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# Agriculture and degrowth: State of the art and assessment of organic and biotech-based agriculture from a degrowth perspective

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ABSTRACT

Agriculture stands as the foundation of modern human societies. Any changes in social functioning should seriously consider how to guarantee people a proper supply of food, in terms of both quantity and quality. Degrowth is a movement that aims at achieving a radical change in the societal metabolism of societies, toward a more frugal, sustainable and convivial lifestyle. The movement envisages a society where concepts as sharing, conviviality, care, commons, justice could stand at its foundation, and replace the call for economic growth, which is, obviously, biophysically unsustainable. This paper aims to (1) review how agriculture has been addressed within the degrowth discourse, (2) analyse the relation between agriculture and societal metabolism and its relevance from a degrowth perspective, (3) discuss how different agricultural techniques and technologies may represent appropriate technologies (*sensu* Schumacher, 1973), and meet the call for conviviality (*sensu* Illich, 1975). The latter point focusses on a comparison between organic agriculture (OA, which bans the use of agrochemicals and Genetically Modified Organisms - GMOs) and biotech-based agriculture (BTA, reliant on GMOs). The paper points out that although many relevant socioeconomic, political and environmental issues have been addressed by degrowth scholars, agriculture is still poorly analysed. Recommendations are made with regard to studying possible alternative transition paths, by assessing their impact on society's structure and functioning. It is argued that "conviviality" and "appropriate technology" concepts are rather complex and multifaceted. Therefore, different practices might be considered convivial and appropriate under some criteria, and not under others. With regard to conviviality, organic agriculture might not fully respond to the call for autonomy. Notwithstanding claims made by GMOs supporters, BTA does neither suit the call for appropriate technology, nor represent a convivial tool under any criteria.



## 1. Introduction

Agriculture stands as the basis of human life; therefore, it is important to adopt management strategies to preserve our support system and enhance its resilience, *i.e.* its capacity to recover from stressors (but slightly different definitions exist[1]). It is also important to reduce the impact of agricultural activities on resources, on the environment and on human health. The problems caused by intensive agriculture have been widely discussed. They include depletion of soil fertility and soil erosion, the wide use of harmful agrochemicals (Stehle and Schulz, 2015, argue that water contamination from pesticides should be considered a planetary emergency), large GHGs emissions (particularly in relation to livestock and land use change), the depletion of the water table and biodiversity loss (Foley et al., 2011; Gomiero et al., 2011a; Gomiero, 2016). More sustainable agricultural practices should be devised to reduce such impact, also in view of the challenges posed by climate change, fossil fuel depletion, and the rising global food demand, as world population is expected to grow from the present 7.5 billion to 8.5–9 billion in 2030, and to about 10 billion in 2050 (Alexandratos and Bruinsma, 2012; Gerland et al., 2014; UN, 2015). Scholars working within the mainstream "growth paradigm"

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[1] Resilience can be defined as the capacity of a system to recover from stressors (Carpenter et al., 2001; HLPE, 2012). Gunderson and Holling (2001), refer to resilience as the magnitude of disturbance that can be absorbed by a system before the system changes its structure by changing the variables and processes that control behaviour, and describe it as "ecosystem resilience".

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envisage that solutions can be found in "more growth", *i.e.*, increasing economic growth, more technology (*i.e.*, adoption of Genetic Modified Organisms - GMOs), pushing productivity, more free markets, more globalisation (The Economist, 2010; Carlson, 2016; Taylor and Uhlig, 2016). In a 2010 editorial, The Economist titled "Economic growth: The solution to all problems" (The Economist, 2010). A different view is taken by people working within the "degrowth paradigm". Such scholars believe, instead, that the proper answer to our increasing problems should be found in the reduction of societal metabolism (reduction in the flow of energy and materials transformed by societies). This should be coupled with a reorganization of society toward a more convivial and frugal lifestyle aimed at self-sufficiency (e.g., Illich, 1975; Latouche, 1993, 2012; Kallis et al., 2012a). The degrowth movement envisages a society where concepts as sharing, conviviality, care, commons, justice could stand at its foundation, and replace the call for economic growth, which is, obviously, biophysically unsustainable [see D'Alisia et al. (2015), for a review of the concepts].

The paper aims to (1) review how agriculture has been addressed within the degrowth discourse, (2) analyse the relation between agriculture and societal metabolism and its relevance from a degrowth perspective, (3) discuss how different agricultural techniques and technologies (e.g., organic farming, GMOs) may fit into the degrowth discourse. The paper is organised as follows: Section 2 provides a review of the concept of degrowth and analyses how agriculture has been addressed by degrowth scholars. The paper focuses in particular on food procurement. It has to be pointed out that degrowth scholars carried out much work concerning non-food crops (e.g., the impact of biofuels), with particular reference to conflicts with food production and environmental justice issues (Martinez-Alier, 2012). Although this is surely an important issue, in this paper I focus on the analysis on food production as "endosomatic energy flow", i.e. the energy that flows and is metabolized by humans to sustain themselves (Giampietro et al., 2012, 2014; Sorman and Giampietro, 2013). (The "exosomatic energy flow" refers instead to the flow of energy that humans control and use to manage and sustain their external activities and environment). Section 3 analyses the relation between energy efficiency in food production, energy flow (both as food and as the amount of energy provided by energy carriers) and societal metabolism. The degrowth movement is very concerned with energy issues, such as peak oil (Hall and Day, 2009) and the decreasing efficiency of energy production, concerning both fossil fuels and renewables (Kallis et al., 2012a, 2015; D'Alisia et al., 2015). It is argued that a transition to renewable energies will inevitably support smaller economies, and that it will be a degrowth transition (Kallis et al., 2015). Discussions often focus on declining EROI (Energy Return On Investment, or EROEI, the Energy Return on Energy Invested), (e.g., Kallis et al., 2012a, 2015) i.e. the amount of energy returned from one unit of energy invested in an energy-producing activity (Hall et al., 1992, 2011). In this section, it is pointed out that, in order to better understand the role of agriculture in societal metabolism, energy flow per time unit (labour), i.e. the power of the agricultural sector, is also a very important indicator to study societal transitions (Giampietro et al., 2012, 2013, 2014). Departing from concepts of efficiency, power and societal metabolism, an analysis of some scenarios envisaged by the degrowth movement is carried out (*i.e.*, the possibility to achieve food self-sufficiency on low-input traditional agriculture, basically without the use of agrochemicals and with a limited amount of fossil fuels). Section 4 reviews how different agricultural techniques and technologies, namely organic agriculture (OA) and biotech/GMOs-based agriculture (BTA), may fit into the degrowth discourse and represent "convivial tools" (*sensu* Illich, 1975), and "appropriate technologies" (*sensu* Schumacher, 1973; see also Kirk, 1982). The above agricultural practices are discussed because organic agriculture is often referred to in works concerning degrowth and biotechnology are proposed as a sustainable way forward by those who back the growth paradigm. It has to be pointed out that these two concepts, although crucial for degrowth, are actually part of a broader and more complex discourse (see D'Alisia et al., 2015). Given the space constraints associated with this type of publication, I chose to focus only on these key concepts. Section 5 offers some conclusions.

## 2. Degrowth and agriculture: state of the art

This section first provides a brief review of the development of the idea of degrowth, with particular reference to natural resources; it then focuses specifically on agriculture and degrowth.

### *2.1. The limits of growth and the raise of the degrowth movement*

The roots of the degrowth movement can be traced to the discussions that took place in the 1960 and early 1970s concerning the fossil fuel crisis and the side effects of fast industrialization, and to the publication of the *Limits to Growth* report by Meadows et al. (1972), concerning the risks lying ahead if humans continue to consume natural resources and pollute at an increasing rate (Ellwood, 2014; Asara et al., 2015; Kallis et al., 2015). The first analysis of the deleterious and uneconomic effects of growth was probably provided by economist Ezra J. Mishan, of the London School of Economics in his book *The cost of economic growth* (1967).[2] The term degrowth (décroissance in the original French publication) was introduced in 1972 by André Gorz[3] in a discussion organised by Le Nouvel Observateur in Paris, as a follow-up to the *Limits to Growth* report (Gorz, 1972; Asara et al., 2015; Kallis et al., 2015) (published under the pseudonym of Michael Bosquet). Gorz was an Austrian leftist intellectual and philosopher (an engineer by training), who wrote extensively on the theory of society, on political ecology and against the capitalist idea of society. Latouche (2016), in his broad review of the notable figures who shaped and influenced the degrowth movement, refers to Jacques Grineval's 1994 edition of essays by Georgescu-Roegen (first published in 1979), as the occasion that made the term degrowth (in French *décroissance*) widespread within the movement. During the 2000s, in France, the term *décroissance* gained popularity and was adopted in scholarly works and in the press (Kallis et al., 2015; Latouche, 2004, 2006, 2016; see also entry "Décroissance (économie)" in wikipedia[4]). By the mid 2000s, the term was adopted in Italy (*decrescita*) and Spain (*decrescimiento*) (Kallis et al., 2015; Latouche, 2016). In 2003, in the English edition of Le Monde Diplomatique, Latouche (2003) uses "downscaling" as a possible English translation of *décroissance*. In a subsequent 2004 article by Latouche, in the same monthly newspaper, *décroissance* is translated as "degrowth" (Latouche, 2004; see also Latouche, 2006). As "Degrowth", the term had already been used by Latouche in a 2007 publication in The International Journal of Inclusive Democracy (Latouche, 2007a). The English term "degrowth" started to appear in scholarly works in the English language in 2008, at a conference

[2] Mishan was working on the topic already in the early 1960, and had his book ready by 1965, but was unable to find a publisher till 1967, as the publishers he contacted considered the work unsuitable for publication (Mishan and Turner, 2006).

[3] Gerhart Hirsch was his true name; he changed it during the WWII, to hide his Jewish origins.

[4] https://fr.wikipedia.org/wiki/D%C3%A9croissance_(%C3%A9conomie)#cite_note-1.

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on degrowth held in Paris (Kallis et al., 2015).

During the late 1960s and early 1970s, important criticisms to the unsustainability of society's growth process were made by notable scholars from different disciplines such as ecology, economics, sociology and politics. Broadly speaking, two lines of thought developed, representing the interests of these different disciplines. Some scholars were somehow more concerned with the biophysical dimension of the growth-degrowth debate. They addressed issues such as the unsustainable economic cost of growth (e.g., Mishan, 1967), the possible collapse of human societies due the exhaustion of natural resources and energy (fossil fuels) (e.g., Ehrlich, 1968; Meadows et al., 1972), the need to reduce consumption and population growth (Ehrlich, 1968; Ehrlich and Holdren, 1971; Hardin, 1968, 1993), the need to develop new systems of accounting merging the biophysical and socioeconomic dimension of development (e.g., Georgescu-Roegen, 1971; Odum and Odum, 2001), and the importance of addressing the ecological basis of human societies (Commoner, 1971, 1975). Others were more concerned with the social, political and cultural dimension of the issue. Their work was mainly focused on the need to create a new, more human-oriented society, based on a different paradigm (e.g., Gorz, 1972; Schumacher, 1973; Illich, 1975 - for a review of authors see Kallis et al., 2015; Latouche, 2016). In the 1980s, the issue gained momentum and a new generation of scholars became involved in the debate (see the reviews by Ellwood, 2014; Latouche, 2016), and new disciplines were established, aiming at tackling the relation between resources and society functions, such as Ecological economics (Martinez-Alier, 1987; Costanza, 1989).

However, bridges were often crossed. Ecologist Paul Ehrlich (often criticised by social scientists for placing emphasis on the population issue), was very critical towards the opulence of industrial societies. Such “overdeveloped countries”, he argued, “… *consume a disproportionate amount of the world's resources and are the major polluters*.” (Ehrlich, 1968, p.7). This, to a certain extent, makes Ehrlich a precursor of the environmental justice discourse. His call for population reduction does not address only developing countries, but also industrial ones, where a person's impact is much higher (Ehrlich and Holdren, 1971). Of course, some of his forecasts were proven wrong. In his 1968 book *The population bomb* (Ehrlich, 1968), he warned that there was not enough food to feed the world population, and forecasted a “massive famine” to occur in the 1970s (Ehrlich, 1968, p. 25). This was not the case, thanks to a large expansion of agricultural land (by about 20%), at the expenses of natural ecosystems, and to a sustained intensification of agriculture relying on the massive use of fossil fuels to produce agrochemicals, and fuel agricultural mechanisation and irrigation systems (Smil, 2000; Conway, 2012). Commoner (1971, 1975) argued that it is poverty that triggers the rise in population, not the other way round, and concluded that poverty is the main cause of the population crisis. On the other side, Illich (1975) wrote about the importance of addressing the population issue, as other early social scholars (Latouche, 2012). Schumacher (1973, 1979) was concerned with how to develop appropriate technologies that could fit the need of poor countries.

In later decades, degrowth came to be identified with a social movement aimed at establishing a new and more sustainable society, based on different social values, new technologies and a new way to intend economic development (that should not be intended as a synonym of growth). Degrowth, therefore, touches upon all aspects of social life and upon its core mechanisms (Demaria et al., 2013; Videira et al., 2014; Asara et al., 2015). The recent publication “*Degrowth — A vocabulary for a new era* (D'Alisia et al., 2015) provides a comprehensive coverage of the main topics and challenges of degrowth. Latouche (2009, namely: Re-evaluate, Reconceptualize, Restructure, Redistribute, Relocalize, Reduce, Re-use, Recycle) defines degrowth as “… *a political slogan with theoretical implications,… designed to silence the chatter of those who are addicted to productivism*.”, but then describes it as a utopia to bring attention to the issue. According to Kallis et al. (2015, p. 3), “*Degrowth signifies, first and foremost, a critique of growth …. “Sharing”, “simplicity”, “conviviality”, “care”, and the “commons” are primary significations of what this society might look like*.” Degrowth will involve a decrease in GDP as currently measured (Schneider et al., 2010; Kallis, 2011) as well as a transition to a lower metabolism, towards a steady-state economy and a more convivial and frugal society (Kerschner, 2010; Schneider et al., 2010; Kallis, 2013); “… *a stable and equitable downscaling of society's throughput*.” (Kallis, 2013, p. 95).

