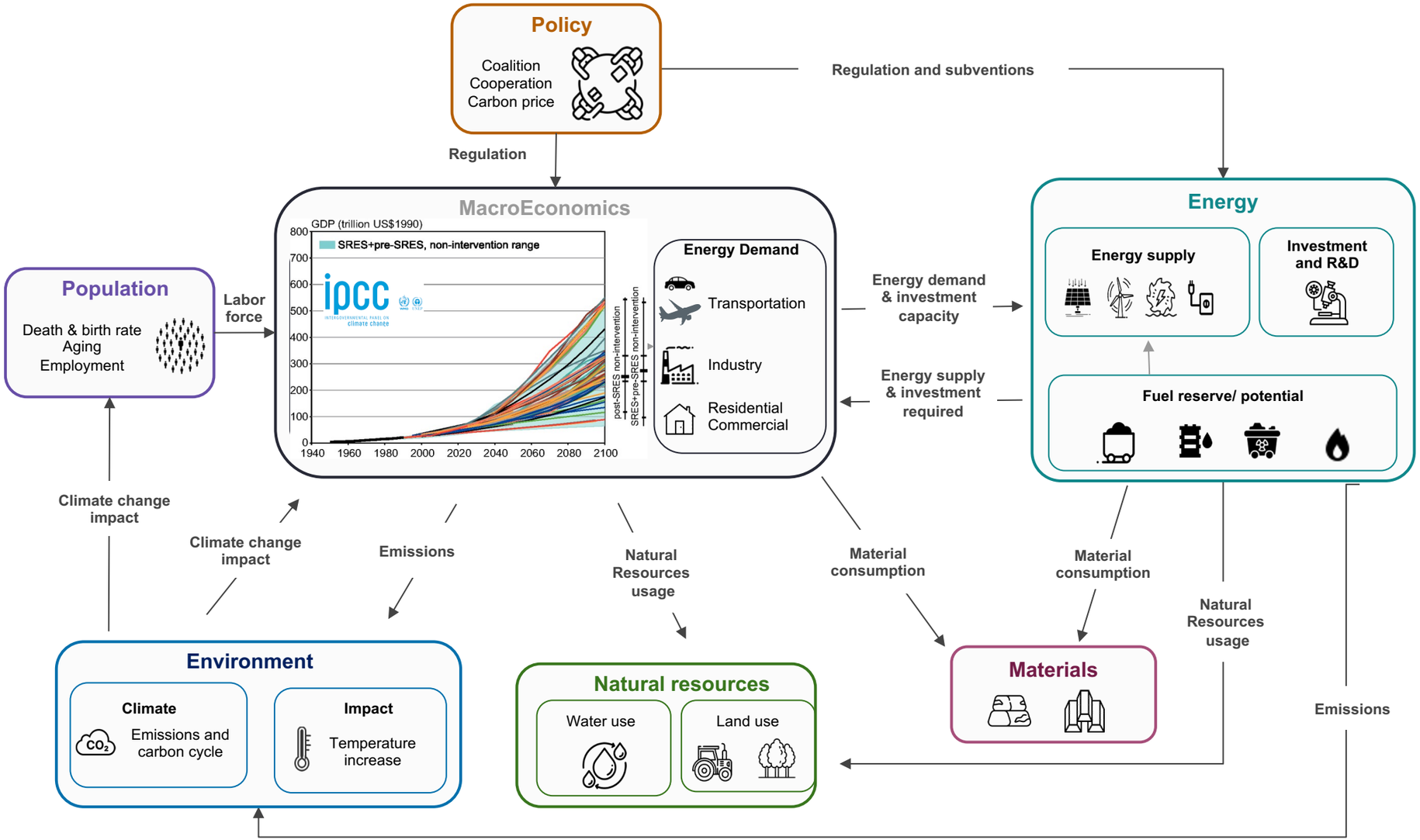
August 1986: Lynch convened a workshop with the goal of explaining what TCP was and what it was not, focused on engineers. Engineers from MIT, Stanford, ISI, and others, attended. The idea was to deal with the problem that "people were mucking up implementations" of the standard, and simply get the engineers talking to one another. HP had three different teams working on TCP, and IBM had five, and they "didn't even know about each other." Several subsequence conferences were packed.

September 1988: Lynch hired a conference organization and setup a larger show at the Santa Clara Convention Center which attracted 5,000 people and 50 vendors, including IBM, 3Com, Cisco, and Sun. He remembers that on the night before the show opened, while he had hired guards to protect the booths, he instead saw engineers in each other's booths, helping to get things working right.

INTEROP grew exponentially through 2001, when (1) the dotcom bubble burst, and (2) TCP had won.

https://www.pcmag.com/news/30-years-of-interop-the-importance-of-making-it-all-work-together

What if we could create a Connectathon for Economic modeling and decision-making?



OS-Climate Transition tool tentative answer

Open source transition analysis tool
Open, transparent, collaborative
multi-scenario tool
allowing shared analyses

Critical mass of actors
sharing strategies for sustainable
paths to overcome transition

"Coopetitive" elaboration of transition strategies

between ecosystem actors at various level
thanks to open, cooperative, transparent, reproductible multi-scenario analyses
improve transition assumptions, impacts and dynamic knowledge

Largely accepted and followed pre-competitive strategy
leading to consistent actions & policies
that ultimately efficiently tackle transition
and make range of possible futures more predictable for everyone
and efficiently associated manage risks

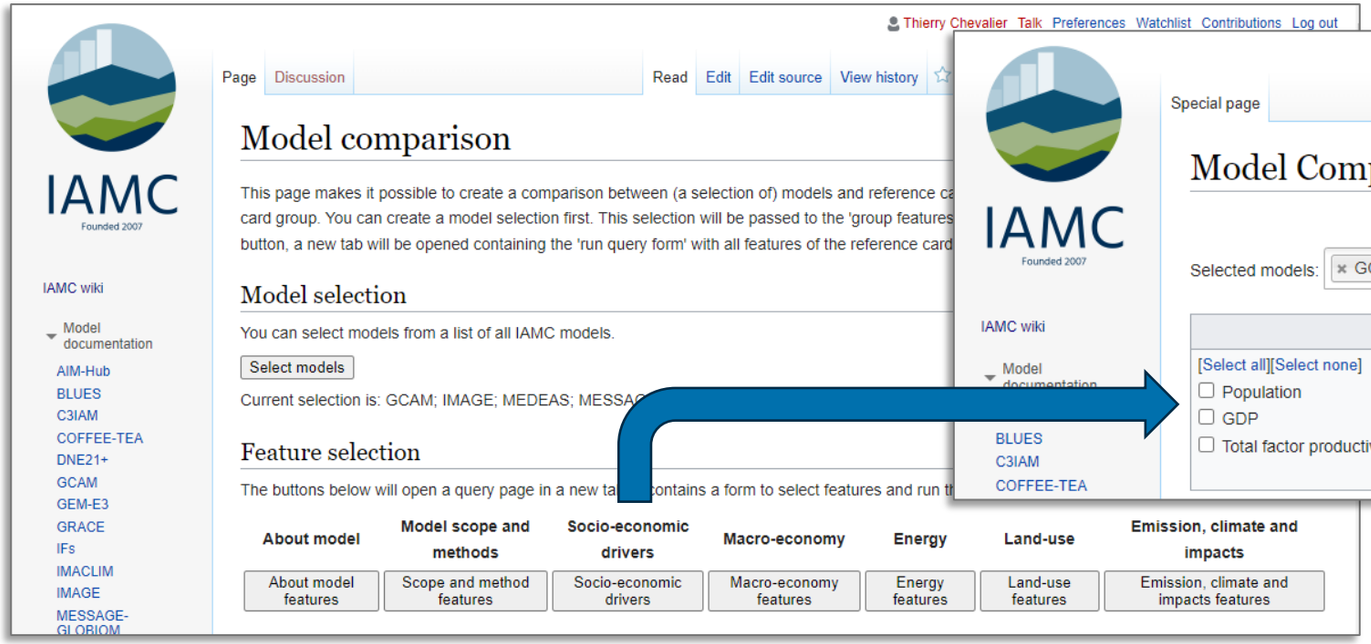
Demo (QR)

