IAM COMPACT

Expanding Integrated Assessment Modelling:
Comprehensive and Comprehensible Science
for Sustainable, Co-Created Climate Action

IAM COMPACT Modelling Seminars

Model Presentation: Input Output modelling – WTMBT & DyNERIO

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The IAM COMPACT project has received funding from the European Union's Horizon Europe Research and Innovation Programme under grant agreement No 101056306.

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The input-output framework

What kind of information can we find on **Monetary Input Output Tables**?

Here a **multiregional** table is presented

We can find:

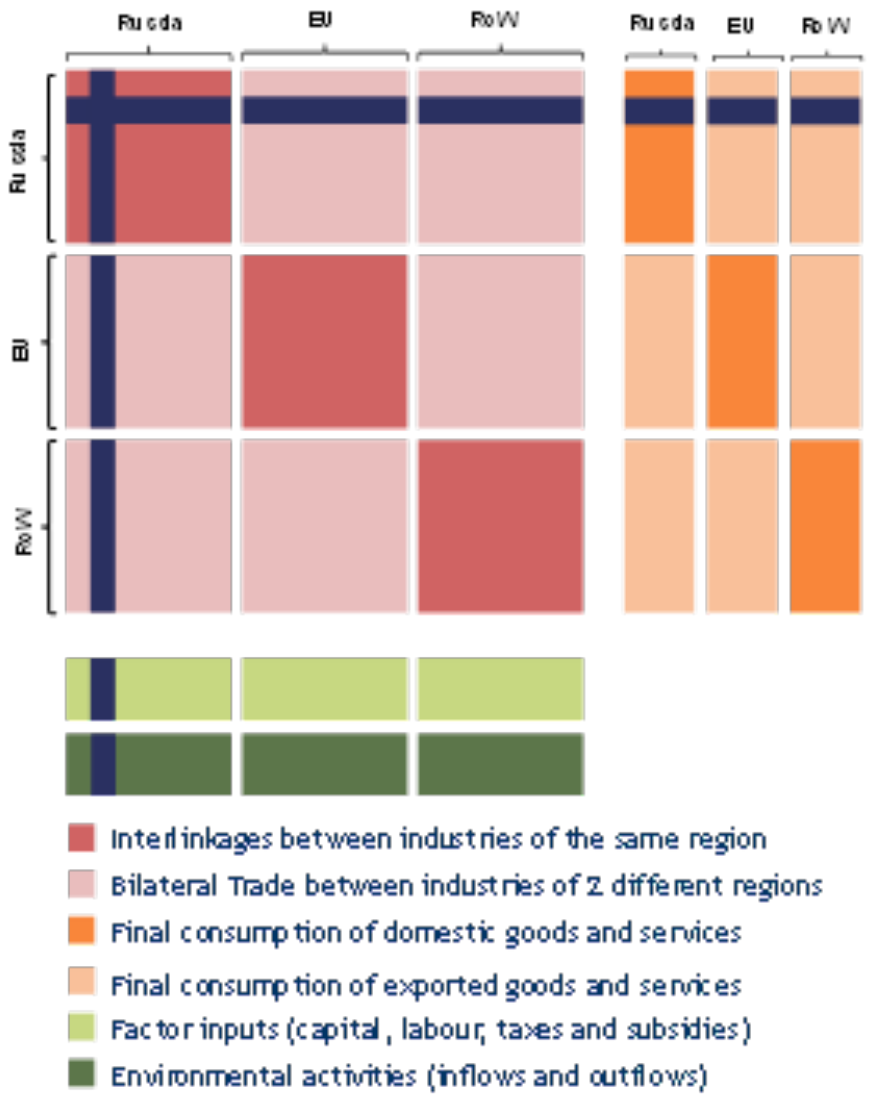
- **Technology**, in the form of a matrix of recipes (what do I need to get one unit of product from the other sectors)

That is distinguished between regions

- **Final Demand**, which can be distinguished into categories (households, government, …)

That is distinguished between regions

- **Value added**, in the form of capital, labour, taxes and subsidies
- Many **environmental layers**, which includes use of energy, water, land, metals and release of emissions



