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Diversity of food systems for securing future food availability

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Introduction

Some authors (Sinaï, 2013; Radanne, 2006) speculate that in the near future new ways of life will emerge, induced by the constraints arising from three geophysical factors: rising sea levels; climate disasters (higher frequency and severity); scarcity of material resources, and especially of energy for transport. The effects of the coming changes, and especially the effects of global warming on agriculture, are a regular study topic (Calzadilla et al., 2011; Altieri et al., 2015), while the effects of the other constraints, and the likely evolution of the food systems as a whole, remain quite overlooked (Servigne, 2013). When there is a general scarcity of resources (as is the case for oil and minerals over the coming decades) - the agro-food value chains based on agro-industrial agriculture may no longer function (Clark, 2011). It is well-known, at least in agronomic circles, that agriculture must head for agro-ecological systems (e.g. Altieri et al., 2015; Malézieux, 2012). However, the consequences for the other members of the food system are considerable. Maybe the focus is on the agricultural step alone, because the environmental footprint of this part of the food system is important and well-explored. However, if the purpose is securing food availability for everyone, the whole food system has to be redesigned according to the new constraints.

Our hypothesis is that only frugal food systems are expected to last. In this paper, we voluntarily leave aside the issue of moderation on the "demand side" (stabilization of the global population, inclusion of less meat and milk within diets, etc.), in spite of its vital importance in achieving secure food systems. We therefore focus here on the "supply side" only, because the main idea of the paper is about considering whole value chains. Accordingly, we describe the likely future evolution of agro-food value chains (including agricultural settings, processing and delivery) in response to the new constraints.

1-Methods

Three optimistic assumptions

To discuss the future of food, we need to make three optimistic assumptions. Indeed, if we do not keep to these assumptions, it is impossible to think about the future of agro-food value chains… because it will not be any organized value chain for long! Why not see for yourself? The first one is that the transition can run without mass destruction, without "collapsing", and that our societies will smoothly adopt ways of life compatible with these new constraints. The second one is that policies will be reasonable enough to give priority to food and agriculture issues. The third is that long-term agronomic performance (productivity per hectare or per head of livestock) will in general be higher than before the agro-industrial revolution. Indeed, agriculture will turn back to the same geo-physical conditions of the past: no synthetic fertilizers, nearly no synthetic poisons, no cheap oil… but with improved knowledge (e.g. to implement organic agriculture, Auerbach, this issue) and varieties. We can expect to generate new varieties adapted to the future situation. It is still possible, provided we are aware of the necessity to prepare for such a future. The three assumptions are plausible, but we have no assurances. However, if one of the three assumptions were not realized, it is likely that nobody would have an opportunity to discuss science for much longer.

Developing proposals from the effects of the three constraints

To develop proposals, we discuss the general effects of the three constraints on agriculture, processing and delivery. Clearly, the three geophysical constraints are not proven to be the main drivers of agro-food evolution. Maybe, other environmental phenomena represent more critical issues for agriculture (e.g. biodiversity loss). Nevertheless, these constraints are frequently quoted in general journalistic information, and **lay people think that they face such challenges**. Of course, the evolution of value chains depends on what actors deem important, and not on what is scientifically sound and proven. Moreover, for agriculture, these three constraints are "cumulative", in the way that they all lead agriculture in the same direction, as we will show later on. From the tightening of the three geophysical constraints, knowledge about the past (Ferdière et al., 2006) and present agro-food sector, we infer the different value chain models that are frugal

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enough to develop in the new context. We will not split the conclusions into developing or developed countries, because they are experiencing the same phenomena, albeit at a different pace. For both the present and future value chain models, we roughly present the workings, and screen the main advantages and drawbacks regarding their direct environmental and social consequences. One important criterion is the long-term effect of the farming system embedded in the value chain upon soil organic matter. Indeed, the organic matter is at the core of future food security. In the absence of synthetic fertilizers (the future inevitable situation), field fertility is restored only by returning organic matter to the soil. Urban and rural sewage facilities will be rethought to retrieve nutrients from sludge, and all the organic matter from food will be composted and will go back to the soil. Already in Sweden, and a few other countries, specialized urine-separating flush toilets are available. Urine is collected by farmers and sprayed onto compost, in order to recycle nutrients (Wilson, 2014). Finally, we justify the combination of the latter four models together by way of adaptation to the future.

