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Introducing a Degrowth Approach to the Circular Economy Policies of Food Production, and Food Loss and Waste Management: Towards a Circular Bioeconomy

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Abstract: There is a growing debate surrounding the contradiction between an unremitting increase in the use of resources and the search for environmental sustainability. Therefore, the concept of sustainable degrowth is emerging aiming to introduce in our societies new social values and new policies, capable of satisfying human requirements whilst reducing environmental impacts and consumption of resources. In this framework, circular economy strategies for food production and food loss and waste management systems, following the Sustainable Development Goals agenda, are being developed based on a search for circularity, but without setting limits to the continual increase in environmental impacts and resource use. This work presents a methodology for determining the percentage of degrowth needed in any food supply chain, by analyzing four scenarios in a life cycle assessment approach over time between 2020 and 2040. Results for the Spanish case study suggested a degrowth need of 26.8% in 2015 and 58.9% in 2040 in order to achieve compliance with the Paris Agreement targets, highlighting the reduction of meat and fish and seafood consumption as the most useful path.

Keywords: degrowth; food supply chain; food loss and waste; Global North; Paris agreement; spiral bioeconomy; circular bioeconomy

1. Introduction

The sustainable development promoted over more than three decades ago with the Brundtland Report [1] is a highly multi-disciplinary field of research that has been extensively studied during the last decades [2]. However, it is being questioned by several critical voices, due to an apparent ineffectiveness of the policies and strategies based on it for articulate responses to halt environmental problems [3].

Therefore, according to Georgescu-Roegen (1993) [4] and Krausmann et al. (2009) [5], the current sustainable development strategies seem to be contradictory, as they avoid questioning the unremitting increase in the use of resources and the environmental impacts generation, although practice often suggests that it is not possible to reconcile an endless economic and productivity growth with environmental sustainability. Moreover, the International Panel for Sustainable Resource Management highlights the fact, that the Global-North lifestyle is damaging not only its own environment, but also that of poorer countries and, in general, the planet as a whole [6] as a big part of the environmental degradation in the "Global South" is due to externalized environmental costs derived from the consumption lifestyles in the Global North, which are not accounted for. This fact is often being hidden with fallacies with a colonialist slant by the Global North such as the claim of the origin of environmental problems being in the presence of totalitarian governments, centrally controlled economies, or lack of freedom, considering that the solution lies in the mantra of a need to bet on the free market with independence of the states, when this independence has never really existed [7].

In this line, the Circular Economy Package of the European Commission puts an emphasis on closing the loop on the material use along the whole life cycle in order to achieve sustainability [8]. Nevertheless, although it promotes strategies of zero-waste and circular economy, it does not set any sustainability limit in environmental impacts and resource use. This fact suggests that despite promoting policies searching for environmental sustainability, they may carry out so-called greenwashing: the act of misleading citizens regarding the environmental benefits of a product or service [9]. As a response to all these critical voices, the concept of sustainable degrowth is emerging aiming to introduce in our societies social values, and new policies, capable of satisfying human requirements whilst reducing the environmental impacts and consumption of resources [10].

In this overall framework, circular economy strategies for food production and food loss and waste (FLW) management systems are following the Sustainable Development Goals (SDGs) agenda of halving by 2030 the per capita global food waste generation at the retail and consumer levels, and the reduction of food losses along production and supply chains, including post-harvest losses [11]. Nevertheless, they are being developed based on a search for circularity, but without setting limits to the increasing amount of resources introduced into food supply chains, and the environmental impacts that it implies. Moreover, the SDG agenda puts the weight of waste halving at the end of the chain, but leaves the vague "reduction" goal in the early stages, all in a framework where at least one-third of all edible food production is wasted worldwide throughout the entire food supply chain (20% in the European Union) [12]. The quantities of FLW could be much more higher, especially in the early stages of the production chain (agricultural production, post-harvest and processing and packaging), as the loss or waste of animal and plant products which are non-edible or not originally intended to be eaten by humans, is not considered as FLW, even if this may have implications for food security and nutrition, or environmental impacts [11].

