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REDISCOVERING AGRICULTURE – ONE HEALTH STARTS WITH COLLECTIVE RIGHTS AND DUTIES ON PRIMARY RESOURCES

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Agriculture occupies a substantial portion of the Earth's terrestrial surface, particularly in areas capable of sustaining significant biological productivity. Since the domestication of selected flowering plants, mammals, and other vertebrates, human societies have progressively redirected primary biological production toward goods and services that sustain human life. For millennia, agriculture has been the dominant form of human labor, shaping social organization, settlement patterns, and economic structures. While the relative share of human labor devoted to agriculture has decreased markedly in many industrialized societies over the last century, the transformation of agrarian systems continues to have profound social and ecological consequences.

The Industrial Revolution and subsequent technological and infrastructural changes have promoted forms of agriculture increasingly dependent on industrial inputs, mechanization, and global supply chains. In many regions, these processes have led to the marginalization of smallholder farming, although the extent of this marginalization varies geographically: in some areas, smallholders remain central to local food production and rural livelihoods. These shifts have contributed to growing inequalities in access to nutritious and secure food and have weakened the political influence of peasant communities in policy and resource governance.

Today, a large proportion of undernourished populations live in rural areas and depend on small-scale agriculture for their livelihoods, highlighting the continuing tension between global agricultural systems, local food security, and social equity. Understanding and addressing these dynamics requires a conceptual framework that considers collective rights and responsibilities over primary biological resources, as well as a renewed examination of agriculture's role in sustaining both ecological integrity and social well-being.

Keywords: Agriculture exception; Critical Zone; Food security and sovereignty; Food systems; Nature based solutions; Peasant rights; Planetary Boundaries; Primary resources – soil, water, biomass; Resource grabbing; Systemic risks.

1. INTRODUCTION

The Latin root of agriculture – *ager* – means "field". Agriculture is defined as the science or practice of farming, encompassing soil cultivation for crop production and the rearing of animals to provide food, wool, and other products (Oxford Languages). In other words, it includes all human activities aimed at producing plants and animals useful for nourishment, care, and clothing. Livestock farming is an integral part of agriculture, as plant and animal production are often interdependent within the same system *(see also:* https://www.cnrtl.fr/definition/AGRICULTURE*)*

When we speak of *agriculture*, we must also think in terms of *food systems*: a comprehensive "from field to fork" organization that encompasses the entire chain from production to consumption (EU, 2020).

Food systems, as I report here, are understood as *social-ecological systems* (Ostrom, 2009; Binder *et al*., 2013). Thus, societies and their governance systems have direct and indirect impacts on ecological systems and their productivity. In turn, the resulting externalities feedback into social and institutional dynamics. As Jason Moore (2015, 2025) argues, social–ecological systems are processes that simultaneously organize nature and society. Yet these processes have so far failed to consider the differing temporal scales and limits that characterize both nature and the social realm (Negrutiu, 2024) – particularly those that transform human activity into labor-power and land into property. This transformation has been amplified by a series of scientific revolutions that reshaped the world “in the image of capital”, producing what Moore (2015) calls “cheap nature” and “cheap labor”. Neither has led us toward a desirable world.

Food systems best exemplify the intimate, inseparable, and reciprocal relationship between humans and nature. The objective of this work is to question how agriculture plays out in the social-ecological system. Three main points frame the analysis:

1. Agriculture and livestock farming were humanity’s first major enterprises and they remain the world’s largest industries today. There is remarkable diversity among agricultural forms – differing in farm size, technologies, productivity, and social status. The industrial agriculture is economically and politically the dominant form today.

2. Food systems are a major share of the ecological infrastructure of the biosphere. Demographic and lifestyle pressures on vital primary resources—land, water, and biomass – collide with the planet’s social and ecological limits (Gupta *et al*., 2023; Negrutiu, 2024). Unlike other economic systems, food systems possess an intrinsic capacity for transformation through a wide range of *Nature-Based Solutions.*

3. Despite its foundational and vital role – even though every person on Earth needs to eat daily – this vital activity is considered marginal, if not discredited. Paradoxically, these challenges – rather than earning rural communities greater social recognition – often result in their marginalization, leaving them vulnerable to poverty and malnutrition (Ellis, 2011; Brown, 2012; De Schutter, 2017; iPES Food, 2019).

Taken together, these considerations frame a social-ecological landscape in which s*ocial dumping* meets the more global *ecological degrowth* (*i.e*., the degradation of the unique natural resources of the biosphere and, hence, agriculture. One Health is the proposed antidote (Negrutiu, 2024).

On these grounds, the analysis dives into some historical and fundamental aspects of the biological, social, economic, digital, and institutional resources that depict the conceptual and actionable landscape of the food system enterprise. More precisely, we analyze

- ***Knowledge resources*** (particularly genetics and evolutionary understanding). The resource is presented in panel format (***Panels 1 to 7***);
- ***Human and social resources*** (particularly family-centred agriculture);
- ***Physical resources*** (land, water, and biomass, within a landscape perspective);
- ***Digital resources*** (data, platforms, and monitoring systems);
- ***Political and institutional resources.***

Together, these elements form an architecture of systemic, slowly developing risks that unfold over the long term, and lies at the heart of the interlinked synergies and feed backs among the various resources discussed here.

The article explores the dynamics of food systems across history, ecology, and society to show that it has been, it still is, and ever remain a vital agency for mankind. At a time of accelerating geopolitical, economic, social, and ecological upheaval, the work calls to reconsider the place and role of food systems in the unavoidable transformations of our societies and leads to some fundamental existential questions: Who owns – or will own – nature? What may prevail next: private interests or common purpose? How can society balance production, equity, and sustainability?

2. THE MULTIPLE FACETS AND DRIVING FORCES OF AGRICULTURE AND FOOD SYSTEMS

The facts and trends analyzed in this section characterize the essence of agriculture and food systems. They provide a broad perspective on the most pressing challenges in the field and support a comprehensive understanding of why agriculture remains unique and vital to societies across time.

Agriculture produces **biomass**, the product of the intertwined “economies” of the cosmos (solar energy) and the biosphere. Biomass is a limited and land-intensive resource. Agriculture, a human-directed process, entails the deliberate appropriation of biomass for human use, the redirection of evolutionary mechanisms in diverse organisms (*i.e.*, domestication), and the simplification of ecosystems and food chains. The controlled human appropriation of a substantial portion of global biomass (coined HANPP; Haberl et al, 2007; Daviron, 2018) has manifold consequences interwoven in feedback loops that systemically affect biodiversity, climate, geopolitics, and society.

Agriculture and food systems mobilized the creativity of human societies along history (***Panels 1 to 4***). For example, integrating evolutionary understanding into education, policy, and agricultural management consolidates society’s capacity to act within biosphere limits. Domestication, breeding, and ecosystem stewardship are all applications of evolutionary knowledge: they determine the productivity, resilience, and sustainability of human-managed life systems.

2.1. The Human Resource

Building on insights from genetics and evolutionary sciences (***Panels 1 and 3***), agriculture can be understood not merely as a technical activity but as a human-directed manipulation of ecosystems and domesticated species.

2.1.1. Agriculture, a social-economic evolving process

If human time is of the order of three million years, the duration of pre-agriculturalism is 2,990,000 years, that of agriculture about 10,000, and that of agro-industry about 200 (Malassis, 2004).

To be practiced effectively, agriculture has required careful observation and knowledge of the skies, natural environments, and living species. Most domestications were achieved by our illiterate ancestors (De Ribou de Bosseoreille *et al*., 2013). According to Jared Dimond (1987), the emergence of agriculture has been no more nor less the worst mistake in human history. The hunter-gatherer societies, such as the! Kung bushmen of the Kalahari desert in Botswana, are known as vegetable gatherers (mongongo nuts in particular). They are occasional hunters for sport and spend 12–19h a week to grab food (Gladwell, 2008). Sedentarization through agriculture, a laborious process in distinct regions of the world (Brown, 2018), has generated nutritional changes and frequent malnutrition, emergence of infectious diseases, population growth and increase in the size of social structures, social inequalities, political and sexual domination, exploitation of the majority by a minority. Agriculture and food have been instrumental in taking political and economical control over water, land, and the appropriation of the generated biomass.

However, Graeber and Wengrow (2021) have a more flexible understanding of such historical processes and argue that the transition from foraging to agriculture was not a civilization trap. It was the crucible of what our societies have become today. In the last two million years hominid species have reliably inherited both information encoded by genes and by culture (Feldman and Laland, 1996). The authors argue that the gene-culture coevolution process has been put to a large scale test during the spread of agriculture. For example, the rate at which hunter-gatherers were converted to farmers was a function of the carrying capacity of the environment containing hunter-gatherers to sustain them (hence the great fauna extinction issue) (and see Section 2.3.4). Farming allowed, as mentioned above, human populations to attain even higher densities and expand geographically as politically organized communities.

Whatever early history may have been, agriculture has undoubtedly supported the emergence of sophisticated civilizations and varied social experiences. The fact that current political-economic systems, the modern state with rigid and permanent unequal hierarchical systems and structures (Graeber and Wengrow, 2021), are the norm, makes almost forget that in past civilizations, conceptions and practices of living together with no evidence of mass enslavement, state violence or patriarchy had indeed been experimented with. More specifically, it must be remembered that, despite ups and downs, historical agrarian developments and/or reforms have been among the political instruments for the colonial making-unmaking-remaking (see ecological colonization, Hickel *et al*, 2022), and evolving inequalities (Mazoyer and Roudard, 2006; Moore, 2015; Daviron, 2019; Varufakis, 2023; Neumann, 2024).

Currently, the agriculture represents a declining labor share in industrial societies, yet is having persistent social and ecological consequences. Globally, the sector employs about 916 million people (26% of the global workforce), occupies approximately 4,780 million hectares of land, and contributes up to 10% of global GDP (FAO, 2024, 2025; Our world in data, 2025).

According to Vanbergen *et al*. (2020), two contrasting agricultural systems operate in the world.

Conventional intensive agriculture is defining the current food production system, based on industrial management of livestock, monocultures, external inputs (*e.g*., fertilizers, pesticides) and mechanization. As simplified landscapes, large scale monoculture or limited rotation practices are considered to work outside ecosystem processes and limits (*e.g*., soil structure and its biodiversity, nutrient levels, water holding capacity).

