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A complex issue requiring new approaches to scientific evidence and quantitative analysis

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Introduction

The problem with the Cartesian dream of prediction and control

The disappointing results achieved so far in relation to sustainability goals (e.g., reduction of greenhouse gas emissions, protection of biodiversity or circularization of the economy) flag the necessity to improve the effectiveness of sustainability policies and the models used to inform the process of decision making. When dealing with complex sustainability issues (“wicked problems”), the conventional approach to purposeful modelling (the Cartesian dream of prediction and control) might not be the most suited approach. Existing quantitative approaches (conventional approaches based on economic narratives) do not allow an integrated analysis of the different factors determining: 1) material standard of living; 2) food, energy, water security; and 3) environmental security because these factors can only be observed across different dimensions and scales of analysis. For this reason, today, relevant sustainability issues can only be analyzed in quantitative terms “one at the time” using nonequivalent models. This is what generates the “silo governance syndrome” – i.e., solving a given problem by setting targets that ignore negative side effects related to other problems. This fact can explain, for example, why many policies dealing with sustainability of agriculture (both in developed and in developing countries) have been so far ineffective and even contradictory with each other.

Quantitative storytelling: a complexity revolution in sustainability analysis

The process of producing numbers is inseparable from the process of defining the meaning and the relevance of the numbers. For this reason, we always need to know: 1) why and how the numbers came into being in the first place – i.e., they depend on the problem definition (decided by whom?) determining the choice of preanalytical narratives driving the choice of models; and 2) why and how they get back in the form of knowledge claims used to guide policy. The meaningful use of numbers requires transdisciplinary research. Unfortunately, at

the moment much of the sustainability discussions are based on numbers that are produced by simplistic analytical tools (mono-scale and mono-dimensional indicators), inept to address complex issues, that are thrown at each other (divorced from the original context) by the discussants. The complexity revolution proposed here entails the combination of two distinct changes:

- 1 *Quantitative Storytelling* – a novel philosophy in the use of scientific evidence for the governance of sustainability
- 2 *Multi-Scale Integrated Assessment of Societal and Ecosystem Metabolism* (MuSIASEM) – a novel accounting scheme used for the structuring of the perception (qualitative choices) and representation (quantitative choices) of the sustainability predicament. This novel accounting scheme based on the concept of the metabolic pattern of social-ecological systems, can be used in a process of coproduction of knowledge claims in decision making to radically change the nature of the information space used as “evidence”.

A different “WHY” for the generation of quantitative information

Quantitative Storytelling is based on the consideration of the following questions: 1) “what if it is not possible to identify the optimal solution to the problem?” (whose problem?); 2) “what if it is not possible to identify an uncontested intervention that will provide an optimal improvement?” (for whom? for how long? at which costs?); 3) “what if it is not possible to eliminate large doses of uncertainty both from our analysis of the existing situation and from our predictions of future events?” If we admit that it is impossible to make reliable predictions and to provide full control about desired futures, what is then the possible role of quantitative analysis? In quantitative storytelling, scientific analysis is applied to answer questions such as: “what cannot happen if” or “what could go wrong if we try to implement this policy?” (in order to eliminate implausible or risky policies!) or “can we define the consequences of proposed policies in terms of winners and losers?” (in order to avoid unfair policies). To implement this new philosophy, we need an analytical framework based on a complex representation of the metabolic pattern of social-ecological systems integrating different types of quantitative information into a salient characterization of sustainability issues.

A different “HOW” for the generation of quantitative information

MuSIASEM accounting scheme allows people to generate a *sustainability sudoku* by preserving coherence across quantitative analyses (integrating indicators) based on different metrics carried out across different levels and dimensions of analysis. This is an extremely important achievement because of the unavoidable existence of side effects (negative/positive consequences of an improvement according to an indicator over other indicators) to be expected when considering the different dimension of the nexus. The “silo-governance syndrome”

is exactly generated by an excessive importance given to the achievement of a specific target at the time, when side effects in relation to other targets are not considered: solving a problem in relation to food, we may generate a different problem in relation to water and so on.