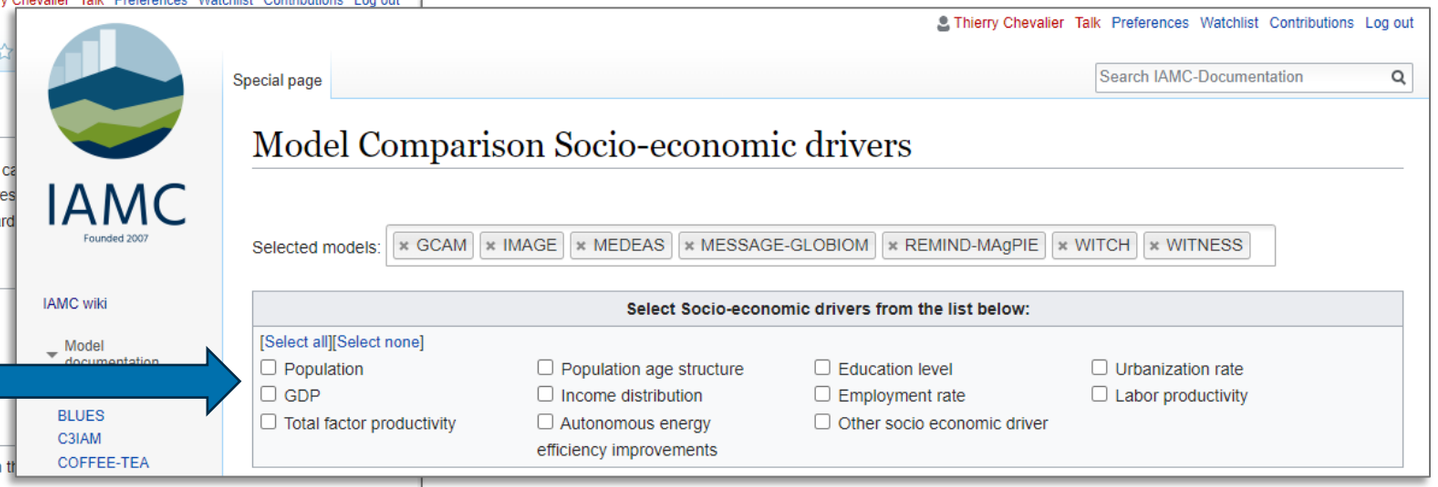
WITNESS 4 CLIMATE

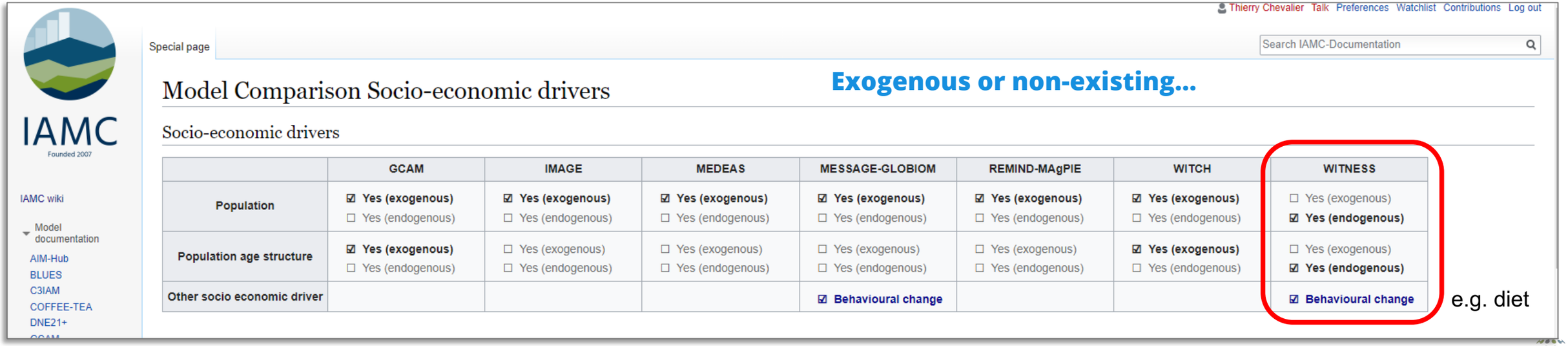
SOS TRADES

WITNESS

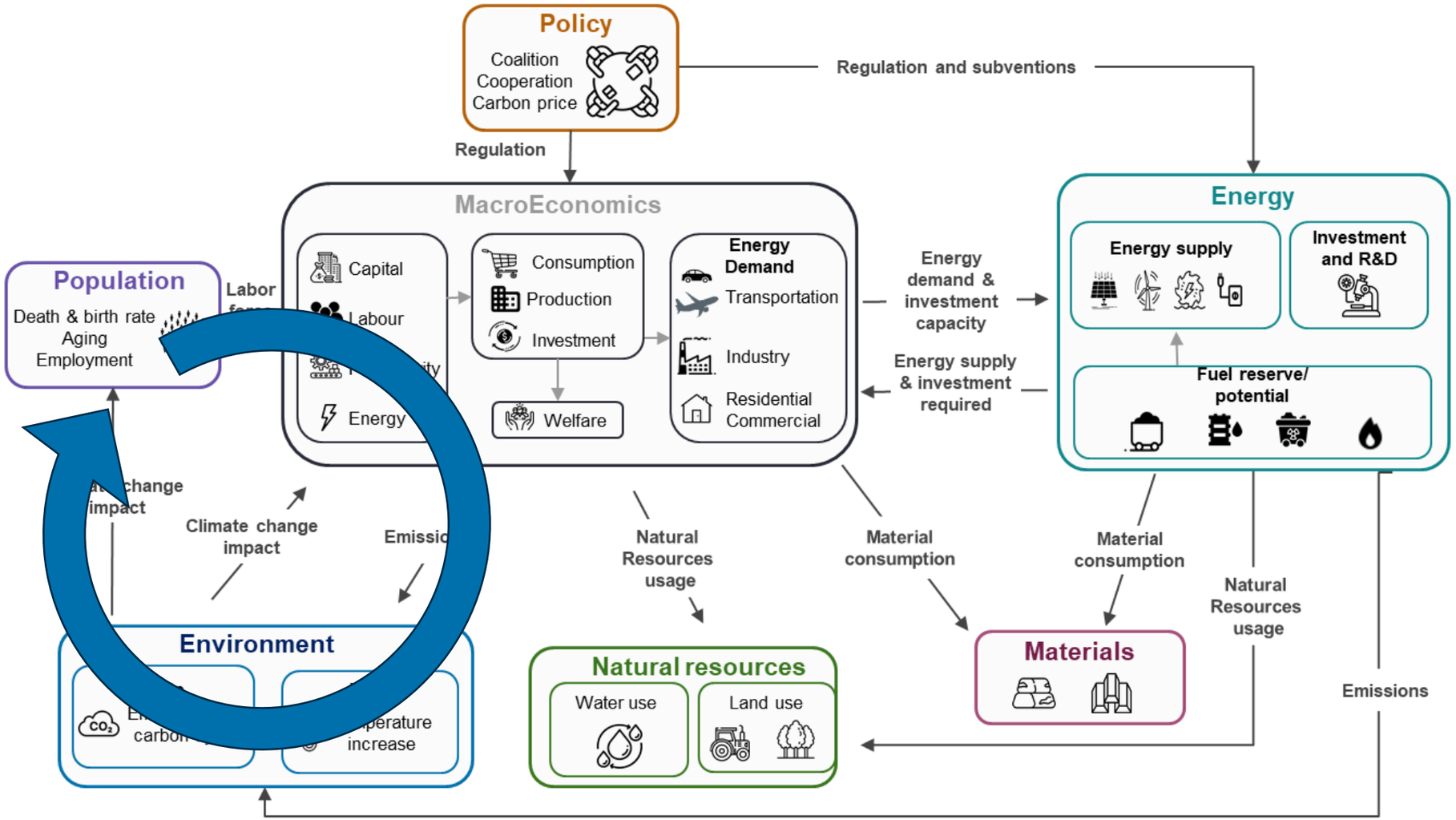
Population & health aspects poorly addressed in current IAM's







Looping effects through the rest of the IAM

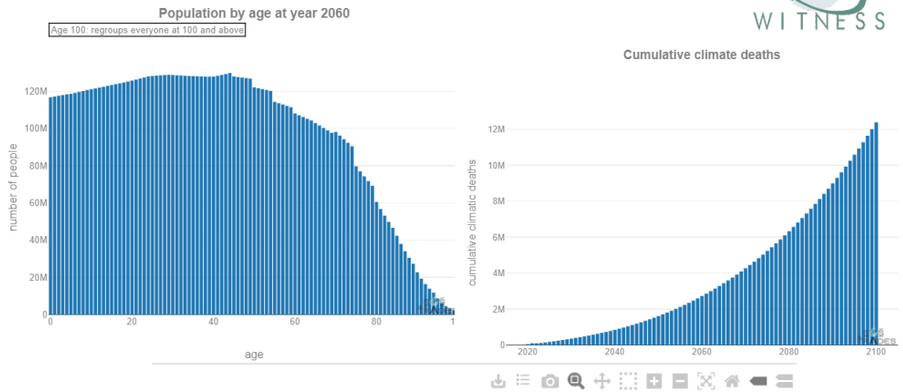


Population in WITNESS

Model documentation in GitHub

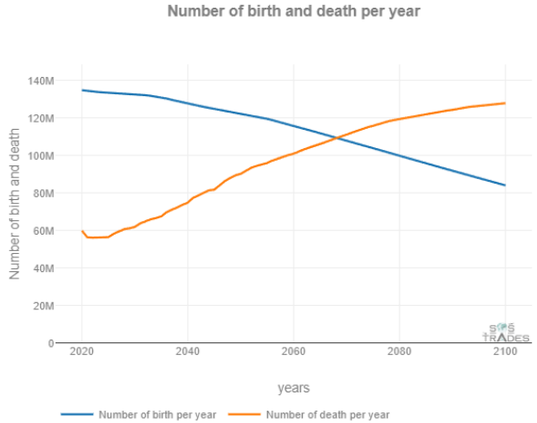
Based on existing literature(*) with modifications

- One year time step and population divided into one year age group
- Evolution of the population depends on birth rate,
  and death rate per 5 years age group
- More detailed 1 year age classes and level of education are considered



Birth rate

- Function of economics activity and a proxy for education
  in case of degrowth we will not retrieve past level of birth rate because of all the knowledge acquired
  (e.g. better access to contraception, higher level of education...)



Death rate

- Classic death rate: function of **economics activity** and a proxy for **education**
- Improved death rate: classic death rate + sum of **climate and nutrition** effect
- Key endemic diseases considered

Key model strengths

- Population dynamic fully considered
- Flexible model allowing fast modelling improvements

Improvement required

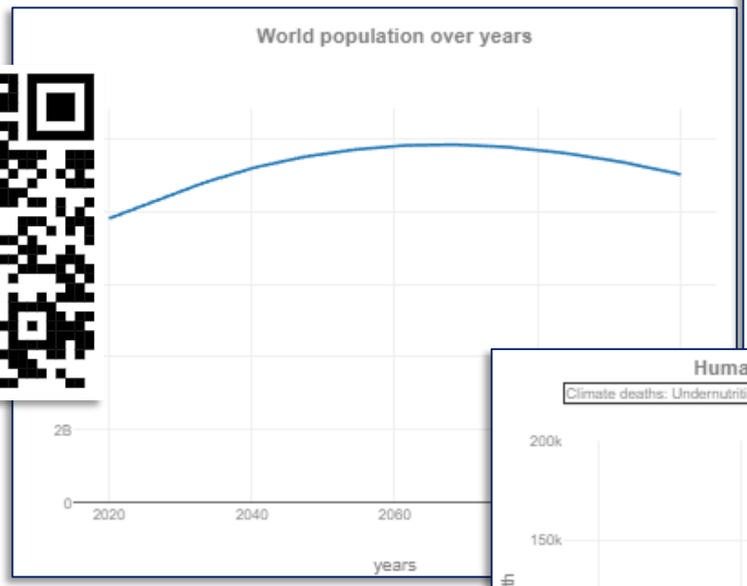
- Better model of labour productivity
- Model additional effects on both birth rate & death rates
- Only at global level, need to work on population distribution