Sustainable / ecological intensification of agricultural systems comprises organic farming, conservation agriculture, agroecology. Each of them differently exploits the state and processes of the natural ecosystems, distinctly shaping ecosystem infrastructure and functions. Nowadays, family-centred agriculture (*i.e.*, farm holdings less than 2 Ha) represents 80% of the global rural population (*i.e.*, more than 2 billion people) with 84% of the 600 million farms worldwide producing an estimated 36% of the world's food from cca. 12% of the agricultural land surface (Vanbergen *et al.*, 2020; see also Losch and Freguin-Gresh, 2014). The spatial and economic pressures on small-scale agriculture are accelerating.

Although numerous studies show that larger farms are more productive than smaller ones, some writers state that whilst conventional farming creates a high output per worker, small-scale, polyculture farmers can produce more food per acre of land (FAO, 2023).

There are additional benefits of peasant / family farming agriculture, namely:

– Practises respecting natural cycles (*i.e.*, supporting carbon storage, soil fertility, water cycling, etc), less environmental impact, relative autonomy;

– Mixed farming, with livestock as a source of local protein, supporting important rural economy;

– Short circuits, local cooperatives, revival of strategic production (oilseeds, vegetable proteins);

– High-tech use (sensors, drones, AI; see section 2.4) to limit inputs and preserve resources.

The current state and scale of farm systems show the tendency: food insecurity is likely to increase mainly in low to middle income economies where the growth of human population is forecasted to be higher (Vanbergen *et al.*, 2020) and the contribution to food systems of small hold farms is highest.

In brief, conventional agricultural expansion and intensification are undermining the natural foundations on which agriculture is built, raising social, economic, technological, and demographic concerns by affecting modes of production, diets, lifestyles, and behaviour. The extreme degree that monoculture and soil less animal husbandry have reached makes agribusiness a structurally regressive form of agriculture (Negrutiu 2025b). In other words, can agribusiness still be called AGRICULTURE? What value does industrial agriculture and the like convey? What is the mindset of farmers who perform it with respect to the fundamental missions of agriculture?

2.1.2. Peasants and small holder farmers, the historic social and economic adjustment variable

The world's peasants have a long way to go to free themselves from their historical servitude; to be recognized as full citizens (...) to escape poverty and achieve the basic objectives of the human economy, to live in dignity and respect… (Malassis, 2004).

Peasants (and fishermen) feed us. They are our mediators with nature, and as such the only ones to be directly dependent and in constant contact with nature and its resources. Neumann (2024) examined the place of peasants and the living conditions of peasants in European societies from the end of the Roman Empire through the feudal domination of the Middle Ages and the revolts during the Modern Era to industrial agriculture. This social class has always been under the yoke of successive powers.

Marcel Mazoyer considers that "from the emperors of China to the very present, history has always shown that the market has never been able to ensure the food security of the people, wherever they are in the world. The market is a formidable machine, but it in no way balances production according to needs: it balances production according to solvent demand... (it is a) machine for creating rural exodus, starving peasants and reinforcing the great imbalances of the world" (Mazoyer *et al.*, 2008).

For example, the emergence of capitalism around the 16th century in Western Europe had important consequences on the life of the peasantry. Its founding mechanisms consisted in the transition from control of land as a direct relation to surplus appropriation (*i.e.*, the landmark of feudalism) to control of land as a condition for raising labour productivity within commodity production and accumulation of capital (Moore, 2015, 2025). Namely, the outcome was and still is cheap labour and cheap nature. For cheap labour to be kept in check, the solution has universal trends: cheap energy, food, and raw materials. Cheap food in particular enabled and still enables to keep the price of labour-power to systematic lows, in the agriculture economy in the first place (Varoufakis, 2023).

The world produces more food per person than ever, yet hunger is not declining. Why? Because, from seeds to fertilizers to machinery, just a handful of powerful corporations and financiers wield power over the global food system, land use and ownership, and speculation (Malassis, 1977; Kaplinsky, 2000; Reardon *et al.*, 2003; Gareffi et al., 2005; Barret, 2008; Galtier & Daviron, 2011; FAO, 2014). This depicts a schizophrenic system. The drift of the Common Agricultural Policy is an example at hand: anti-obesity strategies operate alongside agri-trade policies that make junk food cheap and abundant, young farmers are offered premiums while subsidies drive up land prices and undermine access to land, and strict environmental standards are set up while the advisory services farmers need to meet them are defunded (iPES Food, 2019).

In brief, food systems and the subtending primary human resource are since ages the adjustment variable of policies and economic strategies that ultimately keep food prices low.

2.1.3. Farmers' Remuneration

Peasants and farmers sustain humanity by managing complex systems involving soil and climate variability, markets, financing mechanisms, and administrative frameworks. Yet, paradoxically, the majority of them earn only very low incomes (illustrating deep inequalities between urban and rural revenues; Mazoyer *et al*., 2008). In Europe, for instance, approximately 60% of average farm income is derived from the Common Agricultural Policy, but high disparities remain (EU, 2025).

Why do most of the world's farmers – those who, by the very nature of their work, act as essential mediators between humanity and nature, and who are responsible for feeding us all – struggle to earn a dignified livelihood? In formerly industrialized economies (such as the EU, the United States, and Japan), control over land secures rights to agricultural rents through policy mechanisms (Gylfason, 2018). However, in market economies where consumers enjoy broad access to diverse food choices, it is typically the downstream actors in the value chain – processors, distributors, and retailers – who capture the majority of the value and profit (Malassis, 1977; Kaplinsky, 2000; Gareffi *et al*., 2005; Barret, 2008; Reardon *et al*., 2003; FAO, 2014; Galtier et Daviron B and Vagneron I, 2011).

Nonetheless, the objective of doubling agricultural productivity and the incomes of small-scale food producers by 2030 remains highly ambitious given the scale and complexity of the challenge. Meeting it requires simultaneous transformation across ecological, social, and economic dimensions, such as access to land, water, and capital vital assets, multifunctional landscape planning and cross-sectoral, integrated, and participatory management (Vanbergen *et al*., 2020; see also Section 2.3.2.2).

An instructive example comes from Mexico's *Sembrando Vida* ("Sowing Life") flagship program (2019–2022), which provided monthly income support to 450,000 rural households in exchange for their participation in large-scale reforestation activities. The program successfully generated one million hectares of agroforestry resources (Gonzales-Moctezuma & Rhemtulla, 2024).

In summary, integrating urban, peri urban, and rural interdependencies in policy and business agendas has a great deal to do with strengthening local food systems, food transitions, and redistribution policies. The access of family farming producers to assets such as land, water, capital, education, and health is paramount.

2.2. Agriculture's Primary Resources: Soil, Water, and Biomass

Planetary Boundaries and the Critical Zone (Negrutiu *et al*., 2020) are two notions reflecting particularly well the dynamics of and the interactions operating between these primary resources.

The Planetary Boundary framework targets variables of biosphere integrity, pollution and waste, water and land use, and ocean, air, and climate changes that eventually translate into thresholds, tipping points, warning signs, and state shifts. Aggregating planetary boundaries depicts a two-component integrated system, namely food systems and global pollution. That changes the way major boundary stressors can be dealt with by putting soil and water resources on critical policy agendas (Arguello and Negrutiu, 2019; Negrutiu, 2025b).

The Central Zone, the "skin" of the planet Earth, spans from above the forest canopy down to the successive layers of the soil and to the bedrock (Banwart *et al*., 2013). It represents the convergence and nexus of atmosphere, lithosphere, hydrosphere, and the living. Soil, water, and biomass are the main building blocks of the central zone, the physical support of almost all human activities, agriculture in the first place.

Food systems are the engine of persistent transformations across planetary boundaries and the central zone. They illustrate the fact that ecosystem functions and services embedded in these matrices operate systemically. The unique qualities of the soil-water-biomass framework, namely there being renewable but exhaustible, non-delocatable and non-substitutable, would require taking these resources out of standard economic and political thinking.

The three resources are under increasing stress, tributary to global human activities, namely the sequence of over-extraction, - production, and – consumption, and the unprecedented expanding human population since the 1950s (Ehrlich *et al.*, 2012). For example, land use conversion is the main direct driver of change in habitat structure and function on more that 40 % of the earth terrestrial surface (Vanbergen *et al.*, 2020). The limits of these interacting pressures must be questioned. An absolute limit is the rate of photosynthesis, a determining element in biomass productivity (see ***Panel* 1**).

2.2.1. The biomass resource – a state of being in the world (and in the Universe?)

All living beings are biomass. They are cell and biochemical factories, and water reservoirs. Thus, biomass is a state of being in the world, with its down to earth condition: the capacity of the biomass to reproduce itself. The associated food chains (Negrutiu *et al*., 2020) make up the circular economy of the biosphere. Our guess is that this may not be a universal feature in the universe, life having a range of options to deploy in the cosmic realm.

The rules of the game are tight and generate a "tax" framework in the biosphere, based on who eats who. The tax currency is biomass, with strict energy conversion ratios (i.e., the relevant energy pyramid) across food chains (Negrutiu *et al*., 2020). The only species to defeat these rules is, since the invention of agriculture, the human species.

The biomass global figures challenge simple perception, be it expressed in carbon equivalents, mass or energy units (Smil, 2012). It is worth understanding that, for the first time in the history of the planet, human made mass is surpassing life made biomass (Elbacham *et al*., 2020; Vndetti and Belan, 2021). The cumulative raw material extraction, movement, and consumption, mass aggregation as material use and footprint have exploded (Krausmann *et al*., 2009; Kalt *et al*., 2020; Hickel *et al*., 2022; Elhacham *et al*., 2020; Rosenberg *et al*., 2025).

Plants are by far the largest producers of biomass on land (Smil, 2012; Combemorel, 2018). Of note, only 11% of terrestrial Net Primary Production (NPP) is contributed by Earth's wild lands, while 89% is produced by human-dominated ecosystems (coined anthoms; Ellis *et al*., 2010). In such agro-ecosystems, the yield of wheat amounts 7500 kg/ha, silage maize, 40 tons/ha; potatoes, 50 tons/ha; sugarcane, 60 tons/ha; tomatoes, 80 tons/ha; apples, 30 tons/ha; and saffron, 3–5 kg/ha. On the global scale, the production of oil palm fruit, soya beans and rapeseed, the main oil crops, reached 893 million tonnes in 2023, and represents 3-fold the cumulated production volume of chicken, pig and cattle, the main meats produced worldwide (https://www.fao.org/faostat/en/#data/QCL). On average, plant-based foods deliver 83% and 63% of global calories and protein supply respectively (Vanbergen *et al*., 2020).

