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Exploring Agroecology Transition Scenarios: A Pfaundler's Spectrum Assessment on the Relocation of Agri-Food Flows

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Abstract: In response to the climate emergency and other dimensions of the current global environmental crisis, the world is facing an agroecology transition aimed at scaling up the best sustainable ways of farming into circular agri-food territories. No one knows, however, in advance, how they will perform. To explore several feasible, viable, and desirable future scenarios for these agroecological territories, we have developed a nonlinear programming model called Sustainable Agroecological Farm Reproductive Analysis as a bottom-up deliberative tool. In this article, we use it to explore the sustainable degrees of trade openness of these bio-economically circular territories by evaluating the advantages and limitations of conceiving them from an interdependent network of basically self-sufficient areas rather than as autarkic islands. Using SAFRA optimizations in a Catalan case study, applied as a preliminary test, we found that autarkic self-sufficiency would reduce the food supply capacity of the studied territory by one-third. At the same time, however, up to a point, trade openness would face growing problems and barriers to maintaining a circular replenishment of soil nutrients, as well as the landscape diversity required to house enough farm-associated biodiversity needed for other supporting and regulating ecosystem services. These results confirm the conceptual approach of the issue developed by Leopold Pfaundler in 1902, and call for more empirical studies in broader areas conducted together with local farmers and other stakeholders that jointly define boundary conditions, constraints, capabilities, and ranges of fair-trade openness evaluated for a true bottom-up agroecological transition.

Keywords: agroecology transition; fair-trade openness; bioeconomic circularity; bottom-up scenario exploration

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1. Introduction

1.1. Scaling up Agroecology: What Will the New Relocated Territories Look Like?

The current agri-food system generates 34% of the world's GHG emissions [1], and the Paris Agreement of not endangering the habitability of our Earth with global temperature increases above 1.5–2 °C cannot be complied without deeply transforming it [2], including the prevailing dietary patterns and trends [3,4]. There is a growing consensus among global governance institutions and policymakers, such as the United Nations Committee on World Food Security [5–8], the FAO [9,10] and the European Commission [11,12], that this entails an agroecology transition [13,14], capable of scaling up the best farm practices [15] and other sustainable-oriented ways of food provisioning and consumption into bio-economically circular, integrated agroecological territories [16–18].

No one knows in advance what these bioeconomic circular and integrated agroecological territories will be like, or what scope and overlapping areas they will have. As a science, practice, and movement, agroecology has principles and elements, but not ready-made recipes that fit anywhere [19]. While these agroecological transitions will proceed bottom-up, by trial and error, based on the site-specific circumstances in each context, the scaling-up they entail cannot be addressed by simply adding new sustainability-oriented farming practices and spreading them out [20]. They will need to address the emerging properties, available synergies, barriers, and lock-in situations of any systemic transformation [21,22]. This article seeks to address this knowledge gap by using SAFRA, a model called Sustainable Agroecological Farm Reproductive Analysis, which we have recently developed [23], to analyze how open an agroecological territory can be to commercial links with others while, at the same time, seeks to close the basic biophysical flows through a circular bioeconomy that guarantees a healthy replenishment of organic matter and nutrients in their cultivated soils.

1.2. Relocating Agri-Food Systems into Agroecology Territories: Top-Down or Bottom-Up Models?

What agroecology analytical tools can help address this endeavor by providing reliable ways to envision feasible and desirable transition paths, bearing in mind that sustainable systems are much more complex to create than unsustainable ones? [24]. A recent example is the Ten Years For Agroecology (TYFA) modeling of a European multifunctional agriculture for healthy eating in 2050 [25]. Based on the "one-farm-EU" method, this IDDRI-AScA study demonstrates that, despite an average 35% reduction in the yields per unit of land in energy terms (Kcal), the widespread adoption of agroecology and the adoption of healthier diets by 2050 can provide healthy food to 530 million Europeans while maintaining export capacity, phasing out the current vegetable protein imports and lessening the food footprint of Europe, as well as reduce 40% GHG emissions from the sector, gain biodiversity, and conserve natural resources. The results of this model dismiss the claims of those that had argued, incurring in a composition fallacy that ignores the large bioconversion losses of the current agri-food system [26], that a widespread adoption of agroecological farm management could not feed the world without invading forestland and endangering nature conservation areas [27,28]. The TYFA results might also be very useful for a backcasting participatory debate to plan and adopt agroecology transition policies at the European level or other large territories [29]. At the same time, however, the top-down analytical approach of the "one-farm-EU" method adopted by the TYFA model raises important concerns when their reliability is addressed, considering the strong differences among European bioregions, and the manyfold local variations in natural and social resource endowments within them. An analytical alternative, very prone to the general approach of agroecology, would be a bottom-up scenario exploration and planning of different agroecological transition paths. To that aim, we have developed the SAFRA modelling that is described in detail in [23].