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Impact assessment with input-output

Leontief Production Model (LPM)

$$\mathbf{X} = \mathbf{z} \cdot \mathbf{X} + \mathbf{Y} \rightarrow \boxed{\mathbf{X} = (\mathbf{I} - \mathbf{z})^{-1} \mathbf{Y} = \mathbf{w}\,\mathbf{Y}}$$

$$\boxed{\mathbf{X} = \mathbf{X}(\mathbf{z}, \mathbf{Y})}$$

Rationale of LPM:
to express the total production of each process of the system, characterised by given technologies, that is required to fulfill given final demand yields.

Leontief Impact Model (LIM)

$$\mathbf{E}(m \times n) = \mathbf{e} \cdot diag\left[(\mathbf{I} - \mathbf{z})^{-1} \mathbf{Y}\right]$$

Production-based accounting (PBA)

$$\mathbf{E}(m \times n) = \left[\mathbf{e}(\mathbf{I} - \mathbf{z})^{-1}\right] \hat{\mathbf{Y}}$$

Consumption-based accounting (CBA)

Rationale of LIM: express total exogenous transactions of each process of the system, characterised by given technologies, that is required to fulfill given final demand yields.

$$\boxed{(\mathbf{E}, \mathbf{R}) = (\mathbf{E}, \mathbf{R})(\mathbf{A}, \mathbf{B}, \mathbf{f})}$$

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- The region and sectoral coverage depends on the underlying input-output database adopted to build the desired model.
- According to the database we can have:
  - 49 regions and 164 sectors (Exiobase)
  - 190 regions and 26 sectors (EORA)
  - 71 regions and 45 sectors (OECD/ICIO)
  - and others…

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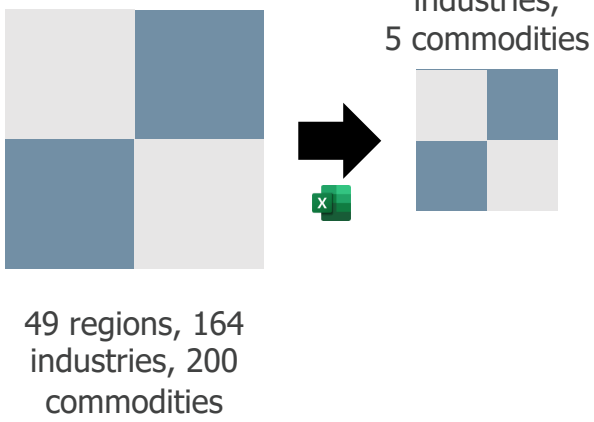
MARIO is an open-source platform aiming at easing input-output analysis operations

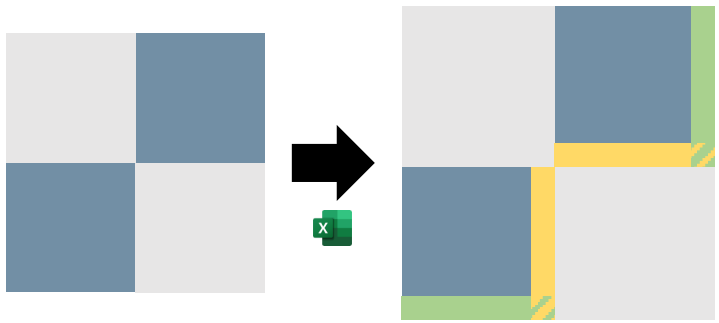
- MARIO stands for Multifunctional Analysis of Regions through Input-Output
- It handles some of the most well-known input-output tables with dedicated parsing functions…but it virtually handles whatever table, **including customized ones**
- It is based on Python and available on Github, Zenodo and comes with a full documentation (including tutorials and installation guide)

It allows to:

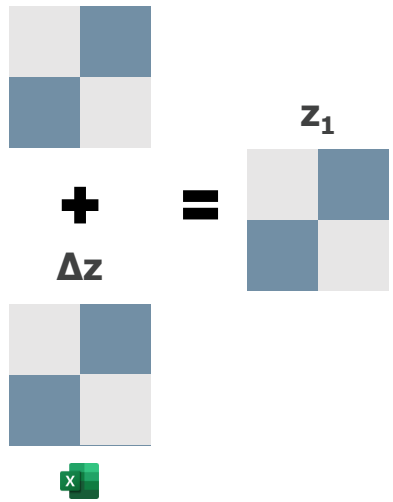
Rearrange regional & sectoral structure



Model additional industrial activities and/or commodities



Perform impact assessment analysis



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- Scientific literature collects many different models which are based on Input-Output principles.
- For IAM, we propose the World Trade Model with Bilateral Trades and DynERIO

WTMBT

DynERIO

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World Trade Model with Bilateral Trades (WTMBT)

Introduction to WTMBT

- Theoretical formulation by F. Duchin, S.H. Levine and A. H. Strømman, based on classical input-output framework
- WTMBT stands for World Trade Model with Bilateral Trades
- It is a meso-economic linear optimization model
- It is based on the comparative advantage principle
- Considering *m* world regions with *n* industries each, the WTMBT enables to endogenously determine the production yields and trades patterns required to satisfy an exogenously specified final demand yield in each region, minimising the use of labor and capital by complying with regional factors endowments (e.g. availability of natural resources, land, work-force...

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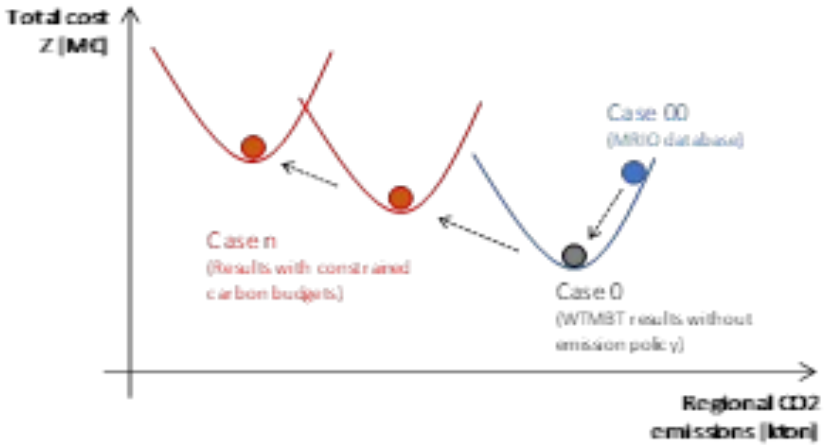
Assessing the global impact of an environmental policy

Application of CO_2 taxes to the EU: comparison of taxes applied according to PBA and CBA paradigms



$$Min \quad Z = \sum_i \pi^T_i \mathbf{F}_i \mathbf{x}_i$$

Minimize global cost while…

$$s.t. \quad \begin{cases} \mathbf{x}_i + \sum_{j \neq i} \mathbf{ex}_{ji} \geq \mathbf{A}_i \mathbf{x}_i + \mathbf{y}_i + \sum_{j \neq i} \mathbf{ex}_{ij} + \sum_{j \neq i} \mathbf{T}_j \mathbf{ex}_{ji} & \forall i \\ \mathbf{F}_i \mathbf{x}_i \leq \mathbf{f}_i & \forall i \\ \mathbf{x}_i \geq 0 & \forall i \end{cases}$$

…satisfying demand

…not exceeding available resources

…producing non-negative

Modelling approach:

- Linear optimisation + Multi-regional Input-Output = **World Trade Model**
- Comparative statics (**overnight**): what if tomorrow morning the world is like how I model it?
- No technological change is allowed. Only degree of freedom: for every good or services demanded, who is **producing** and who is **importing**?
- The region that can produce at **lower costs** will produce until it has enough factors of production and natural resources available (**comparative advantage**)

M. V. Rocco, N. Golinucci, S. M. Ronco and E. Colombo - Fighting carbon leakage through consumption-based carbon emissions policies: Empirical analysis based on the World Trade Model with Bilateral Trades (2020) on Applied Energy