Forests represent 90% of the green biomass, with yields of 40 tons/ha of timber (standing trees). As for the rest of the living, the forests are under stress. According to the European Carbon Observation System, the consequence of increasing harvest demands and of natural disturbances associated with the warming climate have been that their capacity to capture CO_2 diminished by a third during the last 10 years (Luhtaniemi, 2023). This means that beyond certain limits (such as +4°C increase in average global temperature) climate change is expected to result in loss of forest biomass. It is important to consider that the life cycle of forests is centuries long. Therefore, forest planning is a sensitive challenge in the face of adaptation to climate change.

For example, at the rate at which climate is expected to change in the Mediterranean area with enhanced drought in lowlands, the projections anticipate the disappearance of forests in the planes to the benefit of shrubby and xenobiotic savanna-type vegetation (Penuelas *et al*., 2017). In the Amazon, the figures are 10% deforestation and 38% strong degraded forest, indicating that deforestation remains at high levels (estimates for the period 2000–2022; RAISG, 2023; see also Richie, 2024).

More provocatively, consider a world without trees: Richard Powers' eco-fiction, *The Overstory*, goes about the poetry of trees and their relationship with reality or illusion; or imagine societies deprived one of a sudden of the products of coffee or tea plantations. They have been around for just a couple of centuries. To put it differently, the large scale expansion of crops, such as cereals, sugarcane, or rubber trees in the 1900 and oil-palm plantations today, creates a reciprocal (a)symmetric dependency: the crop to yield for us, us to care for the crop.

In essence, the current chemical potential energy stored in biomass underwent a reduction by half since the Palaeolithic, and by 11% since 1990, essentially through deforestation. We must accept the fact that most human civilizations have been and still are forest predators. In addition, conventional agriculture tends to lower the potential biomass by one order of magnitude compared to the reference ecosystem (Smil, 2011). More precisely, at agro-ecosystem level, agriculture productivity is comparable to savanna ecosystems, that is 3 to 4-fold less than tropical rain forest or swamp and marsh ecosystems (Barbault and Weber, 2010). Human appropriation of biomass is therefore changing critical zone equilibria (Haberl *et al*., 2007; Ellis, 2011; Barnosky *et al*., 2012). Concerning global warming and biomass, a warmer world is unlikely to become a greener world (Chase, 2015).

In summary, biomass is a marker of societal state and challenges. The increased demands for food, fuel, and fibre in an expanding human population and urbanization process are putting land under increasing pressure to meet those demands. Because biomass is a limited resource, planing the most valuable uses of biomass becomes a strategic political and economic task (Leslie-Bole *et al*., 2025). Human appropriation of biomass has been proposed as additional planetary boundary (Running, 2012), considering increased demand caused by economic and population growth. The consequence is an increasing demand for land. The boundary is being transgressed by high income countries, while low-/mid-income countries are following the trend (Wang *et al*., 2024).

2.2.2. The land-soil resource – no healthy soils, poor quality or quantity biomass

Soils and their multifunctional interactions are a remarkable by-product of life evolution. They are the most complex and fragile ecosystems we know of, operating at the intersect of Central Zone processes and Planetary Boundary pressures (Negrutiu *et al*., 2020).

Soil fertility is one of the most neglected issues in contemporary agriculture, coupled with societal ignorance on why and how organic matter content and water balance are critical for long term soil fertility and conservation. The main reason stems from the illusion of how mechanics (and machines) and chemistry (fertilizers and much more) have been able to transform and control biological processes in soils through industrial agriculture, and supporting raising yields during several decades (Brown, 2012; Birre, 1976). The preservation of organic matter in the soil is the "secret" of cultivation methods adopted, for example, in Asia for millennia (true crop rotation with legumes and mixed farming (i.e., crops and livestock) (Gladwell, 2008).

The critical organic matter in soils is hummus. The Latin word *humus* (*i.e.*, earth, soil) and the word *homo* (man) come from the Indo-European root *dh(e)ghyōm-*, meaning earth.

Humus from forests, grasslands, or cultivated soils is a biologically active and dynamic material produced by the combined aerobic and anaerobic decomposition of animals, fungi, and bacteria. It results from organic matter cycles involving humification (biochemical transformation and polymerization) and associated complex mineralizations (https://fr.wikipedia.org/wiki/Humus).

The presence of metal cations (iron, calcium) and clays insolubilizes humic and fulvic acids and prevents their migration. Humus types vary with soils, climates and vegetation, while organic matter is found in soils at all stages of their transformation, some still young, others almost completely or completely transformed. Obviously, hummus is absent from deserts. For example, forest soil stores three times more carbon than the trees above ground (Luhtaniemi, 2023).

Humus is actually part of what makes the soil bio-physico-chemical "magic" with fascinating uniques properties: soils are permeable environments that undergo absorption-desorption, adsorption, transfer/migration processes at different interfaces (e.g., liquid, solid-liquid, liquid-gas). There, clay-humic assemblages take place, comprising a large-scale physico-chemistry with remarkable balances and reversibility (https://www.fao.org/soils-portal/data-hub/soil-classification/numerical-systems/chemical-properties/en/).

The world's soils are classified into categories based on fertility and other biophysical qualities. (https://en.wikipedia.org/wiki/World_Reference_Base_for_Soil_Resources). Chernozem, a class 1 soil with high fertility qualities, covers about 230 million hectares of land (*i.e*., less than 5% of agricultural land). There are two "chernozem belts" in the world. One is the Eurasian Steppe that extends from eastern Croatia, along the Danube (northern Serbia, northern Bulgaria (Danubian Plain), southern and eastern Romania (Wallachian and Moldavian Plains), and Moldova, to north east Ukraine across the Central Black Earth Region of Central and Southern Russia into Siberia. The other stretches from the Canadian Prairies in Manitoba through the Great Plains of the United States as far south as Kansas (https://en.wikipedia.org/wiki/Chernozem).

Soil preservation is a daunting task requiring knowledge, permanent monitoring, and long-term commitment. Desertification is by far the threat to be kept in constant check as promoted by the work of the United Nations Convention to Combat Desertification (UNCDD, 2022). The program was a direct initiative of the Agenda 21 Conference, adopted in Paris in 1994 and entered into force in 1996. It represents the only coherent attempt to think soil issues systemically and systematically.

2.2.3. The water resource – no water, no soil, no biomass

Water is an astonishingly simple molecule with three distinct physical states, namely liquid, solid, and gaseous. It is the major component of biomass. You and me are 65 percent water (https://en.wikipedia.org/wiki/Body_water), the inner fluid that possibly makes biomass the forth state of water: bio-water.

Water related issues are known in the society at large (Steffen *et al*., 2015; Negrutiu *et al*., 2020), so we will not expend on the subject. Of note, the *European water charter* is promoting water conservation on the continent (Council of Europe, 1966; https: //rm. coe. int), and the EU Water Directive 2000/60/EC defines a framework for water policy (https://eur-lex.europa.eu/eli/dir/2000/60/oj/eng). They highlight the strategic importance of water and current challenges.

We summarize the World Resources Institute's data outlined in its water risk atlas (WRI, 2023). The document warns on future water stress worsening without urgent drastic water policies and responsible stewardship through investments and management:

– Increased water demand by regularly using up almost the entire available water supply on a planet with a fast growing population. Main users are irrigated agriculture (sugarcane, wheat, rice, and maize in particular), livestock, energy production, and manufacturing;

– At least 50% of the world population (*i.e*., approx. 4 billion people) live under highly water-stressed conditions for at least one month of the year, and one quarter of the global population faces extremely high water stress each year;

– The most water-stressed regions are the Middle East, North Africa, and South Asia. This corresponds to a continuous band of land stretching from Morocco to Bangladesh, with neighbouring deserts or arid lands. The regions are exposed to extremely high water stress, averaging 80% of their population;

– 42 countries are exposed to extremely high water stress annually (*i.e*., they use over 80% of the available water supply). Bahrain, Cyprus, Kuwait, Lebanon, Oman, and Qatar are the top 6, due to low natural supply;

– Water use and dependencies extend to water embedded in international trade from lower-middle income countries to high income countries;

– The situation is poised to worsen, in particular in Sub-Saharan Africa between now and 2050. Overall, the water resource crisis will impact the global GDP as much as 30% by 2050, in particular in countries such as India, Mexico, Egypt, and Turkey. China and USA are equally concerned.

In brief, water, more than ever, is becoming a factor of political instability and food insecurity. For example, rice – one of the most consumed agricultural commodities, plays a vital role in the global food system. Its cultivation is highly vulnerable to water shortages, requiring qualified freshwater resource management (Zhang, 2018).

2.2.4. The Soil–Water–Biomass nexus: the physical framework of Carrying Capacity

Soil, water, and biomass – the three primary, non-substitutable resources – remain fundamental life-support systems across all societal contexts and political scales. Accelerating erosion of these resources undermines equitable access, integrated management, and sustainable use, raising profound demographic and ecological concerns within planetary boundaries.

The societal and political sensitivity of soils is exemplified by unbridled land-grabbing practices, i.e., problematic land acquisitions that displace communities and undermine livelihoods (Land Matrix database: http://www.landportal.info/landmatrix). While Europe has long-standing directives for air and water protection, soils remain largely unregulated (https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_3637).

Beyond classical Malthusian perspectives and Paul Ehrlich's 1968 "population bomb" (Mann, 2018), these resources arguably provide the most concrete measure of ***physical carrying capacity*** (*i.e*., the number of people, animals, crops, etc. a region can support without environmental degradation; Negrutiu, 2024). Social-ecological systems under stress are directly related to pressures on carrying capacity (Daily & Ehrlich, 1992; Mote *et al*., 2020). Resource efficiency and justice are expected to act faster than demographic growth and policy mechanisms (Bradshaw & Brooks, 2014) to reduce systemic social-ecological dis-equilibria.