Given that alongside the exhaustion of resources we may expect an economic decline to take place, it is of crucial importance to envisage alternative and sustainable ways to manage the social fabric. In these times of generalised crisis, the message put forward by the degrowth movement is extremely relevant, and new models of development are needed. A lot of work has been done by degrowth scholars concerning many social issues. However, it is now important that actual scenarios are worked out (in a participative way, including different social actors, researchers and policy makers) to instigate a learning process by which we could better grasp how new models of society could function, bringing together the socioeconomic and biophysical dimensions of degrowth.

### *2.2. Degrowth and agriculture: A literature review*

Since the early 1970s, many works have been published about degrowth (with degrowth I refer broadly to a school of thought, not to the moment in which the terms appeared in scientific publications). In the last decade, many papers concerning degrowth appeared also in scientific journals and dedicated special issues.[5] Degrowth scholars did a massive amount of work on social issues and environmental justice, as well as on more technical topics such as urban and industrial ecology, and peak oil (see for example the list of topics in D'Alisia et al., 2015). Nevertheless, research on agriculture is still lagging behind.

A search for works concerning agriculture and degrowth was conducted in scientific journals, books of proceedings and books. An in-depth google and google scholar search was carried out in order to identify grey and lay publications, in addition to scientific literature. A few scholarly works mentioning agriculture were found, but none included scenario analyses. Within grey and lay literature, only one work provided a model of agriculture in a degrowth scenario (P.M., 1983). Agriculture and the food system are rarely discussed (usually in brief) in papers, books, short conference papers, or in other electronic material. Lay publications, such as P.M. (1983), are to be praised for their attempt at tackling the issue; however, the analyses provided tend to simplify matters, leading to overly optimistic conclusions about the performance of a rural, low-input, self-sufficient society.

Within the scientific literature on degrowth, the work by Infante Amate and González de Molina (2013) on the Spanish agri-food system is the only scientific paper that touches upon the issue. According to Infante Amate and González de Molina (2013, p. 32), “*Economic degrowth, in order to be sustainable, must pay particular attention to how this process is carried out. We think that only a shift towards organic farming and corresponding changes in consumption*

[5] See Kallis et al. (2010) in the Journal of Cleaner Production, vol. 18; Kallis et al. (2012b) in Ecological economics vol. 84; Cattaneo et al. (2012) in Futures, vol. 44; Sekulova et al. (2013) in the Journal of Cleaner Production, vol. 38; Kerschner et al. (2015) in the Journal of Cleaner Production, vol. 108.

*patterns can contribute to substantial reductions of resource use in the food system and to sustainable degrowth*". The authors, paraphrasing the 8 Rs proposed by Latouche (2009, namely: Re-evaluate, Reconceptualize, Restructure, Redistribute, Relocalize, Reduce, Re-use, Recycle), propose the strategy of the 4Rs: namely: re-territorialisation of production, re-localisation of markets, re-vegetarianisation of diet, and re-seasonalisation of food consumption, as the way forwards for degrowth. Yet the paper does not explore what that would mean for the Spanish food system and the country's food security. Jackson (2009) briefly addresses the impact of intensive farming and calls for a more sustainable agriculture, offering only some general warnings. The systemic approach provided by the Odums (Odum and Odum, 2001) has great merit as it addresses the energetic and EMergetic constraints of societal metabolism. With EMergy (Embodied energy), H.T. Odum (1971, 1988) referred to the available energy of one kind previously used up directly and indirectly to make a product or service. Nevertheless, the authors do not apply it further in their work, to provide scenarios concerning the functioning of a society organised differently.

In a review by Schneider et al. (2010) on the state of the art of "degrowth thought", agriculture, farming and food are not included. In the recent "*Degrowth: A vocabulary for a new era*" (D'Alisia et al., 2015), agriculture, farming, and the food system are included. "Urban gardening" is the only entry that touches upon agriculture, focusing on the social dimension of the production of vegetables in urban areas. In an exchange of comments concerning the content of the Vocabulary between one of the authors of the book (G. Kallis), and another degrowth scholar (B. Davey) (Kallis, 2014; Davey, 2014), a long list of topics are discussed that should have deserved to be included in the Vocabulary. Agriculture was not mentioned.

The fact that the primary production system is still an underdeveloped territory within degrowth studies has been addressed also by some degrowth scholars. Kallis et al. (2012a, p. 178), in their section "5. Future Research and Conclusion", point 5, "Economic and metabolic scenarios", do actually address agriculture as a topic for which future research is needed, "*What would plausible degrowth futures at the national, regional or local level look like? How much would people work, paid and unpaid, how much materials,* ***food calories or energy would they consume, how efficient would they be in their production, how many will they be****? This is an exercise of putting numbers to degrowth proposals agriculture and food system as a matter of future research*" (words highlighted in bold are the author's). The recent review by Videira et al. (2014) on degrowth pathways, also cites "Agro-ecology" and "food sovereignty", as "Main topics of degrowth proposals" (Table 1, p. 60), as topics related to the "Overarching questions" "Can we feed the world with locally produced organic food and if yes, how?"

### 2.3. The importance of producing sound scenarios on agriculture and degrowth

Degrowth supporters call for the adoption of a more frugal lifestyle, based on local production and food self-sufficiency, and of short food chains (urban agriculture perfectly represents this model) (Latouche, 1993, 2008; D'Alisia et al., 2015). Some people envisage a somewhat autarchic society (Latouche, 1993; Pallante, 2005, 2011 - Maurizio Pallante is a leading figure of the Italian degrowth movement). Latouche (1993, p.164–166), distinguishes between "auto-subsistence", where the farmers of a country would produce only for their survival, turning their back to the market (and to the urban population), and "self-sufficiency", where farmers would produce a surplus for the market, able to feed the urban population of the country. Nevertheless, this policy, according to the author, should have the global market as a benchmark. However, this relies on the assumption that a country has enough agricultural land to produce all the food it needs, and sufficient internal energy and natural resources (i.e. fuel, machinery, labour) to run agricultural activities. This may not be the case for European countries, for example.

Some authors (e.g., Latouche, 1993, 2008; Pallante, 2011; Kallis et al., 2015) argue that a more rural society relying on renewable energies would be able to quickly create hundreds of thousands of new jobs, thereby helping to reduce unemployment. At the same time, a working week of four days should also be possible, and allow people to dedicate themselves to cultural activities and social relations (Kallis et al., 2013). While such ideas can offer food for thought, actual research on agriculture and degrowth is much needed in order to start providing models and scenarios for public debate. Feasibility (the compatibility of the effort with the external constraints imposed by the environment), and viability (the compatibility with internal constraints) analyses are needed to provide insights on the potentials and constraints of agricultural practices (Giampietro et al., 2013, 2014). Giampietro points out that the concept of "desirability" (compatibility with human expectations), is also relevant when addressing sustainability, as there can potentially be viable solutions that people might not like or accept (Giampietro, 2004; Giampietro et al., 2013, 2014). Large-scale scenario analyses will allow scaling up local production systems, and check whether, and how much, local food self-sufficiency, short food chains, and low-input farming practices are compatible with a country's food security, and how new farming practices would impact on its societal metabolism. At present, this is a key step forward that needs to be taken. Alternative agricultural practices have been suggested that are surely of interest. Nevertheless, a sound analysis of the role they might play in sustaining society, or of how society should change to rely on such agricultural practices, is still missing. For example, permaculture has been referred to as a sound model for food production (e.g., Latouche, 2012). Nevertheless, to date, there are no scientific publications, and, to my knowledge, no other publications either, presenting sound data concerning the performance of this type of farming system (see also Gomiero et al., 2011a). Lately, Ferguson and Lovell (2014, 2015) published two reviews confirming that data concerning the performance of this practice are still missing. Therefore, at the moment, it is not known how much food permaculture can supply, nor at what cost, both financial and environmental. Concerning organic agriculture, quite a few works are available on its performance (Gomiero et al., 2011b; de Ponti et al., 2012; Seufert et al., 2012). Nevertheless, the overall sustainability of organic agriculture is still debated, and there is a lack of scenario analysis in relation to the impact of a large-scale transition to low-input agriculture on the food system and society. That is to say, linking the agricultural system to societal metabolism. Georgescu-Roegen advocated the adoption of organic agriculture, but he was aware that a reduction in yield was to be expected. Therefore, he argued that population should be reduced accordingly, "*mankind should gradually lower its population to a level that could be adequately fed only by organic agriculture*." (Georgescu-Roegen, 1975, p. 378). Kallis et al. (2015, p. 7) also recognises that "*A solar civilization can only support smaller economies, given the low EROI of renewable energies compared to fossil fuels. A transition to renewables will inevitably be a degrowth transition.*" It is important, then, to carry out sound research on what the transition implies, e.g., how many people can we expect to be living in a new solar-powered society? With what standard of life?

A process of deintensification of agriculture is certainly needed, in particular in regions such as Europe and the USA. Nevertheless, different realities face different problems. In some densely populated areas of Asia, de-intensification may not be possible due to the high demographic pressure and the lack of economic resources to import more food (Smil, 2000; Conway, 2012; Seufert et al., 2012). Concerning deintensification, the issue of how much a return to a more rural, self-sufficient society is biophysically feasible and viable in the long-run, and how this can be desirable for people, should be properly addressed. For example, turning European society into self-sufficient, no-inputs family farms may not even be feasible, because of a simple biophysical constraint: the lack of land to meet the food demand of its large population. Let us consider Germany as an example. Below, Table 1 illustrates the feasibility of Germany becoming self-sufficient under traditional/organic farming, using the currently available data. Germany has a population of 82 million people, and its arable land amounts to 11,846,000 ha ("arable land" is the term used to describe the most productive land). To maximise the production of calories for Germany to feed its people, the following rather optimistic assumptions are made: all soil is of the best quality, best practices are used and best yield obtained. Full mechanisation is available, irrigation is available when needed, pest and weed control is provided and fully effective. There are no losses in the production-food chain (losses may reach 20%). To maximise the production of calories and protein, while providing a natural fertilisation of fields, wheat-pea rotation is assumed as the farming system. It is also assumed that all peas are used as human food; no animals are fed with crops from arable land. Yield for conventional wheat in Germany is 7t per ha, and 3t per ha for organic wheat (EC, 2013), a good yield of organic peas is about 4t per ha.

*In the field:* In some years, yield has to be expected to be lower due to pests and climate extremes; Phosphate fertilizer should be added, or alternatively composted manure has to be applied every four years (that would require livestock to be fed, reducing the amount of crops for humans); The rotation cannot be sustainable, as pest outbreaks would emerge, a one-year break should be introduced after a rotation, or other crops used.

*In the food system:* A conservative 10% losses in the food chain (field, storage, etc.) should be accounted for. If that is done, the production system fails to cover the cost of the basal metabolism; The diet is too poor in fats and other key nutritional elements, that required an important fraction of the arable land be allocated to different crops and to feed animals; If fossil fuels are not used, a lot of animal power is required for the farm works. That means that some land should be allocated to feed the animals.

From Table 1 we see that, even using all the country's arable land to crop wheat and peas (to have a mix of energy and proteins) and assuming maximum productivity, no animals to be fed and zero loss in the production chain, the productivity (7.5 $10^{13}$ kcal $yr^{-1}$) would barely suffice to sustain the population's basal metabolism (6 $10^{13}$ kcal $yr^{-1}$ assuming an average energy intake of 2000 kcal cap. $day^{-1}$), and fail to meet the energy demand of an agrarian society whose work is physically demanding (9 $10^{13}$ kcal $yr^{-1}$ assuming an average energy intake of 3000 kcal cap. $day^{-1}$). If we consider that the real productivity may be lower than the highest possible, as assumed in the model: 10–20% of the production may be lost along the food chain, an animal population is to be fed, and other crops, with lower energy and protein content, have to be cropped in order to have a more balanced diet, we may conclude that under old traditional farming practices ("traditional organic agriculture" Tello et al., 2012), or current organic agriculture, German agriculture may sustain maybe 50%, or less, than the present population, and provide a much lower quality diet (perhaps facing hunger in winter time). If intensive agriculture were to be allowed, but not food imports, the German population would have to put up with a diet based mostly on the direct use of cereals (no beer allowed!). Estimates suggest that to provide for a vegetarian diet, a minimum 0.1 ha per capita are necessary, while 0.15 ha per capita are needed if some animal products are added (Smil, 2000). Of course, the example provided in Table 1 is completely hypothetical and far from reality. We should also account for the demand for labour (if fossil fuels were to be excluded, maybe an 80–90% of the population should be working in the fields), the final cost of the food, as well as the overall effect on the organization of society (on the latter issue see Sorman and Giampietro, 2013). To conclude, if the urban population (75% of the German population, WB, 2016b), were to be become rural, with most families relying on their own farm's production (as some proponents of degrowth seem to suggest, e. g, Pallante, 2005, 2011), there would be little agricultural land left to crop. The environmental impact of this ruralisation process would be devastating and the socioeconomic cost enormous: it would be impossible to deliver to people even the most basic services. This is not to say that it is not possible to have a more rural society and reduce the environmental impact of agriculture (which we actually urgently need - Foley et al., 2011; Gomiero et al., 2011a; Stehle and Schulz, 2015), but that we have to analyse the possible impacts that such changes may have on the functioning of society, and the feasibility, viability and desirability of the potential alternatives.

### 2.4. Agriculture and population: a link that has to be addressed

Population pressure plays a key role in the functioning of agriculture: the larger the population, the greater the amount of food that has to be provided and the higher the intensification of agricultural systems (Smil, 2000; Giampietro, 2004; Mazoyer and Roudart, 2006). Along with agriculture, population is also a topic that has not been studied much by degrowth scholars. While many earlier degrowth scholars were concerned with the issue (in the early 1960s, Schumacher also worked on models, see section 4 for details), with time, it seems that the topic faded out of research interests/agendas. Recently very few works have addressed the issue. Kallis et al. (2012a), in the section "Future Research and Conclusion", mention population as a topic on which more work needs to be carried out. Considering Ecological economics related to degrowth, Alcott (2012) is one of the very few authors who have recently produced scholarly work on the issue. He states that "*In the early years of ecological economics analysis of population size was often explicit, including advocacy of population-reducing policies … . The topic has since diminished in importance.*" (Alcott, 2012, p. 116), and concludes that humanistic hopes have to face with biophysical limits. Kerschner (2010) provides an important contribution on this issue; an attempt to put population back on the degrowth research agenda. The author claims that degrowth can benefit from the works by Herman Daly on steady-state economy, and notes that "*Unfortunately statements on demography are inconsistent and underdeveloped in the degrowth literature.*" (Kerschner, 2010, p. 544). Nevertheless, the top-down approach that Daly seems to advocate does not meet the call for participatory approaches (voluntary birth control) that characterize the degrowth movement (Kerschner, 2010).