This work presents a methodology to determine the degrowth needed in the food sector at any national, regional, or local level, aiming to achieve compliance levels with the Paris Agreement targets. Among them, the goal of limiting global warming to well below 2 °C above pre-industrial levels and pursuing efforts to limit it to 1.5 °C stands out [13]. The methodology combines life cycle assessment (LCA) with a degrowth approach, searching to highlight a spiral bioeconomy path, towards a circular bioeconomy, which is an emerging concept representing the renewable segment of the circular economy, necessary to build a carbon neutral future in line with the climate objectives of the Paris Agreement [14].

The concept of circular bioeconomy has been interpreted in this work as the level of degrowth calculated by the presented methodology, from which the circular production and consumption strategies should be implemented. It aims to be an easy-to-implement methodology for policy makers in the Global North, in order to develop strategies looking to achieve real sustainability levels in which circular bioeconomy strategies can be implemented, as shown in Figure 1. It is based on the 4 R's strategy suggested by Latouche (2006) [15] and Amate and González de Molina (2013) [3]: re-territorialization of production, re-vegetarianization of diet, re-localization of markets, and re-seasonalization of food consumption.

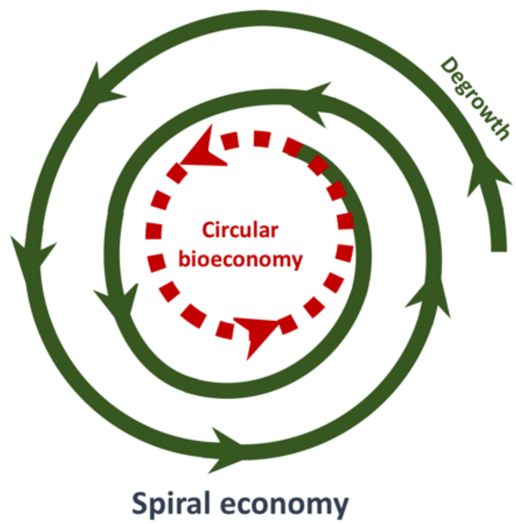

Figure 1. Degrowth transition needed through a spiral bioeconomy path, towards a circular bioeconomy [16].

2. Materials and Methods

2.1. Goal and Scope

The main goal of this work is to present a methodology to quantitatively assess the need of degrowth for implementing circular bioeconomy strategies, by reducing the emissions of greenhouse gases (GHG) in compliance with the Paris Agreement targets. In order to implement the methodology, the case study of the Spanish food supply chain and FLW generation in 2015, as a country in the Global North, was presented. The methodology includes a first step of modeling the different scenarios in GaBi, an LCA software [17], following the LCA international standards ISO 14.040 [18] and ISO 14.044 [19]. The developed model considers that the food supply chain is divided into four stages: agricultural production, processing and packaging, distribution, and consumption. According to a FAOSTAT definition [20], the model includes 11 different food categories: cereals, sweets, vegetable oils, vegetables, fruits, pulses, roots, dairy products, eggs, fish and seafood, and meat. Regarding the definition of FLW, food loss is often associated with the decrease of edible food mass available for human consumption in the earlier stages of the food supply chain (agricultural production and processing and packaging). Food waste is most often associated with the behavior of retailers, the food service sector, and consumers (i.e., the stages of distribution and consumption) [21]. In the present study, FLW refers to food loss and waste occurring at every stage of the food supply chain [22]. The environmental performance of the presented scenarios was evaluated for the period 2020–2040, considering compliance with the Paris Agreement targets every five years related to 2015. The simulations over time were based on the energy mix projections developed by the energy systems model TIAM-UCL [23]. It considers 16 regions covering the countries of the whole world. For this study, data for the Western European Region, which includes Spain, were used. A methodological framework of the work is represented in Figure 2.

The main function of the system is the production of food and FLW generation, under four different simulated scenarios (explained in Section 2.2). In order to measure this function, a suitable functional unit has to be defined, to which all the inputs and outputs are referred. The functional unit should describe qualitatively and quantitatively the function(s) and duration of the analyzed product [24]. In this case, one ton of produced food and generated FLW in Spain in 2015 was assumed as the functional unit.

In this work, the term "degrowth" is defined as the descent of any of the four pillars by increasing their respective targets (described in Section 2.2), and the term "reduction" is defined as the descent of GHG emissions produced through a degrowth of any of the four pillars.

