Towards a transparent land-use design tool for sustainable urban metabolisms focusing on energy, food, and water

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Resource Depletion & Insufficiency
- A Major Pressure to Sustainability

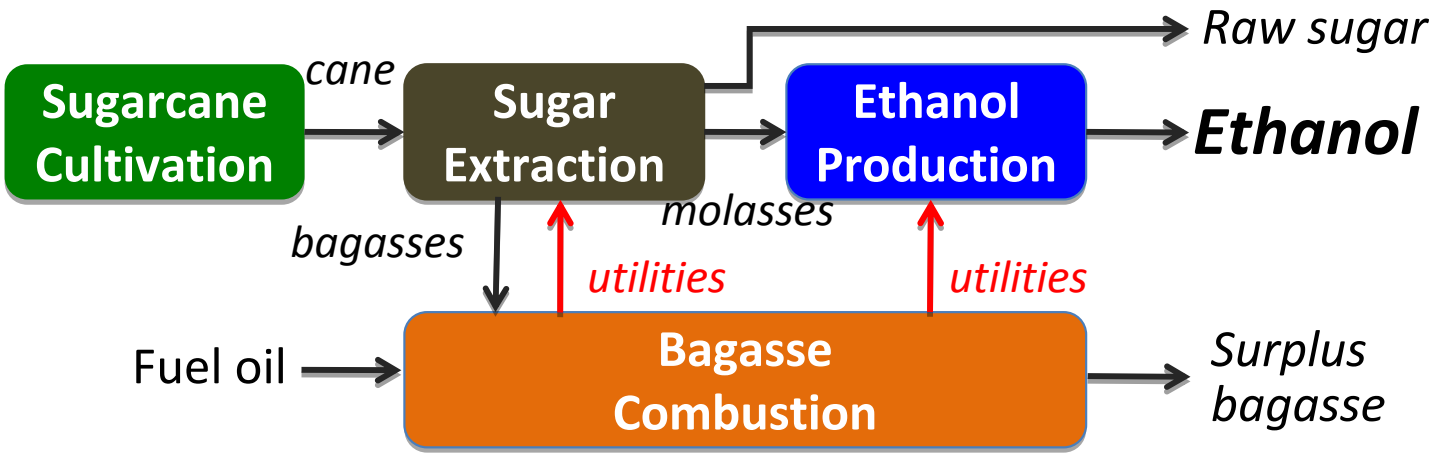
- **Resources that are potentially insufficient in the future include:**
  - Energy: Electricity generation, Production, Fuels for vehicles
  - Water: Drinking, Sanitary, Food production
  - Metals: Ex. Pt, In, Li, …
- **Inevitable actions for the human being**
  - Shift to renewable resources
  - Improve resource use efficiency
  - Control consumption