Effects of rising sea levels

Most major cities are located by the sea or a river. This proximity allows the occupants to take advantage of good alluvial soil, and of maritime and fluvial freight (which is and will remain the least expensive means of transport, in energy terms, from Wingert, 2005). During the 20th century, the sea level rose initially at the rate of 1.7 mm per year, then 3.2 mm per year between 1993 and 2014 (Guéguen and Renard, 2017). The Intergovernmental Panel on Climate Change envisions a supplementary rise ranging on average from 260 to 820 mm, during the 21st century (Guéguen and Renard, 2017). Faced with rising sea levels, two management paths are possible for the areas threatened by flooding. The concerned countries can choose either to give up the threatened territories to the sea, or to mobilize huge resources in coastal engineering (in competition with the other actions vital to survival, as noted by Dahlberg, 1994). As the need will become more and more pressing as time passes, it will not be possible to fight against the rising sea levels everywhere and at all times. Large coastal territories – which are presently urbanized and cultivated - will disappear under the sea. A group bringing together four associations[1], assuming the most probable climate hypothesis, suggests that 570 cities accounting for over 800 million inhabitants will be threatened by rising sea levels by 2050. More accurately, 270 power plants are located at an altitude below 5 m, and will end up under water by 2050 (Loury, 2018). It will be therefore mandatory to reorganize the remaining land territories, in order to relocate populations driven out by rising sea levels, but also to relocate the equivalent lost agricultural land, i.e. increase yield per hectare.

Effects of climate disasters

The increased frequency and/or severity of climate disasters is already the present reality. In the future, climate disasters will become commonplace, thereby putting an end to insurance, subsidies, mitigation systems, and so on. Indeed, an organized human society is able to provide compensation for exceptional catastrophes… as long as they remain exceptional. To date, the compensation systems allow actors to withstand disasters, so they do not trigger any notable evolution[2]. In the future, actors will be committed to change, including farmers. Indeed, agro-industrial agriculture is based on specialized farms – which grow the same crop over large areas, whether wheat, canola or banana. Yet, these farms are especially sensitive to climate disasters, whereas herb farms and farms combining several crops on the same plot (e.g. by agroforestry) are more resilient. Resilient systems are much trickier to establish and manage than agro-industrial ones, so much so that some groups are already training farmers in the new systems. Inevitably, the agricultural structures will evolve in this direction, under the pressure of both climate disasters and the third factor.

Effect of scarcity of fossil fuels for transport

The third factor is the increasing scarcity of fossil fuels for transport, entailing many restrictions on transport, especially long-distance. Indeed, our societies are largely dependent on fossil sources of energy, as is shown in the diagram (Figure 1) below. The diagram displays the average quantity of each kind of primary energy in use by a single inhabitant of the planet. It highlights the huge quantities of oil (red) in use and the small upper layer (pink) which represents all the new renewables (solar farms, wind power plants…) including biofuels (made from any crops, wood, waste, etc.).

[1] The C40: Cities Climate Leadership Group, the Global Covenant of Mayors for Climate & Energy, the urban Climate Change Research Network, and Acclimatise.

[2] After Hurricane Irma in the West Indies, the project is to rebuild housing on the devastated islands.

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Figure 1

Most researchers consider that there is no equivalent available resource and technology to replace oil as the "backbone resource of industrial societies" (Friedrichs, 2010; Turner, 2012). Huge quantities of oil are presently devoted mainly to transport of people and goods (Friedrichs, 2010). It will be impossible to replace this by the same quantity from biofuels. This would require unacceptable quantities of arable lands to be diverted from the provision of food crops. Consequently, biofuels will be reserved for priority activities such as medical emergencies or military operations (Radanne, 2006; Friedrichs, 2010). Agriculture will be forced to do without oil, inorganic pesticides, and fertilizers (Hignett, 1999; Van Vuuren et al., 2010). This inevitable situation will upset the management of biological soil fertility (Altieri et al., 2015), compelling farmers towards both composting organic waste and increasing crop diversity. Indeed, the solution is diversity: keeping either forest or grassland systems, or combining several crops on the same plot (e.g. agroforestry). In fact these systems are much more resilient (Malézieux, 2012) than others.