Food security in Africa is definitely a complex issue

In Africa, the continuous increase in the population pressure associated with a generalized raise in expectation for better economic conditions – new parents want a better future for them and their children – is generating the need for a dramatic expansion of economic activities. The aspirations for a quick increase in the level of personal monetary income in the time span of a generation translates into a “mission impossible” due to the huge requirement of infrastructure, capital and resources that this expansion would require. Therefore, the dramatic process of transformation taking place in Africa is at risk of jeopardizing human well-being, the environment, the richness of cultures and the fragile sociopolitical institutions all over Africa. The problem is especially clear in relation to food security because traditional agricultural production faces important external constraints such as limited land available, poor soils and scarcity of water. In this situation an attempt to boost the traditional yields above their specific benchmarks can only be obtained through high impact on the environment and a very low economic gain for the farmers. As a result of this situation, we witness a massive migration away from rural areas. However, differently from what happened in the industrial revolution in Europe, this migration is not driven by the availability of better jobs in the cities. Rather, rural migrants are running away from unacceptable living conditions in the countryside. This mass of migrant population is generating another critical situation in shanty towns where the poor settle around mushrooming urban agglomerates. In this urban context the access to food is strictly determined by market laws: the food security of the urban poor depends on cheap food supply. This situation translates into an internal tension in the society because cheap food supply for the cities means low economic revenues for the farmers feeding the city (or vice versa). To make things worse, in many areas of Africa, the problems associated with a scarcity of resources are worsened by: 1) a generalized collapse of social fabric (due to an excessive speed of cultural changes or the occurrence of wars), making it impossible to guarantee the satisfaction of basic needs; 2) the effect of climate change that are disrupting the traditional patterns of agricultural activity; and 3) land grabbing from foreign investors. In this situation the use of complex analytical tools capable of generating a more robust and articulated diagnostic and anticipation of problems is a must because:

- 1 The systems of agricultural production in Africa are extremely diverse reflecting the diversity of cultural contexts and environmental conditions in which farmers operate. This diversity represents an additional problem because it requires an “ad hoc” tailoring of the management of plantations,

pastures, agricultural or horticultural crops to specific conditions and a continuous adjusting of the original choices in response to the effects of climate change. This challenge calls for an analytical approach capable of identifying the relevant factors (referring to different scales and dimensions) determining the sustainability of food production across the mosaic of situations experienced in Africa.

- 2 The sustainability of food security of Africa depends on the ability to handle when deciding policies complex dilemmas associated with direct tensions/trade-offs: 1) “intensification of agriculture” vs. “impact on the environment”; 2) “development of urban areas” vs. “development of rural areas”; 3) the implications of the nexus between water–energy–food (the various flows are entangled and it is impossible to optimize just one of them without affecting the others); 4) “modernization” vs. “protection of the existing culture” – i.e., the war on poverty ends up eliminating the poor.

The next section shortly illustrates a holistic toolkit capable of identifying and characterizing a set of factors relevant for an informed policy deliberation.

Analyzing food security from multiple perspectives, dimensions and scales

The Drivers–Pressure–State–Impact–Response (DPSIR) framework

This section presents an application of a toolkit developed in the EU project MAGIC (Moving Towards Adaptive Governance in Complexity: Informing Nexus Security – <https://magic-nexus.eu/>) that applies insights of complexity to the analysis of food security, addressing the implications of the nexus. It is based on the causal Drivers–Pressure–State–Impact–Response (DPSIR) framework proposed by the European Environment Agency in 1999, to study the interactions of socioeconomic systems with their environment (EEA, 2018). The DPSIR framework allows the integration of different “types of indicators”: 1) indicators referring to the “state” are those referring to what is going on inside the society (the technosphere – referring to the set of processes under human control); 2) indicators referring to the “pressure” are those referring to the pressure exerted on the environment (the biosphere – referring to the set of processes outside human control). It should be noted that the indicators of pressure do not translate directly into indicators of impact. Because of the openness of modern society based on trade, imported food can be associated with an environmental pressure that is generating impact elsewhere (in the ecosystems of the agricultural systems producing the imported food). In the same way exported food does generate an environmental pressure inside the system without contributing to the local food security. For this reason, when applying the state–pressure analysis it is necessary to address another key aspect of the analysis of food security: how much open the system is, in relation to imports and exports of food commodities.

The MuSIASEM toolkit

An accounting system called Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) – Giampietro et al., 2012, 2014 – makes it possible to establish a bridge across different indicators defined across different levels and dimensions.

After having characterized the level of openness of the system under analysis it becomes possible to characterize four key aspects of the system:

- 1 the local *end use matrix* – the quantity of inputs required in the process of food production taking place in the technosphere (labour, energy, fertilizer, power capacity, etc.) inside the considered system
- 2 the local *environmental pressure matrix* – the quantity of primary sources (land, soil, green water, abstraction from ground water) and the sink capacity (natural processes absorbing pollution) that would be required to maintain the metabolic pattern without affecting the health of ecosystems
- 3 the *externalize end use matrix* – the quantity of inputs required in the process of food production taking place in the technosphere (labour, energy, fertilizer, power capacity, etc.) but outside the border of the investigate system; they are embodied in the commodities crossing the border of the system
- 4 the *externalized environmental pressure matrix* – the quantity of primary sources (land, soil, green water, abstraction from ground water) and the capacity of sinks (absorbing pollution) required for the production of the traded food commodities; they are embodied in what is crossing the border.