Early degrowth scholars such as Illich, Georgescu-Roegen, Castoriadis, Dumont and Ellul addressed population issues in earnest (Latouche, 2012). Latouche (2012), argues that of course population is an important issue, but that those scholars were, nevertheless, more concerned with an increase in consumption, as, even if the population were to be reduced, a constant increase in consumption would not be sustainable. I do not feel comfortable with this interpretation. Latouche himself, in his early works (e.g., Latouche, 1993, p. 37) claimed that "*Demographic growth and a globalized economy has destroyed traditional agrarian systems*", and argues that "*The population explosion is not solely the result of the benefit of the*

**Table 1**
Can Germany be food self-sufficient with organic farming in terms of food energy supply? A very basic assessment.

| Energy demand | Energy supply | |
|---|---|---|
| *Assumptions* | *Assumptions*[a] | |
| Population = 82 million | Arable land (AL) = 11,846,000 ha<br>Average arable land per capita = 0.14 ha | |
| Energy intake: Assuming two scenarios<br>(A) 3000 kcal cap. day$^{-1}$<br>(people are employed in rural activity)<br>(B) 2000 kcal cap. day$^{-1}$<br>(minimum consumption) | Cropping system: wheat-pea rotation<br>***Wheat*** (W) - assuming<br>Yield organic wheat 3 t per ha<br>Wheat (full grain) 3200 kcal per kg<br>Total 9.6 $10^6$ kcal per ha | ***Pea*** (P) – assuming<br>Yield 4 tons per ha<br>Peas 800 kcal per kg<br>Total 3.2 $10^6$ kcal per ha |
| ***Results***<br>*Total demand of the population* | ***Results***<br>*Supply from the agricultural system* | |
| Average demand per person per year<br>(A) 1.1 $10^6$ kcal cap. yr$^{-1}$<br>(B) 0.7 $10^6$ kcal cap. yr$^{-1}$<br>Demand at the population level per year<br>(A) 9 $10^{13}$ kcal yr$^{-1}$<br>(B) 6 $10^{13}$ kcal yr$^{-1}$ | Energy supply per ha of arable land (ESha) for the wheat-pea rotation<br>ESha = (W+P)/2 = 6.4 $10^6$ kcal ha$^{-1}$ yr$^{-1}$<br>Energy supply per total arable land (ESAL)<br>ESAL = ESha*AL = 7.5 $10^{13}$ kcal yr$^{-1}$<br>Energy supply per 0.14 ha (average arable land per capita) = 0.9 $10^6$ kcal yr$^{-1}$<br>The production system cannot feed a rural population, and can barely sustain its basal metabolism (the energy demand just to stay alive). | |

[a] See the text. Main limits of the assumptions.

*medicine; it stems equally from deculturation and Westernization*." (Latouche, 1993, p. 222). It has to be pointed out that a larger food supply provided by the "green revolution" played a part in population growth, in countries of both the global North and South (where population began to rise quickly since early XIX century, Smil, 2000; Conway, 2012). Latouche's (2012) statement appears to be a late reinterpretation of the author's earlier writings. Scholars such as Illich and Georgescu-Roegen considered population degrowth a key issue and were actually in favor of active population control (on Georgescu-Roegen, see Latouche himself – Latouche, 2007b, p. 89). Illich strongly advocated for population control in order to halt the impact of people on the planet (Illich, 1975, e.g., pp. 62–65, 80–81,106). In *Tool for conviviality* (1975), Illich argued, "*Honesty requires that we each recognize the need to limit procreation, consumption, and waste …*" (p. 63), and pointed out that "*People for decades refused to open their eyes to the urgency of population control*" (p.106). It is interesting to note that Illich (1975, pp. 63–64) was worried that "radical monopoly", i.e. the industry sector, was going to hinder the adoption of family planning, because of its interest in having more workers and consumers. Illich, writing in the late 1960s and early 1970s, could not foresee that industrialization would eventually lead to families having very few children. Illich also seems to fail to grasp the fact that in human-powered agrarian societies the population tends to grow because people are needed to power the production system. Even Latouche, in his early works (e.g, Latouche, 1993), seems to miss this outcome. Although in its early stage the industrial revolution spurred population growth through improvements in medical knowledge, sanitation, agricultural practices, higher food supply and better nutrition (by achieving higher yields, converting more land to agriculture, trade), eventually the population reached a steady state characterized by low birth and death rates. The Demographic Transition Theory (Kirk, 1996; Lee and Reher, 2011), proposes that, in mature industrial societies, the reduction in the economic value of children and the increase in the costs of raising them, led parents to have fewer children and invest in their education and wellbeing. Recent studies seem to indicate that the decline in childhood mortality had a strong role in the decline in marital fertility (Lee and Reher, 2011; Reher et al., 2017). Nevertheless, this is not true for many regions of the globe, where, in spite of low child mortality, marital fertility remains high and the population keeps increasing. Changes in cultural and religious attitudes greatly affect reproduction choices (see for example the importance of the emancipation of women in the West) (Giddens, 2006). However, changes in the structure and functioning of society (long schooling for all the young population, better nutrition, health care system, a better material standard of living, a large job market open to women) may not have occurred without a major change in society's productive system and energy throughput (Odum, 1971; Krausmann et al., 2008; Giampietro et al., 2012).

In the early 1960s, Schumacher produced some or the first scenario analyses concerning the worldwide increase in energy demand in relation to the increasing world population (Schumacher, in Kirk, 1982, p.71). He also argued that population growth would have a major impact on the rate of energy consumption and would require the intensification of agriculture, and forecasted that by 1980 world fuel requirements would have been twice as large as those of 1954 (Schumacher, in Kirk, 1982, p.32). In the Epilogue of Small is beautiful (1973, p. 205), Schumacher writes "*Pollution must be brought under control and mankind's population and consumption of resources must be steered towards a permanent and sustainable equilibrium*." More recently, in their work *The prosperous way down* (2001), taking a biophysical view of the process of degrowth, the Odums claimed that population should decrease along with the decrease in energy supply. Thus, power per person would remain constant, thereby allowing the standard of living to be maintained (the prosperous way down can be just seen as a gradual reduction in population!). Jackson (2009, p. 221) argues, "*Indeed an increasing population may in and of itself be regarded as a driver of economic growth*". He is also concerned about the impact of population on the carrying capacity of the planet, "*With a finite pie and any given level of technology, there is only so much in the way of resources and environmental space to go around. The bigger the global population the faster we hit the ecological buffers*" Jackson (2009, p. 45). Demographic transitions, however, are a complex phenomena and greatly impact on societal metabolism (Giampietro et al., 2012; Sorman and Giampietro, 2013), as well as on the economy, on social security and health care systems, the labor market, etc. (for an analysis of Europe's demographic transition see EC, 2014; Fotakis and Peschner, 2015).

## 3. Energy efficiency, power and societal metabolism

The degrowth movement calls for a transition to a lower metabolism and a more frugal society. It is thus important to assess how such transition, or, better, how different potential models of transition, will affect the present organization and functioning of society. The efficiency of the energy and food production systems are certainly key performance factors to assess. Within the degrowth movement, indicators such as Energy Return On Investment (EROI - Hall et al., 1992; Hall and Klitgaard, 2012) and EMergy (Odum, 1971, 1988) have been used as reference indicators by which to assess the energetic performance of a society (e.g., Kallis et al., 2015, p.7), and its agricultural system (e.g., Latouche, 1993, p.165). Latouche (1993) backs his claim about the need to turn to auto-subsistence, pointing out that modern mechanized agriculture is much less energy efficient (lower energy into output (in food) per unit of energy input, or low EROI) than traditional farming practices. Energy efficiency and EMergy are certainly important indicators. The fact that the productivity of industrial agriculture increased while its energy efficiency decreased is well known (Pimentel and Pimentel, 1979, 2008; Grigg, 1992; Mazoyer and Roudart, 2006). We face the paradox that the higher the socio-economic development of a society, the lower the energy efficiency of its agriculture in terms of the energy input into agricultural activities and energy output as food (Martinez-Alier, 2015; Smil, 1991; Hall et al., 1992). Wilson (1992, p. 218) argued that "… *while agriculture has become efficient technologically, it has become less efficient in its use of energy.*" This is closely related to the availability of energy, mainly fossil fuels, which made it possible to use heavy machinery, irrigation systems, and large quantities of synthetic agrochemicals. Nevertheless, in order to better grasp the functioning of society we should deal with societal metabolism (the study of the flow of energy and materials in society – for a review of the concept see Fischer-Kowalski, 1998a,b; Giampietro et al., 2012, 2014; Gomiero, 2017). Other than efficiency, we have to address the speed at which energy is supplied to society, both as food, "endosomatic energy" (under human control, inside the body), and as "exosomatic energy" (under human control, outside the body), fuelling society activities (the distinction was proposed by Alfred J. Lotka (1880–1949) and by Sorman and Giampietro, 2013). We can describe the power of an agricultural system as the speed at which it can produce and deliver energy in food (and other nutritional elements) to society, and it is strictly related to the power of the energy system. For example, when comparing maize production in traditional (using only human labour) Mexican farming systems and in intensive US farms (Table 2), when framing the assessment from an energy efficiency perspective, we find the efficiency (output/input) of the former being 11:1 and only 2:1 for the latter. It has to be noted that when oxen are used, the efficiency of maize production in Mexico falls down to 4.3:1, due to the food needed to feed the animals (Pimentel, 1984).[6]

When we frame the assessment from the food system perspective, that is to say in terms of society implications, we see that in the USA maize production is 4 times more productive on a per ha basis (productivity of the land), and, what is more important from a metabolic perspective, it is 435 times more productive per hour of labour. The higher productivity of the land means that more food can be produced per unit of surface, generating a large amount of food supply for society. The high labour productivity allows the USA to feed its population with less than 1% of the country's workforce (agriculture and forestry account for 1% of the workforce) (CIA, 2016). Such high labour productivity in the agricultural sector allows society to change its working time pattern toward activities that are de-linked from food production, such as industry, schooling, services, and leisure. A low labour productivity implies that most of the society's time has to be allocated to the food production sector, leaving little room for anything else (Giampietro, 2004; Giampietro et al., 2012). Fig. 1 presents an illustrative model of the metabolic pattern comparison between industrial and developing countries (or the global North and global South, using the terminology preferred by the degrowth movement).

The high flow of energy supplied by a country's energy sector induces, at the same time: (1) a shift in the pattern of activities and working time allocation, with working time shifting from food procurement to the industrial and service sectors, (2) the increase of the dependency ratio (non-working vs. working population).

When analysing metabolic transitions such as the adoption of novel energy carriers, or agricultural practices, we should assess: (1) the efficiency of the proposals, (2) whether the new process of energy production is able to supply energy at a rate that matches the rate of energy consumption by society, and (3) what are the implications of the transition for society's structure and functioning. Therefore, we have two groups of indicators, one concerning the assessment of energy supply and the efficiency of its production (ratio: J/J, kcal/kcal), (methods such as Life Cycle Analyses or indicators such as Output/Input, EROI and EMergy), and the other concerning the speed of energy flow (J/sec, kcal/hr). The indicators of the first group may be defined "*indicators of feasibility*", as they inform us whether the process of energy production gains or loses energy (if the EROI <1 it means that energetic enterprise is not feasible). Nevertheless, when dealing with metabolism we have also to deal with the speed at which flows take place (energy per unit of time). Such indicators may be defined as "*indicators of viability*", as they inform us on whether the speed at which the energy is supplied (when the efficiency is positive) meets the speed at which energy is consumed by the metabolic processes of the organism/society. Both sets of indicators may be considered indicators of sustainability, as they are necessary to assess sustainability at different scales.

An EROI >> 1 informs us that our energetic investment is highly positive, and then that the enterprise is *feasible*. Yet, we cannot know whether it is also *viable*, that is to say, whether the net energy gained from our investment can sustain society's rate of energy consumption. To answer this key question we have to assess the speed of energy flows. We can have a highly efficient agricultural system producing wheat at an EROI of 20:1 (referring to the energy in the wheat), yet, if the system delivers energy to society at a speed of just 1000 kcal per capita per day, while the consumption is 3000 kcal per capita per day, it is not viable in guaranteeing the survival of both farmers and society (on this issue see the in depth analysis concerning biofuels provided by Giampietro and Mayumi, 2009). Then, the "*desirability*" of a new model of production has to be decided by society, according to its perception of the multiple pros and cons that a given course of action may imply.

Therefore, when addressing the sustainability of a new energy carrier, or an agricultural system, or an energetic transition path, we have to address at least three key issues:

(1) Does the new system have the characteristics to be a feasible option (EROI >1)?
(2) Does the new system have the characteristics to be a viable option (appropriate power level)?
(3) How will the system's structure (total population, distribution per age class, type of productive activities etc.) and the functioning (flows of energy and matter in the different

[6] One must note that many farm models are used to estimate energy and GHGs emissions, leading to different results (Camargo et al., 2013). For maize production in the USA, more recent works by Pimentel and colleagues provide an output/input of 4:1 (Pimentel et al., 2007). This was possible thanks to the adoption of better agricultural practices and technologies, which, nevertheless, might be seen as an energetic cost (investment) for society. Further to that, if externalities (i.e., environmental impact, effects on human health) associated with such a highly energivorous system were accounted for, the USA system might be considered far more inefficient.

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**Table 2**
Performance of maize production in subsistence agriculture in Mexico (using only manpower) and industrial agriculture in the USA (data for mid 1970s) under different perspectives: energy efficiency *vs.* food system.[a]

| *Perspective (framing the assessment)* Indicator | USA Industrial agriculture | Mexico Subsistence Agriculture (only manpower) | Ratio USA/Mexico |
|---|---|---|---|
| *Energy efficiency (field level)* | | | |
| Input energy ($10^6$ kcal ha$^{-1}$) | 9.3 | 0.64 | 15 |
| Output energy ($10^6$ kcal ha$^{-1}$) | 20.5 | 6.9 | 3 |
| Output energy/Input energy | 2.2:1 | 11:1 | 0.2 |
| *Food system (societal level)* | | | |
| Land productivity (kg maize ha$^{-1}$) | 7400 | 1944 | 3.8 |
| Labour productivity (kg maize hr labour$^{-1}$) | 740 | 1.7 | 435 |
| Labour productivity (kcal produced hr labour$^{-1}$) | (2.6 $10^6$) | (0.006 $10^6$) | |
| Labour intensity (hr labour ha$^{-1}$) | 10 | 1140 | 0.07 |

[a] Data for Mexico from Pimentel (1984) and Pimentel and Pimentel (2008), Data for the USA: energy efficiency from Hall et al. (1992, p.136), data based on figures supplied to the authors by D. Pimentel, food system from Giampietro and Pimentel (1994).

compartment of the society, time allocation per activity, etc.) have to change, and what might that imply?