Yet, it will become expensive to send harvested crops out to far-away processing plants, and even to those located relatively close at hand. Today, in the European Union, raw agricultural products and food account for ¼ of road transport: 1/3 of the raw agricultural products travel less than 50 km, 1/3 travel between 50 and 150 km, and 1/3 travel more than 150 km. Regarding food, only ¼ is sold within a 50 km radius around the processing plant, 1/3 travel between 50 and 150 km, and the rest travels more than 150 km (Martinez Palou & Rohner-Thielen, 2011). Most agricultural products will be processed on-site, and consumed within a distance of a few km. Farmers will choose varieties of crops and livestock because they can be processed, stored and/or sold as close as possible to the farm. Only the farms located near the ports will still have the possibility of achieving large mono-varietal harvests, and loading them on international trade shipping. International sea-freight will involve scarce foodstuffs (coffee, salt…), and will be undertaken also to manage emergency situations (delivering to troubled areas). For the other farms, the energy cost of transport would be too high. We will return to this topic in the following description of the future agro-food value chains.

2- Results: Present and future models of agro-food value-chains

Because of the developments above, various business models are emerging (as summarized in Table 1) involving the whole value chain, and not the agricultural part only. Soon new models will go together with the ones born from the agro-industrial revolution. Some of them- like the first one- are a residue of “fossil capitalism” (Campagne, 2016), while the persistence of some others (e.g. no.3) are a faint signal of what is coming again.

Table 1

Type 1 “Today”.

This value chain model is a reality over nearly the whole of the planet, even if the less well-off populations do not have permanent access to it. It is the basis of the European World-Economy described by Wallerstein (1980). For the most part, it mobilizes only simplified agronomic knowledge and many material inputs (oil for tractors and transport, synthetic fertilizers and biocides). By any means (sea freight, rail freight, air freight) this model conveys across long distances not only commodities, but also delicate fruits and vegetables, and favors distribution in big outlets, via purchasing groups. It is the agricultural avatar of the society of “fossil capitalism” (Campagne, 2016).

In light of ecological and social consequences, this model uses rare resources (oil, synthetic fertilizers, plastic packaging) which are highly polluting, and which soon will no longer be available. Intensive agriculture has been proven responsible for some diseases (Loeillet, this issue), and dissemination of harmful molecules into the environment (Nicolopoulou-Stamati et al., 2016). In the West, this model has driven farmers off the land. It seems to be very efficient in the short term (regarding yield/direct human work involved), but it damages arable lands (organic matter loss, scarcity of water for irrigation), threatens biodiversity, and contributes to concentration of people in cities. Clearly, this model is not sustainable (Clark, 2011).

Type 2 “Amazon”.

The nickname of this model might be: anything, at any time…in metropoles. It was developed first to sell and distribute manufactured products to people living in densely populated zones, keen to avoid wasting time shopping. The main feature of this model is the distribution of any food – as if it was any other good- all year round. The food comes from any type of agricultural system (direct selling from the producer, organic agriculture, fair trade, intensive farming, etc.), provided that it is "organized" enough – thus excluding subsistence agriculture. Already present for canneries and processed food, the next frontier for the "Amazon" model would be the distribution of fresh food.

Its most obvious drawback is the huge ecological cost (Wakeland et al., 2012), and especially for packaging and transportation, because food is individually packed and distributed to the place of consumption. The increased pressure for road traffic networks in residential areas is another concern (Visser et al., 2014). From the social point of view, it contributes to the digital fracture, because an efficient internet service is mandatory for making an order. In fact, only the well-off and educated households in densely populated areas can afford it, which pushes the logic of individualization of services into the ridiculous. It thus contributes to widening inequalities between households living in the same area.

Type 3 "Cart".

People could see through this model a comeback by the "charrettes des quatre saisons", which could be drawn by animals or simply by hand, and which were a common sight in Paris each morning, in the 1960s, carrying asparagus, strawberries, apples or spinach, depending on the season. This model is common around Asian and African metropoles (as highlighted by Paganini and Schelchen, this issue). It is not very complex to implement (it is possible to grow small mono-varietal plots), but it is highly labor intensive (to grow, harvest, transport, and sell the food). It develops thanks to the green belts around cities, if not from urban agriculture itself (Servigne, 2013). Also, this model takes advantage of the synergies between vegetable/fruit farms and livestock farming, generating organic fertilizers. It can also yield shellfish, crustaceans and fish, stemming from the sea or from aquaculture (as can be seen on the pavements of Ho Chi Minh City), as well as dairy products.