With the global population exceeding eight billion in 2022, and more than half of planetary ecosystems heavily anthropized (Barnosky *et al*., 2012; Ellis, 2019), resource scarcity and planetary health are increasingly strained, though in context-specific ways. This resource rush, combined with stressors such as climate change, over-consumption, political instability, conflicts, and the failure of multilateral governance, stretches carrying capacity to its limits. The erosion of biodiversity is a case in point (***Panel 4***). In effect, at current population levels, societies are confronting both political and temporal boundaries: global institutions and sovereign states often struggle to coordinate objectives, resources, social cohesion, and fundamental rights (Hulme, 2020; see Section 2.5).

In conclusion, thinking the soil-water-biomass nexus within food systems and beyond is essential in reconciling ecosystem functions, productivity, and regeneration-restoration capacities. This means achieving high agro-biodiversity, nutritional diversity, yield quality, soil fertility and carbon storage, water cycling, and plant health. The necessary means imply high labour, intensive knowledge, availability of tools and machinery, and enabling policies (Jacobi *et al*., 2025). Interlinking the state of soil-water-biomass systems and the associated societal objectives can reveal feedback loops behind and between macro- / micro-economic decisions, public health, climate change, to name just a few. These critical resources are structuring factors for land tenure, markets, and policy in the first place. Unavoidably, the intricate processes and interdependencies that tie the three primary resources of agriculture should make the matrix of all future policies, from farm to fork to dedicated artificial intelligence and back.

2.3. Agriculture and the Territory – Scaling Carrying Capacity

2.3.1. Food systems – culture, urbanization, landscapes

Hunters-gatherers marked their territory with resource appropriation strategies, food chain interactions, and related conflict practices. Sedentarization and land use change through agriculture is being considered the biggest human geo-engineering activity ever (Verburg *et al*., 2015). The very "wander" in human history? Nowadays practised on approx. 40% of the land surface, the impact of food systems on ecosystem infrastructures and productivity is considerable (Smil, 2012). The direct consequences of land use change are the erosion of biodiversity (***Panel 4***), and soil and water resources degradation.

Agriculture and cities. Until the advent of the railway, cities were generally established in the heart of a resource (generous) territory and contained within their natural boundaries. Food supply issues shaped the cities, their squares, their streets, and their ports. Markets further influenced the political organization of urban-rural territories (Steel, 2008). I quote: "Feeding cities requires gargantuan efforts, which arguably have more physical and social impacts on our lives and our planet than any other of our activities." Until the late fifties and the beginning of food globalization, peri-urban agriculture was widespread in many regions of the world. In the era of highway projects, high-speed trains, and the attractiveness of metropolitan areas, rural areas have been relegated to the status of territories to be crossed. The inhabitants of rural and peri-urban areas were marked by an industrial past and/or conventional agriculture.

The explosion of urbanization and urban encroachment have reframed the food systems in general. Real estate dynamics of urban and peri-urban land in particular has amplified the transformation and disjoined urban and rural trajectories. Larger cities have become ecological and real estate "black holes". There is a large disconnect between the financial value of land (*e.g*., tenure systems) and the value of land according to multifunctional capabilities of land, including agriculture (Blanc, 2018). This is because land provides food, income, and many other amenities that are critical for both vulnerable individuals, communities, and countries in terms of food, health, and energy security. Frequently, the most vulnerable human populations live on degraded, degrading, and less favored agricultural lands.

These considerations raise several questions. How is the economic and social division of space currently evolving? Who are the landowners today? How are essential social, economic, and environmental issues being played out in emerging "rurbanities"? What role does financial capital play? How do the ecological crisis and the land issue intersect? (Lipietz, 2013). The landscape approach to territorial land management in general and agriculture in particular is thought to help address such questions.

The Landscape thinking and land planning. After decades of plot or farm scale thinking and performing agriculture, times have evolved to the benefit of a broader frame, the landscape. The landscape highlights a socio-ecological reality with a convenient spatial coverage of essential resource systems (Vanbergen *et al*., 2020). It engages processes and relations between different ecosystems, biotops, and land uses at different scales (Botequilha Leitao and Ahern, 2002; ***Panel 5***).

The world landscapes are the building blocks of the critical zone that interwind in networks of positive and negative feedback loops. Their structure is directly and indirectly affected by food system patterns, namely agricultural practices, socio-cultural, economic, technological, and demographic factors (Scherr *et al*., 2013; Dade *et al*., 2025).

An appreciation of landscape change is important to analyzing, predicting, and coping with environmental change (Phillips, 2021). It is also important in channelling efforts to manage the environment for conservation, preservation, economic exploitation, supporting human populations, or ecosystem services. Practically, landscape assessment to customer needs tailors landscape actionable size at at least 100 sq.km (Landscale, 2025).

Agricultural landscape scale approaches can ensure a coherent use of ecological infrastructure and ecosystem services, *i.e*., a multiple nested spatial scale agriculture and human activities at large. They can inform with relative accuracy on complex ecological states, on nature contribution to people and nature-based solutions, including the social dimensions and economic scales of food systems trends and dynamics (Mijer et al, 2020). For example, we have developed a socio-ecological unit metrics enabling to assess the state and dynamics of the natural capital at watershed scale (Arguello *et al*., 2023; Landscale, 2025).

In summary, the landscape scale allows rediscovering agriculture's multifunctional role. Landscape management facilitates maintaining diverse habitats within and around agricultural areas. In a landscape perspective, the soil fertility – land value and real estate conflict can be addressed with different instruments and trade-offs to surpass a tensed situation subtended by vested interests. It ultimately facilitates multifunctional planning with cross-sectoral and participatory management.

2.3.2. Agriculture, Biomass and Energy issues

The biosphere equilibria known for the last 11,000 years within the Holocene age are evolving at a pace whose rapidity makes some of the discussed threats increasingly apparent (Rockström *et al*., 2023). While modernity has based its historical legitimacy on the project of emancipating humans from their original vulnerability through the benefits of technological progress and unlimited growth, its paradox comes from the fact that this mode of development leads to an even greater vulnerability because it is no longer local but global.

Two examples, energy transition and biofuels and climate illustrate the paradox.

2.3.2.1. Metabolic and thermic energy transitions

The different types of energy – fossil, renewable, etc. – with their respective regimes of extraction, circulation, and waste, exert very concrete constraints on our lifestyles (Szeman, 2017).

Take the bias in the energy transition thinking: that transition is focusing exclusively on housing and transportation, which are thermic energy issues. It ignores the fact that humans are equally concerned by access to food, a metabolic energy component of that same transition considered holistically. The two dimensions are obviously interconnected: meeting the level of renewable energy production needed to replace fossil fuels involves significant trade-offs, including land allocation for biomass necessary for food versus biofuels, or the construction of large river dams for hydroelectric power and irrigation (Brand *et al*., 2021).

Energy transitions have a double dimension:

(1) Thermic energy refers to transportation, urban metabolism, building heating. The matter is on main political and economic agendas since decades and is beyond the scope of this paper.

(2) Metabolic energy refers to the life-long need of people to nourish themselves ((*you are what you eat*, the saying goes). The transition refers to the necessity to access qualitative and quantitative food through healthy diets, a societal horizon yet to attain for a large fraction of humanity (Negrutiu, 2025b). The links between agriculture, food and health (*food is medicine*) reflect the ability of every human being to provide substantial work. Food, work, and health are also the materialization of fundamental human rights.

Food has long lasting effects on economic issues. The biggest improvements in economic productivity tie back to improvements in health (*health is wealth*). When considering how much time individuals spend in the workplace (globally, 45 years of life), it only stands to reason that having a healthy workforce is essential to driving strong economic output and boost productivity (McKinsey, 2025).

These interdependencies are better understood at present. For example, “The campaign to change the nutritional condition for Americans”, promoted by the Food is Medicine Institute and Food Tank at Tufts University, the FDA, the Rockefeller foundation and others, has received the support of US congress members. The campaign advocates nutrition and food as therapy with fast return on improving health (*i.e*., life style, eating patterns, exercise, eventually medication) and managing healthcare spendings) (Tufts, 2025).

2.3.2.2 Agriculture, fossil fuels, and climate change

The dominant food system is hooked on fossil fuels, from fossil-based agrochemicals to plastic food packaging to ultra-processed diets. Food and farming now account for 15% of global fossil fuel use and 40% of petrochemicals, particularly fertilizers and plastics, fuelling climate change and pollution, destabilising food prices, and deepening hunger (IPES Food, 2023).

The widely promoted tech 'fixes'—from 'blue' ammonia to digital agriculture—risk locking in fossil dependence, tightening corporate control, and harming people and the planet. Delinking food from fossil fuels is a challenge because it requires investing in agroecology and making shorter supply chains.

The impacts of climate change, namely increasing temperatures, droughts, and extreme weather events are reducing food system productivity. These changes have already led to a rise in pesticide use, a headlong rush to cope with yield fluctuations. They are likely to worsen this dependency in the future (Bareille *et al*., 2024). One critical question is At what temperatures ecosystem productivity is going to peak? The best possible scientific assessment would allow projecting more accurately the levels of global carbon uptake (Wang *et al*., 2025).

More broadly, climate change affects food systems on several dimensions, such as agricultural practices tied to specific crops and ecosystems, and thus the landscapes, traditional diets, ceremonies, etc, therefore undermining cultural traditions and eroding rural and community heritage (Chase, 2015; Tarolli *et al*., 2025).

Biofuels, a potential game-changer, now at a third/fourth generation stage, is facing reality: limited biomass availability (*i.e*., feedstocks derived from agriculture and forestry residues and non-food energy crops), land-use constraints and land misuse, biosafety concerns, energy density and quality, demand from competing sectors such as plastics and construction (Kalt *et al*., 2020; One Earth, 2025). Thus, crafting high-quality, energy-dense biofuels for a low-carbon future, particularly with respect to decarbonizing transportation systems, remains a formidable challenge. This is due to competition for land, the chemical complexity of biomass, and the absence of advanced catalytic processes (Leslie-Bole *et al*., 2025). These are clearly energy issues relevant to both understanding of energy demands and economic growth trends, and the ambivalence of nature-based solutions. This perception contrasts with big industry scenarios on energy and decarbonization security (WEF, 2025) targeting a new wave of economic growth driven by productivity improvements and catalysed by artificial intelligence. Such scenarios investigate what the world would need to do to achieve net-zero emissions by 2050 and limit global warming to 1.5°C.

In summary, the combined understanding of territorial carrying capacity and food system issues would enable considering what is ultimately at stake: building a social-ecological horizon that integrates systemic risks with ecosystem resilience, and long-term societal planning (***Panel 6***). Narratives such as “food is medicine” and “wealth requires health” provide essential social and economic framing. Those imperatives require quantitative and qualitative assessments: what and how to measure in the first place?