2. Materials and Methods

2.1. SAFRA as a Bottom-Up Deliberative Tool for Exploring Future Scenarios

SAFRA is a nonlinear programming model fed with biophysical data on the site-specific restrictions and contour conditions, either in natural or social resource endowments, as well as the capabilities already demonstrated by the best sustainable farming practices previously recorded in each territory [30], including the retrieval of traditional peasant knowledges understood not as a 'frozen memory' but as an adaptive resource for the future [31,32]. The SAFRA modeling optimizes the biophysical interactions among the live fund components of the agroecosystem—healthy soils, livestock, and farming community— considering the matter-energy reproductive requirements of each of them as a basic sustainability criterion [23]. It brings about a specific land-use and livestock configuration of the agroecology territory where those best farming practices would have been scaled up and integrated by closing their biophysical cycles through specific types of diets to be decided. As with any optimizing model, to solve the system of equations that account for all the interactions and reproductive needs of the living funds of the agroecosystem considered, SAFRA needs an objective function that defines the social aim that is to be optimized as a priority [23]. Different social priorities will give rise to different optimized agroecological territories, all of them sustainable in the strict sense of having guaranteed the reproduction of their living funds over time. This objective function becomes the keystone of the modeling: What are the social values for which we want to optimize the agroecosystem? (Figure 1).

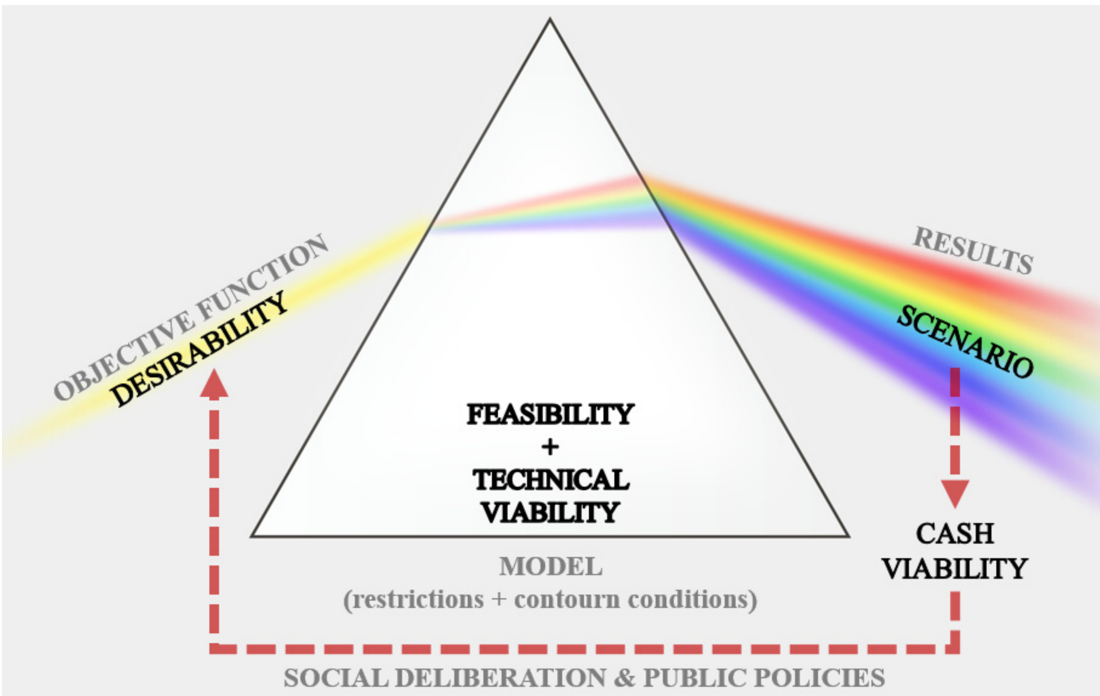

Figure 1. Conceptual scheme for the capabilities considered in SAFRA modeling. Source: Our own, based on [23]. The background drawing on the refraction of light has been taken from the free media repository of Wikipedia Commons (https://commons.wikimedia.org/wiki/Prism).