A visualization based on the rationale proposed by the European Environment Agency is given in Figure 33.1.

In order to carry out an analysis of environmental impact, one has to contextualize the various typologies of pressures – e.g., flow of nitrogen per hectare in the soil, abstraction of blue water per hectare for irrigation, requirement of land in production determining destruction of local habitat – against the characteristics (qualitative and quantitative) of the local ecological funds. Therefore, the analysis of impact requires the use of spatial analysis (information organized in GIS layers) because each type of pressure has to be assessed in relation to a specific relevant information layer – e.g., the impact of the abstraction of water for irrigation on the water table depends on the relation between the volume of the abstracted flow and the pace of recharge of a specific aquifer. The two have to be compared on a GIS layer focusing on the location of aquifers. As mentioned earlier in the case of Africa it is important to apply the toolkit to study the dynamic relation of food supply and food demand between urban and rural areas. That is, we can define for both an urban system (a city) and a rural system (identified by an administrative area):

- 1 The desirability of existing situations, identifying the factors associated with a given level of bio-economic pressure in the society: 1) the minimum

Figure 33.1 The state-pressure relations in an open Social-Ecological System

Source: Own representation

- return of labour expected in a given community (operating below this threshold would imply the crumbling of the social fabric) – the productivity of labour can be assessed both in terms of monetary value and in biophysical terms, depending on what is produced in the various tasks; 2) the minimum level of services expected in a given community (operating below this threshold would imply the crumbling of the social fabric) – this factor can be measured in “hours of paid work per capita per year” in the community for services (health care, education, police and other administrative tasks).
- The viability of existing situations, identifying the factors associated with the given level of productivity of production factors: 1) what are the factors determining the economic viability of farmers, the combination of land available, productivity of land (yields) with the structure of costs and revenues; 2) what is the level of intensification of agricultural production (the profile of inputs and outputs per hectares) at the moment? – are we dealing with “high external input agriculture” (market agriculture), “low external input agriculture” (subsistence agriculture) or a mix of the two?
 - The feasibility of existing situations determined by the severity of external biophysical constraints. Is the existing demographic pressure generating

problem of limited access to land or rather the limited access to land is due to institutional settings? Is the requirement of land compatible with the preservation of terrestrial habitats? Is the pressure associated with existing production activity representing a threat to the health of ecological funds when considering existing drivers? Can we characterize the limits imposed by biophysical processes as distinct from those imposed by institutional settings?

- 4 What is the level of openness of the systems of agricultural production: are they producing food to feed rural people (and themselves)? Are they producing food to feed the cities? Are they producing food for international exports? Answering these questions is essential if we want to understand the nature of the trade-offs over intensification of agriculture, food security, human well-being and environmental impact. In fact, as discussed earlier there is a direct relation and tension between urban and rural areas. Basically, cities import all the food they consume from their surroundings: the supply of food to the city has to come from local rural areas or has to be imported from other countries. The chosen solution makes a huge difference in the dynamic of rural development. In addition to that, today in Africa, land grabbing is implying that some of the natural resources available in rural areas are used to produce food that will leave the country. In general, the decisions about the origins and the destinations of food flows in Africa are not taken by the local farmers, even though they are affected by these decisions that have an overwhelming effect on the resulting trade-offs. Foreign investors may be willing to use the best land for commercial activities, reducing in this way the options of local farmers for local production. We can expect that a strategy having the goal of increasing as much as possible the supply of food to the local people while reducing the impact on the environment and boost the well-being of rural communities against a very heterogeneous set of external biophysical constraints can only result in a mosaic of production systems: subsistence farming (integrated by a multifunctionality of the landscape in marginal areas), mixed farming and high external input farming (on the best land) depending on the specificity of geographic and economic situations. If we accept this hypothesis it is really important to control the overall effect of the demographic pressure on the availability of land and the distortion that foreign investors can generate, in order to evaluate the pros and cons of increasing or reducing the trade of agricultural commodities.
- 5 Last, but certainly not least, it is essential to address the issue of the nexus over water, energy, food and landscape both in diagnostic mode – what is the level of nexus impact associated with the existing state (the giving mix and quantity of production systems)? – and in anticipation mode – what types of impact can be anticipated because of changes in population, changes in the mix of activities or changes in climatic conditions? Can we track the flows of consumed inputs and produced outputs from and to the technosphere (having an economic relevance in terms of costs and revenues)? Can we track the flows of required inputs and resulting wastes and

emissions from and to the biosphere (having an environmental relevance in terms of constraints and impact)? Can we fractionate this analysis across levels and scale of analysis using GIS layers?