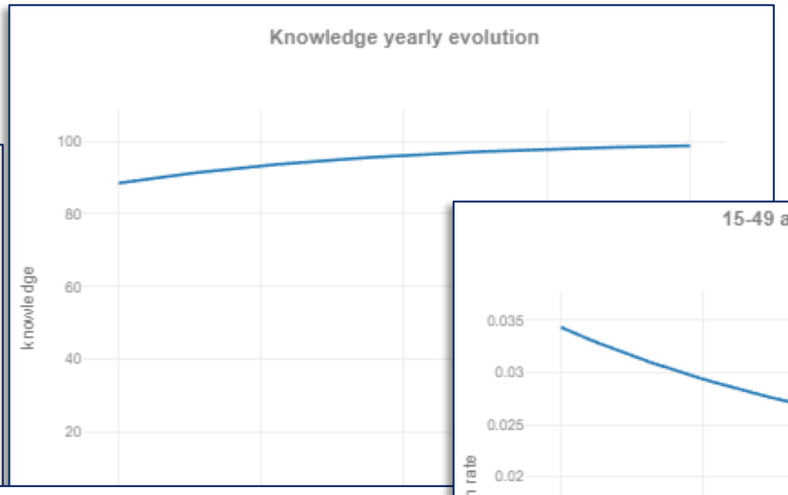
Table 6 Proportion of the additional deaths provided by WHO [61] assigned to each age-group

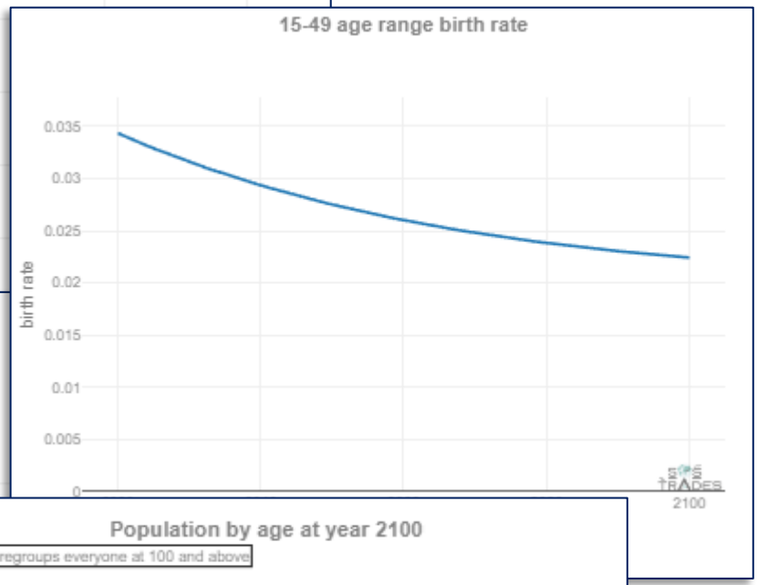
	Undernutrition	Malaria	Dengue	Diarrheal diseases	Heat waves
0–4	1	1/14	1/14	1/3	0
5–9	0	1/14	1/14	1/3	0
10–14	0	1/14	1/14	1/3	0
15–19	0	1/14	1/14	0	0
⋮	⋮	⋮	⋮	⋮	⋮
60 – 64	0	1/14	1/14	0	0
> 65	0	1/14	1/14	0	1

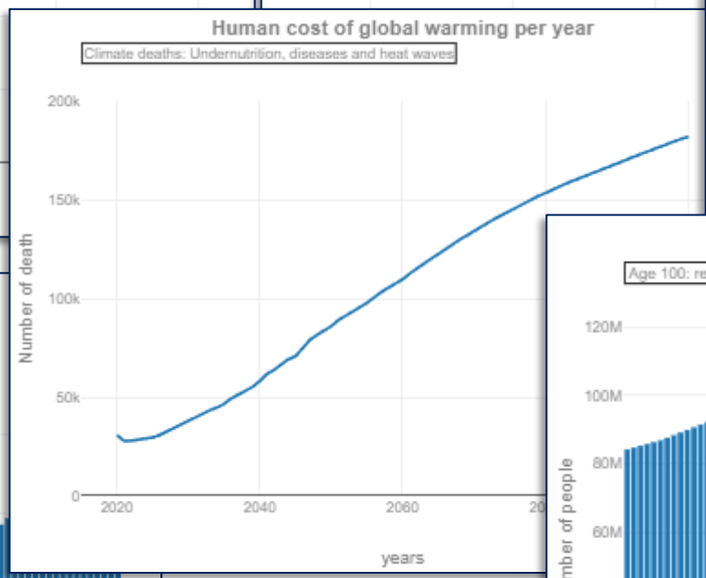
(*) McIsaac, F. (2020) "A Representation of the World Population Dynamics for Integrated Assessment Models. Environmental Modeling & Assessment", pp.611-632.
WHO. (2014). Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. Geneva: World Health Organization

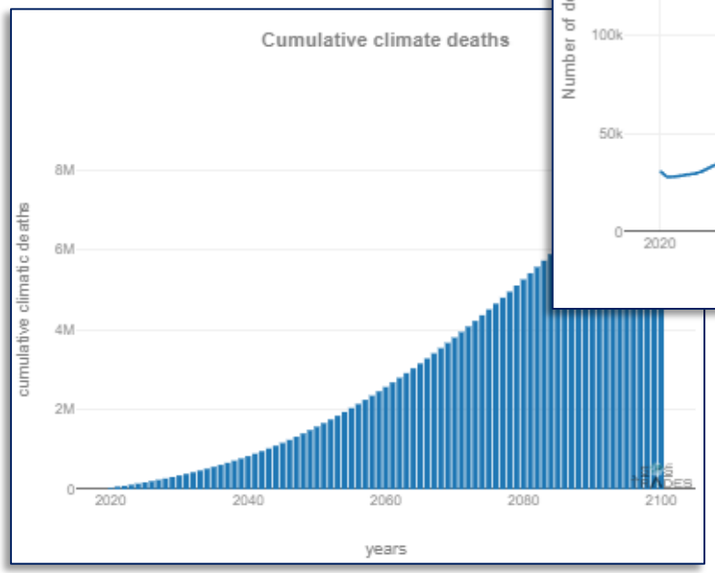
Demo focused on health (QR)