Therefore, SAFRA is not a prescriptive top-down scenario but a bottom-up exploration tool of different feasible and sustainable scenarios whose desirability needs to be discussed and decided on in participatory policy-making deliberations [23]. As a deliberative tool to choose among different feasible and sustainable paths of agroecological transition, the main outcomes provided by the model are a landscape agroecology configuration whose capabilities for housing farm-associated biodiversity can be assessed with other models [33,34]; a specific set of labor requirements whose cash viability must be assessed from a socioeconomic point of view; a specific type of diet that sets the coherence between food production and consumption, and determines the relocation degree of the agroecology territory considered as a foodscape, together with its trade openness, and, through a sensitivity analysis, the discovery of the main drivers, bottlenecks, trade-offs, and potential synergies of each optimization performed [23].

2.2. What Does Agri-Food Relocation Mean? In Search of a Pfaundler's Spectrum

Scaling the best sustainable farming to agroecology integrated territories [17,18,22], where the recirculation of organic matter back to healthy soils is feasible through a circular bioeconomy, requires a certain degree of agri-food relocation of current globalized food flows. Along with this biophysical circularity, agroecological territories also aim to bring food producers and consumers closer together from a socioeconomic and cultural point of view through shorter and fairer agri-food chains. SAFRA modeling is aimed at informing these systemic transformations, which involve profound changes of the prevailing food regime [35,36]. Food Sovereignty is one of the main aims of this big transformation [37–39], a goal that also requires to avoid falling into the so-called local trap [40]. Therefore, among the multidimensional issues to be considered and debated, the degree of trade openness that would imply the necessary relocation of the main agri-food flows into sustainable agroecological territories stands out. In 1902, addressing the question of how much of the world's population could be fed on a limited Earth, the Austrian physicist and chemist Leopold Pfaundler (1839–1920) pointed out that the answer would depend on whether we simply added one by one the capacities of each territory where different limiting factors prevail; or, on the contrary, we admitted some degree of trade between them that would increase the total availability of food through local specializations in the ecological optimums of each locality, even though knowing that the energy costs and environmental impacts of these food transports over long distances would impose a limit to them [41,42]. As a result, he suggested that the right answer would be somewhere in between an autarkic self-sufficiency (which would limit the sustainability of the world's population) and an absolute trade specialization in an unrestricted global economy (which would lead to unbearable energetic and environmental costs). The specific characteristics of this intermediate level of agricultural specialization would stem from the biophysical comparative advantages in soil and weather conditions, geographic locations, as well as on labor availability. The intermediate spectrum of trade openness put forward by Pfaundler would correspond to the 'fair trade' currently claimed by the peasant organizations of Via Campesina, and the agroecology movement as well [43].

Although we consider Pfaundler's approach to be a good starting point for a debate on the extent to which agroecological territories can engage in some degree of sustainable specialization, the evolution of science from the early 20th century onwards has also called into question his view of what the limiting factors of his argument were. We now know that the so-called 'Liebig minima' (i.e., the growth of any living being will improve only by increasing the amount of the most limiting factor) require further elaboration, due to the ability of biodiversity to cope with them through synergistic strategies between species [44,45]. We now know that the gap between both extreme situations, autarky versus specialization, could be narrowed by promoting agrobiodiversity synergies such as intercropping, complex rotations, no-tillage conservation agriculture, mixed farming, agroforestry, and bioeconomic circularity capable of improving the productivity and variety of local products [14,19]. However, although any agroecological territory can improve its degree of self-sufficiency by taking advantage of these agroecological synergies, it is still worth addressing the degree of commercial openness compatible with a sustainable closure of the basic biophysical cycles that ensure the replenishment of organic matter and nutrients in cultivated soils on an agroecologically feasible scale [46].

