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Parameter reconciliation for designing biophysically consistent socio-technical alternatives

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A research axis of the STEEP team (steep.inria.fr) wishes to enrich debates around possible alternatives by helping actors produce narratives of the future which are consistent from a biophysical viewpoint (see e.g., Giampietro, 2021). The approach adopted does not seek to optimize the existing system but to imagine and assess radically different futures. In an ever more constrained world, this means being able to identify and decide on trade-offs relative to the different aspects of the problem (Courtonne, 2016).

We define a socio-technical alternative as a consistent arrangement of modes of production and modes of consumption. This includes biophysical and socio-political dimensions, but for the time being the emphasis is laid on the circulation of materials, energy and human work between sectors and down to final consumption.

In the MFA field, data reconciliation enables to translate incomplete and inconsistent data to flows respecting e.g., mass conservation. This relies on constrained optimization; it was in particular popularized by the STAN software (Cencic, 2008) and proves very useful to describe the state of past or current systems. For imagining alternatives, though, directly setting flows is not intuitive: the most common way of thinking is rather to tune a set of parameters which represent levers of change (e.g. a population's average diet). These parameters are in turn translated into flows, which are subject to constraints. Parameters must be reconciled in order for flows to meet the constraints.

In practice, the economy is depicted as an arrangement of production and consumption activities. These are classified in categories, agriculture, construction etc. on the production side, and housing, mobility, diet etc. on the consumption side. For each category, several modes are possible (e.g., organic/conventional farming, vegetarian/meat diet). Each mode is represented by a unit production function describing the relationship between inputs (factors of production) and outputs. Finally, biophysical constraints are applied to the system (mass conservation, constraints on resource use, on pollution etc.).

The user provides: (i) level of population (ii) percentages of each mode inside each category (these are the model's parameters), (iii) how important these percentages are for him/her (relative weight). Since the input set of parameters usually does not meet the constraints, they need to be reconciled and this is what our prototype does.

Another way of exploring biophysically feasible alternatives consists of setting parameters one-by-one and at each step computing the option space for the remaining parameters.

Parameter reconciliation raises mathematical questions linked to the optimization problem. In particular, we study the consequences of choosing absolute vs. relative (%) parameters to depict the same alternative and show that these options lead to different results. Furthermore, this way of framing the problem, i.e. using production functions, is common in serious games related to resource

management. In that context “reconciliation” is done manually and the solution space is discrete. For the moment, however, we only consider continuous option spaces.

After a brief presentation of the theory, we will focus on two illustrative examples. The first one pertains to nitrogen flows of the French agri-food system (Billen, 2018). Feasible alternatives show trade-offs between water quality, level of autonomy, export capacity, type of farming, and diet. The second example is a toy model of a whole economy, in order to illustrate feedback loops between sectors depending on multiple resources and generating multiple pollutions/wastes subject to thresholds.

References

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