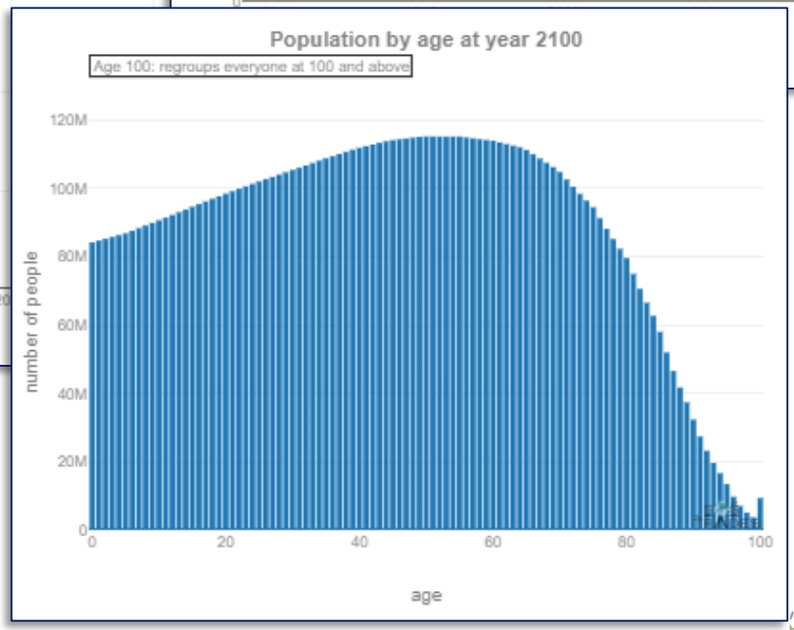




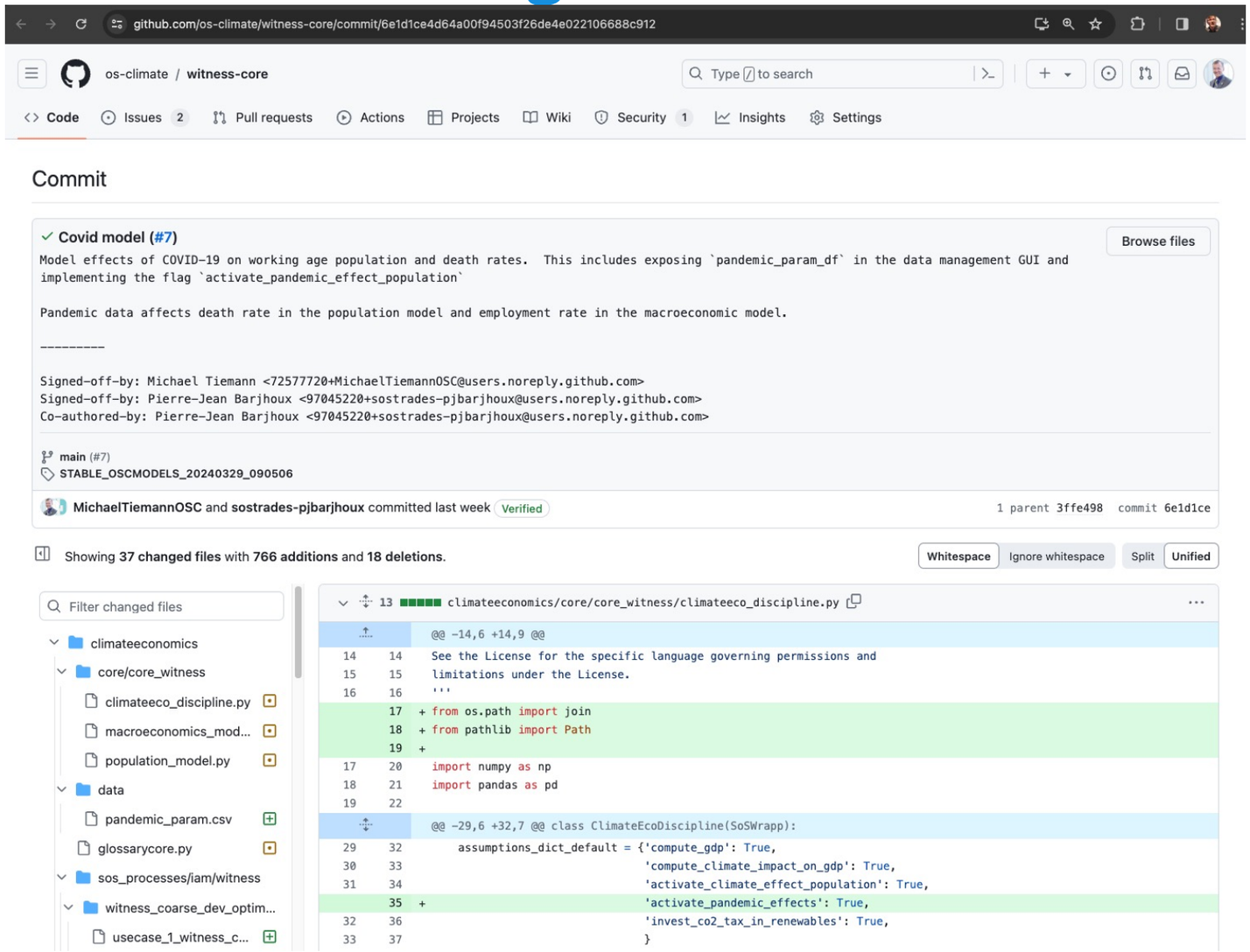




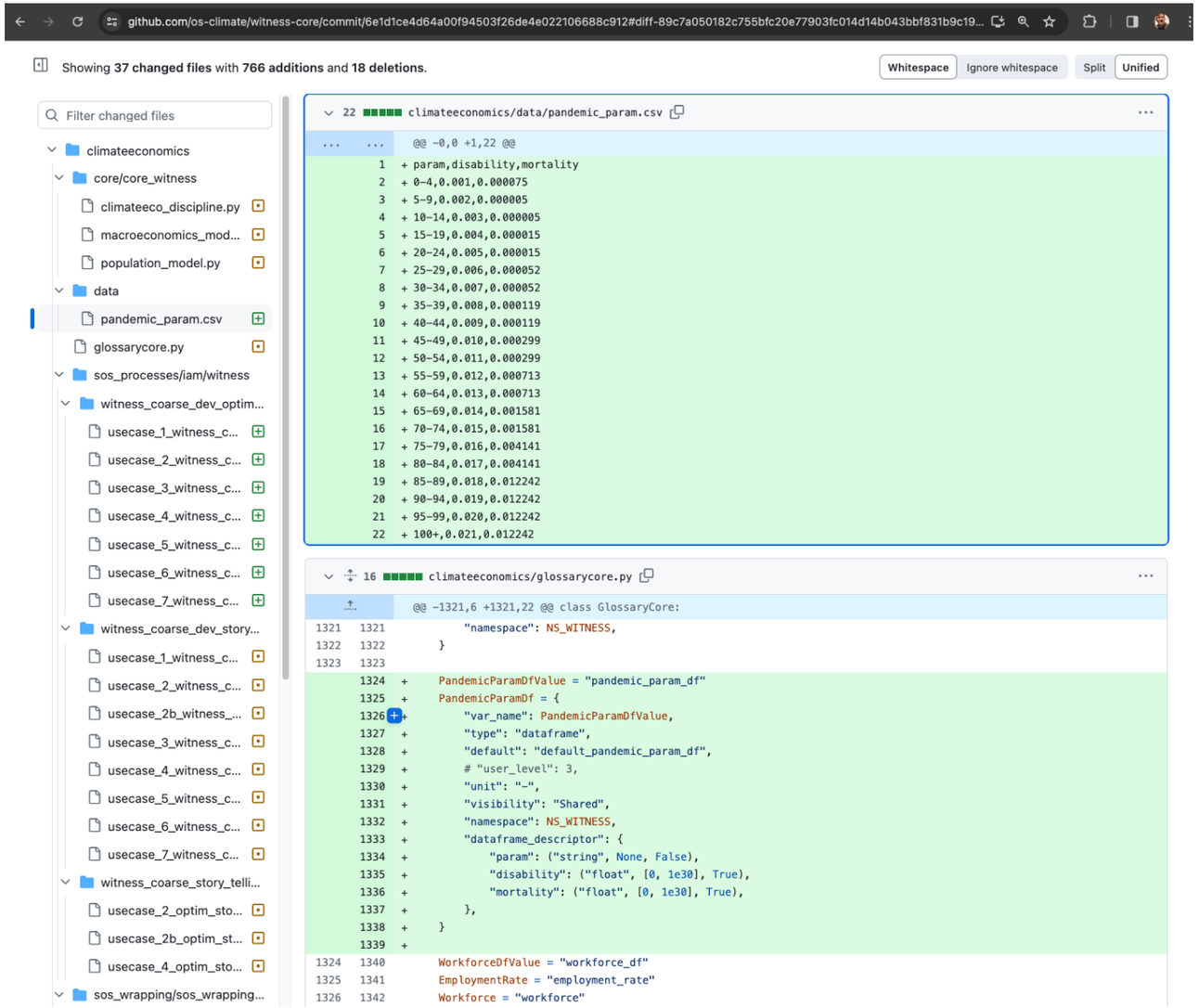




Pandemic Effects on Population and Macroeconomics: Open Source COVID modeling



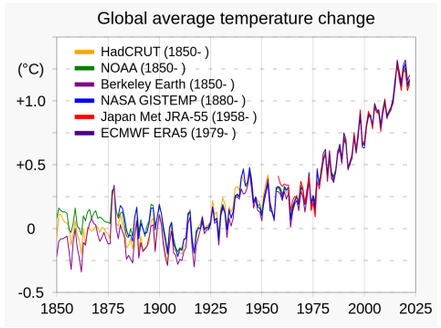
Pandemic Parameters: Pick your science



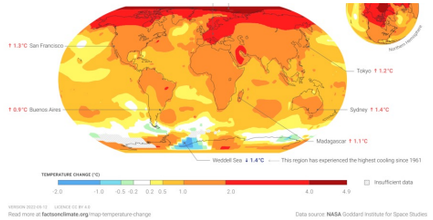
Adjaye-Gbewonyo D, Vahratian A, Perrine CG, Bertolli J. Long COVID in adults: United States, 2022. NCHS Data Brief, no 480. Hyattsville, MD: National Center for Health Statistics. 2023. DOI: https://dx.doi.org/10.15620/cdc:132417

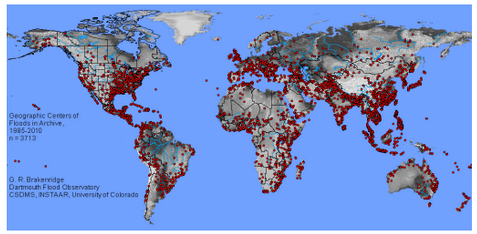
Possible developments: Advanced damage functions

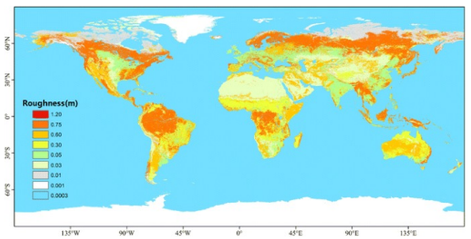
Proposal of a damage function based on geo-spatial data (1/3)



Build correlations between local information and global temperature change







Extracted from CMIP5 or future CMIP6

Resulting models

- Local temperature change (Global T)
- Flooding occurrences (Global T)
- Extreme weather occurrences (Global T)

…

Possible developments: Advanced damage functions

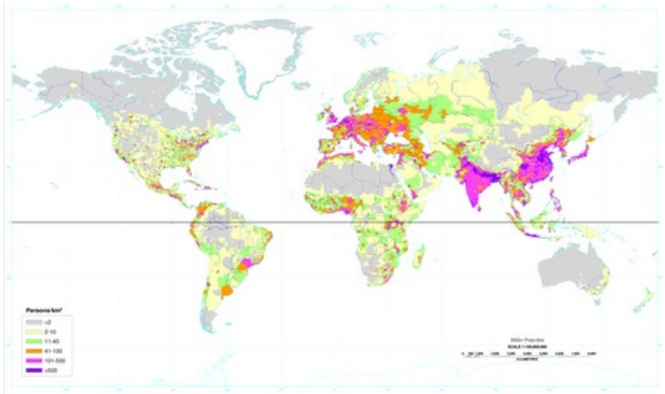
Proposal of a damage function based on geo-spatial data (2/3)

Resulting models

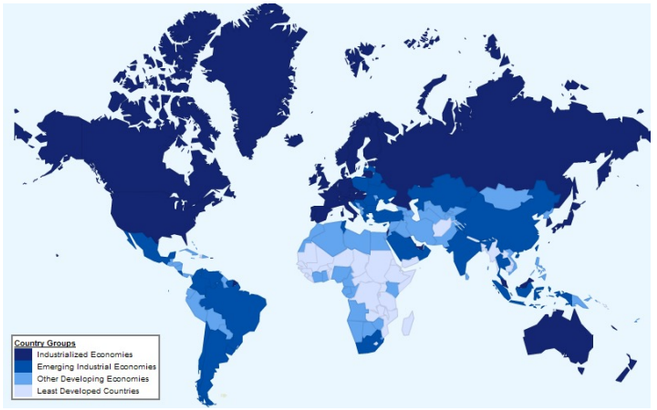
- Local temperature change (Global T)
- Flooding occurrences (Global T)
- Extreme weather occurrences (Global T)

…

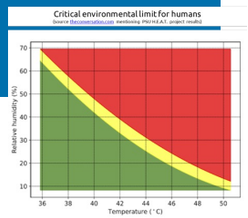
Use models with population distribution data



Use models with capital / Industrialization distribution data



Climate induced death model

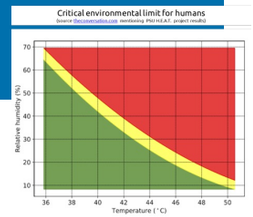


Physical damage & loss model

Possible developments: Advanced damage functions

Proposal of a damage function based on geo-spatial data (3/3)

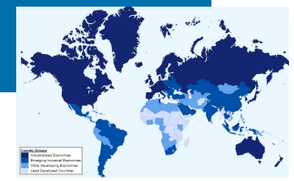
Climate induced death model



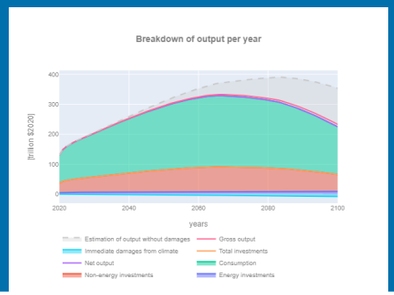
Human Labor impacted by climate change

Capital loss due to climate change

Physical damage & loss model



Macro-economics impacts with advanced damage functions



We are looking for financing of this initiative

GEMSEO uses 1998 math to leap-frog 1992 limitations

gemseo.readthedocs.io/en/stable/disciplines/jacobian_assembly.html

GEMSEO v. 5.3.0 User Guide API Examples Modules More Go

Prev Up Next

GEMSEO 5.3.0

Please cite us if you use the software.