2.4. Food Systems, Big Data and Platform Resources

This section attempts to assess ways in which a trust economy can come to light in recognizing the role of farmers, protecting consumers in co-constructed policies in order to strengthen social and societal dialogue and cohesion. To that end, (near)-real time approaches to assess the health of the environment, economy, and finance are becoming widespread and accessible to various players and communities.

2.4.1. Traceability as game changer – the trust economy

Assessing the adequacy and examining the trade-offs between the sustainable supply (ecological stocks, regeneration rates of resources) and the societal demand (needs) across geographical and administrative scales implies resolving normative conflicts and institutional fragmentation toward policy coherence that sets the balance right between stewardship and ownership of defined resources (Wynberg *et al*., 2021). This is about the economy of trust that requires reconsidering the entire supply chain and demands that standards and practices be put in place by all players ensuring social equity through benefit sharing, and thus viable economies and fair politics (Coleman *et al*., 2021).

The food system as economy of trust draws on the variety of signatures in food systems to design the sequence of identification, authentication, tracing, and tracking along the entire process of production to ensure the traceability, compatibility, and auditability. The challenge is to protect resources, brands, and margins for farmers all the way to the consumer. The model is an avatar introducing the tools and data that enable to monitor the commitments made by each party and make the players more accountable. The notions of authentication and traceability become key to guarantee, for example, the quality and conformity of products (Negrutiu *et al*., 2023). They are multifaceted: biological identity (DNA signature) and proof of origin (a signature of the location and growing conditions, such as the nature and quantity of inputs), and the integrity of data and processes throughout the production and the downstream chain. The digital process links these processes and results in a system that protects the producer and the consumer and makes the system auditable from end to end. Blockchain technologies, complemented by artificial intelligence tools, make it possible to follow the "data pipe" that underlies all transactions, from the primary product to the product reaching the consumer.

Issues of the kind in food production should not be the exclusive realm of large firms, lobbyists, unions, technicians, and engineers. They are also social and political matters that deserve more than ever to be treated as part of a democratic process. Within the democratised food system each citizen would be a consequential actor who can judge, taste, evaluate and choose, with the result that public opinion would no longer be something consulted at the end of the production chain. And this holds true for the producers, at the entry point of that chain.

2.4.2. Digital platforms

The major contribution of digital technology is the orchestration of multi-sided markets by global platforms that have access to information resources at all levels of granularity. The platforms consume data and help determining flows of tangible resources in near-real time (*e.g*., Sorano *et al*., 2015; Land Carbon Lab, 2025). For example, digital tools make it possible to integrate ecological metrics and socioeconomic information giving wider access to multiple stakeholders and communities (Evans and Schmalensee, 2016, Parker *et al*., 2016).

The digitalization of food systems is reshaping how farmers manage operations, optimize yields, and engage with markets, how food is produced, distributed, and governed. Large-scale platforms such as Climate FieldView and John Deere Operations Center offer integrated solutions for precision farming, using IoT sensors, satellite imagery, and analytics to monitor crop health, soil conditions, and machinery performance in real time. These platforms aim at empowering farmers with data-driven insights, reducing input costs and improving productivity (Monney, 2022; https:// www.g2.com/products/climate-fieldview/reviews; https:// operationscenter.deere.com/).

Beyond the global players, smaller and localized advanced digital platforms are emerging to support circular economy principles in agriculture. These tools facilitate the redistribution of surplus produce, the sharing of farm equipment, and the recycling of organic waste into compost or biofertilizer. In many regions, startups and cooperatives are building mobile apps and online marketplaces that connect farmers directly with local consumers, processors, or urban gardens—reducing food waste and transport emissions (Tajammul *et al*., 2025).

This digital shift enhances access to knowledge to foster sustainability across the agricultural value chain. As in other areas, it results in a concentration of power in the hands of large economic players at an increasingly global planetary scale. As connectivity improves in rural areas, even small holder farmers are likely to benefit from precision tools and peer-to-peer platforms, levelling the playing field. Digital agriculture is no longer just about efficiency. Its ambivalent nature is surfacing the double-edge question – does it make food systems more resilient and environmentally responsible, or is it further enslaving farmers to ag-biotech strategies? For example, healthy nutritious foods require transformations that restore the health of soils and rivers (i.e., regenerative agriculture) in the first place. Sundiang *et al*., (2025) have modelled coordinated sector-integrated measures on agricultural productivity, food loss and waste reduction, healthy diets, and climate mitigation to show how the bundling of such measures helps decision-making in prioritization of resource allocation and risk reduction.

Assessing the state and dynamics of ecosystems has made great progress in the last decade, to the extent of making the data open and actionable for all stakeholders. For example, Global Nature Watch, Land & Carbon Lab, and Global Forest Watch (WRI, 2025; Land Carbon Lab, 2025) are developing extensive and coordinated programs of land monitoring science that covers grasslands, wetlands, croplands, pastures, forests and trees outside forests. Such tools enable monitoring structural change in various contexts and scales, strengthening carbon accounting, or guiding smarter land use, and many other applications for restoration monitoring at lower costs. Also, monitoring vegetation productivity worldwide at 30-meter resolution (Global Pasture Watch research consortium), allows measuring Gross Primary Productivity (GPP) to provide a detailed global view of the rate at which plants absorb carbon through photosynthesis. This is an early indication of how actively plants are growing and producing biomass.

On such platforms monitoring can be combined with the power of Artificial Intelligence (AI). AI for real time environmental monitoring combines satellite, drone, and ground data to track deforestation, map air-quality, and spot wildfires, to name just a few. In a simple chat-style AI interface delivers clear, actionable insights for practitioners, communities and decision-makers working to protect and restore nature, to enforce land rights for indigenous people, to help smallholder farmers improve pasture management, to assess the state of the world's most biodiverse areas, and channel finance on biodiversity issues.

For farmers that can afford it, the combination of AI and Earth Observation is impacting farm management, but also risk assessment. AI analyses vast datasets from satellite imagery to forecast yields, identify crop stress, and guide resource use more efficiently. Multi- and hyper-spectral imaging detects changes in plant and soil conditions. Combined with AI, this enables early interventions and more rational practices, such as optimised fertiliser use and better water management. Together, these technologies offer farmers near-instant insights and long-term planning tools that drive both profitability and sustainability (https://www.innovationnewsnetwork.com/how-earth-observation-is-cultivating-the-future-of-agriculture/57176/ AND https://www.fao.org/land-water/water/drought/en/).

In summary, the question is whether trust economy and digital shifts can join ends through local-to-global democratic processes. Well-designed AI-powered interfaces are expected helping building the transparency required to give decision-makers the understanding required to intervene effectively, and enabling clearer insight on where to direct priorities and resources. To allow that happen, the Earth for All platform (Dixson-Declève *et al*., 2022), a non-prescriptive framework, makes use of a total of 11 synthetic parameters (>100 variables and 80 fixed parameters, including feedback effects) to assess the state of territorial entities and their resources. This is the instrument of choice enabling to systematically and comparatively assess the world at various scales.

2.5. Food Systems and the Political and Institutional Resources

*Eating is certainly the first vital act, but, because of this iniquity, it is a social, political, legal, moral and, without doubt, also sacred act, since almost all religions make it a rite (*Michel Serres, 2016).

Food is an all-place all-time vital resource, that is the source of our daily subsistence and work capacity. Food is so much more than the calories we eat. It's about power systems and creating empowerment.

The UN Special Rapporteur on the Right to Food, Olivier de Schutter (2017), noted that "our food systems are making people sick", and they make one in ten people go to sleep hungry while driving harmful ecological impacts (Sundiang *et al*., 2025). Beyond health problems and hyper consumption, which is a source of obesity and diabetes, agri-food malaise has several other attributes and dimensions: moral (distrust of industry and loss of dietary diversity); social (proletarianization of farming); environmental (erosion of biodiversity, alteration of habitats and ecosystems); political (disengagement of public authorities); economic (omnipotence of oligopolies and the free trade system).

2.5.1. Resource scarcity and soil-water-biomass

Resource scarcity, soil and water in particular, drives complex geopolitical and economic strategies. Sovereign powers (*e.g*., China, Russia, Gulf monarchies), multinational corporations, private finance, and even mercenary actors deploy mechanisms to secure control over limited food and water supplies (Halverson and Cowperthwaite, 2022). The war in Ukraine is a stark illustration: it has been partly motivated by denial of water access to Crimea following the 2014 Russian invasion. Since the 1970s, global raw material trade –

including oil, minerals, and food – has concentrated in a handful of giants such as Cargill, Glencore, Trafigura, and Vitol (Blas & Farchy, 2025). Controlling these resources grants decisive influence over global macroeconomic functioning, sometimes extending into legally ambiguous or illicit activities (*e.g.*, tax evasion, corruption, violation of embargoes, etc).

Two examples to illustrate the institutional and political strategies on biomass.

Despite historical evidence of biomass having been the engine of (geo)political power games since colonial times (Smil, 2012; Daviron, 2018), a political wake-up for biomass is relatively recent and reaching rush time.

In Europe, the Copenhagen Declaration (2012) details the European Union bio-economy strategy, with seven out of the ten recommendations targeting biomass and plant resources, while the roadmap 'Resource-efficient Europe' is biomass centred (BioStep, 2016; COM, 2011).

A US strategy for biomass has been assessed relative to ambitious decarbonization objectives and managing increased demand for bio-fuels and renewables from crop-based biomass (Leslie-Bole et al, 2025). The strategy is requiring holistic land use policies to rationalize biomass use. Modeling studies to 2050 indicate that biomass provides the highest decarbonization value when used as alternative/substitute to fossil materials. These include biomass from agriculture and forest waste and residues, together with herbaceous energy crops as feed stocks for a diverse range of refined products of high added value. Non-food crops can also provide carbon capture and carbon removal through products that store carbon over longer time horizons (such as asphalts and plastics).

2.5.2. Scarcity **generating** *institutions – assessment and reframing*

Massive political efforts are needed to tackle the causes of hunger and food misallocation: conflict, poverty, inequality, food traded for profit or wasted. So long as inequality goes unchecked, no amount of technology can ensure people are well fed. The solution is not charity, it is social and economic justice.