Evaluation of key technologies - typical Life Cycle Assessment studies

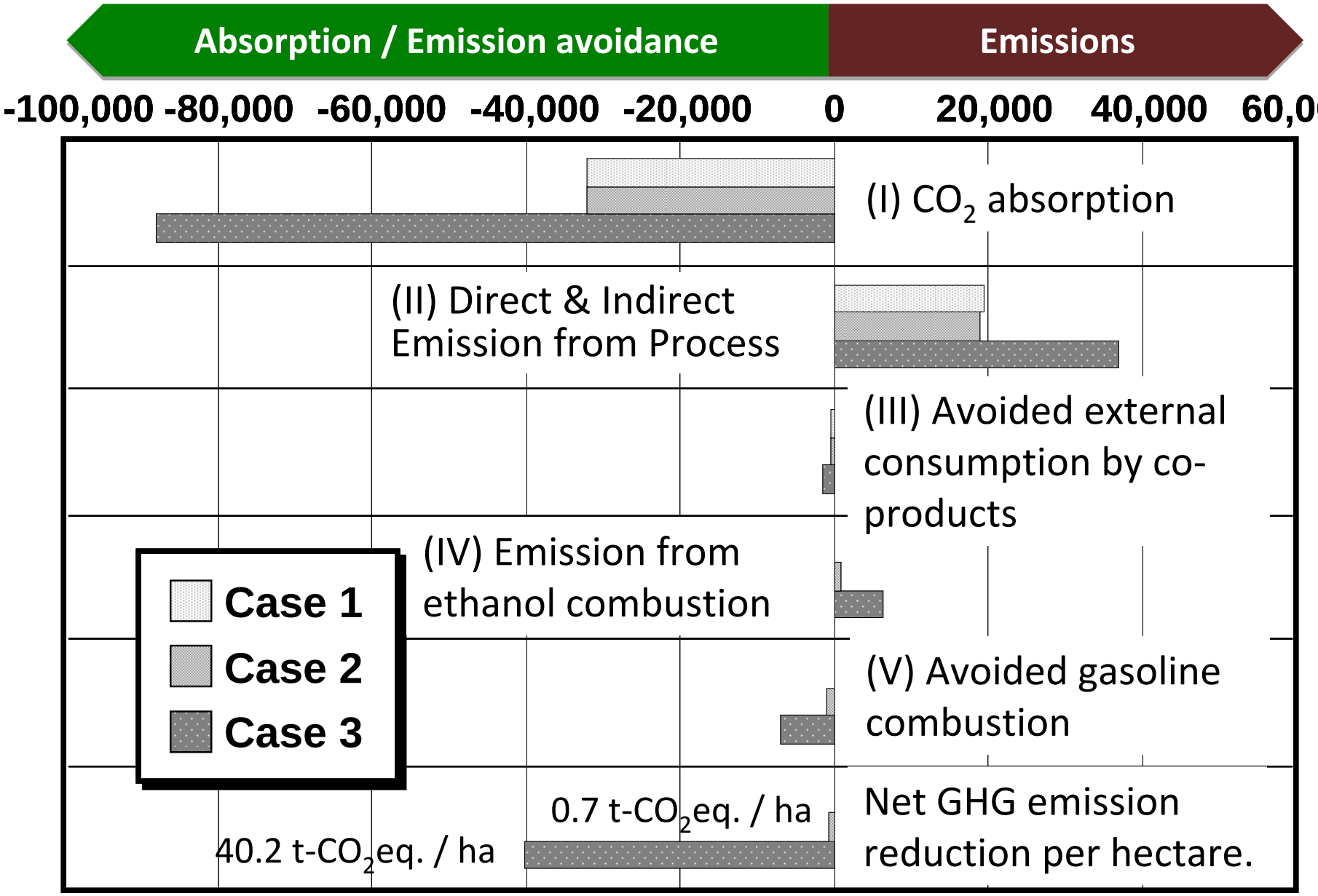
- **Shift to Renewable Resources**
  - **Bio-ethanol**
    - Sugarcane molasses-derived bio-ethanol (TW)
    - Cultivar modification & Process Retrofitting to enhance productivity of molasses-derived ethanol (JP)
  - **Bio-hydrogen from Cellulosic Substrates, Wastes, and Wastewater** (TW)
  - **Bio-diesel from cultivated green algae (TW)**
  - **PV (solar) cells**
    - Carbon footprint (kg-CO_2eq. / pc) of Crystalline-Si PV cells and effect of process improvement (TW)
    - Effect of PV cells on the pollutants emission from power grid system (TW)

Ethanol derived from “Monstercane”

Ie Island, Okinawa, Japan



- **Cultivar modification**
  - Greater sugar yield, Greater fiber yield
  - Ratio between fiber and sugar is adjusted to maximize productivity of sugar and supply all the bagasses for fuel.
- **Enhanced productivity**
  - same amount of raw sugar (5.8 ton-dry/ha)
  - 7.5 times more ethanol (0.44 → 3.30 kL/ha).
- **More energy-efficient sugar extraction**
- **Bagasses is not any more insufficient.**
  i.e. Consumption of 0.25kL-fuel/ha was eliminated.