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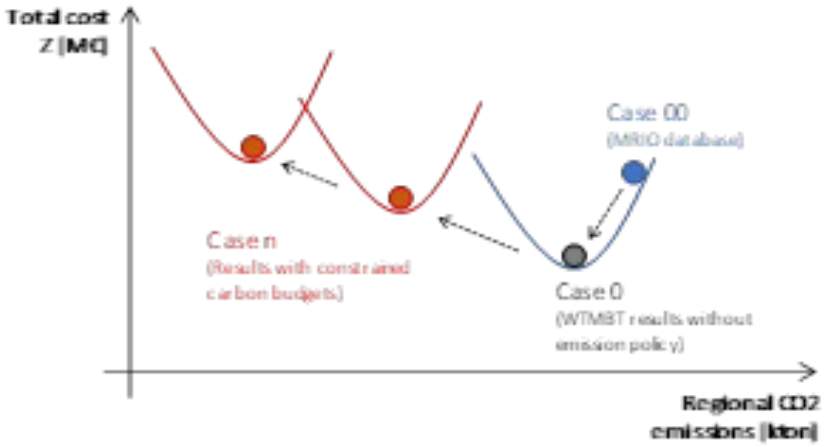

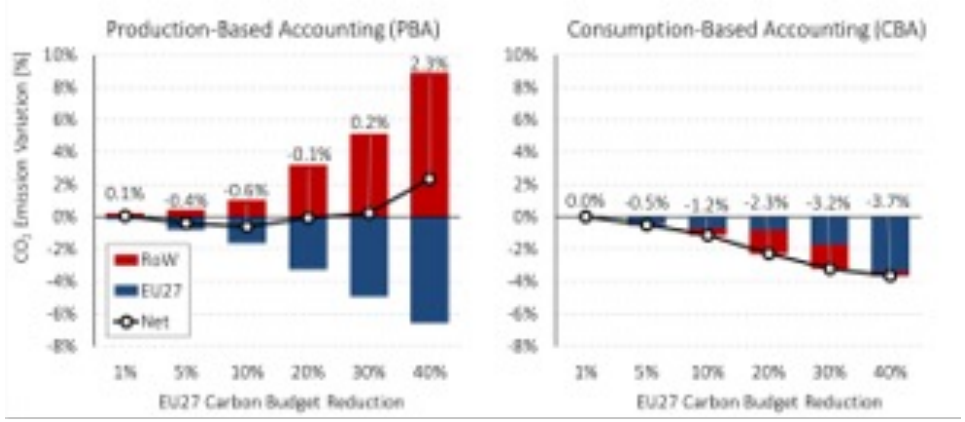

$$Min \quad Z = \sum_i \pi^T_i \mathbf{F}_i \mathbf{x}_i$$

Minimize global cost while…

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A CBA policy seems to prevent Carbon Leakage for the EU case

M. V. Rocco, N. Golinucci, S. M. Ronco and E. Colombo - Fighting carbon leakage through consumption-based carbon emissions policies: Empirical analysis based on the World Trade Model with Bilateral Trades (2020) on Applied Energy

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- Which is the effect of different carbon taxation schemes applied in specific regions on the global emissions trend? https://doi.org/10.1016/j.apenergy.2020.115301
- How to investigate the bottlenecks, in terms of industrial productive capacity or resources availabilities, in the global supply chain system?
- What is the impact on emissions of the variation of production mixes and/or increase in consumption of specific energy commodities?

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SDG	Details
§8. Decent work & economic growth	Input-output frameworks are built to track the effect of shocks (to be interpreted as policy actions) onto the economic system, in terms as (among many) GDP variations and job creation.
§12. Responsible Consumption and Production	WTMBT allows to assess the impact (both economic and environmental) of policies on the supply and on the demand side. The model is constrained to respecting regional resources availabilities.
§13: Climate action	Environmental extensions of input-output tables, account for emissions and other environmental indicators. The scenarios modelled are evaluated therefore also in terms of impact on this dimension.