Among the international institutions designed to avoid geopolitical conflicts after the second World War (in particular for food, finance, and labour; Collard Dutilleul, 2018), FAO has been conceived to provide food security and know how worldwide (FAO, 2022a and b). The FAO member states have decided to retain that "food security exists when all human beings, at all times, have physical and economic access to sufficient, safe and nutritious food allowing them to meet their energy needs and their food preferences for a healthy and active life" (http://www.fao.org/docrep/003/w3613f/w3613f00.htm). FAO's political weight was and remains relatively weak compared to the World Bank, the Monetary Fund, or the World Trade Organization.

At the other end of the institutional spectrum, there is the financial system. Global uncertainties, such as geopolitical tensions, climate disruption, uncertain regulations, speculation on resources, etc, are driven by the pursuit of short-term profits and are enforced by a financial system that channels capital (borrowing, lending, and investments) with disregards on social, environmental, and long-term economic consequences (Thompson *et al*., 2025; see also WRI, 2025). As a matter of fact, the entire framework threatens business success. The report argues that the costs of inaction outweigh the investments needed to meet global sustainability goals. For example, with current climate change trends, the global GDP is expected to shrink by 50% in coming decades. Redirecting capital stands to reason: a $4 trillion annual financing gap in sustainable financing is a drop in the ocean of the private sector, considering the estimated $210 trillion in assets the sector could mobilize in the short run. The challenges reported in this work are obviously at the heart of anticipatory sustainability finance.

Other examples are worth considering, in particular those having systemic approaches to resources and in which coherent and systematic data enable the accurate assessment of natural capital (land, water, biomass in particular): the New Zealand Resource Management Act (since 1991 and upgrades on resources management system reform) and the International Resource Panel (IRP) at UNEP (since 2007, helping countries to use natural resources without compromising present and future human needs) (RMA, 1991; UNEP, 2019).

Taken together, the above dynamics illustrate the ongoing resource-grabbing processes. Power over food systems entails control of land, water, and biomass; mastery over associated data and platforms; and the ability of vested interests to circumvent regulations. The process is taking place under our eyes. To change trends, global institutions in particular need reframing their missions, culture and practices toward defending the general interest and the commons (Negrutiu *et al*., 2023).

2.5.3. Food sovereignty and security

The international system of production, distribution, and consumption of food is managed by states, corporations, and, to a lesser extent, by international organizations. Nowadays, FAO has become part of the quadripartite alliance, One Health, associating World Health Organization, World of Animal Health Association (WOAH), and UN Environmental Program (UNEP) in an effort to promote systemic thinking and doing at global to local levels (Negrutiu, 2025a).

Below we develop three aspects concerning food sovereignty and food security in terms of resource availability and accessibility.

Based on the fact that controlled agricultural policies and production are the basis of ***food sovereignty***, not every country can afford food security strategies made in China, US, or EU (see also below). For example, the Law 2025-337 in France (https://www.legifrance.gouv.fr/dossierlegislatif/JORFDOLE000051344375/) defined agriculture as an activity of major general interest. It is on this basic argument that were then posed:

– food security, involving the availability, access, use and stability of food goods;

– the need to ensure the vital needs and fundamental rights of people;

– the management of pedo-climatic hazards, but also and more broadly of a "heritage" (between nature and culture, rural landscapes);

– the control of land, despite the outlined problems and rigidity, makes this issue almost insoluble.

While food (and protein) autonomy through local production, meant to limit dependence on imports and to secure supply, is gaining traction, it can also justify intensive and polluting production models, as well as (contested) protectionism.

It must be kept in mind that ***food security*** is having very high standards. This presupposes a permanent availability of food in sufficient quantity, means of subsistence for each person so as to have permanent access to this food, the guarantee of food of nutritional and health quality adapted to each individual according to their needs, with respect for cultural, taste and religious preferences.

The annual State of Food Security and Nutrition in the World (SOFI) report rings the alarm bell (SOFI, 2025). According to the report, while some regions have seen modest gains in Southeast Asia and South America from 2019 to 2024, still 1 in 3 people around the world could not afford nourishing food (and more prevalent in women). The number of people unable to afford a healthy diet fell from 2.76 billion to 2.60 billion (*i.e*., 8.2% of the global population). However, by 2030, an estimated 60% of all chronically undernourished people worldwide will be in Africa, where the poorest and more vulnerable are living.

In Brazil, since 2022 the number of people experiencing moderate or severe food insecurity fell from 70.3 million to 28.5 million. Thus, solving hunger is a political question having much to do with addressing both inequality and food affordability (rather than just food availability and charity). Several solutions were set in motion: school meals sourced from local and agroecological producers, higher minimum wages, support for smallholder and Indigenous farmers, expanded food banks, and legal recognition of the right to food.

At global level, the impacts of food security policies on the food system can be illustrated by China's "going out" agricultural strategy (Zhang, 2018). Confronted with the limits of food self sufficiency (*e.g*., limited arable land), and dependence on feed and food imports, China is securing long term access to stable food and biomass supply (Gills *et al*., 2022). China top imports are oilseeds, oleaginous fruits, maize, fish, meat, animal feed, etc. To do so, China became engaged in large scale agricultural trade, a strong support to agricultural input sectors, and domestic and abroad investments (coined the Chinese Global Agribusiness project). The State controls assets in grain, meat, and biotech supply. In parallel, significant investments are being operated in agricultural programs in Latin America, Africa, Central and SE Asia mainly through the Belt and Road initiative (Negrutiu *et al*., 2023).

In brief, China's extractive strategy is a global quest for key resources, mainly energy, food, and water. Such trends are enforced by similar and competing activities and interests of other major players in the field. Taken together, one can anticipate that the resources needs and rush of today are feeding the current and future resource conflicts.

To summarize, since "we are what we eat" and "food is medicine", it would be more democratic if the vote of every eater determined food system policies, which policies would then become public health policies (***Panel 7***). As far as global food security is concerned, the long term social-ecosystemic thinking, embodied here in the One Health approach (Negrutiu, 2014), is expected to be integrated in all policy frameworks of international bodies and agendas.

3. PERSPECTIVES – SHARED WEALTH REQUIRES SYSTEMIC HEALTH

Reflection on food system has reached a level that allows for the implementation ofcoherent policies and practices at local and regional scales (Negrutiu, 2025b). Yet this potential remains largely unrealized because stakeholders – corporations, governments, and international bodies – often pursue conflicting interests, and political will is insufficient (Clapp *et al*., 2021).

This is problematic because there is no society, and no human agency, outside nature. There is no complex society beyond food systems and agriculture, in the plural. Food – whether in excess or scarcity – is a daily struggle and social act, performed under the shadow of geopolitical power games. Modernity itself depends on energy and food systems, previously taken for granted (Szerman, 2017). More specifically, food systems, and the broader framework of resources outlined in this work, raise fundamental questions:

1. Are food systems, and agriculture *stricto sensu*, economic activities like any other?
2. Is food a commodity like any other?
3. Is a world without peasants and smallholders possible or acceptable?
4. Who owns – or should own – nature?

Agriculture – a human economic activity like any other?

After World War II, the General Agreement on Tariffs and Trade (GATT) acknowledged an exceptional legal regime for certain cultural products, such as cinema and national treasures. A similar exception was envisaged for natural resources, including agriculture, forestry, and fishing, under the Havana Charter (1948). However, the Charter was never ratified (Collart Dutilleul, 2018). In contrast, UNESCO's 2005 Convention on the Protection and Promotion of the Diversity of Cultural Expressions established a lasting "cultural exception". A comparable "agricultural exception" has yet to emerge (Collart Dutilleul *et al*., 2023).

Two pathways could support such an exception:

1. The right of peoples to feed themselves – advocated by Via Campesina, the international coalition of peasant movements founded in 1993, opposing industrial agriculture.
2. Subsidized agriculture promoting sustainable development – subsidies would support farmers without funding negative social or ecological externalities, *e.g*., making subsidies conditional by, for example, encouraging sustainable practices and the inclusion of young farmers.

Instead, under the pretext of reducing costs and feeding the world, of uniformizing and moralizing the conditions of competition, export subsidies and protective measures for domestic markets were banned. In rich countries, these were replaced by disguised aid mechanisms, allowing farmers to offload surpluses cheaply to poorer nations. Countries of the Global South, unable to reciprocate, were forced to open their borders, leaving peasant agriculture threatened by globalization. In the North, farmers' living conditions have deteriorated (Berthelot, 2016). International trade, investment, and aid, while intended to improve access and efficiency, often concentrate resources, production, and wealth, while exacerbating social-ecological inequities (Gupta and Lebel, 2020).

To reverse these trends, food systems should be treated as matter of public interest and a front line framework for systemic health challenges affecting citizens, societies, and ecosystems (De Schutter, 2017; Negrutiu *et al*., 2020; Collart Dutilleul, 2021; Waage *et al*., 2022; Blesh *et al*., 2023; Clapp *et al*., 2025).

Food – a commodity like any other?

Eating is an inherently human, vital, and social act, affecting mind, body, and spirit. Yet increasing numbers of people lack access to nutritious, culturally appropriate food that respects the global diversity of gastronomy and farming systems (Vivero Pol, 2013; Manifesto IMS, 2017; Coleman *et al*., 2024; Stiglitz and White, 2025).

Consumers' motivations extend beyond price: they are moral (mistrust of industrial practices and loss of diversity), social (farmers' indebtedness and declining quality of life), environmental (loss of bio-cultural and genetic diversity), political (weakening of public oversight), and economic (dominance of multinational corporations) (Collart Dutilleul *et al*., 2023; Lord *et al*., 2025).

Free trade advocates argue that low-cost food promotes democracy, but in practice, it reduces food's perceived value and opens it to speculation. Rethinking food pricing at scale would require supporting local food networks, investing in rural areas, and respecting geographic and cultural diversity in agriculture.

Agriculture without peasants and smallholder farmers?

Peasants and smallholders produce roughly one-third of the world's food (Negrutiu, 2025a and references therein). While industrial agriculture could theoretically replace peasant farming, the environmental, social, and economic costs would be immense. Smallholders maintain agroecological practices, seed diversity, traditional knowledge, and local food systems. Last but not least, rural populations depend on small-scale agriculture. In contrast, industrial agriculture prioritizes profit and efficiency, too often degrading soil, water, and biodiversity.