Metabolic performance assessment has to address at the same time the "intensive characteristics" of the system (e.g., energy use per capita - indicators of intensity), and the "extensive characteristics" of the system (e.g., total energy use per year - indicator of quantity). Addressing intensive and extensive indicators at the same time requires the accounting system to be framed better, as obtaining the society-wide total as the sum of the total per capita values is not straightforward. Giampietro (2004, p.44), for example, argues that there may be at least four different ways to assess the kilograms of cereal consumed per capita by a society in a given year, leading to widely different results. It is also important to define the relation between the structural elements of a system that, in a given timeframe, provide its identity (funds, e.g. population), and those elements that are produced and consumed by the system in a given time frame (flows, e.g. energy), as such relation plays a key role in shaping society's structure and functioning.[7] Table 3 provides a schematic organization of what is discussed in the text.

The functioning of a society is a complex matter, as it is determined by the interplay of different issues: biophysical, socioeconomic, cultural, etc. (Gomiero et al., 1997, 2006; Smil, 2000; Giampietro et al., 2012, 2014). Furthermore, the technical dimensions of the assessment go along with a subjective representation of the same. For example, when considering degrowth, desirability could be related to its ability to spur conviviality and appropriateness. As Kallis (2013, p. 97), observes, "*What counts as collapse and what as transformation depends on the eyes of the beholder*". This leads to the need to evaluate, aside from feasibility and viability, also the desirability of any changes (Giampietro et al., 2012; Sorman and Giampietro, 2013). In order to achieve such objective there is a need for scholars to work on the biophysical dimension of sustainability collaborating with those working on its psycho-socio-economic aspects, and involving civil society in the process. Concerning the biophysical dimension of sustainability, the recent trend to take a "Nexus approach" to the analysis of problems may help better tackle such complexity. The "Nexus approach", tends towards a holistic analysis of the interplay between the biophysical factors, socioeconomic forces and metabolic characteristics of societies (e.g., FAO, 2014; Giampietro et al., 2014; Howells et al., 2013; UN-ESCAP, 2014).

## 4. Assessing technologies for agriculture: does the degrowth narrative address the right issues?

This section discusses if and how two alternative models of farming, namely organic agriculture (OA) and biotech-based agriculture (BTA), can respond to the degrowth model of agriculture. Two principles will be used for the assessment: if OA and BTA respond to the call for appropriate technologies, *sensu* Schumacher (1973), and if they can be considered to represent convivial tools *sensu* Illich (1975). According to the influential work by Roland and Adamchak (2008), GMOs meet the low cost and low maintenance requirements that are of prime importance in Schumacher's definition of what should be considered an "appropriate technology" (the authors specifically refer to Schumacher's work). Sir Gordon Conway, one of the world's foremost experts on agriculture and rural development, refers to biotechnologies (GMOs) as a way to make the traditional breeding process faster and more precise (Conway, 2012, chapter 7). The author states that all technologies can be appropriate (or better locally appropriate), depending on the environment and on socioeconomic circumstances, and in many cases, he claims, GMOs represent an appropriate option, even for poor farmers. As locally appropriate, Conway (2012, p. 128) means: effective, readily accessible and affordable, easy to use, environmentally friendly, serving a real need. Although the degrowth movement declares to be against the use of GMOs (Latouche, 2012; Flipo and Schneider, 2015; Kallis et al., 2015), the motivations for banning GMOs from the degrowth discourse are not very well stated. Actually, GMOs may fit some criteria that may make them "convivial tools". Conversely, in some cases, considering organic farming as a convivial tool might not be straightforward. The problem lies in the unclear definition of what "appropriate technology" and "convivial tool," actually mean, or in the variety of interpretations they are subject to.

According to the Merriam-Webster dictionary, a technology (the "science of craft") can be defined as the practical application of knowledge, a capability given by the practical application of technical processes, methods, or knowledge. With reference to agriculture, a technology corresponds to any application of knowledge to management, to the field and to the food system. A tool can be defined as: a handheld device that aids in accomplishing a task; anything used in performing an operation or necessary in the practice of a profession. In a broader sense, it can be intended as a means to an end. With reference to agriculture, "tools" are used to represent the set of means used in performing agricultural activities: machineries, technologies, practices. A tool can be a tractor, a

[7] Giampietro et al. (2014) define as "Flows": "*Those elements which are either produced (appear) or consumed during the analytical representation. They reflect the choice made by the analyst when deciding what the system does and how it interact with its context.*"(p. 223); "Funds": "*Structural elements whose "identity" remain the same during the analytical representation. They reflect the choice made by the analyst when deciding what the system is and what the system is made of.*" (p. 223); and as "Stocks": "*Referring to reservoirs or buffer of flows, which change their identity (they are deplete of filled) during the time duration of the analysis.*" (p. 37).

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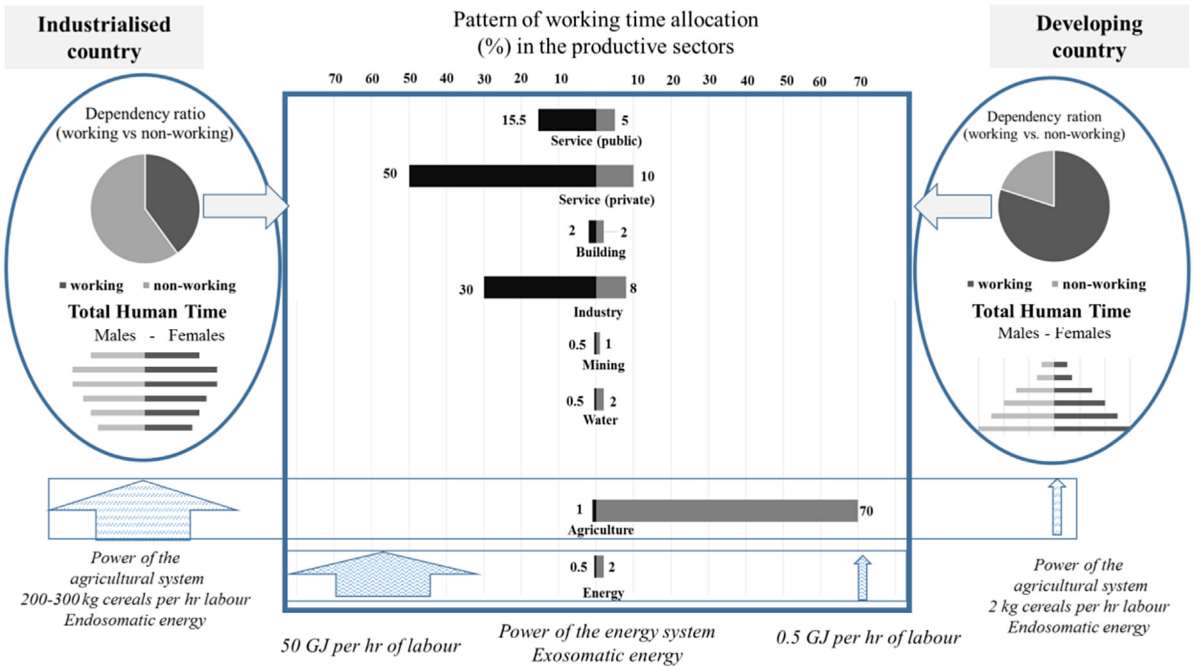


**Fig. 1.** Relation between the endosomatic energy (to sustain human metabolism) and exosomatic energy (to sustain the metabolism of the whole society) flows and the structure and functioning of a society. On the left, a metabolic pattern (energy flow, demographic pyramid, dependence ratio, pattern of working time allocation) corresponding to a highly industrialized country (% working time allocation refers to Germany). On the right, a metabolic pattern (energy flow, demographic pyramid, dependence ratio, pattern of working time allocation) corresponding to a developing country (% working time allocation refers to what is typical of many predominantly agricultural societies). Figures for energy flow and agriculture productivity from Smil (2000), Giampietro (2004), and Giampietro and Mayumi (2009).

rotation system/cover crop (tools to increase the fertility of the soil), a pheromone trap to catch pests, a pesticide. Concerning the latter case, some GM crops are engineered to produce the pesticide internally (NRC, 2000; Nicholl, 2008; NAS, 2016). The new gene(s) inserted to make it possible can also be considered as a tool.

### 4.1. Defining organic agriculture and biotech-based agriculture

As OA, I refer to a farming system regulated by international and national institutional bodies, which certify organic products from production to handling and processing (Gomiero et al., 2011b; CERTCOST, 2012a; IFOAM, 2016). Within the set of regulations, OA is characterized by banning the use of agrochemicals (a few traditional pesticides such as copper sulfate are allowed) and the use of GMOs, as well as of many synthetic compounds used as food additives. Preserving and enhancing soil health lies at the core of organic farming. In organic agriculture, soil fertility and pest control are enhanced by crop rotation, intercropping, polyculture, cover crops, mulching and the proper management of ecological structures such as hedgerows (Altieri, 1987; Lampkin, 2002; Gliessman, 2007; Gomiero, 2013).

As BTA, I refer to the use of "transgenic" Genetic Modified Organisms (GMOs), crops and animals. I do not address the use of biotechnology in medicine, which falls outside the scope of the paper, and presents very different issues and is possibly less problematic. In GMOs, small segments of exogenous (externally derived) DNA sequences are inserted into the genome of a recipient organism to make them express a given character (NRC, 2000; NAS, 2016). It has to be pointed out that the desired gene (a tract of the DNA where the gene can be found) is inserted as a "cassette" (at random in the host DNA), that is to say as a package containing other genes (genetic sequences) too. A cassette contains a promoter that activates the gene, other genes can be present too (usually from bacteria), and often carry antibiotic resistance genes that serve as markers. The cassette is introduced into the DNA of the guest organism by infecting the organism with a soil bacterium (*Agrobacterium tumefacensis*), or through delivery into cells by means of a "gene gun". Such complexity made it difficult to back claims made by GMO supporters that GMOs are just an extension of the traditional breeding techniques used by farmers since the early days. The most important genetically engineered traits in commercially produced crops relate to the production of toxins to fight pests, and to resistance to herbicides, so that herbicides can be used in the field without affecting the crop. The former modification involves the incorporation of specific modified genes from the soil bacterium *Bacillus thuringiensis* (Bt) into a crop genome (Bt-crops), resulting in production of a Bt protein in the plant cells, that, when ingested by some groups of insects (i.e., *Lepidoptera*), disrupts cells in the target insect's digestive system, resulting in the death of the insect. The latter modification allows herbicide-resistant (HR) crops to overproduce those enzymes that are affected by the herbicide (e.g., glyphosate-resistant crops), and then to resist the herbicide. Some crop varieties have been engineered as both Bt and HR crop, or to withstand one or more herbicides (NRC, 2000; NAS, 2016). Some crops have also been engineered to express other types of characteristics such as drought tolerance, resistance to viruses, delayed ripening, synthesis of nutritional elements (e.g. beta-carotene, a precursor of vitamin A, in the edible parts of rice, a variety known as "Golden rice") (NAS, 2016).

The literature on GMOs is huge; the literature cited here highlights some representative works (important papers, reviews, and influential publications).

### 4.2. Appropriate technologies

Schumacher (1973) refers to appropriate technology as a technology that is able to create jobs in developing countries, while preventing unemployment, thereby reducing poverty and despair

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**Table 3**
An example of intensive and extensive indicators that have to be used to assess the feasibility and viability of an energy source.

| Indicator typology | Supply power/production system | | Demand metabolic system |
|---|---|---|---|
| | Feasibility/Efficiency | Viability/Metabolism | Technical characteristics of the society (i.e., number of people, level of consumption) |
| Intensity (rate; per unit) | Energy return of the investment (EROI; output/input) | Energy flow generated by the system per hour of activity | Metabolic rate per type of user/activity (e.g., human metabolism) |
| Quantity (total quantity) | Total net energy produced (output − input) | Total energy flow delivered to the society | Total users/total demand (e.g., structure of population, overall consumption of goods and services) |

(Schumacher writes in the early 1970s when Asia was the poorest continent and on the edge of possible mass starvation). According to Schumacher, an appropriate technology should be an "intermediate technology", that is to say labor-intensive, as opposed to the capital-intensive technology typical of industrialized countries. Schumacher (1973) argued that poor developing countries who followed industrialized countries in the adoption of capital-intensive technologies would have worsened their social situation by generating a large amount of poor and hungry people. Intermediate technology should not be as basic as indigenous technology, the sort of we find in hunter-gather societies, but nevertheless should be much less advanced than technologies in use in industrial countries. It should be characterized as being simple and understandable, suitable for maintenance and repair. Since such solutions must be tailored to the particular society in which they are applied, they are now often called "appropriate technologies" (appropriate to the local context and to people's needs). In 1966, he founded the Intermediate Technology Development Group (ITDG) in London, to put his ideas into practice.[8]

***Biotech-Based Agriculture:*** According to some authors (e.g. Roland and Adamchak, 2008; Conway, 2012; NAS, 2016), GMOs are simple to use, can help increase yields and, in turn, improve the living conditions of poor farmers (and improve those of the farmers of the Global North too), and can reduce the use of agrochemicals. Therefore, they should be considered "appropriate technologies". Nevertheless, GMOs raise a number of issues that require in-depth assessment and reflection.

GM crops engineered to produce toxins (i.e., Bt crops) or to resist herbicides, along with practices based on extensive monoculture, lead pests and weeds to develop resistance, becoming super-pests and super-weeds (many cases already reported), forcing farmers to use larger and larger amount of agrochemicals (Benbrook, 2012; Fagan et al., 2014; Tabashnik et al., 2013; Keim, 2014). For the USA, Perry et al. (2016) found that GMOs did not reduce the use of agrochemicals, and that adopters of GM soybean and maize use increasingly more herbicides relative to non-adopters due to the emergence of glyphosate weed resistance (glyphosate is the active ingredient in Round Up®). In the case of GM crops engineered to resist herbicides, this trait leads to the replacement of mechanical weeding with herbicides. Therefore, increasing the use of herbicides is a direct result of the technology itself. It has to be pointed out that the International Agency for Research on Cancer (IARC, 2015), indicated Glyphosate as probably carcinogenic to humans (Group 2A, sufficient evidence for carcinogenicity in experimental animals), therefore increasing the presence of such chemical in the environment may not be a good idea.