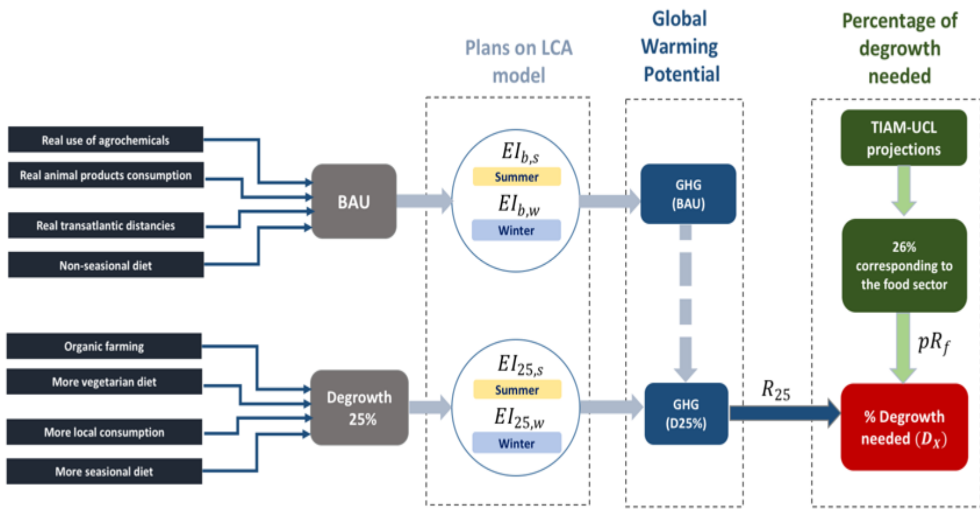

Figure 2. Methodological framework of the work.

2.2. Scenario Analysis

As shown in Table 1, in order to measure the degrowth needed, four scenarios are considered and modeled, representing, on the one hand, the actual situation of food production and FLW generation (business as usual, BAU), and, on the other hand, a 25% degrowth framework regarding the four pillars (D25%), which is based on an approach suggested by the Joint Research Center [25] where a scenario test is assessed, in which the options of 25% and 50% reduction regarding diet changes are considered. The results of the methodology for a given reduction percentage are proportional to each different percentage. Therefore, it was decided to apply the 25% reduction to the scenarios studied (including summer and winter), but other percentages would have given the same results.

The 4 R's strategy implemented in the scenarios suggests that a shift towards organic farming and corresponding changes in consumption patterns can contribute to substantial reductions in environmental impacts and resource use in the food system and, therefore, to sustainable degrowth [3,15]. As seen in Table 1, this strategy considers four pillars in order to achieve sustainability through a degrowth transition: (i) re-territorialization of production (P1), (ii) re-vegetarianization of diet (P2), (iii) re-localization of markets (P3), and (iv) re-seasonalization of food consumption (P4). These four pillars are translated into four targets: to switch to organic farming, to change over to a more vegetarian diet, to produce and consume locally, and to promote the consume of seasonal products (as explained in Figure 3).

Table 1. Considered scenarios highlighting if any of the four pillars are implemented. P1: re-territorialization, P2: re-vegetarianization, P3: re-localization, P4: re-seasonalization.

Scenario	P1	P2	P3	P4
Baseline summer (BAU-s)	NO	NO	NO	NO
Baseline winter (BAU-w)	NO	NO	NO	NO
25% degrowth summer (D25%-s)	YES	YES	YES	NO
25% degrowth winter (D25%-w)	YES	YES	YES	YES

(i) Re-territorialization of production: The P1 is assumed to be represented in an increase in the level of organic farming. This path is being highly promoted, as organic farming is a market set to continue growing and entails positive impacts on the environment and the biodiversity, as well as in creating new jobs, and attracting young farmers [26]. Although according to several published scientific meta-analyses, organic farming yields range between 0.75 and 0.8 of conventional agriculture, there are positive effects of organic farming on soil fertility (i.e., almost total avoidance in the use of agrochemical products), biodiversity maintenance, and protection of the natural resources of soil, water, and air [27]. Moreover, yet all too often, it is precisely the emphasis on yield as a measure of the performance of a single crop that blinds analysts to broader measures of sustainability and to the greater per unit area productivity and environmental services obtained in complex, integrated agroecological systems that feature many crop varieties together with animals and trees [28]. Additionally, there are many cases where even yields of single crops are higher in agroecological systems than in conventional crops [29]. Finally, hunger is caused by poverty and inequality, not scarcity, and the world currently already produces enough food to feed 10 billion people, the world´s 2050 projected population peak [30].