A world without smallholders may be technically possible in extreme techno-industrial scenarios (Dorin *et al*., 2013), but it would be neither sustainable nor just. Displacement would erode local food sovereignty, weaken communities, and threaten food sovereignty. The ethical question is clear: people and planet must be valued over profit (Negrutiu, 2025a).

Smallholder agriculture is deeply entangled with the biosphere and creates value through non-destructive activities, including nature-based solutions and landscape stewardship (Parrique, 2022; Chaplin-Kramer *et al*., 2019; Vanbergen et al., 2020). Scaling actionable nature-based solutions requires bridging science and diplomacy, as exemplified by the UN Declaration on the Rights of Peasants and Other People Working in Rural Areas (UNDROP, 2018), which recognizes rights to land, natural resources, and food sovereignty (Wynberg *et al*., 2021; Kemp *et al*., 2025).

Who owns nature?

If peasants and smallholders are displaced, land, water, and other natural resources would likely concentrate in the hands of corporations, investors, and state actors (ETC group, 2008). Such concentration exacerbates inequalities, accelerates land grabs and ecological degradation, and erodes local knowledge (Negrutiu, 2025a). For example, by 2050, up to 5 billion people may be at risk from diminishing ecosystem services, particularly in Africa and South Asia (Chaplin-Kramer *et al*., 2019). A scenario is created where nature is commodified.

The deeper question is whether nature should be owned at all. If food, water, and land are treated purely as private commodities (this work does not discuss intellectual property rights on the living), essential life-supporting systems risk becoming assets for profit, controlled by a few. This scenario would intensify overshoot of planetary and societal boundaries (Negrutiu, 2024). This is paradoxical, because at the age of big data and real time monitoring, resource stewardship in near-real time has finally become achievable. Instead, more than ever, power games struggle to simultaneously control physical, informational, and legal capacities. Even corporate with social ecological managerial rhetoric suffer a permanent tension between virtuous and profitability objectives, *i.e*., avoiding societal responsibility by externalizing risks and costs.

Addressing these challenges is extremely difficult, as it requires balancing inequalities through human rights principles, including distributive, corrective, and restorative justice (Brand *et al*., 2021; Gupta *et al*., 2023).

4. CONCLUSION – RECONSIDERING COLLECTIVE RIGHTS OVER PRIMARY RESOURCES

This work has explored the interconnections between nature, society, and people in food systems, highlighting agriculture as a foundational pillar of the shared and reciprocal health of nature and society. Agriculture and food systems are not only the basis of our biological life, but also our social and even imaginary life; yet they are marginalized in terms of financial weight (a few points of GDP) and power (decreasing weight in the political agenda). Therefore, transforming the global food system demands simultaneously reducing social and economic inertia, improving food production practices, reducing food loss and waste, and shifting diets (Clark *et al*., 2020; Vanbergen *et al*., 2020)

Central to all efforts remains the triad of soil, water, and biomass. Those foundations need to be carefully safeguarded. This is not an easy task because the four perspectives outlined above constitute a "chain reaction" in which "who owns nature" or "should nature be owned at all" depends on what the social framework will evolve into in various parts of the world (see also Hulme, 2020).

Redesigning food systems requires both addressing the tension and conflict between society and markets and large-scale social change focused on the conditions of smallholders and rural communities. It involves shifts in norms, values, power structures, and institutions—including the societal valuation of food, ecosystems, goods, and services. Agricultural models to be adopted, urbanization, peri-urban agriculture, and land-use planning must all be considered in reconstructing ecological infrastructures and deploying nature-based solutions (Vanbergen *et al*., 2020).

All these are expected to redesign lifestyles, dietary expectations and choices with positive consequences on balancing the economic scale of industrial-to-small scale agricultures.

Ultimately, food systems can drive a virtuous transformation: the economy must be seen as a subsystem of the biosphere, constrained by social and ecological limits, and measured in real social and ecological costs. Human rights, access to natural resources, and the health of rural communities must guide policy. In this light, agriculture should be treated as a Common Pool Resource (Ostrom, 2009), foundational to societal resilience, and therefore health.

That kind of adjustment is a law of life, because such needs are those that, to be guaranteed, require a significant withdrawal of and access to natural resources. In that perspective, the rule of the market, namely the adjustment between supply and demand, must be subordinated to the law of life (Collart Dutilleul *et al*., 2023; Negrutiu, 2024). These are good reasons to advocate a radical change in the way all of us reframe the place of agriculture in society and of the society in agriculture: from an adjustment variable in policy and economy, to a social-ecological way of life. Let us call it making society with nature.

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Panel 1. The Knowledge Resource – Photosynthesis and biomass. Sunlight is at the origin of a cosmic-born economy provided by photosynthetic organisms. It consists of transforming cheap and diffuse sun light energy into high added value products, mainly but not only, sugars, lipids, and proteins. Of those, cellulose, a sugar polymer, is the dominant molecule on Earth. All these compounds are encapsulated in biomass and as such make the daily food and feed of the planetary living.

Photosynthesis is an oxygen generating process. It is a miracle considering the silent violence of the toxic side effects of the electron chain reactions taking place. The cellular metabolism has succeeded achieving a relative protection at the expense of energy efficiency: the rate of photosynthesis is below 1% of incident solar light in real life (Negrutiu *et al*., 2020). The process mobilizes few ingredients, hence the miracle – green cells, atmospheric CO_2, soil minerals, and water. Worth understanding that photosynthesis is the equivalent, albeit at environmentally friendly conditions, of solar nuclear energy reactions (Bühlmann, 2019). Surprisingly, this is something we rarely fall in admiration, despite the fact that humans can economically mimic atomic energy power, but not (yet) photosynthesis reactions.

The chloroplasts, specialized light harvesting structures in green cells, are likely one of the, if not the top, evolutionary innovation(s). Chloroplasts preferentially respond to the blue and red wavelength of the light spectrum via photosynthetic pigments such as chlorophylls, beta-carotene, fucoxanthin, or phycocyanin.

Taken together, three evolutionary considerations come to mind (Negrutiu *et al*., 2020):

– The phytoplankton, namely cyanobacteria and single-celled algae, is the ocean equivalent of tropical forests in the carbon and O_2 cycles. These are actually the very inventors of photosynthesis on Earth and the dominant biomass producers in the ocean.

– Those bacteria further contributed to an endosymbiotic process of major evolutionary significance, namely the intake (phagocytosis) of cyanobacterial ancestors into eukaryotic cells to provide them with chloroplast activity. That alliance was at the origin of multicellular algae and plants. The engulfed cyanobacteria structures have maintained certain genetic and functional characteristics of their origins.

– The structure of chlorophyll and haemoglobin are similar; they share a pyrrole ring. The first absorbs solar energy, the second transports oxygen in our bodies (and other vertebrates). Interestingly, experiments have shown a significant increase in important haematological parameters (including haemoglobin, red and white cells) in response to exogenous chlorophyll (injectable or dietary; Tagauov *et al*., 2023).

Panel 2. The Knowledge Resource – Genetics

All new scientific discoveries arise within the culture that produces them – and are always susceptible to misuse (Rutherford, 2022).

From both societal and scientific standpoints, domestication and associated agricultural practices have served as the inspirational arena and “laboratory” for genetic and evolutionary studies. The process was popularized through clubs and societies dedicated to animal improvement – of sheep, pigeons, dogs, and others – and culminated in the discoveries of Darwin and Mendel (Berry & Browne, 2022). Since then, genetics and evolutionary theory have profoundly shaped society – philosophically, politically, and economically. Of note, genetics and evolution enclose probabilistic processes, hence their contrasting perception through history and cultures.

Genetics: a distinct field of biology and key to understanding evolutionary processes

The history of genetics throughout the 20th century reveals a threefold societal reframing (very schematically):

1. ***Racial genetics***, first promoted under Nazism, influenced eugenic policies and practices in several countries during the 1950s and 1960s (Rutherford, 2022).

2. ***Social (class) genetics***, championed by Stalinism as a reaction to racial genetics, rejected classical genetics through *Lysenkoism* – a so-called "proletarian and revolutionary" biology advocating the emergence of the *homo sovieticus* (Kotek & Kotek, 1986).

3. ***Business/Market genetics***, flourishing today, promotes large-scale genetic manipulation, the commodification of life, transhumanism (the myth of genetically augmented humans), and the pharmacology of behavior (de Bosseoreille de Ribou *et al*., 2013; Harari, 2017; Negrutiu *et al*., 2020).

In the context of agriculture and food systems, genetics has been central to breeding strategies and, more recently, to modern biotechnology. While rejecting natural selection and classical genetics, *Lysenkoism* emphasized environmentally based crop manipulation (*e.g*., hybridization, grafting – known as *Michurinism*) (Kotek & Kotek, 1986). *Market genetics*, by contrast, is best exemplified by decades of controversy over genetically modified organisms – ranging from microbes to plants and animals (Negrutiu *et al*., 2020).

Panel 3. The Knowledge Resource – Evolution is about how species interactions operate in space and time

Darwin desperately needed Mendel. ... The modern theory based on the marriage between Mendel's and Darwin's ideas as forged most comprehensively by R. A. Fisher is both Darwin's achievement and Mendel's (Berry and Browne, 2022).

Biosphere emerged on a hostile abiotic geological ground. The various life forms that deployed from inception through the successive great extinctions have created nearly all the conditions necessary for the maintenance and diversification of life itself (Vernadsky, 1986; Meyr, 2001). The buffering effect of life on the planetary environment is the work of biomass and the ensuing ecological reserve (Negrutiu *et al*., 2020; and see Section 2.3.1).

Biological populations (who reproduces with whom? and species' life-cycle), food chains (who eats who?), and more generally ecosystems (who lives with whom?) are functionally systems of interactions. Evolution therefore needs to be understood as co-evolution. Co-evolution networks are at work from food chains to ecosystem and biosphere scales. Therefore, conservation actions (rewilding, restoring, etc) can affect or constrain evolutionary trajectories in terms of species composition, stability, and ultimately ecosystem functions (Sarrazin and Lecomte, 2016).

Agroecosystems are highly modified, simplified, impoverished, and more vulnerable ecosystems than their wild counterparts. Thus, the biomass potential of the former can be on average up to 10 times lower than the ecosystems they replace (Smil, 2011).

