Modular Approach to Material Flow Analysis

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May 4, 2021

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5/04/2021

In this paper, we refer to a socio-technical system as a model for the organisation of production and consumption in a given territory.

This work is part of the STEEP team's "Socio-technical alternatives" research axis, which aims to provide tools and methodologies that allow stakeholders in a territory (public authorities, associations, companies, citizens) to deliberate in order to imagine and evaluate together long-term alternatives (two or three decades) for their territory. These alternative socio-technical systems should meet the needs of the populations while being compatible with various local and global constraints and limits (environmental, social). Our work focuses more specifically on a step-by-step tool for designing coherent alternatives.

1 Material flow analysis, a tool for reconciling socio-technical systems

The monetary or material flows of a socio-technical system can easily be modelled on the basis of use-supply tables.

National accounting, in order to describe the functioning of the economy as a whole, often uses this framework in which sectors are distinguished between which product flows circulate. These flows are summarised in two matrices with products in the rows and sectors in the columns. The first matrix, the Supply table, indicates where the products come from. The second, the Use table, shows where they go.

The national accounts use the monetary unit but there is no limitation on the choice of the unit of measurement. Thus, the use-supply formalism can be used to describe a socio-technical system from a biophysical point of view (unit of mass, unit of energy, etc.), which makes it possible to study the environmental sustainability of the system.

The national accounts have an efficient data collection and processing network, which explains the quality of the use-supply tables they produce. In general, when data are collected to fill in tables, they are incomplete, uncertain and inconsistent with each other, for example when they come from different sources or simply when the sources are missing. The material flow analysis ([1], [2]), of which a diagram is given in figure 1, makes it possible to obtain "reconciled" use-supply tables from "raw" use-supply tables, i.e. incomplete, uncertain and inconsistent. More precisely, by solving a constrained optimisation problem, one obtains use-supply tables that are close (in the least squares sense) to the initial tables and which, in addition, verify a certain number of constraints. For example, it can be imposed that the quantity entering a sector is equal to the quantity leaving the same sector (material-sector balance). Or one can impose that a product is produced as much as it is used, there is no "leakage" in the system through which the product arrives or leaves (product material balance). There are other constraints, all linear, which we will not list here.

While the reconciled tables give an ideal, because coherent, image of a socio-technical system, the comparison with the initial tables gives retrospective information on the quality of the input data or on the modelling hypotheses. With this comparison, one can judge the improbability of the magnitude of a given flow or the poor estimation of the uncertainty of another.

2 Modules for modelling alternatives

Thus, material flow analysis can be used to model existing socio-technical systems. However, this framework can also be used to study systems that are modelled but do not exist and whose plausibility we want to question, which we call socio-technical alternatives. A diagram of the reasoning is given in Figure 2, which is detailed below.

In this case, the method can no longer be data collection - reconciliation - comparison with the collected data, because the data does not exist. It is the modelling of the socio-technical alternative that provides the data. To carry out this modelling, we will build modules.

From a formal point of view, a module is a function that takes indicators as variables and gives the values of certain flows as output. To construct a module, we must first define the set of flows whose values will be calculated concomitantly. There is a modelling choice here consisting of isolating, within the socio-technical alternative that we wish to study, a subsystem that functions in a coherent manner. In the context of an agricultural sector alternative, we are thinking, for example, of the livestock farming subsystem or the soil cultivation subsystem.

Once this subsystem has been defined, the indicators needed to determine the flows in question are identified. The list of indicators and their combination in calculations to obtain the value of the flows gives a quantitative description of the functioning of the sub-system. For the livestock subsystem, indicators of herd size, feed requirements, meat or dung production come to mind. In this case, it is important to combine this quantitative table with a more qualitative description of the module, a narrative account that makes it possible to identify the different aspects and the overall coherence. This dual quantitative-qualitative level makes it possible to check that the module has a real internal skeleton.

As the scope of a module only covers certain flows, it may be useful, in order to describe a socio-technical alternative, to use different modules, each one modelling a sub-system making up the alternative.

3 Reconciliation and control of modules

Once the value of different flows has been calculated with the modules, a reconciliation is performed. From a general point of view, the comparison between the data calculated by the module(s) and the reconciled data gives an appreciation of the likelihood of the alternative. Thus, a socio-technical alternative model providing data that would be subject to too much reconciliation would be a model for which it can be said that the alternative it describes could not happen in reality, as its functioning is not coherent or balanced[1].

More precisely, because of the construction of the modules, we will not be led to judge the plausibility of the alternative as such, but specifically of the set of indicators that we have combined to obtain the value of certain flows. Thus, given one or more modules, some families of indicators will be admissible, i.e. the flows obtained from them will be poorly reconciled, and other families will not, without calling into question the entire construction of the modules. On the other hand, the size of the space of the admissible families will allow an appreciation of the capacity of the socio-technical alternative to absorb modifications in the organisation of production. A socio-technical alternative for which the space of admissible families is very limited is thus a fragile alternative. This assessment can then be used in a more general study of the plausibility of the alternative, while not exhausting it.

It is also information on the compatibility between the different modules involved in the modelling of the alternative. Taking the agricultural example again, we can imagine (and this is an assumption) that the space of admissible families associated with an intensive crop production module and an extensive livestock module is relatively restricted.

We may therefore be interested in doing a reverse reasoning, i.e. to find, from one or several modules, the families that will be admissible. This amounts to looking for the antecedents of the data reconciled by the module functions.

In this way, we can distinguish certain indicators, for example those that we consider to be the most relevant for summarising the socio-technical alternative or those on which we have information, and study how the determination of these indicators delimits the values that the others can take in order to obtain an admissible family. Variations in these indicators of interest then change the space of possibilities for the other indicators.