From an ecological viewpoint, when farmers are educated enough to limit the use of synthetic fertilizers and biocides, the model helps preserve the natural environment, and is very frugal and energy-efficient. By recycling local nutrients (organic waste from household consumption, local collection of biomass, manure and organic sludge), it restores soil organic matter. In social terms, it brings value even to very small plots, and is highly labor-intensive. Thus, it provides employment and income to many people, surrounding cities and inside cities (Paganini & Schelchen, this issue). The main drawback is that it rarely provides energy foods (cereals and food oil), which are the staples.

Type 4 "Roman villa".

This model always combines farming of several livestock species and the growing of many different crops. Thanks to this variety, the villa system mitigates the climate risk, adapts to the small size of the local market, and spreads out the harvest periods. The Roman villa needs various facilities to process raw food (wheat and oil milling, wine cellars, cider presses, dairies, canneries). As already discussed, long-distance transport will become too costly for lay people. That is true for agricultural workers too. To date, they come from far-away places, to perform the most labor intensive agricultural tasks, such as fruit harvesting (e.g. in the South of Calabria). The "Roman villa" will need workers in the vicinity. It will take advantage of rural locations sufficiently populated by competent workers, or from the proximity of urban areas coupled with available short-distance collective transportation systems. The principal distribution channels of fresh produce will be the internal consumption, and transportation by temporary workers bringing back home fresh food, for neighbors and for their own consumption. The rest of the food will be processed and stored in the villa, to be distributed out of season, by slow and frugal means. Nearly everywhere on earth, this model can yield not only fruit and vegetables, but also the basic energetic foods (peas, cereals, fish, food oil, eggs, milk, cheese, etc.).

As for the original villas, the spirit of the new countryside Roman villa is self-sufficiency, gathering farms, vineyards, olive groves and so on. Indeed, the Roman villa "closes the loop" between nutrients, soils and harvests. It protects and restores soil organic matter, by combining livestock and crop farming. Today, the Roman villa distribution model already exists in the forms of "pick your own" farms, or other kinds of consumer-farmer contracts such as the AMAPs (community-supported agriculture associations) in France. Their present environmental performance is low, because the consumers are supposed to use their own car (Coley *et al*., 2009). Given the future prospect of oil scarcity, this environmental fault will no longer be an issue. From the social perspective, this model requires both many skilled and unskilled workers, as was the case in the old Roman villas. As the Roman villa model of *villa rustica* has lasted for over six centuries (an example is the Loupian Roman villa, in Hérault, France), it is likely a robust and fairly general model for the future. We come back to this point later on.

Type 5 “Survival”.

In the West, until the industrial revolution, natural climate risks and social constraints involved a few months’ famine (rationing period, when only one food was available) about one year in every decade. In numerous African and South-East Asian countries, rural populations still suffer from a “hungry season” just before harvest (du Pont de Romemont, 2014). On the other hand, since antiquity[3], food imports have been essential for feeding urban populations. To avoid chronic shortages, and to face recurring local climate disasters, large homogenous grain stocks will be placed under the control of a public authority. Harvests will be transported by rail or sea freight to the troubled places. The food stocks will be generated by large farms growing several crops (for instance durum or soft wheat, rice, cassava, maize, canola, Jerusalem artichokes, peas, beans), and located on favorable rich arable lands (Limagne, Ukrainian chernozem). The crop rotations should be long, in order to prevent soil erosion and to mitigate pest pressure. Spreading large quantities of organic manure -coming from livestock farms and/or from urban sewage[4] facilities- is essential to avoid humus loss.

In a nutshell, the farms are managed according to the principles of organic agriculture. Unfortunately, this model does not recover all the nutrients included in harvesting, especially, because the food is not consumed where the grain grows. Nevertheless, setting up this model where appropriate is justified, because its social utility is indisputable. Moreover, its future extension on arable lands will be limited to growing survival stocks.

Type 6 “Export foods”

In certain regions the variety of local crops will remain limited. It is thus justified to transport certain foods (seen as rare and expensive). The long-distance transport of precious fresh food has long existed (e.g. fresh shellfish in Dupont, 2012). In ancient times, ships intermittently berthed in harbors, bringing precious goods, including spices, salt, dried fruit, etc. This model will likely be present in the future, and will last over time. Goods will originate from areas able to export food, despite the new environmental situation. To make the point clear, we present an example. Within dry tropical climates, the Cavendish banana grows well in organic agriculture. In such locations, despite the proliferation of events such as storms, one can expect bananas to grow in the future (on plantations mixing several crops). But the banana will not remain a commonly consumed fruit any more. It will become a rarer and more expensive delicacy. It will be brought to temperate latitudes by ships consuming non-fossil energy. The same will probably be true for coffee, cacao, spices and some nuts, as was the case centuries ago.