In order to measure this pillar, the D25% scenarios assessed the reduction in GHG emissions by a 25% degrowth in the use of agrochemicals (fertilizers, insecticides, and herbicides) if organic farming increases. For it, a GaBi 6.0 Software 17] process was implemented in the LCA plans, which was assumed to be representative for the use of agrichemicals.

(ii) Re-vegetarianization of diet: The P2 is analyzed by comparing the GHG emissions of the current diet and a diet based in a 25% reduction in the consumption of meat and fish and seafood, which are the animal products categories with the highest primary energy demand and embodied energy loss according to the data shown in Table 2. In the literature, within animal products consumption, meat is highlighted as the most relevant in terms of carbon and water footprints in high-income countries [31]. This pillar will be translated in the target of increasing the 25% reduction of meat and fish and seafood in the rest of the categories. The 25% reduction in the quantities in each of the stages of the plans in GaBi Software [17] was relocated in percentage terms as explained in Section 2.4. The exceptions are the categories of vegetables and fruits, which stayed with the same quantities, without increasing, since of the remaining nine categories, they are the ones that clearly need a greater consumption of water resources and cold storage [32], impacts out of the scope of this work but which have been taken into account for this decision. On the other hand, this second reduction target is in line with the recommendations of many works in the literature as well as with the new Farm to Fork strategy, as a more plant-based diet shows better environmental performance [33], and will reduce risks of life threatening diseases [26].

(iii) Re-localization of markets: The P3 is correlated to a 25% reduction on transatlantic boat transport, related to the percentage of imported food in 2015, and considering an average transport distance of 4000 km [23]. To calculate this, the reduction of 25% of the import values obtained from Hoehn et al. [34] was implemented in the developed plans in GaBi Software [17].

This reduction target, the so-called "food miles" reduction, is considered of high relevance in terms of degrowth as there are thousands of initiatives throughout the world claiming the need to close the circuits of production and consumption via development of local markets [35]. Moreover, transportation is one of the most challenging sectors in which to achieve sustainability due to its high dependence on fossil fuel products and increasing energy demands. According to a DEFRA report [36], reducing food miles will have a beneficial effect on sustainability, by reducing the environmental and social burdens of transport. It is not always clear whether a decrease in food transport would necessarily lead to an increase in sustainability, and there are even studies suggesting that "longer" supply channels generate lower environmental impacts per unit of production when measured in terms of food miles and carbon footprint [37]. Nevertheless, in general, it appears that an increase in food miles is correlated with negative sustainability impacts, by improving the environment through reduced pollution and increased biodiversity [38]. Exceptions are assumed to be marginal and were not include within the scope of this work.

(iv) Re-seasonalization of food consumption: Finally, the P4 is assumed to be represented by a 25% substitution of vegetables and fruits by the remaining food categories in a winter plan for BAU and D25% in the modeling in GaBi Software [17]. Meat and fish and seafood stayed with the 25% degrowth target of P3. The remaining seven categories (i.e., eggs, dairy products, cereals, sweets, pulses, vegetable oils, and roots) are assumed to be much more seasonal, or more easily to be preserved, than vegetables and fruits to be eaten during the Spanish winter. This reduction target has also been widely cited in the literature, and the advice on climate-smart food consumption given by many authorities and NGOs worldwide includes the recommendation to eat seasonal foods [39]. For measuring this target, the creation of an extra winter plan was required for the BAU and D25% scenarios, assuming summer as March to August (i.e., including the spring) and winter as September to February (i.e., including the autumn).