Case 1: Sugar only **Case 2:** Sugar and Ethanol with conventional cane
Case 3: Sugar and Ethanol with Monstercane

Examples of typical assumption

- **Products substituted by the co-products**
  - Surplus bagasses (residual fiber)
    → Burn? Use as Cow's Bed? Energy recovery?
- **Availability and Efficiency of relevant resources**
  - Fertilizer, Water, …
- **Competing usage of raw materials**
  - Raw sugar is produced as much as before, the rest is used for Ethanol
    → Before ethanol production, are molasses disposed or utilized?
    → Will we have the same demand (of Ethanol and Sugar) in the future?
    → Is there any other emerging application?

All of those assumptions are critical and related to the unique characteristics of the region.

The emerging applications/technologies could harm if used inappropriately

… just like relationships between medicines and poisons.

- LCA results just describe how much environmental impacts are reduced as a result of use of the technology… under some conditions.
  (just like instructions of a medicine)
- it could be of **help** if appropriately used
- it could be of **harm** if inappropriately used

Therefore, we need to construct methodology to …

- examine the patient (i.e. a region)
- write a prescription for a patient

- **Goal 1: Understand the direct & indirect metabolisms of a region**
  - Case study: Tainan Area (Tainan City + Tainan County)
  - Energy, Food, and Water will be the first target
    - Competition over land (land-use planning) → Design variables
    - Competition over water → Constraint
- **Goal 2: Evaluate how a technology would influence the region's metabolisms, when land use is optimized for various objective functions**
  - Case study: Monstercane-derived bioethanol by Asahi's Process
  - Ex. of objective functions
    - GHG emission
    - Self-sufficiency of food, water, and energy (=renewability of energy)

Mathematical Formulation of Constraints

- **Ex. Freshwater consumption**
  - Available freshwater in the region
  - Water consumption in different production activities of the region
  - Consider interaction with other regions by analyzing “Virtual Water Trades”

“ Virtual Water” Concept

When a country imports one tonne of wheat instead of producing it domestically, it is saving about 1,300 cubic meters of real indigenous water. - Wikipedia “Virtual Water Trade”

- **Consumption of freshwater (surface, ground) is embodied in a product**
  - By trading products, the embodied water (=virtual water) is traded.

- **Ex.** *“Because Tainan is lack of water reserve in 2010, agricultural fields will be lied fallow. Food production will decline.”*
  - Food products (with virtual water) will be less taken out from the region
  - Food must be produced elsewhere.