Obviously, the transport of food generally impedes ecological performance. Moreover, it must be balanced in both directions (South towards North and North towards South), to enable fair return of organic matter to soil. It is worth noting that trade linking traditional Southern export products to the North is increasingly shifting toward South-to-South, with the support of international institutions (ITC, 2018). Nevertheless from a social perspective, export crops are often important for producers’ incomes, and for consumer well-being. If human beings are willing to preserve food variety by trade, ships propelled by solar or wind power remain by far the most frugal mode of transportation (Wingert, 2005).

Among the six models, the first is presently dominant, while the second is tending to develop (PIPAME et al., 2009). The literature confirms that the third and fourth are slowly emerging (Lamine et al., 2012). The fifth is not yet a major model for securing food for populations, but its agricultural aspect looks like the large organic farms as run in the USA (Clark, 2011). The sixth has existed for centuries.

3 - Discussion

The suggestions about the different emerging value chain models are largely convergent with those depicted by some authors (e.g. Clark, 2011; Servigne, 2013), and with various findings (Lamine et al., 2012). Table 2 sums up the main services rendered, and their advantages and drawbacks, according to the social and ecological scopes.

Table 2

[3] Thus the “Trastevere” hill, in Rome, was a mountain of amphora, which brought wheat, oil and wine to the capital of the Roman Empire, coming from everywhere around the Mediterranean, when the city had one million inhabitants (around the first Century BC).
[4] From new collection systems excluding pathogens and heavy metals!

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Because of their fatal drawbacks, we must do without both model 1 and model 2. Models 3 and 4 are both labor intensive, but can muddle through the pending scarcity of natural resources. The 5th will become a necessity to escape the "hunger gap", often experienced by pre-industrial societies. The 6th has always worked, from antiquity to the present day. Our conclusion is that we will experience a combination of the four models from 3 to 6, under the forms discussed below. We do not forget the issue of for the need for a large workforce in models 3 and 4. The direct effects of the implementation of this combination of models will generate permanent jobs in agriculture and processing, increase regular involvement of urban and rural populations in agricultural tasks (in addition to their own job), and will accompany a shrinking of city size.

Connection between the remaining models

The connection between models will be seen through the lens of food provision, but also regarding the governance which should secure the peaceful cohabitation between the different models.

According to us, the central model is the so-called *Roman villa*, which will develop in the countryside and close to the remaining urban agglomerations as well. We suggest that the new *Villas* will stem from one- and more likely from several- present neighboring farm estates, in order to provide all the necessary synergies. Each of the farms will diversify its own agricultural productions, while the whole will set up facilities to process and store foodstuffs. The villas will be the main and usual source of staple foods (cereals, meat, milk, canned food…) for neighboring persons. In the remaining small cities, more diversified seasonal foods (vegetables, fruits, fish, shellfish…) will be provided by the Cart model. In the future context, this model depicts the logical evolution of the small plots, or indeed the smallholdings, which surround cities today. It provides the possibility of relative food security to all households able to cultivate a plot, as long as access to land by all is a reality. The contribution to usual foods of the Survival model is zero… except in case of shortage. Moreover, by producing and preserving food for the long term, this model enhances the population's feeling of food security. In the harbor cities – and more marginally in the rest of the territories- the Export model will bring spices and foods coming from other continents (tropical fruits, coffee, cocoa, towards Northern countries, and Northern food towards Southern countries). Most of the present import-export flows of tropical fruits and vegetables will take place between Southern countries.

One can imagine any type of governance to run the Roman villas, from slave-based *latifundia* to worker cooperatives, because all types have existed in history. Conversely, the Survival model must be managed by an authority above any private interests (The State in a democratic system) for two reasons: 1) The purpose is to ensure food security, not to do business; 2) the harvest must not compete with the food produced by other models. On the other hand, the blossoming of the Cart model is based on secure access to land. The balance between the three models therefore requires democratic governance, or at least governance which seeks fairness. Regarding food imports and exports, their very long history has proven they can withstand nearly all forms of governance and situations.