We start from the premise that the search is for sustainable and fair-trade patterns that do not generate unequal ecological and social exchanges [47,48]. Although avoiding extreme situations of extractivism, such as those currently prevailing in global South-North trade, which are relatively easy to assess [49], there can be others in which food trade exchange products embodied with very different natural resources make the multicriteria evaluation grayer, for example, land-intensive goods, such as cereals, versus labor-intensive goods, such as wine [50]. We assume that the search for socially and environmentally desirable trade patterns can only be solved when a set of several optimal values at different multi-scalar levels have been defined.

As a starting point, we can consider two opposite situations. On the one hand, the maximum level of autarky, and, on the other hand, the maximum level of potential food production taking advantage of technically feasible land-use synergies in the agroecosystem. They set the range in which we consider that a Pfaundler optimum can be explored, following the method proposed by Busch and Sakhel [51]: Start by defining the creation of self-preserving autarky islands, and then search for feasible and complementary specializations and synergies by following a bottom-up process from the local to the global scale. That means adopting a strategy opposed to the current unsustainable globalization, that imposes top-down trade rules from the global to the local scale. According to these authors [51], looking for fair-trade options from a previously theoretical autarkic state will encourage innovative local solutions that are nature-based, oriented towards strong sustainability, and supported by participatory democracy [23]. We must bear in mind, however, that a necessary condition for this approach will be that the regulatory decisions are within the same territories engaged in their own process of agroecological transition that engage in partial but complementary trade specializations [36].

2.3. Using SAFRA to Assess Sustainable Degrees of Trade Openness: An Exercise of Political Agroecology

We are going to apply a SAFRA model to obtain a preliminary assessment of the degree of trade openness that would contribute to advance towards an agroecology transition that would scale current best farming practices up to an integrated territory. We conceive this modeling not as an end in itself, but as an exercise of political agroecology addressed to inform deliberative processes to cocreate strategies of agroecological transition towards more sustainable agri-food systems [21,22]. In this regard, Tello and González de Molina [46] point out several elements that need to be considered when designing agroecology landscapes: (1) the need to close socio-metabolic cycles; (2) the impacts of any decision on the landscape ecology functioning, so as to maintain high levels of biodiversity; (3) the improvement of the energy efficiency of farming and the reduction of greenhouse gas emissions of the entire agri-food system; (4) the role of biocultural heritage in the maintenance of site-specific knowledges on resilient agroecosystems, and, finally, (5) the democratization of market power and the attainment of fairer value chains. Being that this is only a preliminary test, we will focus our exercise on the first and second points, and on the first part of the third point related to the energy efficiency of farming, leaving aside the other dimensions for future research. The fifth point is only indirectly incorporated in the explicit intentionality of the objective function adopted as a desirable goal (Figure 1).

According to Saltelli and Giampietro [52], the assessment of the likelihood of success in the application of a proposal through public policies comprises three main types of capabilities:

Feasibility: These are processes which are out of reach to human control—i.e., internal processes. In our case, SAFRA modeling considers as restrictions or contour conditions all the biophysical processes related to the underlying thermodynamic, physical, chemical, and biological parameters of the local agroecosystem functioning.

Viability: These include processes that are under human control, which, at the same time, affect to the interaction between society and nature. As we will show later, a further differentiation is included in our SAFRA model between *technical* and *cash* viability.

Desirability: This is a fundamental feature, mainly considered in the SAFRA modeling through the adoption of a social priority to be optimized through the objective function. Some specific societal goals can also be incorporated by means of the restrictions considered in the kind of agrarian practices accepted, on the type of food to be provided, or in the constraints set by environmental regulations. In the latter case, they become backcasting elements incorporated in the scenario exploration through the optimization exercises. In one way or the other, the model is run under a clear social and political *intentionality.*

The aim of the SAFRA modeling addressed in this article is to contribute to exploring the functioning of markets understood as subsystems of an ecology-dependent human economy from a strong sustainability point of view [53]. This means identifying how these market mechanisms can be compatible with society-nature relations that do not jeopardize the healthy reproduction of the living funds of the agroecosystem in the studied territory. Note that, by construction, SAFRA modeling adopts a sustainability-first principle because the operation of market flows is at the service of the sustainable reproduction of the agroecosystem in a good ecological state, and not the other way around [29]. These restrictions include not only what Cronon [54] defines as first-nature variables (the boundaries strictly relying on biophysical constrains the determined *feasibility*), but also the second-nature ones related to the social fabric (that determine *viability*)—i.e., cultural practices, technological developments, and relationships between the different agents of society.