Toggle Menu

Coupled derivatives and gradients computation

Introduction

The use of gradient-based methods implies the computation of the total derivatives, or Jacobian matrix, of the objective function and constraints.

$\mathbf{f} = (\mathbf{f_0}, \ldots, \mathbf{f_N})^\mathbf{T}$ with respect to the design vector $\mathbf{x} = (\mathbf{x_0}, \ldots, \mathbf{x_n})^\mathbf{T}$:

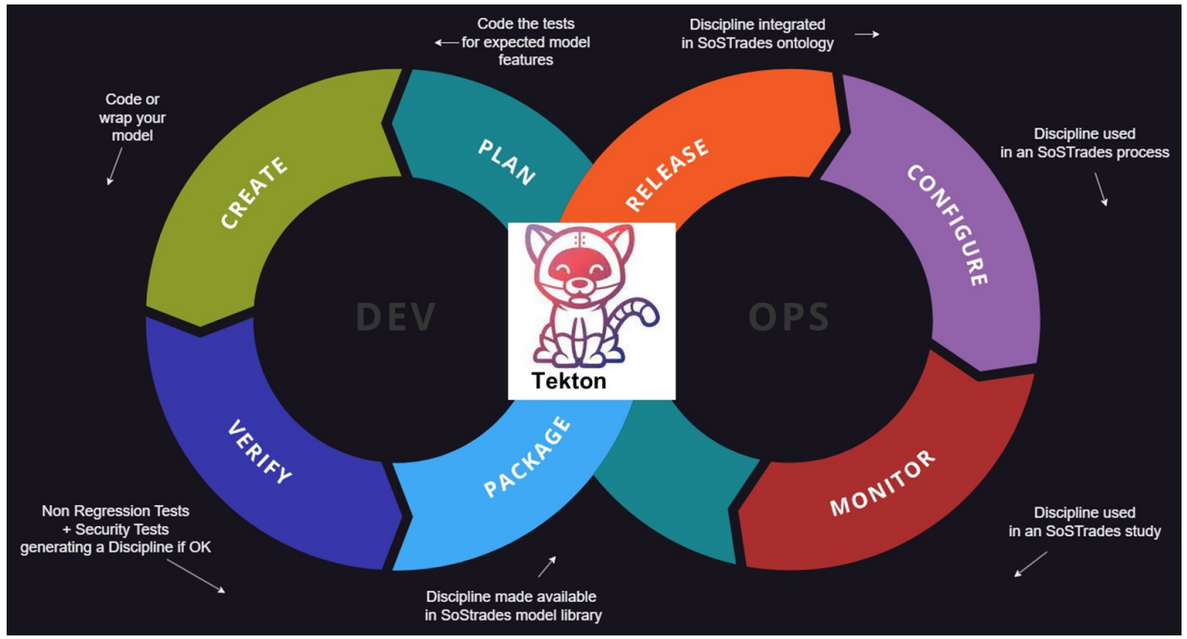
$$\frac{d\mathbf{f}}{d\mathbf{x}} = \begin{pmatrix} \frac{df_0}{dx_0} & \cdots & \frac{df_0}{dx_n} \\ \vdots & \ddots & \vdots \\ \frac{df_N}{dx_0} & \cdots & \frac{df_N}{dx_n}. \end{pmatrix}$$

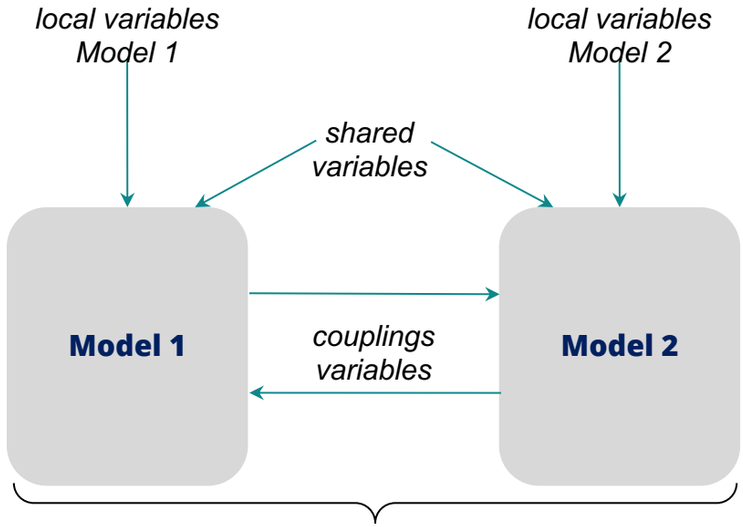
The Jacobian matrix may be either approximated (by the finite differences and complex step), or computed analytically. Both options are possible in GEMSEO.

https://www.researchgate.net/publication/222112601_The_Complex-Step_Derivative_Approximation

SoSTrades Model DevSecOps

1. Develop your core model (Python)
2. Wrap your model
   - check parameters ontology for your interfaces
   - write the wrapper code (Python)
     - grab inputs by name in proper namespace**
     - run your core model
     - transfer outputs by name in proper namespace**
   - add post-processing graphs (Plotly)
   - write the doc (markdown language)
3. Add your new wrapper in proper simulation namespace
4. Check in your developments and write validation tests
5. Wait next DevSecOps batch (triggered after a push on integration pipeline)
6. Use your new features (or fix regression or security issues ☺)





Multi-Disciplinary Analysis (MDA)

GEMSEO
A Generic Engine for Multidisciplinary Scenarios, Exploration and Optimization

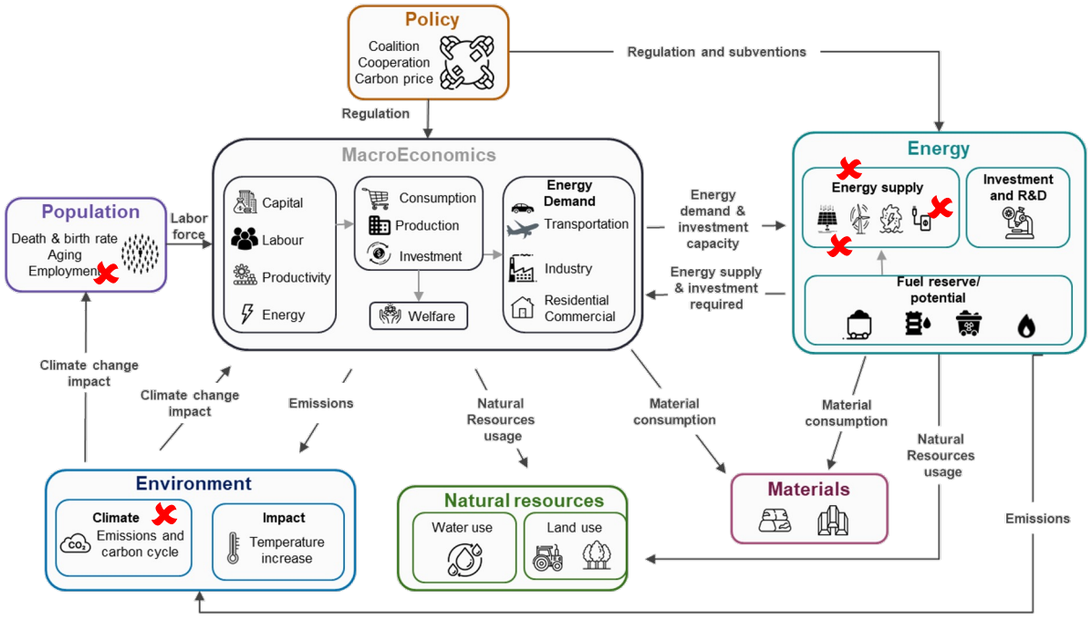
** according to the discipline I/O names,
couplings variables are **automatically** identified,
and multi-disciplinary analyses automatically built

Easy to complete or evolve with new effects, parameters…

Let's say you want to add impact of ODS(*) on health

(*) ODS : ozone-depleting substances

1. Complete ontology with main elements/variables to be exchanged
   (ODS emissions, ozone layer thickness…)
2. Add ODS emissions from any relevant sources as needed
   (energy, macro-economics…)
3. Add environment system impact from all ODS emissions
   (ozone layer reduction, CFC contribution to green house effect…)
4. Add death rate impact in population model due to Ozone layer thickness reduction