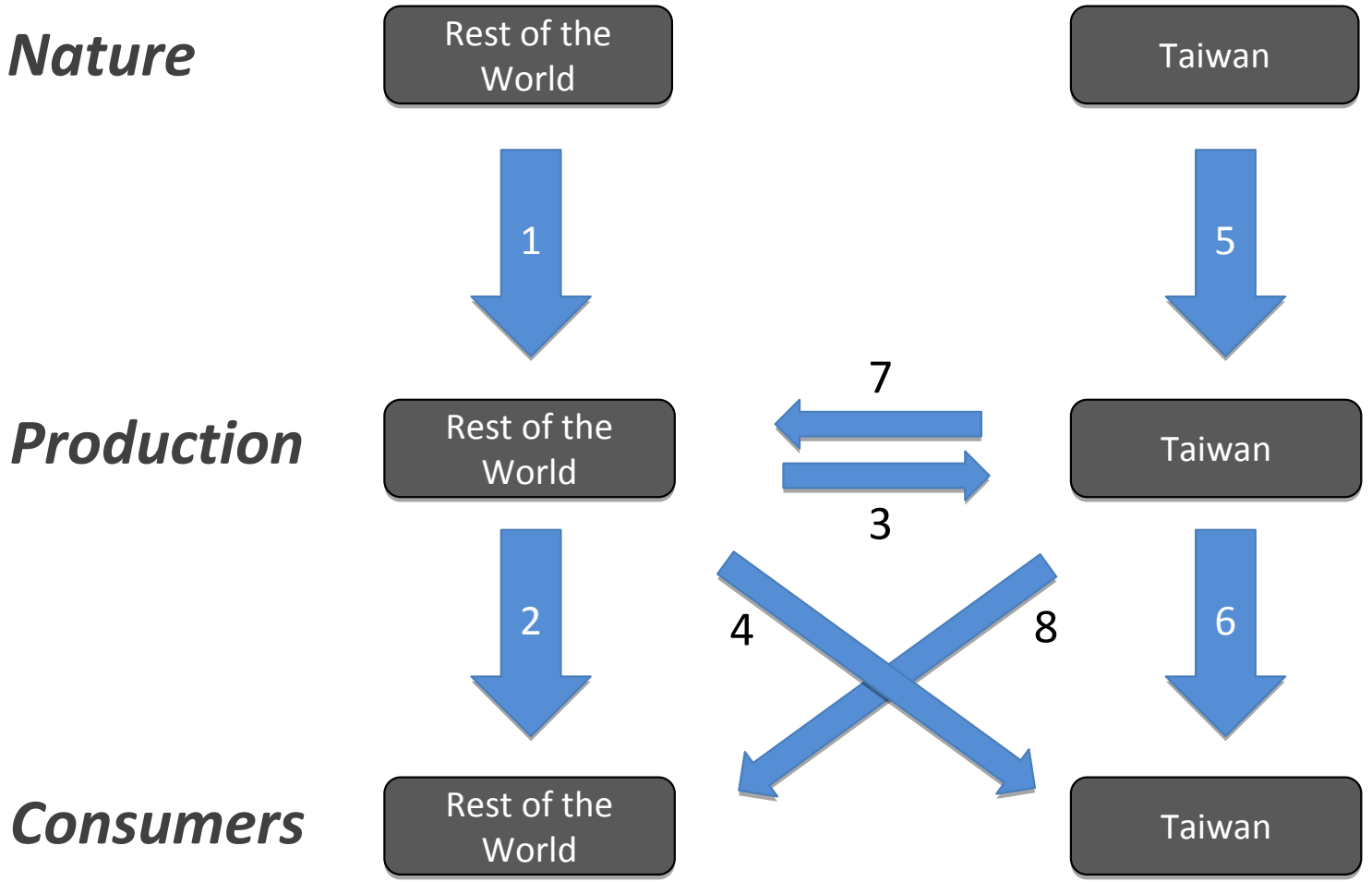
→ Induce water shortage in other region?