Practical applications

Sound policies for agricultural transformation will require a holistic contextualization of the variety of different inputs of scientific information used in the decision process. The worrisome trends experienced across the planet of political instability, the progressive shortage of resources and environmental deterioration leading to geopolitical turmoil entail an increased responsibility for decision makers.

It is time to guarantee a better quality of policies in terms of robustness, fairness and transparency, and this requires a revolution in the production and use of quantitative analysis in agriculture and food production.

A new generation of quantitative information has to be used to address simultaneously the four challenges to the governance of sustainability as it relates to agriculture:

- 1 *How to characterize, in biophysical and quantitative terms, the factors that can be used to deliberate about a desirable standard of living* – how to define a GOOD QUALITY OF LIFE? What should be considered as a desirable standard of living when considering the various attributes of sustainability?

This is an issue very often raised in sustainability discussions – e.g., prosperity without growth, post-growth economy, sufficiency economy – and it has been proposed by several governments as a working concept – e.g., “*buen vivir*” (Ecuador), *happiness index* (Nepal) and *Det Goda Livet* (Sweden).

- 2 *How to assess the level of food and energy security of a country.* The analysis of the metabolic pattern of countries should be used to identify dangerous dependences on imports in relation to: 1) energy security and food security – when the internal demand cannot be met by local supply because it exceeds external biophysical constraints (available primary sources and sinks in the country); and 2) the effects of the exports of a country on the rest of the economy (not only in terms of natural resources but in terms of technology and capital).
- 3 *How to track the impact of the various pressures across scales using GIS.* In order to be able to geo-localize the effect of the environmental pressure against the characteristics of local ecological funds – assess the level of environmental loading – one has to use the lens of the *microscope*. Different type of impacts can be calculated in relation to:
 - 1) the need of protecting habitats and biodiversity
 - 2) GHG emissions (direct and indirect associated to changes in land uses)
 - 3) water resources, both on the supply side (over drafting of aquifers) and the sink side (leakage of NP in the aquifers)

- 4) pesticides (effect on pollinators) and other dangerous pollutants
- 5) waste management (plastic and urban wastes), etc.

The possibility of mapping the pressures generated by the technosphere onto the characteristics of natural ecosystems across scales to calculate the resulting impact is a natural feature of the MuSIASEM accounting scheme.

- 4 *How to establish an interactive interface capable of visualizing and communicating the results of the analysis in the form of an effective decision support.* The simultaneous analysis across different scales and dimensions translates into an excessive density of the quantity of information to be processed (too many results).

What needs to be done by policymakers?

It is essential for policymakers to:

- 1 Support the development of better decision support tools based on software to build an interface with those creating policies for transformation of agriculture (using dashboards, visualization tools and interactive features). These tools have to be used when deliberating over policies regarding the future of agriculture and food production.
- 2 Give financial support for capacity building to produce local scientists that can develop such toolkits using, for example, the MuSIASEM accounting scheme.
- 3 Strengthen in-country scientific capacity for working with these tool kits in *diagnostic mode*: based on the current situation in agriculture and food production in the country they should identify: 1) the quantitative and qualitative characteristics of the constituent components of the agricultural food system in terms of benchmarks; 2) the important functional and structural relations to be considered in policies; and 3) bottlenecks, critical situations and potential factors that can hamper the implementation of policy in relation to changes in interrelated conditions.
- 4 Strengthen in-country scientific capacity for working with these tool kits in *anticipatory mode*: they should explore, using contingent analysis over “what if” scenarios, the internal and/or external limits – i.e., the option space – in order to identify policies for agricultural food production systems avoiding not feasible, not viable or not desirable outcomes in relation to the goal of agricultural improvement of food production.

In conclusion, the MuSIASEM toolkit gives decision makers the ability to identify and study the factors determining the:

- 1 Feasibility = compatibility with external constraints: processes outside human control
- 2 Viability = compatibility with internal constraints: processes under human control

- 3 Desirability = compatibility with aspirations and social norms required to preserve the social fabric of proposed policies to improve agricultural production.

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