Therefore, following Saltelli and Giampietro [52], SAFRA modeling distinguishes among *biophysical feasibility* and *technical viability*. Both restrictions set the technical-agronomic context that frames the degrees of freedom for the model to search for optimizations in the landscape agroecology functioning within the territory considered. Then, these optimizations are run according to different societal goals adopted as the structuring information [55] driving the circular agri-food system explored in the agroecological territory [29]. This introduces the *desirability* that determines what is going to be maximized or minimized in the modeling exercise, leading to different scenarios. As explained, other societal goals can also be included in the model as backcasting restrictions, but it is the definition of an objective function which sets the main choice, according to which the available resources will be optimized.

In short, the aim of this exercise is to examine the potential of an agroecological specialization strategy by applying the SAFRA model to a local case study. The modeling considers the capacities of the explored agroecological territory to maximize the local output of food provisioning through trade specialization (MO) compared with self-provisioning a healthier Mediterranean diet (HD), only with the capabilities of this territory. The case study used for this exercise are four municipalities in the Catalan Vallès County which our research team has been using as a test bench for a long time (Figure 2).

2.4. Features of the Catalan Case Study Used for a Preliminary SAFRA Test

We know that the case studied is too limited an area to create a true agroecological territory, but the exercise is only meant as a preliminary test to demonstrate that SAFRA can search for the Pfaundler's spectrum, and to see how a sustainable trade openness might look. Figure 2 shows the distribution of land use of this study area in 2009. The most predominant use was woodland and scrubland, which covered 62% of the total surface, mainly in the Northern and Western sides of the four municipalities (Castellar del Vallès, Sentmenat, Caldes de Montbui, and Polinyà). *Pinus halepensis* or *Aleppo pine* cover three-quarters of these woodlands and scrublands, while the remainder features *Quercus ilex subs*. *ilex* (or Holm oak), shrubs, and riparian or other forests. Urban sprawl had a severe effect on the landscape, with 19% of the land dedicated to urban (16%) or other unproductive uses from an agricultural point of view (3% of rocky areas, ravines, and riverbeds). Between 1956 and 2009, cropland was practically halved by two land-use changes: The urban area quintupled, swallowing up formerly irrigated, high-quality cropland, and a process of forest transition subsumed marginal lands that could not be mechanized and became abandoned. Cropland decline has resulted in a subsequent loss of traditional landscape mosaics [33,56,57]. Within this landscape, grapevines had represented the main crop before the Phylloxera plague (1888), but in 2009, they occupied little more than 0.7% of cultivated land [58,59]. By contrast, the predominant use of cropland were grains for animal feed, which accounted for 75% of all crops, followed by fruit trees and olive trees. The predominance of feed for animal consumption was consistent with the extremely high livestock density in the four municipalities, 111 standardized Livestock Units of 500 per km^2 of total agricultural utilized area (compared to 7 LU500/km^2 in 1860) [58,59]. As for human population, the proximity of the Barcelona metropolitan area resulted in an explosive upward trend until 2009, when residents numbered 55,433, and the population density was 462 inhab./km^2, with only 0.25% of total population dedicated to farming (compared to the Spanish national average of 92 inhab./km^2, or with the 1950 figure of 100 inhab./km^2 in the case study).