4 An example: suckler cattle farming

In order to put this formalism into practice, a two-module model of suckler cattle farming (the "meat breeds") was constructed. The first module is that of crop production, the second that of animal production. These

[1]The question of the threshold beyond which reconciliation becomes too important is one of the open problems.

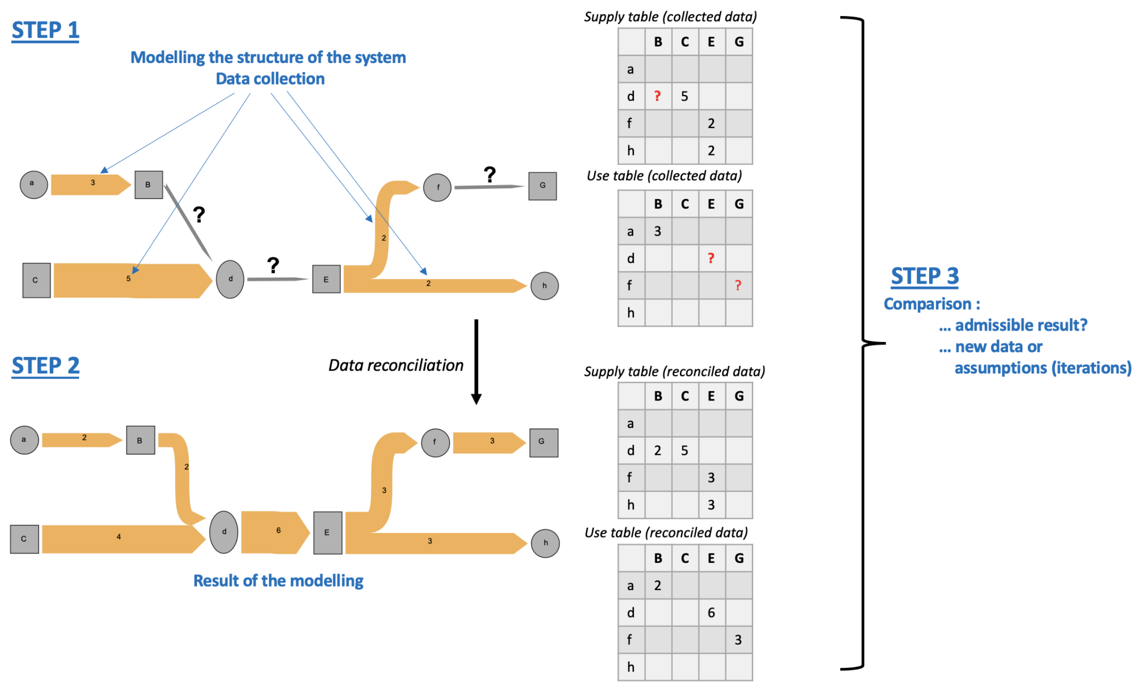

Figure 1: Diagram of the material flow analysis for an existing socio-technical system. Note, for example, that sector E and product f are constrained by a material balance.

two modules are closely linked: the main purpose of plant production is to feed the animals and the main product of the animals, their excrement, is brought to the soil to fertilise it. This metabolism between farm animals and the soil, which replaced the metabolism between humans, who were then low meat consumers, and the soil, is at the heart of some of the current problems in agriculture (opening up of the nitrogen [3], [4] and phosphorus cycles [5], competition between humans and animals for access to plant products [6], [7]).

The two modules we have built are part of these debates. Taking up again what we developed in the section 3, one of the questions we are trying to resolve is that of the incompatibility between certain organisations of plant production and certain organisations of livestock.

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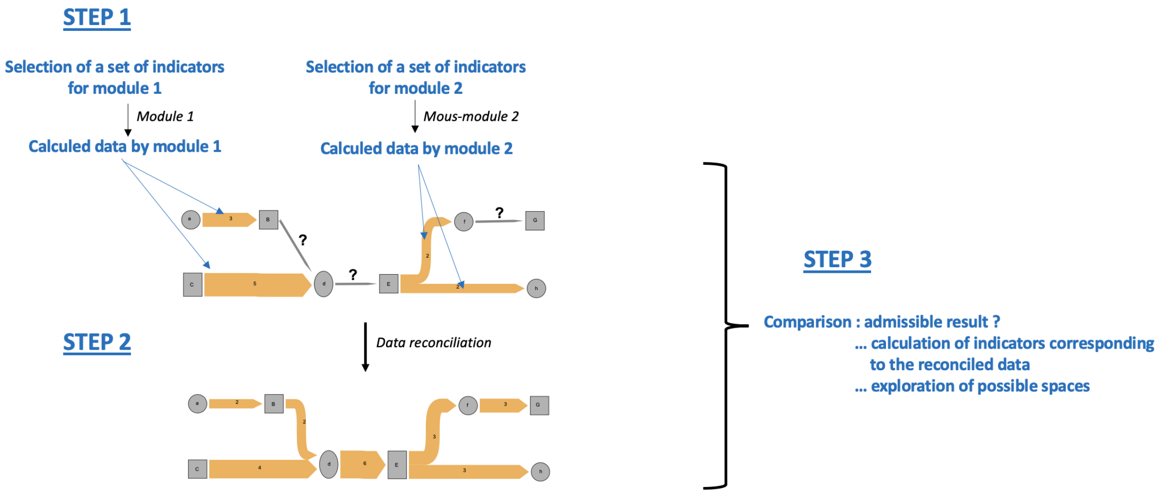

Figure 2: Material flow analysis scheme for a socio-technical alternative

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