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Duchin F. (1989), International Trade and the Use of Capital and Labor in the US Economy, Economic Systems Research, 1(3), 345-350, https://doi.org/10.1080/09535318900000023

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Duchin F., Levine S.H., Strømman A.H. (2016), Combining Multiregional Input-Output Analysis with a World Trade Model for Evaluating Scenarios for Sustainable Use of Global Resources, Part I: Conceptual Framework. Journal of Industrial Ecology, 20(4), 775-782, https://doi.org/10.1111/jiec.12303

Duchin F., Levine S.H., Strømman A.H. (2016), Combining Multiregional Input-Output Analysis with a World Trade Model for Evaluating Scenarios for Sustainable Use of Global Resources, Part II: Implementation. Journal of Industrial Ecology, 20(4), 783-791, https://doi.org/10.1111/jiec.12302

Rocco M.V., Golinucci N., Ronco S.M., Colombo E., (2020), Fighting carbon leakage through consumption-based carbon emissions policies: Empirical analysis based on the World Trade Model with Bilateral Trades, Applied Energy, 274, https://doi.org/10.1016/j.apenergy.2020.115301

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Dynamic Extraction and Recycling Input-Output Framework (DynERIO)

Introduction to DynERIO

- As many other models in our suite, DYNERIO applies input-output analysis and integrates it with other modelling practices.
- Theoretical formulation inspired by the work of Nakamura and Kondo, and Manfred Lenzen on waste-input-output analysis
- DynERIO stands for Dynamic Extraction and Recycling Input-Output framework
- It is an integrated economy-energy modelling framework, consisting of three modules:
  - A multi-regional input-output (MRIO) module, capturing the whole economic spectrum of industrial activities
  - A technology capacity stock module, which calculates the evolution of the energy technology capacity
  - An extraction and recycling module, deriving the impact of such policy on raw materials exploitation at the net of recycling

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Context

The energy transition from fossil-fuels based to renewables system brings along **intensive raw material consumption**

Gaps

- Need for proper modelling of structural technology change
- Need for explicit accounting and estimations of the time-evolution of technology capacity stock
- Need to track all the steps of critical raw materials supply chain

Aim of the work

- To propose a **novel framework** which addresses the 3 gaps and allows **to quantitative assess the impact of energy scenarios on material exploitation**
- To test the framework on a **simplified 2-regions case study** based on Exiobase

The DYNERIO framework

Module 1.
Multi-regional Input-Output
- Captures economic and environmental impact of energy scenarios
- Tracks future energy demand

Energy demand

Module 2.
Technology Capacity Stock
Ccalculates the technology capacity to install and to displace to satisfy energy demand

Capacity stocks

Module 3. Dynamic Extraction and Recycling module
Keeps track of all the steps of the supply chain of critical materials

Extensive set of results for each module

Rinaldi L., Rocco M.V., Colombo E., Assessing critical materials demand in global energy transition scenarios based on the Dynamic Extraction and Recycling Input-Output framework (DYNERIO)

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How energy services are linked to materials demand. Example: electricity from renewables production