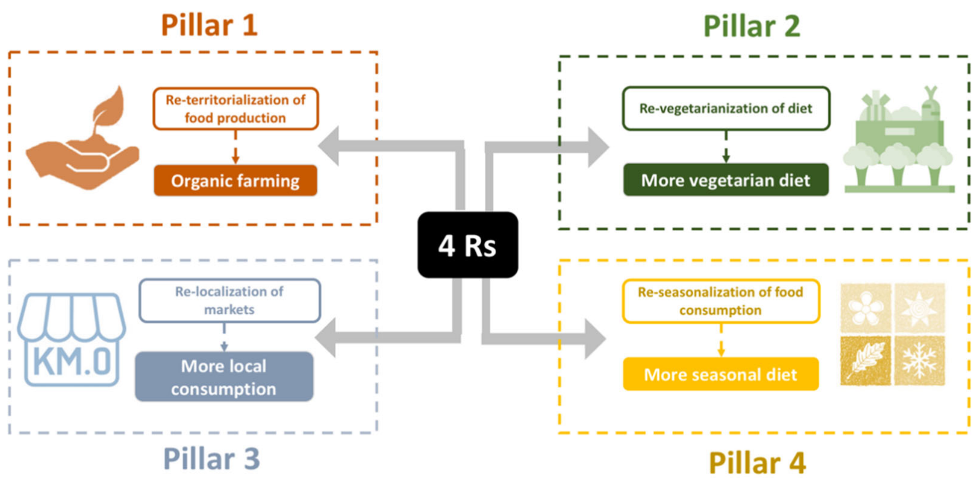

Figure 3. Diagram of the 4 R´s strategy based on Latouche (2006) [15] and Amate and González de Molina (2013) [3].

2.3. System Boundaries

As presented in Figure 4, the developed LCA has a cradle to grave approach, including within the system boundaries the food and FLW generation in four stages of the food supply chain: agricultural production, processing and packaging, distribution, and consumption. The mass and energy balances from two previous studies have been used [34,40] in order to consider the FLW and embodied energy loss of the considered food categories. Within the system boundaries, the primary energy demand of food transportation was included, but the collection and transportation of FLW were not considered, since it was assumed that it would not vary between the different scenarios.

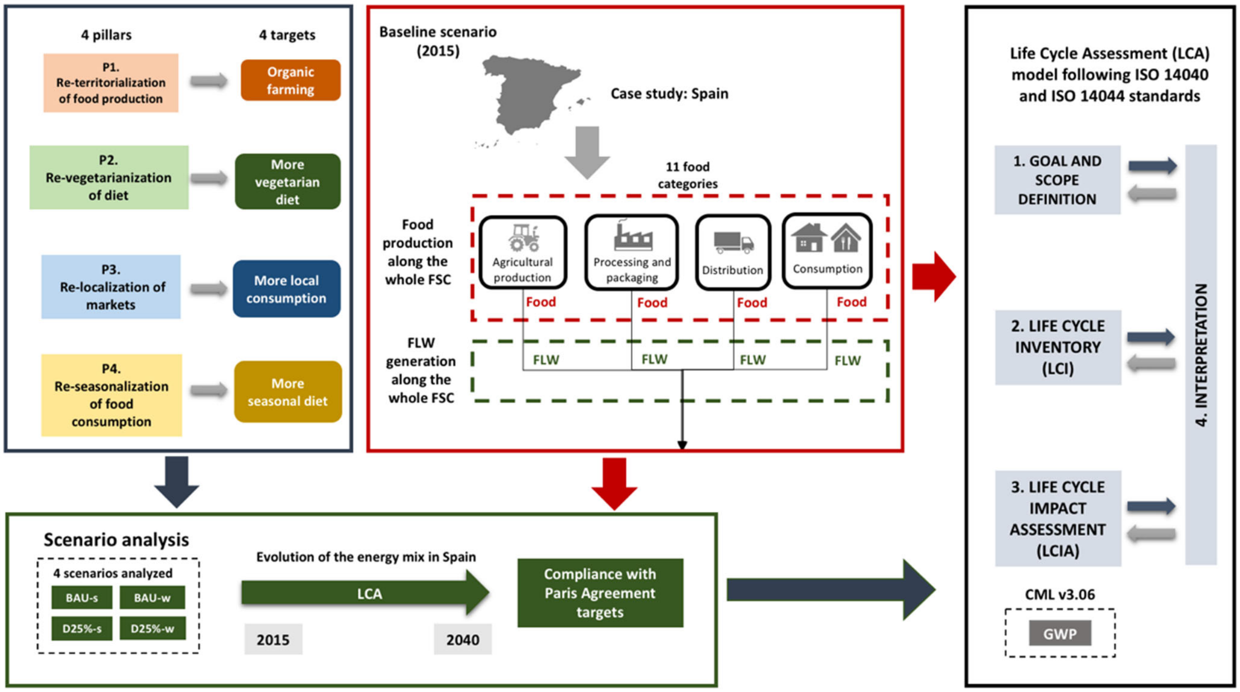

Figure 4. Conceptual diagram of the life cycle assessment methodology developed.