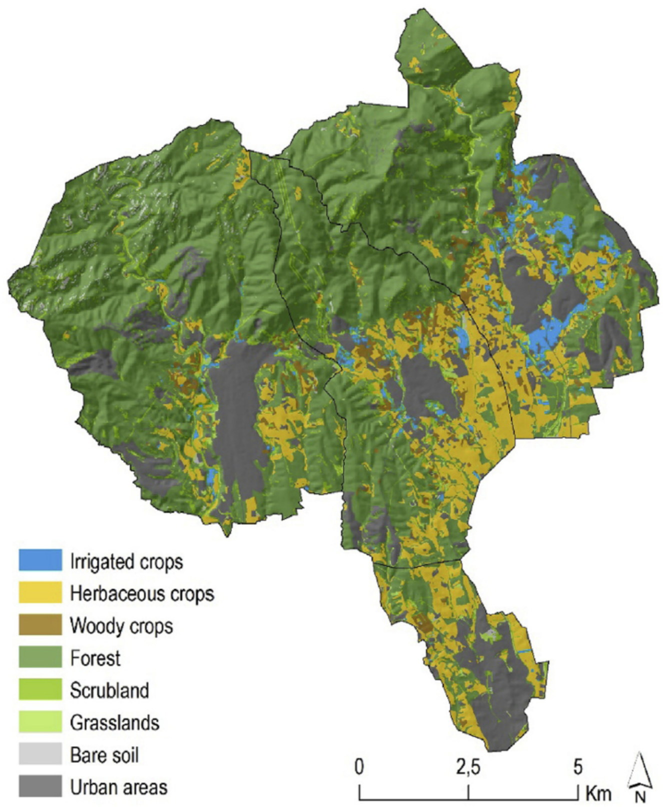

Figure 2. Land-use map for the Vallès case study in 2009. Source: Our own, adapted from the CREAF 4th edition of the soil cover map of Catalonia.

3. Results

Table 1 compares the amount of food that might have been produced in this area in 2009 with a closed self-sufficiency farming strategy aimed at locally providing a healthy diet (HD) to the local population, with the food basket provided by another farming strategy aimed at maximizing output (MO) through trade specialization. The quantities are compared in grams per person and day of each ingredient of the food basket accounted in absolute terms, together with the differences between both scenarios, and the yields of each vegetable product in metabolizable energy (ME) per unit of land.

The comparison allows to infer that trade specialization would increase by 32–34% in ME of the total food produced, which would increase up to 136–204 inhab./km^2 of the equivalent population densities that could be locally provided by food, depending on the diets adopted. The top population density obtained in the MO scenario would be nearly 44% of the actual territory's total human population in 2009, compared to the maximum of 16% that could be fed with conventional farming and diet, keeping the territory in an autarkic state. As found in other modeling exercises, the change to healthier diets both for humans and the environment is key for any transition to more sustainable scenarios [24,26,27]. To this, our exploration analysis adds the relevant increase that allowing some degree of trade openness would mean in order to avoid falling into a local trap.

Table 1. Resulting diets for the scenarios HD and MO in grams per person and day, the difference between both scenarios, and the energy yields of human metabolizable energy per unit of cropland in each vegetable product. Source: Our own SAFRA modeling.

	HD	MO	Difference	MJ/ha
Vegetables	400.0	0.0	400.0	22,115
Fresh fruit	367.9	701.4	−333.5	21,017
Wheat	207.7	30.2	177.5	37,762
Legumes	40.1	5.6	34.5	7722
Olive oil	31.8	0.0	31.8	8900
Almonds	30.0	0.0	30.0	15,675
Potatoes	0.0	0.0	0.0	17,814
Wine	120.0	1524.4	−1404.4	22,255
Pork	7.2	0.0	7.2	
Lamb	43.8	30.8	13.0	
Chicken	0.1	0.0	0.1	
Eggs	1.8	0.0	1.8	
Sheep milk	324.1	310.4	13.7	
Fish	90.2	90.2	0.0	

For these higher human densities to be sustainable from an agroecological standpoint, however, the gaps in the food basket components that appear as differences in Table 1 must have been filled by trading the exchange of surplus products for deficit products. The results are also indicated in Table 1 in grams per person and day. The last column shows the local yields of each vegetable product in metabolizable energy per unit of land. These figures highlight that maximizing local food availability through an agricultural specialization in cash crops would involve significant deficits and surpluses with respect to maximizing a HD locally produced. The local production of vegetables would be null, while the production of fruit would be more than twice the required amount. For wheat and legumes, only 14% of the required amount would be locally produced. In the case of animal products, they would account for 19% of total output needed, which would be slightly lower than 23% of the local healthy diet case. The higher deficits appear in the provision of olive oil and almonds because their local yields are relatively low (266 liters of olive oil and 624 kg of almonds per hectare per year in 2009), and would provide a metabolizable energy of 8900 and 15,675 MJ/ha, respectively, far below the 22,700 MJ/ha provided by grapevines.