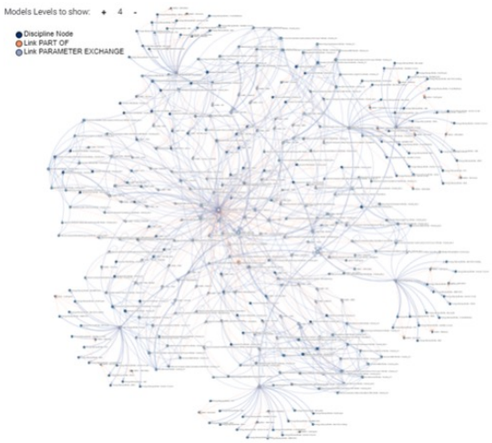


Automated

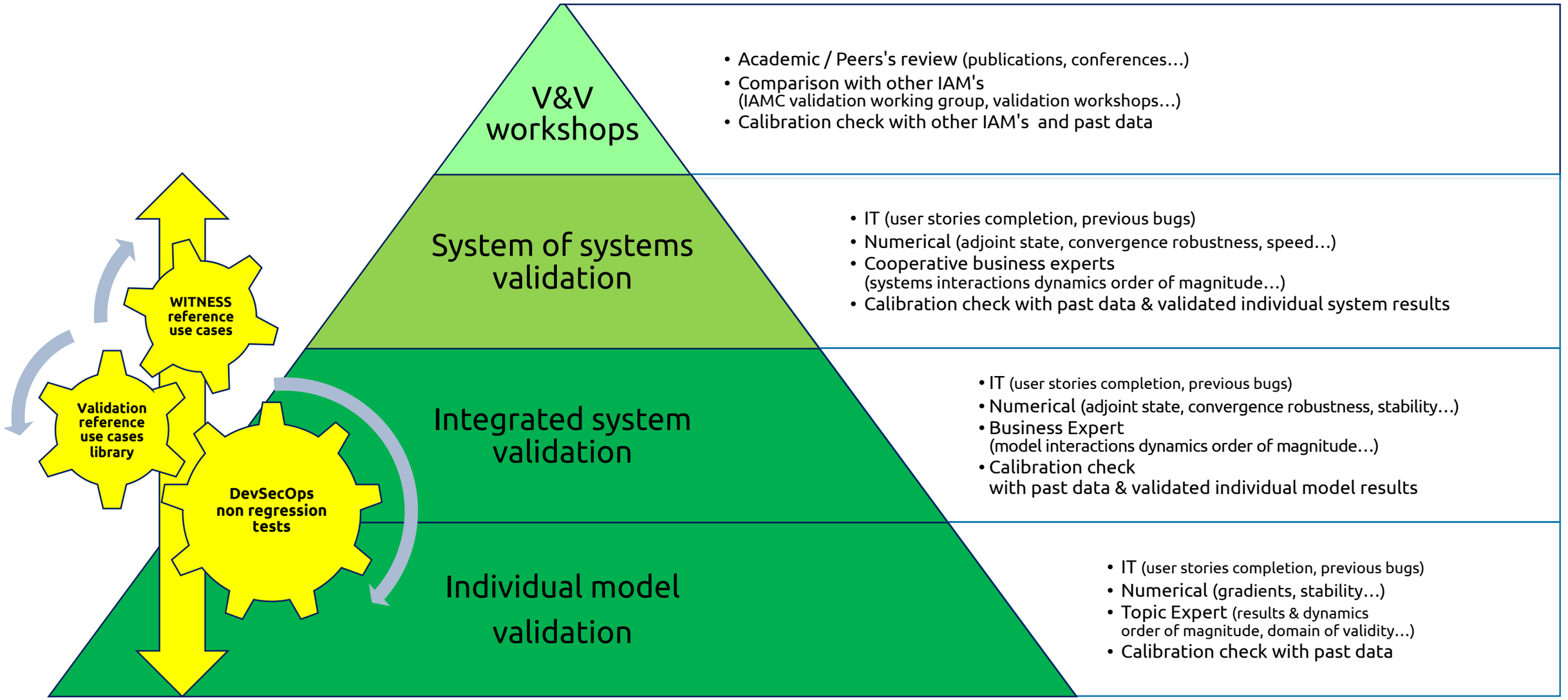
- Collection of all ODS emissions
- Cumulating greenhouse effect of ODS on top of other factors
- Population evolution due to population damage generated by thinner ozone layer
- Impact on labor for macro-economics

Just add your model

Taking into account interactions and loop-back is automated



Verification and Validation in WITNESS as of Jan'24



Follow-up or work with the project

For users

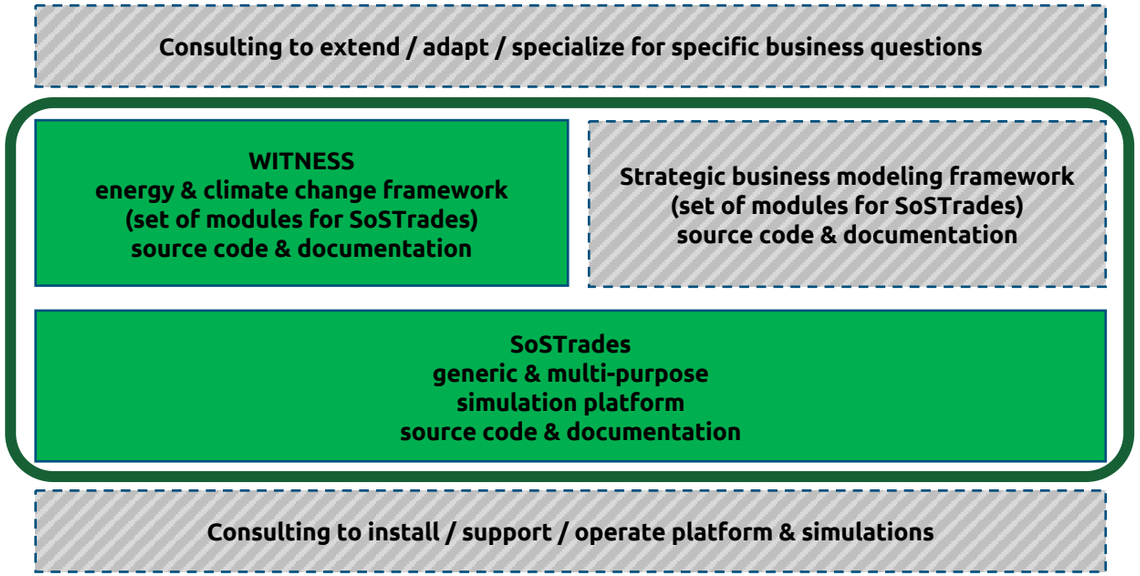
- Follow-up OS-Climate progress as a whole
  ➔ "All hands meeting"
  1h every second Tuesday of the month, 10:00 AM ET
- Follow-up Transition tool more specifically
  ➔ "Transition tool weekly"
  1/2h every Wednesday, 10:00 AM ET
- Specific interaction with Transition tool team
  ➔ "Come as you are"
  2h every Thursday, 08:00 AM ET
  register at https://www.witness4climate.org/events/
- User's training
  ➔ Training development in progress with Linux Foundation
  First MOOC's should be available in Q2'24

For developers

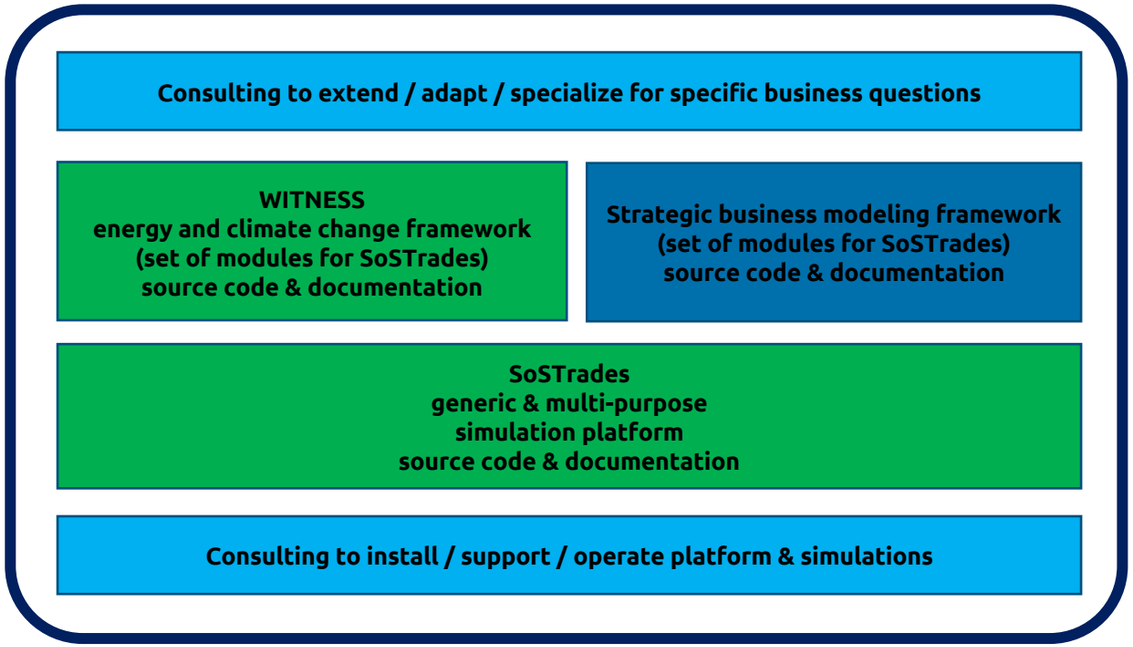
- Start your own developments
  ➔ Setup development environment on your laptop
  (native or Docker containerized image available)
- Get specific support
  ➔ "Code as you are"
  2h every Wednesday, 08:00 AM ET
  register at https://www.witness4climate.org/events/
- Contribute source code or documentation
  ➔ Contact project to get a GIT branch
  where to contribute your developments
  https://github.com/os-climate
- Test integration of your code
  ➔ Automated through DevSecOps loops
  when your code is properly contributed on project GitHub
- Developer's training
  ➔ Training development in progress with Linux Foundation
  First MOOC's should be available in Q2'24

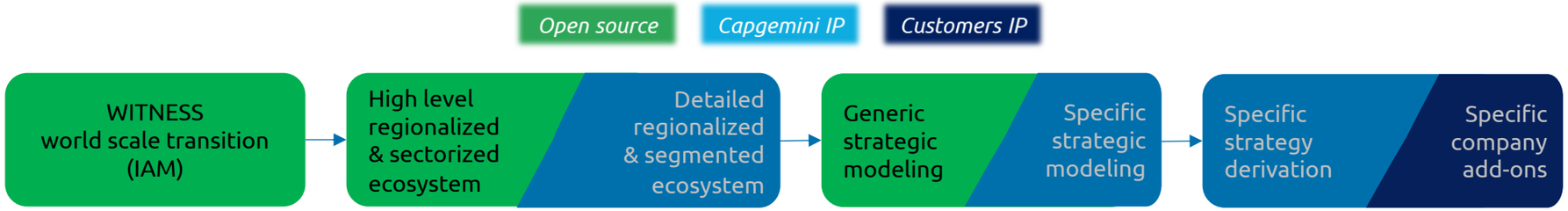
Barebones open source offer can be completed by commercial support if needed