GM crops may lead also to unexpected ecological effects. For example, the emergence of secondary pests has been reported in cotton fields in China (Lu et al., 2010): they damage other crops, as well as GM crop itself, because they are Bt-resistant. It is well known that gene flow takes place between crops and their wild relatives (Quist and Chapela, 2001; Anderson and de Vicente, 2010). The effect of gene flow between GM crops and their wild relatives may spur the insurgence of super-weeds, or contaminate native species (many cases have been reported so far e.g., Pilson and Prendeville, 2004; Chandler and Dunwell, 2008; Schafer et al., 2011).

Yield may be volatile due to the uneven expression of GM genes in plants (e.g. Bt crops), which expose plants to the attack of pests, or to the side-effects of the technology (the energetic cost that a plant incurs in the production of new compounds reduces its productivity: yield drag) (Gurian-Sherman, 2009; Fagan et al., 2014). Actually, some review works report no difference between the yield of GM and non-GM crops (e.g. Gómez-Barbero et al., 2008; Shi et al., 2013; Gobierno de Aragón, 2015). For the USA, Shi et al. (2013, p.112), stated, "*Yet, with the exception of the ECB trait, we were surprised not to find strongly positive transgenic yield effects*", and NAS (2016, p.7) states that "*… there is no evidence from USDA data that they have substantially increased the rate at which of U.S. agriculture is increasing yield*".

Crop quality may not be ensured, causing important problems to the economy of farmers, especially in developing countries. This was the recent case of cotton in Burkina Faso, which was rejected by traders due to its poor quality, causing a major economic crisis for the country (Anonymous, 2015; Dowd-Uribe and Schnurr, 2016; GeneWatch, 2016). GM crops may make farmers more dependent on a few, or even a single corporation, which may act as a monopolist (Engdahl, 2007; Drunker, 2015). GM seeds are more costly, which goes against the principle of appropriateness and which, for poor farmers, might mean taking large loans and ending trapped in debt (Krimsky and Bruber, 2014). NAS (2016) highlights that, although GM crops seem to have had favorable economic outcomes for producers, social and economic effects are characterized by high heterogeneity in outcomes, and the cost of GE seed may limit adoption by resource-poor smallholders. These issues pose high risks for farmers, especially poor ones, which have no means to cope with the loss of their crops, or other side effects from GMOs. Due to the oligopolistic nature of the technology, farmers may become even more dependent on a very few corporations. Furthermore, focusing on GM as the solution of complex problems may hide their real nature (which may be better understood as rooted in social conflicts, poor policies, etc., rather than in increasing yield), leaving such problems unresolved and growing (IAASTD, 2009; Krimsky and Bruber, 2014; Stone and Glover, 2017).

Therefore, we should conclude that the claim that GM crops are an appropriate technology *sensu* Schumacher, as claimed by BTA supporters, is not tenable.

***Organic agriculture:*** Organic agriculture is referred as a grassroots, non-capitalistic production practice that meets the requirements of degrowth, while reducing the demand of input and GHGs emissions and increasing the demand for labour, therefore

[8] The Schumacher Centre is an international development organization that works towards a more equitable and just world in which technology enriches and benefits the lives of poor people. http://practicalaction.org/the-schumacher-centre-for-technology-and-development.

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**Table 4**
How Biotech-based agriculture and Organic agriculture respond to the call of degrowth for appropriate technology and convivial tool.

| Degrowth call | Biotech-based agriculture | Organic agriculture |
|---|---|---|
| Appropriate technology | Some applications might be of use (as it is for any technology). Nevertheless, the technology is very risky for the environment and human health, and it may increase agriculture's environmental impact. The oligo-monopolistic nature of this technology also represents a risk for society. | It is a very promising practice, able to reduce the environmental impact of agricultural activities. OA also has an important ethical dimension. Nevertheless, in the event of large-scale adoption, a viability assessment is necessary to establish its impact on the food system. In some contexts/regions (highly populated poor countries), its adoption might face limitations. |
| *Convivial tool* | | |
| As Do-It-Yourself (autonomy) | BTA does not seem to offer any benefit for increasing the autonomy of farmers, nor consumer choice. Actually, GMOs may reduce the autonomy/choice of consumers. | OA may foster farmers' autonomy in some aspects of production (i.e., seeds reproduction, locally adapted farming practices, marketing). Nevertheless, if market forces take the lead, economic pressure might lead to a reduction in farmers' autonomy. |
| As a tool able to limit growth | BTA is a product of the present economic model (growth oriented). Although GMOs are marketed as able to reduce the impact of agriculture, and to benefit farmers and consumers, they may actually greatly exacerbate the present problems. | If implemented along with cultural and socioeconomic changes, OA may represent an alternative to the productivistic (growth-oriented) management of agriculture, and limit its environmental impact. A word of warning: economic pressure may lead to reframing the nature and goals of OA. In some contexts/regions (highly populated poor countries), its adoption might face limitations. |
| Against radical monopoly and compulsory consumption | BTA has an oligopolistic nature, which is leading to the formation of a radical monopoly. Very few corporations control GMO patents as well as the agrochemical and pharmaceutical industry. They are able to exert huge pressure on policy makers, science and society. | The grassroots origin and ethical dimension of OA may play an important role in enhancing consumers' awareness both concerning their role in determining the impact of agricultural activities, and the need to rethink the functioning of our society. Economic pressure may lead to recreating a process of concentration, leading to an oligopolistic control of the sector and to a change in the nature of the movement. |

contributing to a reduction in unemployment (e.g., Latouche, 2008; 2009; Kallis et al., 2015). We should be aware that the term "organic agriculture" defines products that are produced according to standards established by international and national institutional bodies; once those standards are respected, the food can be labeled as organic food (Gomiero et al., 2011b). Furthermore, it has to be pointed out that: (1) organic agriculture is not necessarily a simple, non-capitalist enterprise. Actually, along with the increasing demand for organic food, farmers and large corporations are entering the organic market while adopting intensive production practices (Guthman, 2004; Sutherland and Darnhofer, 2012); (2) the efficiency of organic farming is debated (i.e., energy use and GHG emissions per unit of produce, cost, the amount of land required), and criticism to the sustainability of organic agriculture has to be addressed, for example, in some poor and densely populated regions its adoption may face limitations (Smil, 2000; Gomiero et al., 2011b; de Ponti et al., 2012); (3) organic products are also being traded over long distances, as occurs for conventional food, and organic farms may require large capitals and inputs too; (4) the debate about the lower yield of organic crops and its implication for food security should be acknowledged (Badgley et al., 2007; de Ponti et al., 2012; Seufert et al., 2012). Nevertheless, when properly managed (even traditional agriculture, when adopting an extractive approach, may greatly damage the soil - Gomiero, 2016), and with the support of simple technologies and tools, traditional and organic agriculture can represent an effective and appropriate means of production for millions of small farmers around the world (Altieri, 2002; Pretty et al., 2003; Badgley et al., 2007). Being a low-capital, labour-intensive and low-risk enterprise (guaranteeing food security), it also fits the definition of appropriate technology (which may also fit the definition of intermediate technology when referring to the global South).

### 4.3. Convivial tools

Illich (1975, 2015) aimed at establishing a triadic relationship between people, tools, and a new collectivity, a society in which modern technologies could serve politically to interrelate individuals rather than manage them. Therefore, the characteristics of the tools are related to the characteristics of society. For Illich, the importance that people preserve their autonomy is a central issue; an autonomy that the bureaucratization of society tends to remove from them (Illich, 1971, 1975, 2015). Illich calls for a "convivial society". Conviviality: "*I choose the term "conviviality" to designate the opposite of industrial productivity. I intend it to mean autonomous and creative intercourse among persons, and the intercourse of persons with their environment*" (Illich, 1975, p. 24). Convivial society: "*A convivial society would be the result of social arrangements that guarantee for each member the most ample and free access to the tools of the community and limit this freedom only in favor of another member's equal freedom.*" (Illich, 1975, p. 25). "*A convivial society should be designed to allow all its members the most autonomous action by means of tools least controlled by others*" (Illich, 1975, p. 33). Samerski (2016) refers to the concept of autonomy in Illich as a discussion distinguishing the "*heterogeneity between convivial and manipulative tools, and, correspondingly, between autonomous and heteronomous human activities*"; differences which are blurred in advanced technological societies.

Illich (1975, p. 29) refers to China under Mao as the only example of a convivial society (at the time of his writing, the major social disaster and human suffering caused by Mao's ideology and regime had not yet been exposed to the world). It is not very clear how Illich's ideas should be translated into practice; for example, Deriu (2015) states that Illich's definitions lead to uncertainty and ambiguity. This may be due to the complexity of the issues he tried to deal with. A complexity that increases when addressing real life, because of the many aspects we may have to consider concerning the use of tools. Therefore, it may be difficult to provide a definitive assessment and to divide technologies according to the absolute categories of "right and wrong". This becomes evident when looking at Illich's own love-hate relationship with computers. Jerry Brown, a friend of Illich, in his introduction to the book *Beyond economics and ecology* (2015), a collection of Illich's writings), tells us that when PCs were introduced Illich said they were an abomination, but that later on he changed his idea. In his 1971 book, *Deschooling Society* (Illich, 1971), Illich suggested (quite ahead of his times), to rely on computer-assisted learning as a tool for the socialization of knowledge, and to create a self-teaching process amongst people. Nevertheless, in his following 1973 book, *Tools for Conviviality,* he was rather critical of the use of computers, as of the use of technology in everyday life, and in the industrialization process itself. In his 1983 essay *The social construction of energy*, Illich (2015, p. 118) is very concerned that people would become addicted to the PC, and that rather than make people free, the PC would make them work even more (this is certainly a brilliant forecast of his!).

According to Illich "*Convivial tools are those which give each person who uses them the greatest opportunity to enrich the environment with the fruits of his or her vision. Industrial tools deny this possibility to those who use them and they allow their designers to determine the meaning and expectations of others*" (Illich, 1975, p. 34). "*Almost anybody can learn to use them, and for his own purpose. They use cheap materials. People can take them or leave them as they wish. They are not easily controlled by third parties.*" (Illich, 1975, p. 78–79).

Illich (1975) argues that the usual concept of monopoly, as the control exerted by a corporation over a good, is very well known. The usual monopoly restricts the choice of consumers. For example, a brand can achieve monopoly of soft drinks in a given country. Yet, Illich argues, people can choose to drink water or beer. Illich (1975 p. 66), defined a "radical monopoly" as "*the dominance of one type of product rather than of one brand. I speak about radical monopoly when one industrial production process exercises an exclusive control over the satisfactions of a pressing need, and excludes nonindustrial activities from competition*". Illich continues (1975 p. 67) by arguing that a "*Radical monopoly imposes compulsory consumption and thereby restricts personal autonomy. It continues a special kind of social control because it is enforced by means of the imposed consumption of a standard product that only large institutions can provide*". He criticises the dominant role of technocratic elites in industrial societies, which "*… have come to exert a "radical monopoly" on such basic human activities as health, agriculture, homebuilding, and learning, leading to a 'war on subsistence' that robs peasant societies of their vital skills and know-how.*"

It seems, therefore, that Illich describes convivial tools in at least three different ways: (1) Do-It-Yourself tools that preserve the capacity of people to be autonomous, (2) tools able to limit growth, i.e. tools that do not lead to an increase in productivity, (3) open-access tools, against radical monopoly and forced consumption, i.e. tools that can be easily replicated by people and are not enforced on people to control their freedom and their ability to choose.

(1) Convivial tools as Do-It-Yourself tools

Concerning the conviviality of tools, Deriu (2015) and Kallis et al. (2015) focus on the concept of "autonomy", namely the possibility for people to provide tools for themselves. Kallis et al. (2015, p.8) state: "*Autonomy instead requires convivial tools, i.e., tools which are understandable, manageable, and controllable by the users. An urban garden, a bicycle or a Do-It-Yourself Adobe house are convivial and autonomous. A weed resistant GMO field, a high-speed train or an energy efficient "smart building" are not.*"

***Biotech-Based Agriculture***: Farmers adopting GMOs do not differ from those using conventional farming practices. They rely on seeds produced by seed companies, on heavy machinery and on high amounts of agrochemicals. They are completely dependent on external knowledge and external inputs. Therefore, GMOs, alike conventional farming, cannot be considered convivial tools that increase the autonomy of farmers. BTA may actually exacerbate the dependence of farmers on corporations. For example, Monsanto sells its GM crops to farmers under a contract that forces them to buy the herbicide produced by the company, forbids them from saving seeds (a possible option for conventional crops), or use those seeds for research purposes and for the generation of herbicide registration data (Monsanto, 2008).

***Organic Agriculture:*** Kallis et al. (2015) maintain that while high-tech GMOs are not convivial technologies, organic farming is. Nevertheless, it is not that obvious to represent organic farming as a self-sufficient, autonomous activity either. Organic farmers may buy seeds and inputs from far away. They can use manure coming from conventional livestock and blood and bone meal, feather meal and fish sludge from conventional animal farms (CERTCOST, 2012b). It also has to be pointed out that standards may vary between countries. In the European Union, EC Council Regulation No. 2092/91 regulates organic farming, nevertheless each country, while complying with this regulation, can adopt different standards. Different national certification bodies may follow different rules too. Concerning the use of fertilizers, the EU requires consideration of the source of manure, allowing manure from organic production units and regulating the amount of manure from conventional sources (EU prohibits manure from "factory farms" but allows it from "extensive husbandry" under certain conditions), while the US does not address manure source (CERTCOST, 2012a,b). Complex chemicals, produced by agrochemical companies, can be used. As a telling example, let us consider one of the most employed and useful pesticides in organic farming, the toxin (or, better, the family of toxins) produced by a group of bacteria, the most famous of which is *Bacillus thuringensis* (WHO, 1999; NRC, 2000) (some GM crops such as maize and cotton have been engineered to express the toxin in the GM plants, Nicholl, 2008). Such toxin cannot be self-produced by organic farmers. This product is marketed by a few companies (large corporations). Such a tool, to be produced, requires sophisticated lab appliances and high expertise that only specially trained biologists have. Some techniques and tools used in organic farming for pest control rely on sophisticated chemical warfare (e.g. pheromone trap, sexual confusion). High-tech machinery are used too (organic farming can be highly mechanized as well). Many of the organic products grown in Spain and Italy are marketed in northern European countries. Similarly, in the USA a large part of organic products grown in states such as California or Vermont are sold all over the country (travelling thousands of kilometers), too far to meet the requirements for a local, short-chain production system. This plays against organic farming being considered a convivial tool, in the same way as GMOs. Therefore, it should be concluded that conviviality intended as autonomy may not help distinguish biotechnology from organic farming (see section 4.1 as well).