This helps explain why grapevines come to have a highly significant weight in the agroecosystem oriented to commercial specialization following the MO strategy, representing 60–62% of cropland, and producing the equivalent of 11.3 times the consumption requirements of the local population. This winegrowing specialization would start a tend towards monoculture, although the landscape would keep a greater diversity of land covers than the actual situation in 2009. Why is it that other crops that would contribute a greater energy content per unit of weight, such as wheat (Table 1), do not contribute more to the market-oriented agroecosystem in the MO strategy? Moreover, why do fruit trees appear as crops with a greater weight than grains when their energy yield is lower than vines? The reasons why SAFRA optimizations can give these results are manifold. Cropland planted in wheat are rotated with legumes, which have much lower yields in energy terms, causing an output drop in the whole rotation to 22,750 MJ/ha, practically the same as the cultivation of vines. In addition, vines also have an associated coproduct, the pastureland of vetch and oats, which would provide 21% of total feed for sheep. If we associate this fraction of animal production as well, vines ultimately exceed the productive potential of the wheat rotation, rising to 24,450 MJ/ha. The combined output becomes 7.5% higher, tipping the balance in favor of grapevines. This is a clear example where the decision to plant associated crops can be a good strategy to increase the agroecosystem's total output [14].

In this situation, it would seem logical to increase the amount of vineyard land as a monoculture at the expense of land devoted to a wheat rotation. However, wheat rotation occupies 230 ha, and fruit trees would cover 607 ha in our MO scenario. This is when nutrient balances come into play, to explain this SAFRA optimization outcome. In the case of vineyards, if we consider all flows adding the main and associated crops (grape juice, pomace, vine shoots, stalks, and pasture), the total soil nutrient requirements would have been 78 kg N/ha, 15 kg P/ha, and 69 kg K/ha. Of these requirements, a portion can obviously be recovered through in situ consumption of the associated crop or through burying by-products. This internal biomass circulation, however, always involves losses. By contrast, the wheat rotation would have low soil nutrient requirements because of the presence of leguminous plants and green manure, falling to 10 kg N/ha, 8 kg P/ha, and 18 kg K/ha. Thus, while the land cost of putting the cereal crop ahead of vines is only a 7.5% loss of productivity in ME terms, the nutrient cost of vines is much higher than that of the cereal rotation. As a result, SAFRA opts for a certain equilibrium between the two, even though the amount of land in vineyards would be greater.

The same thing occurs with fruit trees, which have a requirement of phosphorus, the most constraining soil nutrient, of only 5 kg P/ha compared to 15 kg P/ha needed by grapevines. In the case of nitrogen, the requirements can be very low, of the order of 15 kg N/ha. This estimation assumes the presence of herbaceous covers of leguminous plants that are similar to other woody crops, as well as nutrient entries coming from irrigation. Although the energy yield of fruit trees would be slightly lower at roughly 21,000 MJ/ha, there would be an easing in total nitrogen requirements that would lead the model to replace wheat because it requires more phosphorus. In this set of complex equilibria, the amount of land for fruit trees becomes very important, rising to the maximum possible value of 607 ha set as a constraint by the local irrigation conditions. Once again, this shows the key role played by the difficulties in closing soil nutrient cycles when it comes to deciding agroecological strategies. It also shows the need to take water metabolism into consideration, together with the reproductive metabolic requirements of the other live funds of the agroecosystem.

Before concluding this section, we want to offer a counterpoint on the impact of this strategy in terms of trade. In total, providing 43% of the population needs with the agroecological production in the territory would require annual imports of 6300 tons of foodstuffs and exports of 17,550 tons. These flows are not inert and would have implications for transport energy costs and emissions, and for soil nutrient losses or gains, given that the N-P-K composition of the products traded are different. In terms of employment, the actual situation in 2009 required some 104 standardized agricultural working units (AWU) per year, that would increase to 226 AWU in the HD scenario, and to 307 AWU for the MO one. These scenarios would require between 1.1% and 1.5% of the population dedicated to farming, when the current figure is only 0.25%.