OS-Climate «Transition tool» source & documentation scope



Capgemini « Business for Planet modeling » commercial offer scope





Final Thoughts…

21 Sept 2023: The Net-Zero Asset Owner Alliance calls on policymakers to boost support and unlock up to $275 trillion net-zero investment opportunity

https://www.unepfi.org/industries/investment/unlocking-investment-in-net-zero/

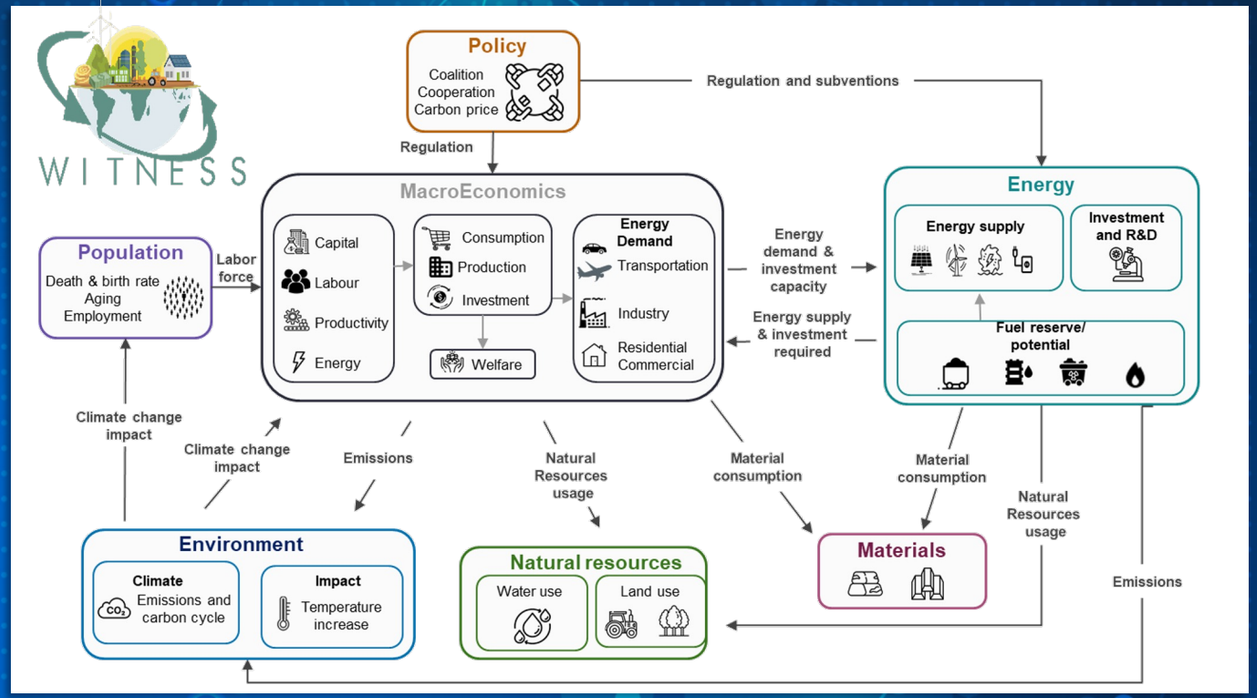
[There is] vast economic opportunity for transitioning to a 1.5°C scenario, with up to US$275 trillion in climate investment opportunities by 2050, and many grave risks associated with the failure to transition, including up to $4-6 trillion in GDP losses *per year* by 2050.

WITNESS is not just cool software with advanced maths. It can help inform the allocation of $Trillions of dollars of capital. This is a real opportunity for meritocratic models to help make the best decisions.

Let's build a Universal IAM For Climate

Thank You!

Interested in Learning More:



https://witness4climate.org

WITNESS presentation and links to OS-C

https://github.com/os-climate

Source code repositories (include all models documentation)

https://stable.osc-tsa.com/

Stable public platform (basic github account needed)

mtiemann@os-climate.org

OS-C Transition risk tool development is proudly sponsored by Capgemini

Links to different resources

https://witness4climate.org

WITNESS presentation and links to OS-C

https://os-climate.org/

Open Source for Climate

https://github.com/os-climate

Source code repositories on GitHub
(include all models documentation)

Public platforms

Stable

https://stable.osc-tsa.com/

Validation

https://validation.osc-tsa.com/

Integration

https://integration.osc-tsa.com/

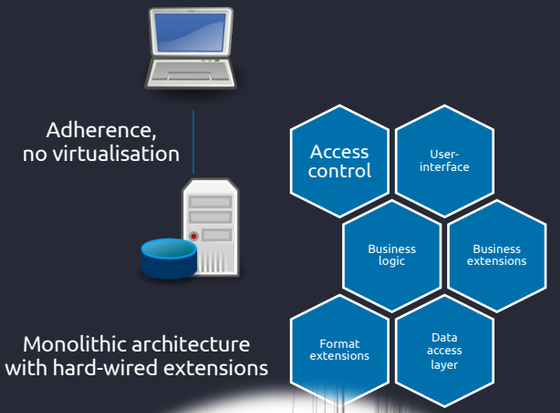
Complex system of systems simulation painpoints

Limited modern cloud deployment or integration

Very few platforms *cloud native* or *containerized*

Most platforms still heavily connected to *real physical* infrastructure

Integration mechanisms often inherited from PLM world & outdated



Poor simulation scalability for complex system of systems

Interactive workflow editor not scalable for *specifying* complex simulation

Dynamic resource allocation is still rare

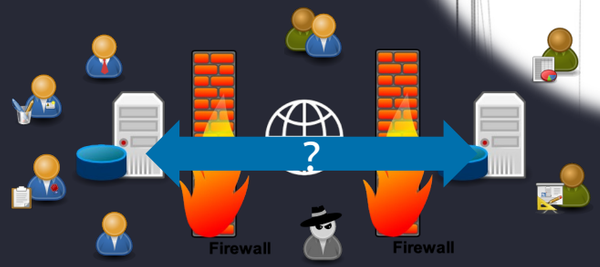
and needed to tackle new simulation challenge

(x10 to x100 models, generating x100 to x1000 instances,
x100 to x1000 optimization design variables, x10000 to x100000 simulation variables, x10 to x100 constraints…)

Limited on cooperation

Cooperative features *focused on simulation* still quite rare

Cooperative *integration* with SPDM also rare



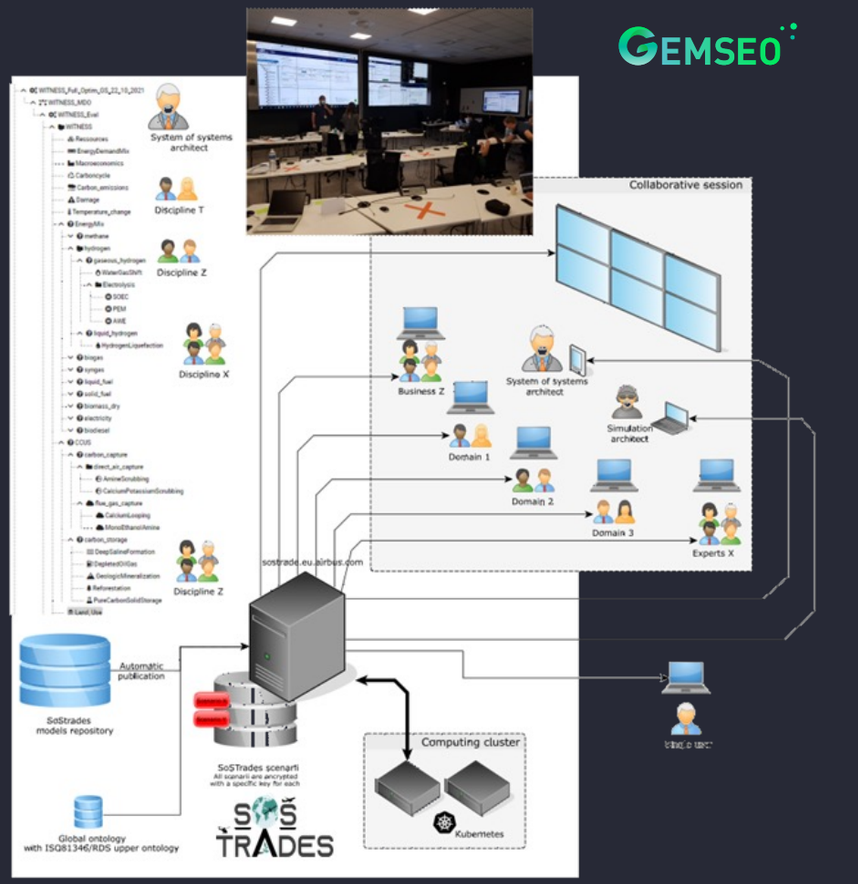
INTRODUCING SOSTRADES* ADVANCED SIMULATION PLATFORM

*SoStrades : System of Systems Trades

Strong differentiating assets for complex / advanced simulation

A generic platform adaptable to the simulation needs of specific projects

- ✓ designed to handle long-term trajectories 2030, 2050, 2100 unlike industrial digital twins or classic “System of Systems” approaches
- ✓ provides all the state of the art in mathematics for simulation:
  design of experiments, sensitivity analyses, optimization, uncertainties…
- ✓ cloud native and scalable,
  able to handle 300,000+ coupled variables
  (demonstrated on the WITNESS model)
- ✓ Automatically interconnect models and orchestrate studies



An open source platform that enables secure multi-stakeholder collaboration

- ✓ collaborative by design, so that multiple actors can cooperate live defining assumptions and analyzing results
- ✓ open-source within the framework of the “Open Source for Climate” project of the Linux Foundation: sovereignty, adaptability, mutualized non-differentiating evolutions
- ✓ web interface, all you need is an internet link to use it, no installation
- ✓ data confidentiality is ensured by individual access rights
  and scenarios encryption on disks

SoSTrades* Advanced simulation platform

*SoStrades : System of Systems Trades

"Commercial" view :

- Web based interface, interactive publication-quality graphs
- Ground up built for collaborative approach
  (multi-user, access rights, validation, encryption…)
- Trace-ability of changes
  modular inputs & outputs validation
- Embedded processing of sensitivities & uncertainties
- Multi-instance / multi-scenario capabilities
- Prescriptive and not descriptive simulation assembly
  (Capability to “dump” new module in a framework without additional coding)
- Strong Multi-Disciplinary Analysis & Optimization capabilities
  with coupling plug-ins allowing multiple numerical coupling strategies
- Full native cloud implementation
  with generic databases access connector
- Containerized based execution possible,
  allowing specific environment management for specific models
  (specific libraries version, licenses…)
- Study as component
  remote referencing / REST API piloting / dashboard display
- Open Source part of Linux Foundation Open Source for Climate project