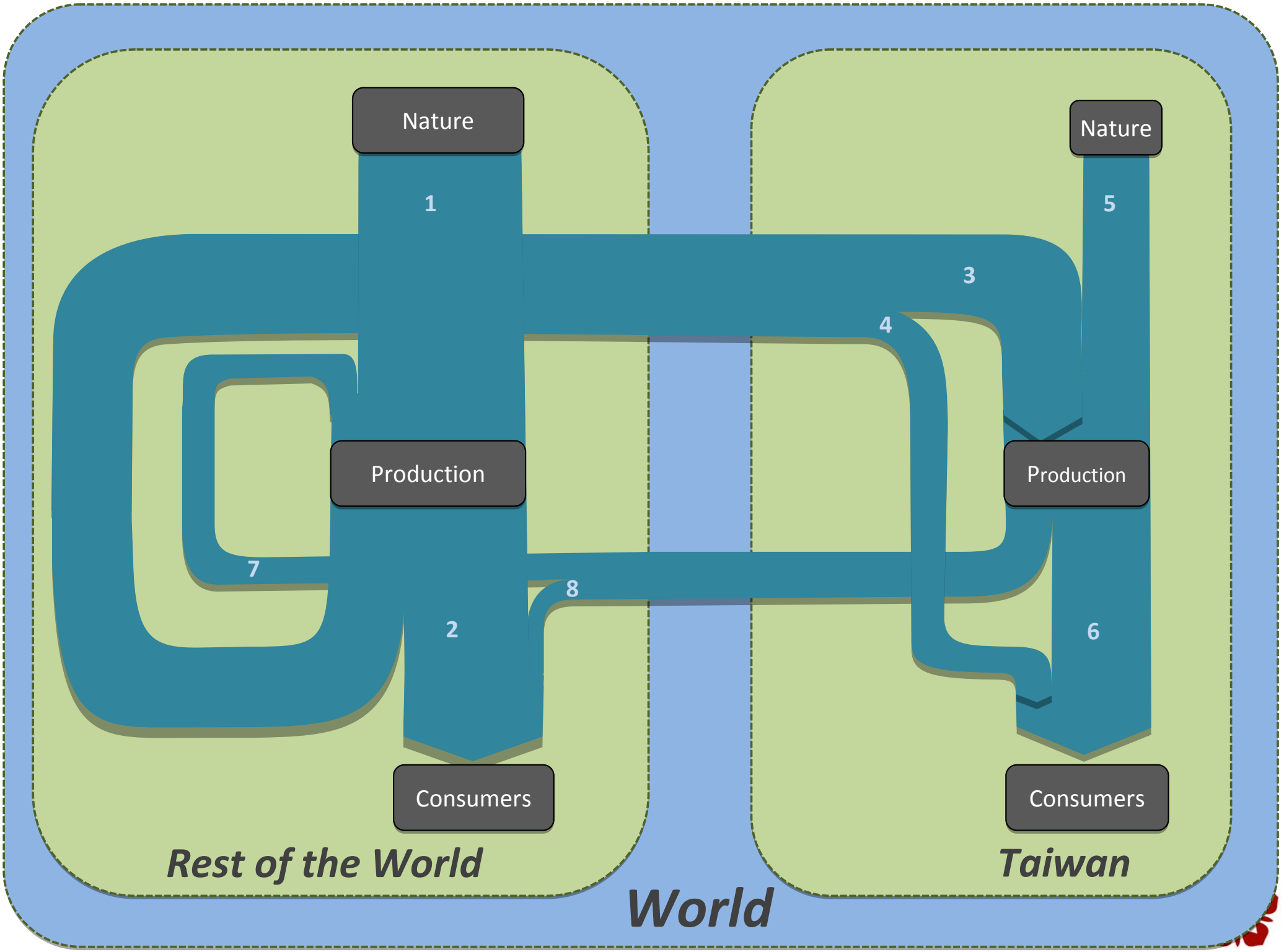
Tainan City and County

- **Freshwater mostly comes from Zeng-Wen (Industrial and Domestic) and Wushantou (Agricultural) Reservoirs**
  - Tainan city – Urban area
    - 770,000 people live in 175.6 km^2
    - Production: Precise machines
  - Tainan County – Urban and Rural area with Industrial Park
    - 1,104,000 people live in 2,016 km^2
    - Production: LCD panels, Semiconductors, Plastics, Fruits, Rice, Sugarcane, …

Virtual Water Trade at Nation Levels

Those flows can be quantified using I/O analysis
→ Please visit poster by Chen and Fukushima