(2) Convivial tools as tools able to limit growth

Flipo and Schneider (2015), in the foreword to "Degrowth: A vocabulary for a new era", focus on the effectiveness of a tool to limit growth, which was also one of the main concerns of Illich. They state that "*Some technologies have to be rejected (nuclear, GMOs, nanotechnologies) because they are not amenable to limits, other(s) are acceptable up to certain limits, which should be deliberated by the whole of society.*" (Flipo and Schneider, 2015, p. xxv).

***Biotech-Based Agriculture:*** a statement such as "not amenable to limits" may have contrasting interpretations. Supporters of GMOs are claiming that GMOs can help limit the use of agrochemicals (pesticides, fertilisers), GHGs emission and the overall impact of agriculture on the environment (soil, water, biodiversity). By helping increase yields (intensification), GM crops would reduce the amount of land under culture, therefore leaving more land available for biodiversity. Some GM crops may also ease the work of farmers while reducing their exposure to toxic pesticides. GMOs would also help limit hunger, by allowing higher yields to be achieved, and guaranteeing a higher income to poor farmers, hence GMOs may help limit poverty as well (Roland and Adamchak, 2008;

Conway, 2012; NAS, 2016). Such wish may be shared also by the degrowth movement and may not represent a problem from a degrowth perspective (degrowth scholars, as many other people, point out that such technology may pose major risks for the sustainability of the food system, e.g., Kallis et al., 2015, but that does not matter here). Even if the claims mentioned were true, the actual problem is that said technology, and the control exerted by a few corporations over it, greatly limits the autonomy of people (Kallis et al., 2015). In this sense autonomy is a criterion under which GMOs are not in keeping with degrowth ideals.

***Organic Agriculture:*** Organic farming may require more land to be cropped, and more working time is required to produce food: this would, therefore, make food more expensive (Gomiero et al., 2011b; Seufert et al., 2012; Reganold and Wachter, 2016). The latter, in turn, may lead people to call for a wage increase. This does not mean that organic farming should not be implemented. On the contrary, Europe, for example, rather than subsidizing the inefficient production of biofuels (Smil, 2003; Giampietro and Mayumi, 2009; MacKay, 2009; Gomiero, 2015), would do better by supporting organic agriculture. The point I wish to make here is that it is not that simple to identify a production technique in absolute terms: tradeoffs need to always be considered. Therefore, policies need to be implemented to address many complex issues at the same time.

(3) Convivial tools to avoid radical monopoly and compulsory consumption

***Biotech-Based Agriculture:*** Illich argued that we have to avoid novel and risky technologies from being enforced upon us by a powerful technocratic-industrial complex, as they may not bring many benefits to society. We might be seeing this happening now in the biotech industry sector, where we have a serious risk to see a few large corporations in control of the whole food system, and able to exert a powerful influence on policy makers and scientists alike (The Ecologist, 1998; Engdahl, 2007; Krimsky and Bruber, 2014; Drunker, 2015). Notwithstanding the major impact that GMOs may have on the food system, no serious public debate ever took place (in the USA consumers are not even entitled to having products containing GMOs labeled). The report by NAS (2016) stresses this point and argues that GM crop governance should be transparent and participatory.

Thus, biotech fails under this criterion. Such a level of power may lead to poor risk assessment and limit independent research (which, when carried out, comes to worrying findings - Ewen and Pusztai, 1999; Malatesta et al., 2005; Domingo and Giné Bordonaba, 2011; Séralini et al., 2014). The pressure exerted by biotech corporations to avoid the labelling of GM food may also reduce the choice of those consumers who, for different reasons, may want to know whether the food they buy comes from GM crops and animals.

The degrowth movement is very sensitive to this issue and can greatly contribute to working towards a process of democratisation of science (D'Alisia et al., 2015). Such an issue stands at the core of the epistemological approach proposed by Post Normal Science (PNS) (Funtowicz and Ravetz, 1990, 1994; Strand et al., 2017). PNS calls for the need of a dialogue within society concerning the uncertainty and the risks involved in the adoption of new technologies. It also calls for setting up a participatory process where legitimate perspectives of different stakeholders can be discussed.

***Organic Agriculture:*** When organic agriculture embraces a capitalist approach (i.e., large land holdings, monoculture, strictly market-oriented strategies aiming at maximizing productivity, use of allowed compounds against weeds and pests over the adoption of good farming practices), we may have difficulties in stating that it is in keeping with the degrowth agenda. Some products used by organic farmers, for example for pest management, may also be produced under a monopolistic system. Nevertheless, the principles of organic farming, as stated by the International Federation of Organic Agriculture Movements (IFOAM, 2016), envisage an agriculture that respects people (both farmers and consumers) and the environment, and oppose a monopolistic and capitalist agriculture.

### 4.4. Summary of the assessment

The results of the analysis carried out in the previous sections are summarised in Table 4.

Distinguishing the different meanings found in the definitions of convivial tools given by Illich allows to envisage a possible convergence of “conviviality as autonomy” with the scope of appropriate technologies (more specifically with the idea of intermediate technology) as proposed by Schumacher. Schumacher addressed the need to improve living conditions in poor countries, and was in favor of increasing productivity. Nevertheless, he was also aware that, for the poor and highly populated countries of Asia (the region that was of concern in the 1970s), a fast process of industrialization, in the western style, could generate massive unemployment with dramatic social consequences. Both authors share a concern for the limits of growth and call for a more frugal society, Illich's writings considering the industrialized societies of the West at the time (the global North), while Schumacher addressed also the situation in the underdeveloped East and South (the global South). The concepts of radical monopoly and compulsory consumption, characteristic of Illich's discourse, do not seem to have been developed in Shumacher.

## 5. Conclusion

During the last decades, we have experienced an intensification of social and environmental problems in the global North and South. The problems at stake are huge and complex. The degrowth narrative suggests actively pursuing a reduction in our impact on the environment and its resources by embracing a different, and more convivial lifestyle, a transition to a lower metabolism and a more frugal society. A lifestyle based on contentment, a reduced level of resource consumption and an enhanced awareness of the social nature of human existence (which along with the concept of sharing, conviviality, care, commons and justice, among others, characterize the degrowth movement).

Concerning agriculture and the food system, a path toward degrowth aims at food self-sufficiency at the level of local communities, shortening the production chains, reducing waste, relying on renewable energies and the ban of agrochemicals. These are important and reasonable proposals. This paper aimed at providing a broad analysis concerning agriculture and the degrowth discourse. The paper reviewed how agriculture has been addressed within the degrowth discourse, addressed the complex relation between agriculture and society in view of a transition to a lower metabolism, and discussed whether two different agricultural techniques and technologies (organic agriculture and biotech-based agriculture) are compatible with the concepts of appropriate technology (*sensu* Schumacher) and convivial tools (*sensu* Illich), and to what extent they might fit within the degrowth discourse.

A sound and comprehensive analysis of how agriculture and the food system should change to meet the call for degrowth has not yet been produced. Due to the importance of the agriculture sector, it is imperative to put this issue at the centre of the research agenda. Along with consumption levels, the role of demographic pressure should also be better addressed (of course, avoiding

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blaming the victims as an easy way out). Degrowth offers a necessary and radical criticism to the present model of development, and some interesting ideas that are worth exploring. The problems we are facing, clearly and urgently call for a new model of development, and lifestyle, to be put forward and implemented. It is important to carry out deeper and comprehensive research work in order to explore the feasibility and viability of possible transition paths and scenarios. Transition paths should be studied by addressing the impact of different alternatives on society's metabolism, and in turn on its structure and functioning. The feasibility and viability of alternative production systems should be addressed, departing from the concepts of energy efficiency and energy flow (power), and embracing a metabolic approach to the study of societal transition. How such process of reorganization is perceived by people (the desirability of alternative scenarios) also needs to be discussed within society. Indeed, such process should be carried out in an inclusive way, involving society. It is argued that indicators of efficiency are certainly important indicators to assess society's performance in terms of energy use and environmental impact (*i.e.*, GHGs). Nevertheless, when dealing with societal metabolism (or metabolism in general), we necessarily have to also address the relation between funds and flows, as it plays a key role in shaping society's structure and functioning. Therefore, transition paths need to be assessed for their effects on society's metabolic performance (and of course on their impact on resource use, water, soil fertility, biodiversity, etc.).

For the early degrowth scholars, along with the level of consumption, population was also an issue that had to be addressed. It is important to have such issue back on the research agenda. We have to refrain from taking the easy way of blaming poor families for not containing their reproduction. Socio-economic constraints that stop people from achieving a minimum level of welfare should be addressed. We may want to ask why countries that are very rich in natural resources, exported all over the world, are unable to provide even the most basic services for their citizens. Again, while worrying about the dramatic effects of mass migration (e.g., from Africa to Europe), the global north still refuses to critically review its role in determining the current state of affairs. I believe that degrowth scholars should and can play an important role in increasing public awareness concerning such complex issues.

With regard to technology for agriculture, the degrowth movement declares to be against the use of GMOs and in favor of organic agriculture, or other low-input practices (e.g. permaculture). The latter should represent those “appropriate technologies” and “convivial tools” that the degrowth movement envisages for a more sustainable society. Nevertheless, such labels are prone to a variety of interpretations, and results may differ according to the criteria used. While biotech-based agriculture (BTA) and organic agriculture (OA) differ in many aspects, under some criteria they may present the same problems. Under the approach proposed in this paper, in some cases, both BTA and OA may not correspond to the idea of conviviality or represent a convivial tool. OA may also not be appropriate in some poor and densely populated regions; there, the adoption of organic agriculture may face limitations. It is also pointed out that the large-scale adoption of OA requires its impact on the food system to be assessed. On the other hand, while we cannot exclude that BTA might not be able to provide some benefits, at present the technology presents important drawbacks and poses very serious risks to the environment and human health. Further to that, BTA represents a form of radical monopoly, and as such it is strongly opposed by the degrowth movement (as well as by many other stakeholders). Such issue is obviously even more relevant in the case of agriculture, as a radical monopoly of the food system represents a threat to humanity. Therefore, I conclude that, notwithstanding claims by GMOs supporters, BTA nor does suit the call for appropriate technology, nor does it represent a convivial tool under any criteria.

## Conflict of interest

There are not any conflict of interests.

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## References

Alexandratos, N., Bruinsma, J., 2012. World Agriculture: towards 2030/2050: the 2012 Revision. FAO, Rome, Italy. Available online at: http://www.fao.org/docrep/016/ap106e/ap106e.pdf.
Alcott, B., 2012. Population matters in ecological economics. Ecol. Econ. 80, 109–120.
Altieri, M., 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. Agric. Ecosys. Environ. 93, 1–24.
Altieri, M., 1987. Agroecology: the Science of Sustainable Agriculture. Westview Press, Boulder, NY, USA.
Anderson, M.S., de Vicente, M.C., 2010. Gene Flow between Crops and Their Wild Relatives. The John Hopkins University Press, Baltimore, CA.
Anonymous, 2015. Le Burkina dit stop aux OGM de Monsanto. Jeune Afrique, 01 June 2015 (in French). http://www.jeuneafrique.com/233742/economie/le-burkina-dit-stop-aux-ogm-de-monsanto/.
Asara, V., Otero, I., Demaria, F., Corbera, E., 2015. Socially sustainable degrowth as a social–ecological transformation: repoliticizing sustainability. Sustain Sci. http://dx.doi.org/10.1007/s11625-015-0321-9.
Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, J.M., Avilés-Vázquez, K., Samulon, A., Perfecto, I., 2007. Organic agriculture and the global food supply. Renew. Agric. Food Syst. 22, 86–108.
Benbrook, C., 2012. Impacts of Genetically Engineered Crops on Pesticide Use in the U.S. – the First Sixteen Years. Env. Science Europe. http://www.enveurope.com/content/pdf/2190-4715-24-24.pdf.
Camargo, G.G.T., Ryan, M.R., Richard, T., 2013. Energy use and greenhouse gas emission from crop production using the Farm Energy Analysis toll. BioScience 63, 263–273.
Carlson, R., 2016. Estimating the biotech sector's contribution to the US economy. Nat. Biotechnol. 34, 247–255.
Carpenter, S., Walker, B., Anderies, J.M., Abel, N., 2001. From metaphor to measurement: resilience of what to what? Ecosystems 4, 765–781.
Cattaneo, C., D'Alisa, G., Kallis, G., Zografos, C., 2012. Special issue: politics, democracy and degrowth. Futures 44 (6) (August 2012).
CERTCOST, 2012a. Organic Rules and Certification. Project CERTCOST Economic analysis of certification systems for organic food and farming EC-7FP. http://www.certcost.org/.
CERTCOST, 2012b. EC Council Regulation No. 2092/91-Fertilizers and Soil Conditioners - Annex II A. Organic Rules and Certification. Project CERTCOST Economic analysis of certification systems for organic food and farming EC-7FP. http://www.certcost.org/. http://organicrules.org/custom/differences.php?id=2bbb.
Chandler, S., Dunwell, J.M., 2008. Gene flow, risk assessment and the environmental release of transgenic plants. Crit. Rev. Plant Sci. 27, 25–49.
CIA, 2016. Labor Force - by Occupation. https://www.cia.gov/library/publications/the-world-factbook/fields/2048.html.
Commoner, B., 1971. The Closing Circle. Random House, New York, USA.
Commoner, B., 1975. Making Peace with the Planet. Pantheon, New York, USA.
Conway, G., 2012. One Billion Hungry: Can We Feed the World. Cornell University Press, Ithaca, NY, USA.
Costanza, R., 1989. What is ecological economics? Ecol. Econ. 1, 1–7.
D'Alisia, G., Demaria, F., Kallis, G. (Eds.), 2015. Degrowth: a Vocabulary for a New Era. Routledge, NY, USA.