Proven capabilities in WITNESS context

MDO
65 disciplines
4240 design variables
265383 variables
1200 constraints

MDA
63 disciplines
25064 coupling variables
262715 variables

Objective	*maximize* **welfare** and *minimize* **CO2 emissions**
Design Variables	**technology investment 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,…)

Main components, technologies and COTS

Applicative components

- sostrades_webgui
  - Angular 9+ framework
  - NodeJs
  - Typescript (strong type verification)
  - Distribute as html/css/js package
- sostrades_webapi
  - Python 3.7
  - Flask framework (Rest API)
  - SQLAchemy (ORM)
  - Interface on SoSTradesCore components
  - Hosted by a gunicorn process
- sostrades_authapi
  - Python 3.7
  - Flask framework (Rest API)
  - Dispatch for CorpSSO IdP
  - One instance for the whole cluster
- So called ‘execution_engine_block’
  - Same as sostrades_webapi
  - Use a command line entry point instead of gunicorn process

Components of the shelf

- MySQL
  - SGBDR
  - Applicative data (user, rights, study, execution, logs)
  - As is : one instance for the whole cluster
  - Target : shift server between dev/int/test and devops/stable
- NGINX
  - Web server
  - Serve sostrades_webgui distribution
  - Reverse proxy on all requests
  - Unique entry point on application
  - SSL supports
- NFS
  - File system storage for the whole cluster
  - Store everything that need to be serialize and backup (database, business data’s)
- Kubernetes
  - Platform
  - API

WHITE BOX MODELS VS BLACK BOX MODELS

Whitebox models	Blackbox models
• Can be built from scratch, no need for data • Need theoretical equations to be available • Need applied math to combine equations properly	• Need data to be built (large and accurate dataset) • Can work on any problem, without need for theory or equation combinations
• Auditable and provable • Clear domain of validity	• Not auditable / not provable • Unclear domain of validity
• Can easily and incrementally add new parameters or new effects • Better for extrapolation • Accuracy can be limited with simple equations	• Need large effort / retraining to add new parameters or effect • Unpredictable for extrapolation • Excellent accuracy where extensively trained
• Coding expensive but computationally savvy to create • Inexpensive to run unless you get really complex [combination of] equations	• Computationally expensive but coding savvy to create • Quite expensive to run but relatively flat cost vs complexity

GENERAL DATA SOURCES USED

(NOT LISTING INDIVIDUAL ENERGY PRODUCTION TECHNOLOGY SOURCES, THAT ARE AVAILABLE IN EACH INDIVIDUAL DOCUMENTATION SHEET

- ILOSTAT database
- Nordhaus, W. D.
  - 2017 | Revisiting the social cost of carbon. Proceedings of the National Academy of Sciences
  - 2016 | DICE-2016R-091916ap.gms
- Moyer, E. J., Woolley, M. D., Matteson, N. J., Glotter, M. J., & Weisbach, D. A.
  - 2014 | Climate impacts on economic growth as drivers of uncertainty in the social cost of carbon. The Journal of Legal Studies
- International Monetary Fund
  - 2019, 2020, 2021 | World Economic Outlook Database.
  - 2019 | Investment and Capital Stock Dataset.
- World Bank
  - World data bank
  - World Development Indicators
  - Cereal yield kg per hectare
- IEA
  - 2022 | World total final consumption by source
  - 2022 | World Energy Balances, World Energy Outlook
  - 2022 | Oil Market Report (2019), World oil final consumption by sector
- World Bioenergy Association
  - 2019 | Global Energy Statistics 2019
  - 2020 | Global biomass potential towards 2035
- BP - Statistical Review of World Energy
  - 2021 | Corporate energy-economics statistical-review
  - 2021 | Statistical Review of World Energy
- Eni S.p.A.
  - 2020 | World Oil Review 2020"
- Nuclear Energy Agency and International Atomic Energy Agency
  - 2020 | Uranium 2020: Resources, Production and Demand
- MDPI
  - 1996 | Crop Residue Removal: Assessment of Future Bioenergy Generation Potential and Agro-Environmental Limitations Based on a Case Study of Ukraine
- Bioenergy Europe
  - 2020 | Biomass for energy: agricultural residues and energy crops
- FUND model
  - Repository on GitHub
  - Model Online Documentation
- World Health Organization
  - 2014 | Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s.
- United Nations, Department of Economic and Social Affairs, Population Division
  - 2019 | World Population Prospects 2019, custom data acquired via website
- Our world in data
  - Literate and illiterate world population
  - Land use over the long term
  - Food Grenhouse gas emissions
  - Environmental impacts of food
  - Carbon footprint and methane
- US Geological Survey
  - 2021 | Copper Statistics and Information
  - 2022 | Mineral Commodity Summaries 2022 Copper
  - 2021 | Platinum-Group Metals Statistics and Information
- U.S. Energy Information Administration
  - 2021 | Coal explained
- U.S. Department of Agriculture
  - 2021 | Manitoba, Crops production costs
  - 2016 | Harvesting Crop Residue: What's it worth ?
- Macrotrends
  - Copper Prices, 45 Year Historical Chart
- www.mineralinfo.fr
  - 2020 | Fiche Critique Platine - Le platine Pt, éléments de criticité
- www.statista.com
  - 2021 | Average global platinum closing price from 2016 to 2022
  - 2021 | Consumption of platinum worldwide in 2021, by industry
- www.fao.org
  - 2021 | FAO, FAOSTAT, Food Balances 2014 –,update: April 14 2021
  - 2021 | Food Balance Sheets A handbook, Annex 1 : Food Composition Tables
  - 2020 | Knoema, Production Statistics - Crops, Crops Processed (https://knoema.com/FAOPRDSC2020)
  - 2019 | The State of Food and Agriculture 2016 SOFA - Climate Change, Agriculture and Food Security

GENERAL MORE SPECIFIC SCIENTIFIC PAPERS USED

(NOT LISTING INDIVIDUAL ENERGY PRODUCTION TECHNOLOGY SOURCES, THAT ARE AVAILABLE IN EACH INDIVIDUAL DOCUMENTATION SHEET)

- Weitzman, M. L.
  - 2009 | On modeling and interpreting the economics of catastrophic climate change. The Review of Economics and Statistics, 91
- McIsaac, F.
  - 2020 | A Representation of the World Population Dynamics for Integrated Assessment Models. Environmental Modeling & Assessment, 255, pp.611-632.
- Court, Victor & McIsaac, Florent
  - 2020 | A Representation of the World Population Dynamics for Integrated Assessment Models. Environmental Modeling and Assessment. 25. 611–632. 10.1007/s10666-020-09703-z.
- Vollset, S.E., Goren, E., Yuan, C.W., Cao, J., Smith, A.E., Hsiao, T., Bisignano, C., Azhar, G.S., Castro, E., Chalek, J. and Dolgert, A.J.
  - 2020 | Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study. The Lancet, 39610258, pp.1285-1306.
- Gollier, C
  - 2011 | Pricing the future: The economics of discounting and sustainable development. Unpublished Manuscript, to Appear with Princeton University Press, Princeton, NJ, USA.
- Höök, M., Zittel, W., Schindler, J. & Aleklett, K.
  - 2010 | Global coal production outlooks based on a logistic model Fuel, Vol. 89, Issue 11: 3546-3558
- M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson
  - IPCC 2007 | Climate Change 2007: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change - Eds., Cambridge
- Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A.C., Müller, C., Arneth, A., Boote, K.J., Folberth, C., Glotter, M., Khabarov, N. and Neumann, K.
  - 2014 | Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. Proceedings of the national academy of sciences, 1119, pp.3268-3273
- Schleussner, C.F., Deryng, D., Muller, C., Elliott, J., Saeed, F., Folberth, C., Liu, W., Wang, X., Pugh, T.A., Thiery, W. and Seneviratne, S.I.
  - 2018 | Crop productivity changes in 1.5 C and 2 C worlds under climate sensitivity uncertainty. Environmental Research Letters, 136, p.064007.
- Maier-Reimer, E. and K.Hasselmann
  - 1987 | Transport and Storage of Carbon Dioxide in the Ocean: An Inorganic Ocean Circulation Carbon Cycle Model Climate Dynamics, 2, 63-90
- Hammitt, J.K., R.J.Lempert, and M.E.Schlesinger
  - 1992 | A Sequential-Decision Strategy for Abating Climate Change Nature, 357, 315-318
- Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D. W. Fahey, J. Haywood, J. Lean, D. C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. V. Dorland
  - 2007 | Changes in Atmospheric Constituents and in Radiative Forcing Climate Change 2007
- S. Solomon, D. Qin, M. Manning et al.
  - 2007 | Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
- Jon Claerbout and Francis Muir
  - 2020 | Hubbert math
- Wang, Jianliang & Bentley, Yongmei
  - 2020 | Modelling world natural gas production Energy. Vol. 1363-1372. 10.1016/j.egyr.2020.05.018.
- Roberto F. Aguilera
  - 2014 | Production costs of global conventional and unconventional petroleum Energy Policy Volume 64 Pages 134-140 ISSN 0301-4215
- Poore, J., & Nemecek, T.
  - 2018 | Reducing food's environmental impacts through producers and consumers. Science, 3606392, 987-992
- Nancy Harris and David Gibb
  - 2021 | World Resources Institute, Forests Absorb Twice As Much Carbon As They Emit Each Year

FOCUS ON HPC INTEGRATION CAPABILITY

SoSTrades sits on top of GEMSEO – which integrate HPC handling capability in a classical "batch" way

- using several // libraries itself (e.g. PTSc for optimization)
- able to wrap discipline in HPC job schedulers (i.e. **wrap_discipline_in_job_scheduler** method)
- has demonstrated track of records doing it
  (e.g. MDA-MDO & R'Evol projects coupling CFD, CSM, CA and Thermal on Pylon optimization,
  or Madeleine European project on Wing optimization)
  and handle the interface with main HPC job schedulers

SoSTrades improve GEMSEO

- handling any data types and not only numerical arrays
- implementing namespaces that allow multi-instances / multi-scenario
- implementing advanced controllers for MDA/MDO patterns
- providing a cloud & containerized execution (that provides a modern "cloud" way to access HPC)
- providing GUI and SPDM functionalities

Capgemini contributed to the historical development of GEMSEO

Business for Planel Modeling team include members heavily involved in GEMSEO (e.g. P.J.Barjhoux)