Working on the farms

Some authors (Servigne, 2013) have already understood that we cannot leave the full weight of the agricultural tasks on the shoulders of the few remaining farmers in the OECD countries. Even if the "back to the land" trend continues, it would be still essential that current non-farmers be involved in the most demanding agricultural tasks (like fruit and vegetables harvesting and processing, or livestock prophylaxis and cheese making). Regarding French agriculture (Bâ et al., 2016), this accounted for the number of jobs gained and lost because of the ecological transition in the "Afterres scenario" (less meat and milk in diets, and organic agriculture blooming), in the economy as a whole. The result is widely positive in terms of job creation. However, this scenario does not account for the coming fossil fuel and mineral resource scarcity, which will restructure the value chains, and will make many other jobs necessary.

When it comes to comparing the six models in their agricultural aspect, something is striking. Indeed, there are only two possible patterns: i) either the model is acknowledged to damage the natural environment (no.1, no. 2) or to be prone to damage it (no. 5), while requiring a limited agricultural work force; ii) or the model is compatible with preserving nature (no. 3, no. 4), and demands a large agricultural workforce (and no less for processing and distribution). It seems that there is no other pattern. If we want to preserve nature, we must **agree to involve more people in the agriculture of the future**.

The new agriculture will use robust equipment, easy to handle, and using mechanical power instead of oil. We can find ideas from ploughs, harrows from the Swiss mountains and from agricultural tools of Asian and African peasants. To do without pesticides, Reboud et al. (2017) advise "widening the range of mechanical

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weeding tools", and so "extending the management of weeds by manual sarclage[5], widely including certain main crops which not previously used it" (Reboud et al, 2017:7).

To adapt agriculture to these new conditions, it is advised to fine-tune "a range of species and plant covers for inter-crop intervals[6] built according to the criteria of easy management" (Reboud et al., 2017:7), and also varieties adapted to sarclage.

Concerning livestock, two trends will shape the picture: a shrinking livestock pool consuming cereals (mainly pigs and poultry, farmed fish, then fattened livestock in developed countries), and the need for processing of forages (Clark, 2011), draught and transportation animals. Indeed, the majority of mobile agricultural tasks will depend on draught animals, while static tasks (crushing grains…) will make use of wind and hydraulic power.

Towards smaller cities

According to the four associations quoted above and with regard to cities, Global Warming will entail killer heatwaves (regularly involving 1.6 billion people by 2050, versus 200 million today), difficult access to drinkable water and food insecurity (Loury, 2018). We can calculate the "food print" of cities in terms of land use, as trialed by Seona Candy et al. (this issue) for Melbourne. In the future, feeding cities using their surrounding land seems to be the cleverest solution (and maybe the only one which will still be available because of transport scarcity). Today, the average food print of one Earth inhabitant is 0.2 ha (1.5 billion ha arable land/7.5 billion people). Keeping this modest requirement in mind, it means that a town of 10,000 inhabitants will have a food print of 2,000 ha (i.e. 20 km²). Therefore, the city (even standing for one point) will lie in the center of a circle of a radius of at least 2.5 km, provided the surrounding areas are on good arable lands. The food print thus calculated of a town of 1000 inhabitants would be only 200 ha (*i.e.* 2 km²), and would occupy the center of a circle of a radius of around 798 m.

Table 3

Table 3 (my own calculations) displays an approximate evaluation of the food print of the city in hectares (N Number of inhabitants x 0.2 ha per capita) and of the minimum required distance between cities of the same population size, when the surroundings are favorable. The supposed circular surface covering the food print is also calculated by the equation $\pi \times R^2$ (R is the radius of the circle). It emerges that:

$$N \times 0.2\text{ha/capita} = \pi \times R^2 \text{, and so}$$

$$R = \sqrt{N} \times \frac{\sqrt{0.2\text{ha/capita}}}{\sqrt{\pi}}$$

As the distance D between two similar cities (represented by a point) must be 2 times R at least, the calculation of the distance D is given by the following equation (1), by rounding the value of D, considering the two cities themselves to be only a point, which is another approximation:

$$D \geq 2 \times R = \frac{2 \times \sqrt{N} \times \sqrt{0.2.10^{-2}\ \text{km}^2}}{\sqrt{\pi}} \quad (1)$$

Where:

D: Distance between two similar cities in km

R: Radius of the circle around one city

N: number of inhabitants in one city

"0.2.10⁻² km²" is the average food print of one Earth inhabitant in km².