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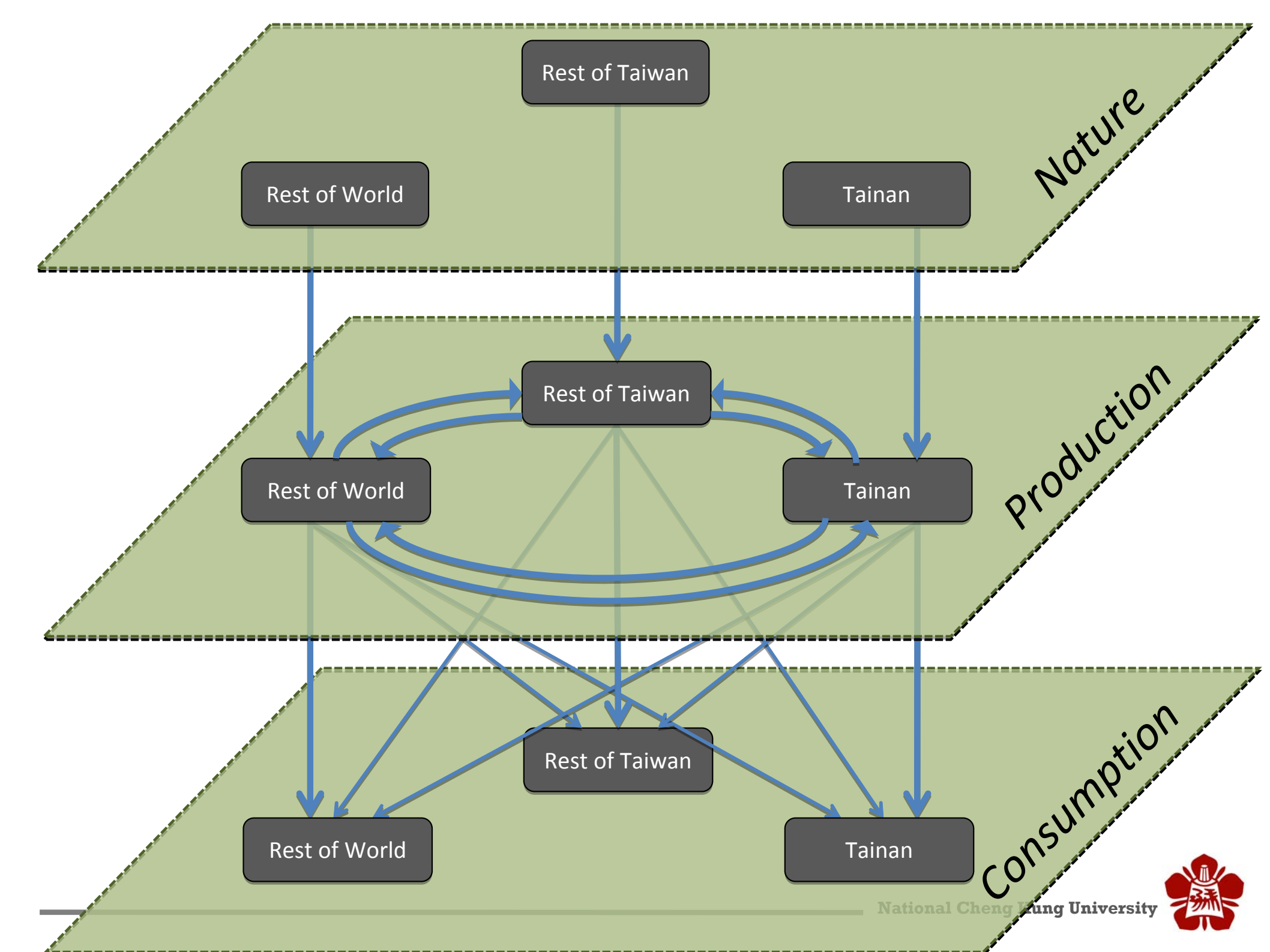
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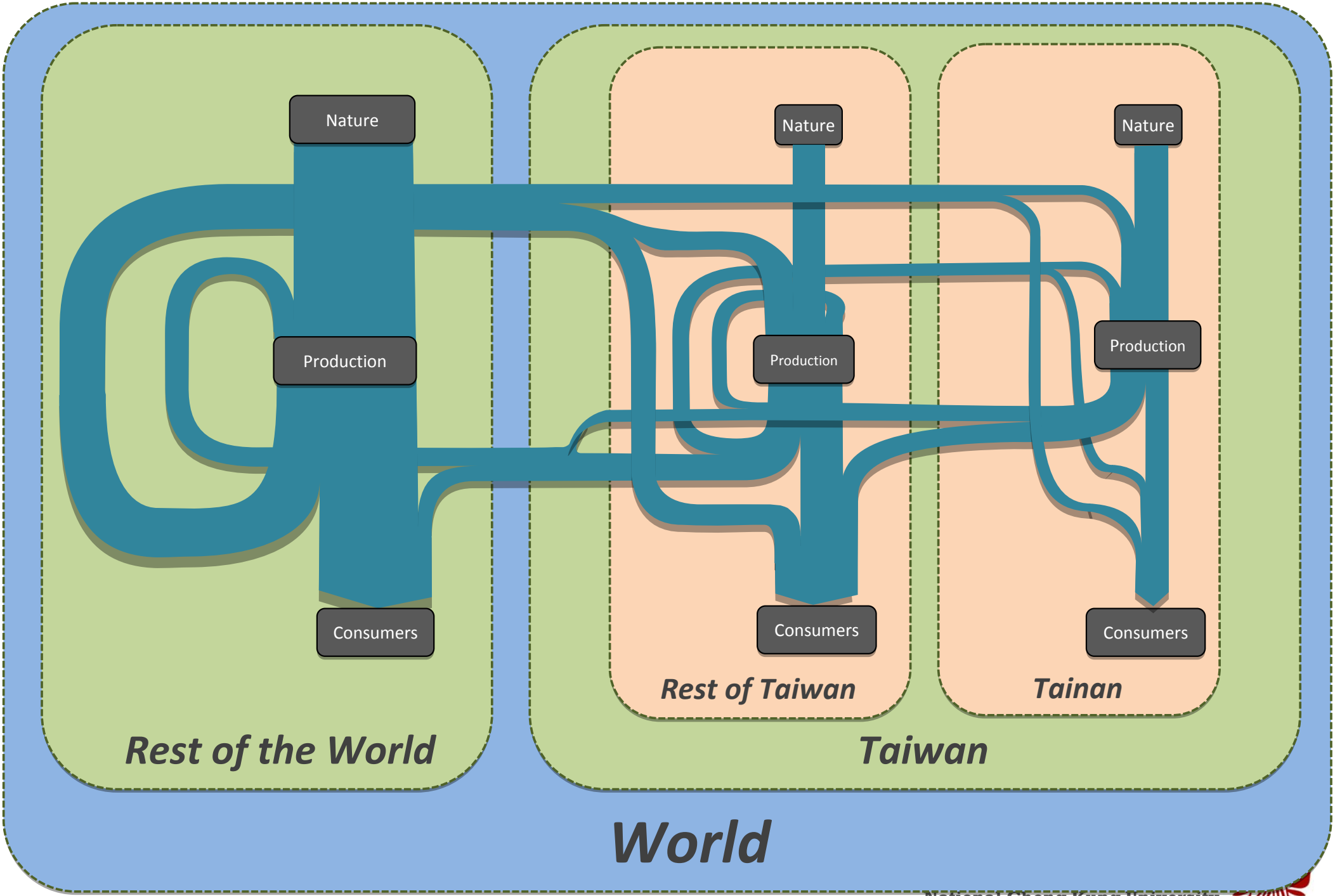
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On-going efforts