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Davey, B., 2014. Review: Degrowth – a Vocabulary for a New Era. Feasta. The Foundation for the Economics of Sustainability. http://www.feasta.org/2014/12/18/degrowth-a-vocabulary-for-a-new-era-review/. http://www.resilience.org/stories/2014-12-18/review-degrowth-a-vocabulary-for-a-new-era.
Demaria, F., Schneider, F., Sekulova, F., Martinez-Alier, J., 2013. What is Degrowth? From an activist slogan to a social movement. Environ. Values 22, 191–215.
de Ponti, T., Rijk, B., van Ittersum, M.K., 2012. The crop yield gap between organic and conventional agriculture. Agric. Syst. 108, 1–9.
Deriu, M., 2015. Conviviality. In: D'Alisia, G., Demaria, F., Kallis, G. (Eds.), Degrowth: a Vocabulary for a New Era. Routledge, NY, USA, pp. 79–82.
Domingo, J.L., Giné Bordonaba, J., 2011. A literature review on the safety assessment of genetically modified plants. Environ. Int. 37, 734–742.
Dowd-Uribe, B., Schnurr, M.A., 2016. Briefing: Burkina Faso's reversal on genetically modified cotton and the implications for Africa. Afr. Aff. 1–12. http://dx.doi.org/10.1093/afraf/adv063.
Drunker, S.M., 2015. Altered Genes, Twisted Truths. Clear River Press, Salt Lake City, UT, USA.
EC (European Commission), 2014. Population Ageing in Europe Facts, Implications and Policies. European Commission, Directorate-General for Research and Innovation. Socioeconomic Sciences and Humanities. Publications Office of the European Union, Luxembourg. https://ec.europa.eu/research/social-sciences/pdf/policy_reviews/kina26426enc.pdf.
EC (European Commission), 2013. Organic versus Conventional Farming, Which Performs Better Financially? No 4, November, 2013. http://ec.europa.eu/agriculture/rica/pdf/FEB4_Organic_farming_final_web.pdf.
Ehrlich, P.R., 1968. The Population Bomb. Ballantine Books.
Ehrlich, P.R., Holdren, J.P., 1971. Impact of population growth. Science 171, 1212–1217.
Ellwood, W., 2014. Degrowth and Sustainability. New internationalist, Oxford, UK.
Engdahl, F.W., 2007. Seeds of Destruction - the Hidden Agenda of Genetic Manipulation. Global Research, Centre for Research on Globalization, Montreal, Quebec, Canada.
Ewen, S.W., Pusztai, A., 1999. Effect of diets containing genetically modified potatoes expressing *Galanthus nivalis* lectin on rat small intestine. Lancet 354, 1353–1354.
Fagan, J., Antoniou, M., Robinson, C., 2014. Myths and Truths - an Evidence-based Examination of the Claims Made for the Safety and Efficacy of Genetically Modified Crops and Foods. Earth Open Source. http://responsibletechnology.org/GMO-Myths-and-Truths-edition2.pdf.
FAO (The Food and Agriculture Organization of the United Nations), 2014. Walking the Nexus Talk: Assessing the Water-Energy-Food Nexus in the Context of the Sustainable Energy for All Initiative. FAO, Rome. http://www.fao.org/3/a-i3959e.pdf.
Ferguson, R.S., Lovell, S.T., 2015. Grassroots engagement with transition to sustainability: diversity and modes of participation in the international permaculture movement. Ecol. Soc. 20, 39. http://dx.doi.org/10.5751/ES-08048-200439.
Ferguson, R.S., Lovell, S.T., 2014. Permaculture for agroecology: design, movement, practice, and worldview. A review. Agron. Sustain. Dev. 34, 251–274.
Fischer-Kowalski, M., 1998a. Society's metabolism. The intellectual history of materials flow analysis, Part I, I 860- I 970. J. Ind. Ecol. 2, 61–78.
Fischer-Kowalski, M., 1998b. Society's metabolism. The intellectual history of materials flow analysis, Part II, 1970-1 998. J. Ind. Ecol. 2, 107–136.
Flipo, F., Schneider, F., 2015. Foreword. In: D'Alisia, G., Demaria, F., Kallis, G. (Eds.), Degrowth: a Vocabulary for a New Era. Routledge, NY, USA pp.xxi-xxvi.
Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockstrom, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D.P.M., 2011. Solutions for a cultivated planet. Nature 478, 337–342.
Fotakis, C., Peschner, J., 2015. Demographic Change, Human Resources Constraints and Economic Growth: the EU Challenge Compared to Other Global Players. European Commission, Working Paper 1/2015. Publications Office of the European Union, Luxembourg.
Funtowicz, S.O., Ravetz, J.R., 1994. The worth of a songbird: ecological economics as a post-normal science. Ecol. Econ. 10, 197–207.
Funtowicz, S.O., Ravetz, J.R., 1990. Uncertainty and Quality in Science for Policy. Kluwer, Dordrecht, The Netherlands.
GeneWatch, 2016. Burkina Faso abandons GM Bt Cotton. http://www.gmwatch.org/news/latest-news/16677-burkina-faso-abandons-gm-bt-cotton.
Gerland, P., Raftery, A.E., Sevčíková, H., Li, N., Gu, D., Spoorenberg, T., Alkema, L., Fosdick, B.K., Chunn, J., Lalic, N., Bay, G., Buettner, T., Heilig, G.K., Wilmoth, J., 2014. World population stabilization unlikely this century. Science 346, 234–327.
Georgescu-Roegen, N., 1975. Energy and economic myths. South. Econ. J. 41, 347–381.
Georgescu-Roegen, N., 1971. The Entropy Law and the Economic Process. Harvard University Press, Cambridge, USA.
Giampietro, M., 2004. Multi-Scale Integrated Analysis of Agroecosystems: a Complex System Approach. CRC Press, Boca Raton, London, UK.
Giampietro, M., Mayumi, K., 2009. The Biofuel Delusion: the Fallacy of Large Scale Agro-Biofuels Production. Earthscan, London, UK.
Giampietro, M., Pimentel, D., 1994. The Tightening Conflict: Population, Energy Use and the Ecology of Agriculture. Negative Population Growth Inc, Teaneck, N.J., USA. October 1993. http://www.npg.org/forum_series/TheTighteningConflict.pdf.
Giampietro, M., Mayumi, K., Sorman, A.H., 2013. Energy Analysis for a Sustainable Future. Taylor & Francis Group, Routledge, London, UK.
Giampietro, M., Mayumi, K., Sorman, A.H., 2012. The Metabolic Pattern of Societies: where Economists Fall Short. Taylor & Francis Group, Routledge, New York, USA.
Giampietro, M., Aspinall, R.J., Ramos-Martin, J., Bukkens, S.G.F. (Eds.), 2014. Resource Accounting for Sustainability Assessment: the Nexus between Energy, Food, Water and Land Use. Routledge, New York, USA.
Giddens, A., 2006. Sociology, fifth ed. Polity Press, Cambridge, UK.
Gliessman, S.R., 2007. Agroecology. The Ecology of Sustainable Food System. CRC Press, Boca Raton, FL, USA.
Gobierno de Aragón, 2015. The Results of the Maize and Sunflower Varieties Testing in Aragon (Resultados de la red de ensayos de variedades de maíz y girasol en Aragón. Campaña 2014. Dirección General de Alimentación y Fomento Agroalimentario Servicio de Recursos Agrícolas, Núm. 256 Año 2015, Servicio de Recursos Agrícolas). (In Spanish). http://www.aragon.es/estaticos/GobiernoAragon/Departamentos/AgriculturaGanaderiaMedioAmbiente/TEMAS_AGRICULTURA_GANADERIA/Areas/FORMACION_INNOVACION_SECTOR_AGRARIO/CENTRO_TRANSFERENCIA_AGROALIMENTARIA/Publicaciones_Centro_Transferencia_Agroalimentaria/IT_2015/IT_256–15.pdf.
Gómez-Barbero, M., Berbel, J., Rodríguez-Cerezo, E., 2008. Bt corn in Spain - the performance of the EU's first GM crop. Nat. Biotechnol. 26, 384–386.
Gomiero, T., 2017. The biophysical analysis of food systems: scales, energy efficiency, power and the metabolism of the society. In: Fraňková, E., Haas, W., Singh, S.J. (Eds.), In Search of Sustainable Local Food Systems: Sociometabolic Perspectives. Springer under review.
Gomiero, T., 2016. Soil degradation, land scarcity and food security: reviewing a complex challenge. Sustainability 8 (3), 281. http://dx.doi.org/10.3390/su8030281.
Gomiero, T., 2015. Are biofuels an effective and viable energy strategy for industrialized societies? A reasoned overview of potentials and limits. Sustainability 7, 8491–8521.
Gomiero, T., 2013. Alternative land management strategies and their impact on soil conservation. Agriculture 3, 464–483.
Gomiero, T., Pimentel, D., Paoletti, M.G., 2011a. Is there a need for a more sustainable agriculture? Crit. Rev. Plant. Sci. 30, 6–23.
Gomiero, T., Pimentel, D., Paoletti, M.G., 2011b. Environmental impact of different agricultural management practices: conventional vs. organic agriculture. Crit. Rev. Plant. Sci. 30, 95–124.
Gomiero, T., Giampietro, M., Mayumi, K., 2006. Facing complexity on agroecosystems: a new approach to farming system analysis. Int. J. Agric. Resour. Gov. Ecol. 5 (2/3), 116–144.
Gomiero, T., Giampietro, M., Bukkens, S.M., Paoletti, G.M., 1997. Biodiversity use and technical performance of freshwater fish culture in different socio-economic context: China and Italy. Agric. Ecosyst. Environ. 62 (2,3), 169–185.
Gorz, A., 19th June 1972. (under the pseudonym of Michael Bosquet) 1972. In: Proceedings from a public debate organized in Paris by the Club du Nouvel Observateur. Nouvel Observateur, Paris, p. IV, 397.
Grigg, D., 1992. The Transformation of the Agriculture in the West. Basil Blackwell, Oxford, UK.
Gunderson, L., Holling, C.S., 2001. Resilience and adaptive cycles. In: Gunderson, L., Holling, C.S. (Eds.), Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington D.C., USA, pp. 25–62.
Gurian-Sherman, D., 2009. Failure to Yield: Evaluation the Performance of Genetically Engineered Crops. Union of concerned scientists (UCD). Food and Environment Program. UCS Publications, Cambridge, USA. http://www.ucsusa.org/sites/default/files/legacy/assets/documents/food_and_agriculture/failure-to-yield.pdf.
Guthman, J., 2004. Agrarian Dreams: the Paradox of Organic Farming in California. University of California Press, Los Angeles, USA.
Hall, C.A.S., Klitgaard, K.A., 2012. Energy and the Wealth of Nations: Understanding the Biophysical Economy. Springer, New York, USA.
Hall, C.A.S., Day Jr., J.W., 2009. Revisiting the limits to growth after peak oil. Am. Sci. 97, 230–237.
Hall, C.A.S., Cleveland, C.J., Kaufmann, R., 1992. Energy and Resource Quality. University of Colorado press, Niwot, Colorado, USA.
Hall, C.A.S., Dale, B.E., Pimentel, P., 2011. Seeking to Understand the Reasons for Different Energy Return on Investment (EROI) Estimates for Biofuels. Sustainability 3, 2413–2432.
Hardin, G., 1993. Living within Limits: Ecology, Economics, and Population Taboos. Oxford University Press, New York, USA.
Hardin, G., 1968. The tragedy of the commons. Science 162, 1243–1248.
HLPE, 2012. Food Security and Climate Change. A Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome 2012. http://www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE_Reports/HLPE-Report-3-Food_security_and_climate_change-June_2012.pdf.
Howells, M., Hermann, S., Welsch, M., Bazilian, M., Segerström, R., Alfstad, T., Gielen, D., Rogner, H., Fischer, G., van Velthuizen, H., Wiberg, D., Young, C., Roehrl, R.A., Mueller, A., Steduto, P., Ramma, I., 2013. Integrated analysis of climate change, land-use, energy and water strategies. Nat. Clim. Change 3, 621–626.
IARC (The International Agency for Research on Cancer), 2015. IARC Monographs Evaluate DDT, Lindane, and 2,4-D. https://www.iarc.fr/en/media-centre/pr/2015/pdfs/pr236_E.pdf.

IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development), 2009. Agriculture at the Crossroad. Synthesis report. Island Press, Washington, USA. http://apps.unep.org/publications/pmtdocuments/-Agriculture%20at%20a%20crossroads%20-%20Synthesis%20report-2009Agriculture_at_Crossroads_Synthesis_Report.pdf.
IFOAM (International Movement of Organic Agriculture Movements), 2016. Principles of Organic Agriculture. https://www.ifoam.bio/en/organic-landmarks/principles-organic-agriculture.
Illich, I., 2015. Beyond Economics and Ecology: the Radical Taught of Ivan Illich. Marion Boyars, London, UK.
Illich, I., 1975. Tools for Conviviality. Fontana/Collins, Glasgow, UK.
Illich, I., 1971. Deschooling Society. Harper & Row, NY, USA.
Infante Amate, J., González de Molina, M., 2013. 'Sustainable de-growth' in agriculture and food: an agro-ecological perspective on Spain's agri-food system (year 2000). J. Clean. Prod. 38, 27–35.
Jackson, T., 2009. Prosperity without Growth. Economics for a Finite Planet. Eaerthscan, London, UK.
Kallis, G., 2014. Response by Giorgos Kallis to Brian Davey's Review of Degrowth. Feasta. The Foundation for the Economics of Sustainability. http://www.feasta.org/2014/12/22/response-by-giorgos-kallis-to-brian-daveys-review-of-degrowth/.
Kallis, G., 2013. Societal metabolism, working hours and degrowth: a comment on Sorman and Giampietro. J. Clean. Prod. 38, 94e98.
Kallis, G., 2011. In defence of degrowth. Ecol. Econ. 70, 873–880.
Kallis, G., Demaria, F., D'Alisia, G., 2015. Introduction: degrowth. In: D'Alisia, G., Demaria, F., Kallis, G. (Eds.), Degrowth: a Vocabulary for a New Era. Routledge, NY, USA, pp. 1–17.
Kallis, G., Kerschner, C., Martinez-Alier, J., 2012a. The economics of degrowth. Ecol. Econ. 84, 247–253.
Kallis, G., Kerschner, C., Martinez-Alier, J. (Eds.), 2012b. Special Section: the Economics of Degrowth, vol. 84. Ecological Economics.
Kallis, G., Schneider, F., Martinez-Alier, J., 2010. Growth, recession or degrowth for sustainability and equity? J. Clean. Prod. 18 (6).
Kallis, G., Kalush, M., O'Flynn, H., Rossiter, J., Ashford, N., 2013. "Friday off": reducing working hours in Europe. Sustainability 5, 1545–1567. http://dx.doi.org/10.3390/su5041545.
Keim, B., 2014. New Generation of GM Crops Puts Agriculture in a 'Crisis Situation'. Wired, 09.25.14. http://www.wired.com/2014/09/new-gm-crops/.
Kerschner, C., 2010. Economic de-growth vs. steady-state economy. J. Clean. Prod. 18, 544–551.
Kerschner, C., Wächter, P., Nierling, L., Ehlers, M.-H., 2015. Special volume: technology and Degrowth. J. Clean. Prod. 108. Part A, 1 December 2015. http://www.sciencedirect.com/science/article/pii/S0959652615008409.
Kirk, D., 1996. Demographic transition theory. Popul. Stud. 50, 361–387.
Kirk, G., 1982. Schumacher on Energy: Speeches and Writing of E.F. Schumacher. Jonathan Cape, London, UK.
Krimsky, S., Bruber, J., 2014. The GMO Deception. Skyhorse Publishing, New York, USA.
Krausmann, F., Fischer-Kowalski, M., Schandl, H., Eisenmenger, N., 2008. The global sociometabolic transition: past and present metabolic profiles and their future trajectories. J. Ind. Ecol. 12, 637–656.
Lampkin, N., 2002. Organic Farming. Old Pond Publishing, Suffolk, UK.
Latouche, S., 2016. The Degrowth before the Degrowth. (La Decrescita Prima Della Decrescita). Bollati Boringhieri, Torino, Italia (in Italian).
Latouche, S., 2012. For a Frugal Plenty. (Per Un'abbondanza Frugale). Bollati Boringhieri, Torino, Italy (in Italian).
Latouche, S., 2009. Farewell to Growth. Polity press, Cambridge, UK.
Latouche, S., 2008. Short Treatise on Serene Degrowth. (Breve Trattato Sulla Decrescita Serena). Bollati Boringhieri, Torino, Italia (in Italian).
Latouche, S., 2007a. De-growth: an electoral stake? Int. J. Incl. Democr. 3 (1) (January 2007). http://www.inclusivedemocracy.org/journal/vol3/vol3_no1_Latouche_degrowth.htm#_edn2.
Latouche, S., 2007b. The Bet of Degrowth. (La Scommessa Della Decrescita). Feltrinelli, Milano, Italy (in Italian).
Latouche, S., 2006. The globe downshifted. Le. Monde Diplomatique (English edition). January 2006. http://mondediplo.com/2006/01/13degrowth.
Latouche, S., 2004. Degrowth economics. Le Monde Diplomatique (English edition). November 2004. http://mondediplo.com/2004/11/14latouche.
Latouche, S., 2003. The world downscaled. Le. Monde Diplomatique (English edition). December 2003. http://mondediplo.com/2003/12/17growth.
Latouche, S., 1993. In the Wake of the Affluent Society. An Exploration of Post-development. Zed books, London.
Lee, R.D., Reher, D.S. (Eds.), 2011. Demographic Transition and its Consequences, p. 275. Population and Development Review A Supplement to Volume 37.
Lu, Y., Wu, K., Jiang, Y., Xia, B., Li, P., Feng, H., Wyckhuys, K.A., Guo, Y., 2010. Mirid bug outbreaks in multiple crops correlated with wide-scale adoption of Bt cotton in China. Science 328, 1151–1154.
Malatesta, M., Tiberi, C., Baldelli, B., Battistelli, S., Manuali, E., Biggiogera, M., 2005. Reversibility of hepatocyte nuclear modifications in mice fed on Genetically Modified Soybean. Eur. J. Histochem. 49, 237–242.
Martinez-Alier, J., 2015. Neo-malthusians. In: D'Alisia, G., Demaria, F., Kallis, G. (Eds.), Degrowth: a Vocabulary for a New Era. Routledge, NY, USA, pp. 125–128.
Martinez-Alier, J., 2012. Environmental justice and economic degrowth: an alliance between two movements. Capital. Nat. Social. 23 (1), 51–73.
Martinez-Alier, J., 1987. Ecological Economics: Energy, Environment and Society. Oxford University Press, UK.
Mazoyer, M., Roudart, L., 2006. The History of World Agriculture: from the Neolithic Age to the Present Crisis. Earthscan London, UK.
MacKay, D.J.C., 2009. Sustainable Energy—Without the Hot Air. UIT Cambridge Ltd, Cambridge, UK. Available online: http://www.withouthotair.com/download.html (Accessed on 20 October 2016).
Meadows, D.H., Meadows, G., Randers, J., Behrens III, W.W., 1972. The Limits to Growth. Universe Books, New York, USA.
Mishan, E.J., 1967. The Costs of Economic Growth. Staple Press, London, UK (Revised ed. 1993, Weidenfeld & Nicolson, London, UK.).
Mishan, E.J., Turner, D., 2006. The costs of economic growth. Soc. Contract J. 17, 1 (Fall 2006). http://www.thesocialcontract.com/artman2/publish/tsc_17_01/tsc_17_1_mishan.shtml.
Monsanto, 2008. Monsanto Technology/stewardship Agreement. St. Louis, Missouri, USA. http://www.monsanto.com/sitecollectiondocuments/tug_sample.pdf.
Nicholl, D.S.T., 2008. An Introduction to Genetic Engineering, 3th ed. Cambridge University Press, New York, USA.
NAS (National Academies of Sciences, Engineering, and Medicine), 2016. Genetically Engineered Crops: Experiences and Prospects. The National Academies Press, Washington, DC. https://www.nap.edu/catalog/23395/genetically-engineered-crops-experiences-and-prospects.
NRC (National Research Council), 2000. Genetically Modified Pest-Protected Plants: Science and Regulation. Committee on Genetically Modified Pest-Protected Plants - Board on Agriculture and Natural Resources. National Research Council. National Academy Press, Washington, DC, USA. http://www.nap.edu/catalog/9795/genetically-modified-pest-protected-plants-science-and-regulation.
Odum, H.T., 1988. Self-organization, transformity, and information. Science 242, 1132–1139.
Odum, H.T., 1971. Environment, Power and Society. John Wiley, New York, USA.
Odum, H.T., Odum, E.C., 2001. A Prosperous Way Down. Principles and Policies. University of Colorado, Boulder, Co., USA.
Pallante, M., 2011. Less and better. Degrowing to progress (Meno e meglio. Decrescere per progredire). Bruno Mondandori, Torino, Italy (in Italian).
Pallante, M., 2005. The Happy Degrowth: the Quality of Life Does Not Depend on the GDP. (La Decrescita Felice. La Qualità Della Vita Non Dipende Dal PIL). Editori Riuniti, Roma, Itaky (in Italian).
Perry, E.D., Ciliberto, F., Hennessy, D.A., Moschini, G.C., 2016. Genetically engineered crops and pesticide use in U.S. maize and soybeans. Sci. Adv. 2 http://dx.doi.org/10.1126/sciadv.1600850.
Pilson, D., Prendeville, H.R., 2004. Ecological effects of transgenic crops and the escape of transgenes into wild populations. Annu. Rev. Ecol. Evol. Syst. 35,149–35,174.
Pimentel, D., 1984. Energy flow in the food system. In: Pimentel, D., Hall, C.-W. (Eds.), Food and Energy Resources. Academy press, Orland, FL, USA, pp. 1–24.
Pimentel, D., Pimentel, M., 2008. Food, Energy, and Society, 3rd ed. CRC Press, Boca Raton, FL, USA.
Pimentel, D., Pimentel, M., 1979. Food, Energy, and Society. John Wiley and Sons, New York, USA.
Pimentel, D., Patzek, T., Cecil, G., 2007. Ethanol production: energy, economic, and environmental losses. Rev. Environ. Contam. Toxicol. 189, 25–41.
P.M., 1983. bolo'bolo. The Anarchist Library. Also in Spanish at. http://www.spaz.org/~jake/pix/p.m.__bolo'bolo.pdf. https://lagenterula.files.wordpress.com/2014/05/bolobolo.pdf.
Pretty, J.N., Morison, J.I.L., Hine, R.E., 2003. Reducing food poverty by increasing agricultural sustainability in developing countries. Agric. Ecosyst. Environ. 95, 217–234.
Quist, D., Chapela, I.H., 2001. Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico. Nature 414, 541–543.
Reganold, J.P., Wachter, J.M., 2016. Organic agriculture in the twenty-first century. Nat. Plants 2. http://dx.doi.org/10.1038/nplants.2015.221.
Reher, D.S., Sandström, G., Sanz-Gimeno, A., van Poppel, F.W.A., 2017. Agency in fertility decisions in Western Europe during the demographic transition: a comparative perspective. Demography 54, 3–22.
Roland, P., Adamchak, R.W., 2008. Tomorrow's Table: Organic Farming, Genetics, and the Future of Food. Oxford University Press, New York, USA.
Samerski, S., 2016. Tools for degrowth? Ivan Illich's critique of technology revisited. J. Clean. Prod. In Press, Corrected Proof detach proof from Schfer (new paper).
Schafer, M.G., Ross, A.A., Londo, J.P., Burdick, C.A., Lee, E.H., Travers, S.E., Van de Water, P.K., Sagers, C.L., 2011. The establishment of genetically engineered canola populations in the U.S. PLoS ONE 6 (10), e25736. http://dx.doi.org/10.1371/journal.pone.0025736.
Schneider, F., Kallis, G., Martinez-Alier, J., 2010. Crisis or opportunity? Economic degrowth for social equity and ecological sustainability. J. Clean. Prod. 18, 511–518.
Schumacher, E.F., 1979. Good Work. Harper & Row, New York, USA.
Schumacher, E.F., 1973. Small Is Beautiful. Harper & Row, New York, USA.
Sekulova, F., Rodríguez-Labajos, B., Kallis, G., Schneider, F., 2013. Special issue: degrowth: form theory to practice. J. Clean. Prod. 38.
Seufert, V., Ramankutty, N., Foley, J.A., 2012. Comparing the yields of organic and conventional agriculture. Nature 485, 229–232.
Séralini, G.-E., Clair, E., Mesnage, R., Gress, S., Defarge, N., Malatesta, M., Hennequin, D., Spiroux de Vendômois, J., 2014. Republished study: long-term toxicity of a Roundup herbicide and a Roundup-tolerant genetically modified maize. Env. Sci. Eur. 26 (14). http://www.enveurope.com/content/26/1/14.

Shi, G., Chavas, J.-P., Lauer, J., 2013. Commercialized transgenic traits, maize productivity and yield risk. Nat. Biotech. 31, 111–114.
Smil, V., 2003. Energy at the Crossroads. The MIT Press, Cambridge, MA, USA.
Smil, V., 2000. Feeding the World: a Challenge for the Twenty-first Century. The MIT Press, Cambridge, MA, USA.
Smil, V., 1991. General Energetics. John Wiley, New York. USA.
Sorman, A.H., Giampietro, M., 2013. The energetic metabolism of societies and the degrowth paradigm: analyzing biophysical constraints and realities. J. Clean. Prod. 38, 80–93.
Stehle, S., Schulz, R., 2015. Agricultural insecticides threaten surface waters at the global scale. PNAS 112, 5750–5755.
Stone, G.D., Glover, D., 2017. Disembedding grain: golden rice, the green revolution, and heirloom seeds in the Philippines. Agric. Hum. Values 34, 87–102.
Strand, R., Saltelli, A., Giampietro, M., Rommetveit, K., Funtowicz, S., 2017. New narratives for innovation. J. Clean. Prod. http://dx.doi.org/10.1016/j.jclepro.2016.10.194 (in press, Corrected Proof, http://www.sciencedirect.com/science/article/pii/S095965261631825X).
Sutherland, L.-A., Darnhofer, I., 2012. Of organic farmers and ‘good farmers’: changing habitus in rural England. J. Rural Stud. 28, 232e240.
Tabashnik, B.E., Brévault, T., Carrière, Y., 2013. Insect resistance to Bt crops: lessons from the first billion acres. Nat. Biotechnol. 31, 510–521.
Taylor, J.B., Uhlig, H., 2016. Handbook of Macroeconomics, vol. 2. Elsevier, The Netherlands.
Tello, E., Garrabou, R., Cussó, X., Olarieta, J.R., Galán, E., 2012. Fertilizing methods and nutrient balance at the end of traditional organic agriculture in the Mediterranean bioregion: catalonia (Spain) in the 1860s. Hum. Ecol. 40, 369–383.
The Ecologist, 1998. The Monsanto Files. Special issue. 25(5) September/October. http://www.theecologist.org/back_archive/dynamic/?url=http://exacteditions.theecologist.org/exact/browse/307/308/5361/1/1.
The Economist, 2010. Economic Growth: the Solution to All Problems. http://www.economist.com/blogs/freeexchange/2010/06/economic_growth.
UN (United Nations), 2015. World Population Prospects - the 2015 Revision: Key Findings and Advance Tables. Working Paper No. ESA/P/WP.241. Department of Economic and Social Affairs - Population Division. United Nations, New York, USA. Available online at: http://esa.un.org/unpd/wpp/publications/files/key_findings_wpp_2015.pdf (Accessed on 20 October 2015).
UN-ESCAP, 2014. Water, Food and Energy Nexus in Asia and the Pacific. United Nation Discussion Paper. http://www.worldwatercouncil.org/fileadmin/world_water_council/documents/programs_hydropolitics_sdgs/Water-Food-Nexus%20Report.pdf.
Videira, N., Schneider, F., Sekulova, F., Kallis, G., 2014. Improving understanding on degrowth pathways: an exploratory study using collaborative causal models. Futures 55, 58–77.
WB (The World Bank), 2016b. Urban Population (% of Total). http://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS.
WHO (World Health Organization), 1999. Microbial Pest Control Agent Bacillus Thuringiensis. World Health Organization, Ginevra, Switzerland. http://www.who.int/ipcs/publications/ehc/en/EHC217.PDF.
Wilson, P., 1992. The inputs to agriculture. In: Spedding, C.R.W. (Ed.), Fream's Principles of Food and Agriculture. Blackwell, Cambridge, MA, USA, pp. 204–227.

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