Flowering plants and mammals represent the matrix of the current biosphere and its ecosystems, and of agriculture in particular (Negrutiu *et al*., 2020). The two groups of species have made the object of early and intense domestication (while sketching the basic trends, other groups, such as birds, are not mentioned). The great majority of domesticated plants and animals have been achieved by our illiterate ancestors. Domestication remains a powerful enterprise because it shows that evolution is an open, multidirectional process. In contrast to natural processes, domestication is essentially a planned and intended evolution. However, human directional selection pressure(s) can end up in unintended and out-of-control consequences by changing local ecological regimes (Sarrazin and Lecomte, 2016). Also, domestication pressures can go beyond the requirements for survival and reproduction (called fitness) in the wild. Maize and silk worm are typical cases where breeding them has rendered these species unable to survive in the wild.

It is worth acknowledging an abundant domestication potential across the East-West latitudinal configuration of the Eurasian continental plate, as compared with the longitudinal North-South geography of the Americas (Cox and Moore, 2010). The main hot spots of diversity have been located in China, India (Hindustan), Central Asia, Asia Minor / Persia, Mediterranea, Abyssinia, Central America / Mexico, and South America.

From the societal point of view, two contrasting aspects make the story round. First, economy is perceived in terms of reciprocal interplay between natural and social systems (Kallis and Norgaard, 2010; Gual and Norgaard, 2010). Second, the denial of fundamental knowledge stemming from evolutionary studies and research keeps gaining ground to the benefit of creationism theories, to take this example alone (*e.g.*, Yahia, 2006). Education curricula are a case in point. The contribution of Darwinian, Neo-Darwinian (modern synthesis theory of Evolution), and more recent developments in molecular genetics and Evo-Devo (development and evolution at organism and population levels) have been instrumental in medicine and plant and animal breeding advances. In the society at large, the modern synthesis is not simply /just a theory, it is factual (Meyr, 2001). For the sake of ordinary logic and coherence, it is urgent to make denialists of all brands understand what it takes to daily abandon the underlying technological achievements in health, nutrition, breeding, conservation ecology, and biodiversity processes (Negrutiu, 2025a).

For example, the co-evolution dimension takes all its societal meanings through the ***biodiversity issue***.

Panel 4. The Knowledge Resource – Biodiversity

Biodiversity evaluations are currently produced in the absence of an agreed-upon and organized observation system based on thorough, systematic, and regular data on the state of the biodiversity in the strict sense, such as genetic, population/demographic, or phenological traits or trends (Brooks *et al*., 2002; Urban, 2015; Mace *et al.*, 2014). Providing near real-time information on a systematic and regular bases (Mace *et al*., 2014; Soranno *et al.*, 2015; Diaz *et al*., 2020; GBO, 2020) would be resource-intensive, and time-consuming. While important from a knowledge point of view, such an approach has little relevance for decision-making (Mazor *et al*., 2018), as illustrated by conservation strategies to halt biodiversity loss under the UN Conservation for Biological Diversity that have largely failed since 1992 (Franks, 2021).

To circumvent such actionable and conceptual limits (Aubertin, 2005; Kwok *et al*., 2020), and acknowledging that habitat loss or degradation, and land-use change are the primary cause of substantial changes in species abundance, distribution, and interaction (Dirzo *et al*., 2014), monitoring change through alterations at ecosystem scale may offer suitable alternatives. The ecosystem approach (Nicholson *et al*., 2021) makes ecosystems the building blocks of biodiversity assessment. Dedicated indicators measure ecosystem area, integrity, and risk of collapse (Dornelas *et al*., 2014; CBD, 2018; Rawland *et al*., 2019; Kwok *et al*., 2020; GBO, 2020). Such indicator sets are central for assessing compositional, structural, and functional processes. Importantly, most changes in these variables can be detected through remote sensing (*e.g.*, vegetation cover and diversity, various sources of biomass, connectivity and fragmentation, land use change, proportion of degraded land, extent of forests and wetlands, etc). They can serve as reasonable proxy indicators of biodiversity states. These ecosystem variables apply at various scales (habitat, biotope, vegetation type or landscape) and can capture significant trends in biodiversity dynamics.

Panel 5. The Knowledge Resource – Integrated Land Management: the coherent use of landscape ecological infrastructure. Sectoral approaches to land use have dominated resource management at various administrative and territorial scales. Landscapes have initially been defined by natural processes. The perspective has evolved to integrate human actors, economic supply chains, community capabilities, etc. Landscapes are a type of place-based, social-ecological system of land use and resource management with a certain cultural identity dimension where various stakeholders and local communities interact to address intersecting and interdependent environmental, economic, social, and political objectives while providing solutions at multiple scales. Interestingly, such recent developments (Scherr *et al*., 2013; Meijer *et al*., 2020; Dade *et al*., 2025) are revisiting Ostrom's concepts and guidelines (Ostrom, 2009).

Geophysical landscape boundaries are project/program/goal dependent and are necessarily arbitrary because activities operating in a given landscape affect, and are affected, by social-ecological processes taking place in other landscapes and at multiple nested scales.

Activities and stakeholders can be local communities, smallholder farms, protected areas, recreational activities, tourist enterprises, commercial industries such as agriculture, forestry, mining ones.

The landscape approach draws integrated spatial planning and land governance to accommodate development and conservation plans at a time of increasing and competing claims on natural resources. This is called Integrated Landscape Management (ILM) (Meijer *et al*., 2020). Integrated landscape governance entails a mix of policies and instruments that together ensure livelihood needs, sustainable uses, nature conservation, and ecological restoration through evolving trade-offs with a long-term view of the players. There is strong need to balance multiple goals, overlapping and competing interests, while managing risks of various kinds. The trade-offs therefore include the management of various sectors that depend on local natural capital while taking into account higher-up drivers, such as higher level institutions, land tenure, government policies (e.g., subsidies), markets and supply chains (*e.g*., prices). To be effective, the process requires clarification of rights and responsibilities (*e.g*., regarding land and resource use), and monitoring and reporting duties.

Panel 6. The Knowledge Resource – Systemic, slow building risks. The Long View

Agricultural processes, social and ecosystem dynamics, and food networks are inherently subject to ***systemic risks***, often slow-developing and insidious risks. A notable example is global pollution, which accumulates over decades with long-term exposure effects that often go unnoticed while continuously harming human health, societies, and ecosystems (IRGC, 2013; Arguello & Negrutiu, 2019). Each day, humans are involuntarily exposed to complex, evolving mixtures of chemicals through air, water, and food – a global, unintended experiment with potentially irreversible consequences, including developmental disorders, sterility, immunodeficiencies, cancers, and mortality (Fuller *et al*., 2022; iPES Food, 2017). A holistic approach to hidden and unintended social and ecological risks enables tackling a critical dimension: examining problems imbedded in current solutions (Bria *et al*., 2025; see also Collart Dutilleul *et al*., 2023).

Mark Carney, former Governor of the Bank of England, coined this problem the “tragedy of the horizon” (2015), highlighting how climate change consequences extend beyond conventional political, economic, financial or technocratic planning horizons. By the time these risks affect financial stability or society at large, it may already be too late.

The pesticide debate in Europe illustrates the challenge of slow systemic risks. Decades of scientific uncertainty, industrial lobbying, and political inertia delayed recognition of the environmental and health impacts of pesticides. In April 2024, the Court of Justice of the European Union issued a landmark ruling, emphasizing that Member States must implement robust, science-based risk assessment frameworks, relying on “the most reliable available scientific data and the most recent international research” (InfoCuria, 2025). This decision is an explicit criticism of the protocol for the evaluation and authorization of pesticides by national agencies, and underscores the urgent need for regulatory reform to safeguard food, environmental, and occupational health.

However, even with high-standard protocols, conventional agriculture remains largely unprepared to adopt alternative, nature-friendly practices. Effective transition requires not only technical changes in agronomic methods but also collective cultural transformation, whereby farmers organize, share knowledge, and coordinate action. Small and medium-scale farmers, often constrained by financial and technical limitations, cannot realistically undertake this shift without substantial improvements in social conditions, access to information, technical assistance, and targeted subsidies.

Taken together, these considerations highlight the necessity of long-term thinking, incorporating the critical zone, planetary boundaries, and societal limits into all agricultural and food system planning.

Panel 7. The Knowledge Resource – Food democracy, from fork to farm, not the other way around

Currently, food availability is essentially a matter of economic, competition, trade, financial, etc. decisions on which people have no say. Thinking that food and food systems are optimal when globalized, standardized, and over traded, while generating health and environmental risks, seems to defeat logic.

The growing problem with commercial foods is their negative impact on diets and health worldwide. The structure of the dominant food system facilitates the concentration of power in horizontally and vertically integrated large agri-food companies (Stiglitz and White, 2025). It results from their acquiring the means of production, the means of retailing and logistics. The economy of scale allows substantial economic gains. The companies perform aggressive marketing on products containing cheap manufactured ingredients (fat, salt, sugar, flour), the commodities being sold at very high volumes as convenient foods.

The business centric agri-food world is the mirror of the illogical route from farm to fork, in which agribusiness oligopoly and influence is at the root of, to name just a few, waste, unhealthy diets, the privatization of profit through intellectual-property law, the inability of the market economy to account for the true cost of farming (Lawrence, 2019; Clapp, 2025).

Interestingly, food can be a lever to democracy and social justice in response to the concentration of power in food systems, *e.g*., all processes from farm to fork. Food democracy has been conceptualized in political (UK), economic and social (US), and judicial (France) terms and has therefore characters in common with political democracy (Collart Dutilleul, 2021). According to the author, food security and sovereignty should result from democratic choices on the degree of food autonomy (based on freely determined criteria) and completed with the free trade of food commodities. Even more so, food systems, agriculture policies, and the market are linked to a territory and its specifics. In other words, food democracy has an individual dimension of each person's access to sufficient, healthy, balanced food in accordance with cultural and taste preferences, and a collective dimension through the implementation of direct democratic governance of a territory.

The food democracy approach is a change of paradigm in the food system governance process (Collart Dutilleul, 2021; Bernard *et al*., 2019). It reverses the socioecological and political perception of food. Food, currently a commodity as any other (Vivero Pol, 2013; Collart Dutilleul, 2018) is becoming a collective health issue. The usual "from farm to fork" strategy (too mechanically conveyed in politics and communication) is shifting to "from fork to farm" democratic practice. Consequently, thinking the other way around the food systems and the supporting core resources required for the production of food (*i.e*., land, water, and biomass) need to be jointly managed (Negrutiu *et al*., 2020).

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