4. Discussion

One of the aims of this research was to find out whether agroecology transition strategies might have to face a local trap that could significantly reduce the potential of many agroecosystems to meet the food needs of the local population. According to the results obtained by the SAFRA modeling in the case study used as a preliminary example, following a strategy of output maximization through trade specialization would result in a production of metabolizable energy one-third larger than an autarkic provision of local healthy diets, thus allowing for a sufficient food provisioning to 204 inhab./km^2.

The consequences for the dependence on other farming systems, however, would not be minor. In total, 43% of the entire diet at the local scale would have to be imported, and the path towards monoculture could limit the positive impacts in terms of biodiversity of the agroecology transition path, owing to a less diverse landscape. In addition, this trade opening scenario would also involve risks in terms of resilience. Once the strategy would have been configured, the increase in produced metabolizable energy with respect to the local diet could plummet in years of crop failure due to climatic hazards or plagues and diseases, as already happened with the Phylloxera plague [60].

To carry out the aforementioned strategy, it would also be necessary to count on areas where the optimal production exported would be cereal and legumes, as well as other areas ready to export fruits and vegetables, and still other areas ready to export olives and almonds. Although such scenarios are not implausible, we would have to add the case of vegetables, whose large-scale cultivation would face severe soil nutrient constraints, making it difficult to maintain in a sustainable, reproductive manner. In any case, what becomes more interesting of the results obtained with our SAFRA exploration is a couple of very relevant confirmations. First, that an autarkic self-sufficiency would actually involve local traps that reduce the food provisioning capacity of each isolated territory. Secondly, that advancing from a theoretical state of absolute self-sufficiency towards greater levels of trade openness would face, up to a point, increasing problems and barriers for keeping a circular replenishment of soil nutrients, as well as the landscape diversity required to house enough farm-associated biodiversity needed for the other non-provisioning ecosystem services of agroecology landscapes [61].

The combination of both results reassesses that an appropriate scenario would lie at an intermediate point between the healthy diet scenario locally provided, and the scenario that maximizes food availability through trade specialization. Such an intermediate scenario would take full advantage of the soil and climate diversity of different local environments without entailing too severe impacts in keeping all of them in a good agroecology state. This confirms the hypothesis put forward by Leopold Pfaundler. Even more, our results suggest that a sustainable horizon within the intermediate Pfaundler's spectrum could be provisionally set somewhere between 33% of local needs provided with a local self-sufficiency strategy, and 44% of trade openness of this local food production. However, we must keep in mind the limitations of this preliminary SAFRA modeling carried out in a too narrow study area. These results must be taken cautiously, and further research is required using better SAFRA explorations in more realistic areas, carried out together with a good deliberative process with local farmers and other stakeholders to jointly define the boundary conditions, restrictions, capabilities, and ranges assessed for a true bottom-up territorial agroecological transition.

5. Conclusions

We have carried out a preliminary test verifying that our SAFRA model can assess the issue of trade openness versus local traps in the advance of agroecology transitions. The preliminary results confirm Pfaundler's hypothesis of an intermediate spectrum capable of avoiding both falling into a local trap, and that market specialization prevents closing the basic biophysical flows of agri-food systems in agroecological territories integrated with heterogeneous landscapes that are complex enough to maintain high biodiversity for the provision of ecosystem services [61]. These results confirm the ability of new types of holistic models such as SAFRA in order to address the dynamics of complex systems such as the agri-food. In this case study, SAFRA made it possible to assess the question of how open an agroecological territory can be to commercial links with other territories while, at the same time, seeking to close the recirculation of basic biophysical flows to guarantee a healthy soil replenishment of organic matter and nutrients.

Further research is needed, however, to simultaneously look at different territories with different agroecological productive potentials, and to see how an appropriate degree of fair-trade specialization in complementary products can actually improve the satisfaction of social needs in all of them, while keeping both the agroecosystems and the society in a good state. This simultaneous modeling would probably imply interlinking several SAFRA models using network theory-based analysis applied to the biophysical interactions (flows) among the different agroecological territories (nodes) in order to search for those that would avoid falling into local socioecological traps, unsustainably degrade their living funds, or setting ecologically unequal exchanges [40,62,63]. This research can also draw on studies conducted in the field of 'foodsheds', where the debate is now addressing the cost of the circulation of foodstuffs [64,65]. These approaches would gradually help us to advance closer to the sustainable fair-trade degrees of commercial openness called for by Leopold Pfaundler in 1902.

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