When the surroundings are not favorable (for instance, when the city is surrounded by suburbs and urban spread), the distance to find arable land may be so high that it makes the survival of the city as such very

[5] Sarclage is the operation to remove or to cut weeds from crops, using a manual tool (e.g. hoeing).

[6] Crops which are not harvested, and which cover soil between two harvested crops, pursuing different aims (protecting soil from erosion, enriching it, competing with weeds…)

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unlikely. The conclusion seems quite clear. We are heading for shrinking cities, for simple thermodynamic reasons.

Final considerations

We expect the picture painted of the future of agriculture and food systems will help us to think carefully about what changes will be needed in food production, processing, distribution and consumption. We caution companies and administrations against fashionable “temptations”. Indeed, certain innovations can be viewed as advantageous in the short term, but they will not contribute to the emergence of a frugal economy. Assessed in the life cycle spirit, certain trendy business models such as home delivery and high-tech solutions are not always environmentally friendly. Individual products by home delivery is costly in terms of energy (Wakeland et al., 2012), and can develop only by using underpaid delivery staff. High-tech solutions use instruments fed with precious metals, and are very expensive in terms of energy. High-tech solutions can be seen as a headlong rush towards a pointless spree of consuming natural resources (Bihouix, 2017).

The value chain models of the future will be frugal… or they will not last long. If the innovation involves material support, it has to be “low-tech”, which means sparing rare materials (whose ores are depleting), easy to maintain (not requiring specialized experts from the other end of the world), repair and recycle. It will be run without fossil energy. Conversely, the innovation must be labor and skill intensive. The issue is not only to save materials or to adopt recycling. Those activities are welcome and necessary, but this is not enough. The point is really to head for the more autonomous models described above (3 to 6). Within farms, protecting and improving biodiversity is the top priority, because the agriculture of the future will be able to feed the planet only to the extent that it rests on sufficient biodiversity. Indeed, biodiversity “has key roles at all levels of the ecosystem service hierarchy” (Mace et al., 2011: 19). The processing of agricultural products offers many opportunities for business. For instance, new universal multi-product canneries (dairies, salting vats, mills…), will be needed, running on renewable energies, easy to manage and to maintain. They will remain small, and will be scaled according to the size of the served farm(s), because they will prioritize supply of local markets (Clark, 2011). They will need a huge design effort. Indeed, the new design runs counter to the current specialized design. It is important to imagine new short-distance modes of transport (Dennis and Urry, 2009) also.

The future will be restrictive on centralized complex systems, where the division of tasks is high. Indeed, their smooth running depends on the (nearly miraculous) conjunction of numerous actors. On the contrary, the ongoing evolutions are favoring decentralized systems, which are simple on the technical scope, independent from remote interventions, but depend on human and material resources available in the vicinity. This aspect is especially crucial for the agro-food systems, as argued here. The systems flourishing tomorrow will not be the ones which invest in high-tech today, nor the ones which rush ahead with the processing of agricultural goods. On the contrary, it is the systems which cleverly develop low-tech that will flourish.

The life of unskilled people is changing too: working part-time in the fields, scarcely eating meat[7], experiencing more healthy diets, but less varied diets at different times of the year. Of course, it will be less easy to travel far away for everyone also. Do we stress that we are heading for the end of the “customer is king” paradigm? Equally, the proportion of household income devoted to food will be much larger than today. In any event, life will be so different that these are only minor aspects of the coming changes.

The emergence of the new ways of life is devaluing the current notion of economic (in fact, the correct term would be “financial”) value, rooted in the search for ever-lasting economic growth. What will the new measure of value be? The decisions must be rooted in new criteria. According to Dahlberg (1994) “*shifts will be required in the evaluative criteria we employ- whether for society at large or for particular sectors like agriculture. Basically this involves a shift from economic growth and productivity criteria to health criteria- where the health of interacting natural, social and technological systems at different levels is evaluated over multiple generations*” (Dahlberg, 1994:174). We reckon that the decision-making tools indicating the fair way right now, are based on an anticipated assessment of improvements regarding the health of human populations and ecosystems. Any change might be assessed in terms of progress in population and ecosystem health. Health is the measure of the future.

[7] Today, 2/3 of the cereals crop are used to feed cattle, that is not sustainable.

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