- **Virtual Water Trades**
  - Methods (incl. data sources) should be systematically described for different layers. (ex. Tainan area, Industrial Park, Company, Household…)
- **Energy and Food:** Energy balances using Exergy analysis
  - Renewable energy and Food are often co-produced. Energy Profit Ratio (ratio of energy output to input depletable energy) often does not provide the complete picture for discussion of sustainability.
  - Both depletable & renewable resources should be most efficiently utilized in total. Efficiency in utilization of renewable energy is often ignored.
- **Potentials of utilization of wastes in urban and rural regions**
  - Food processing waste and wastewater
  - Agricultural waste (cellulosic substrates)
- **Understanding metabolisms of different communities**
- **Construction of mathematical models**
  - Mathematical expression of constraints
  - Interpretation of results from optimization using different objective functions

Concluding remarks

- **Even if a medicine could be a poison, we will not stop using the medicine.**
  - Creating taboo is not an appropriate attitude
  - Need to learn from past events, especially failures
    → Learning from ESSV project in Indonesia
    (Poster by Badariah and Fukushima)
- **A design tool for sustainable land-use supported by technologies is needed. The tool should be transparent.**
  - It becomes possible to illustrate future sustainable society using innovative/emerging renewable technologies
  - Disputes that are based only on qualitative understandings (poison or not) is not likely to reach conclusions. Quantitative design tools are needed, and those tools should be transparent.