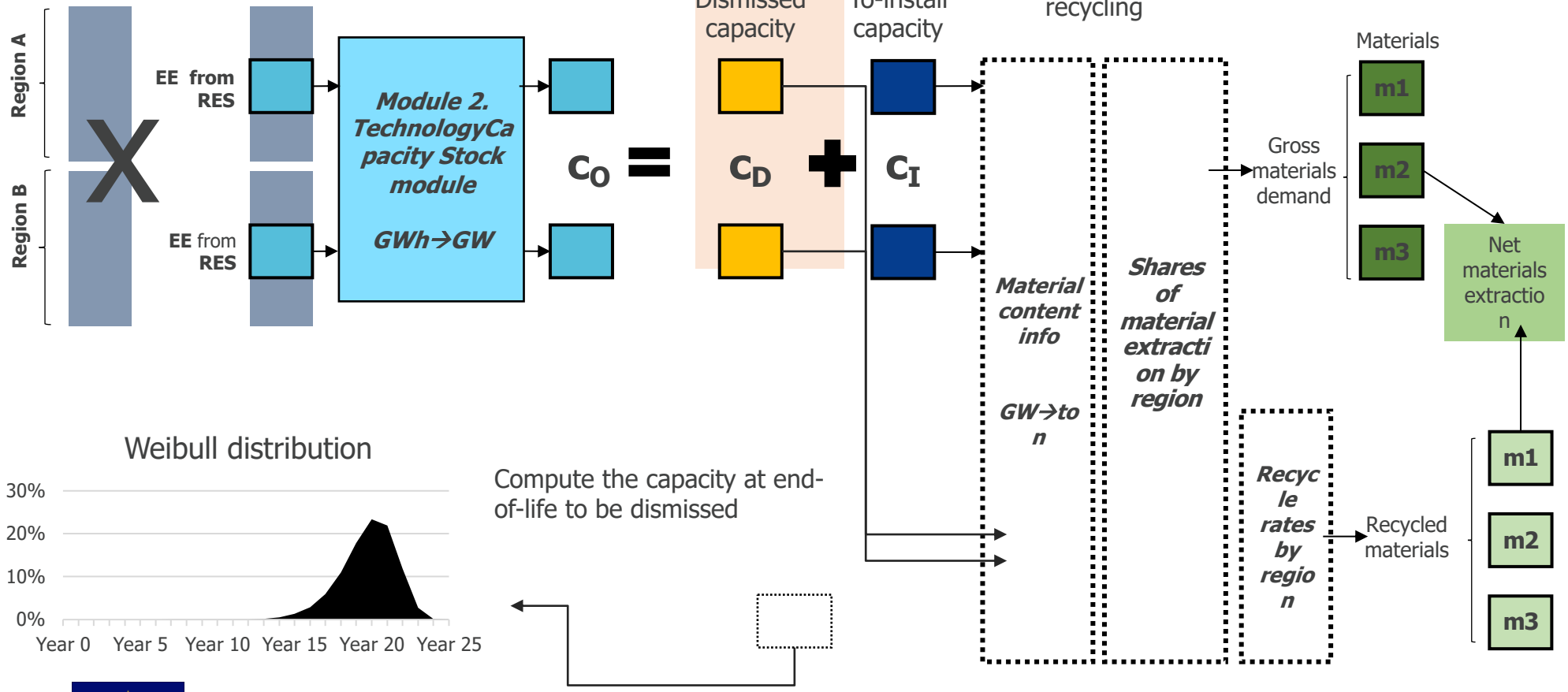
1. Isolate the electricity from renewables((EE from RES) sector

2. Compute the required **operating capacity** of renewable power plants

3. Assess raw materials gross demand…

4. …and materials recovered from recycling

5. Evaluate the net materials extraction



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- How to address the global impact of the penetration of renewable technologies in a determined region, in terms of raw materials exploitation?
- Where such materials are exploited and which may be the implications on energy security of other regions?
- What is the impact on emissions of the variation of production mixes and/or increase in consumption of specific energy commodities?
- What is the impact on jobs of such scenarios?

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§8. Decent work & economic growth	Input-output frameworks are built to track the effect of shocks (to be interpreted as policy actions) onto the economic system, in terms as (among many) GDP variations and job creation.
§12. Responsible Consumption and Production	DynERIO allows to assess the impact (both economic and environmental) of policies on the supply and on the demand side. The extraction and recycling module allocates mining and recycling activities by region.
§13: Climate action	Environmental extensions of input-output tables, which DynERIO can handle together with the underlying database, account for emissions and other environmental indicators. The scenarios modelled are evaluated therefore also in terms of impact on this dimension.

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DynERIO: Relevant references

Nakamura, S., Kondo, Y., 2002. Input-output analysis of waste management. J. Ind. Ecol. 6, 39–63. https://doi.org/10.1162/108819802320971632

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Rinaldi L., Rocco M.V., Colombo E., Assessing critical materials demand in global energy transition scenarios based on the Dynamic Extraction and Recycling Input-Output framework (DYNERIO), Resourc. Conserv. Recycl (Under review). Preprint: https://dx.doi.org/10.2139/ssrn.4179003

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Thank you!

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