2.4. Life Cycle Inventory

The inventory was developed using the material flow analysis of García-Herrero et al. [40], making up an energy flow analysis, which was based on Hoehn et al. [34]. The data on primary energy demand (PED) for food production and the embodied energy loss (EEL) by FLW generation are represented in Table 2.

Table 2. Total primary energy demand and embodied energy loss of food produced and food loss and waste generated in Spain in 2015 (in petajoules per total of tons), (PED, Primary Energy Demand); (EEL,Embodied Energy Loss), based on Hoehn et al. [34].

Stage		Eggs	Meat	Fish and Seafood	Dairy Products	Cereals	Sweets	Pulses	Vegetable Oils	Vegetables	Fruits	Roots
Agricultural production	PED	29.0	149.8	86.9	38.7	74.5	4.3	13.4	19.7	90.4	18.9	9.1
	EEL	1.5	7.9	4.6	2.0	3.9	0.2	0.7	1.0	4.7	1.0	0.5
Processing and packaging	PED	18.7	96.7	56.1	25.0	48.1	2.8	8.7	12.7	58.3	12.2	5.8
	EEL	0.2	10.6	5.8	0.1	4.8	0.1	0.7	1.1	1.9	0.4	1.6
Distribution	PED	33.4	172.4	100.0	44.5	85.7	4.9	15.5	22.6	104.0	21.8	10.4
	EEL	1.3	13.4	12.9	0.4	3.3	0.2	0.5	0.4	2.4	0.5	0.4
Consumption	PED	12.8	66.0	38.3	17.1	32.8	1.9	5.9	8.7	39.8	8.3	4.0
	EEL	5.8	41.3	21.8	6.8	46.6	2.0	5.6	2.0	37.4	7.8	2.7

The allocation, conversion, and FLW factors used were extracted from Gustavsson et al. [41]. The exception was concrete products, such as apples and bananas, for which specific FLW factors from Vinyes et al. [42] and Roibás et al. [43] were used. For the quantitative calculations, data reported by the Spanish Department of Agriculture and Fishery, Food and Environment [44] were used. For the LCA modeling, the total energy embedded in the average Spanish diet for each food category was required. This information was obtained from Batlle-Bayer et al. [45], originally composed by 60 food categories, and grouped into the 11 categories considered in this work (as seen in Table 3). To proceed to the methodological calculations explained in Section 2.6, the percentages of all the categories, with the exception of meat, fish and seafood, vegetables and fruits, were calculated.

Those percentages were used to calculate the amount of food in mass that is redistributed in the rest of the categories (and its associated energies) with respect to P2 or P4. The P4 only takes place in the D25%-w, and due to it, the redistribution in D25%-w includes the 25% of the amount from the four mentioned categories, and the redistribution in D25%-s includes only the 25% of the amount from meat and fish and seafood, keeping the quantities of vegetables and fruits stable.

Table 3. Energy embedded (kcal) for each food category and percentages for the calculations of Pillar 2 and Pillar 4 (described in Figure 2), based on Batlle-Bayer et al. [45].

Food Category	Energy Embedded	(%)
Eggs	1059.1	15.4
Meat	5464.8	-
Fish and seafood	3169.5	-
Dairy products	1410.8	20.5
Cereals	2717.3	33.2
Sweets	155.6	2.8
Pulses	490.4	8.2
Vegetable oils	716.7	11.6
Vegetables	3297.0	-
Fruits	690.2	-
Roots	330.1	5.3
TOTAL	19,501.4	

In order to determine the degrowth need from 2020 until 2040, the electricity mix simulations according to the TIAM-UCL energy systems model for a path of reducing the GHG emissions in compliance with the Paris Agreement targets were used based on the projections presented in a previous work [46]. The evolution in a compliance framework, surprisingly, suggested an enormous increase of nuclear energy until 2040, highlighting, therefore, that certain decarbonization policies in the electricity sector may foster the rise of a controversial energy source (i.e., nuclear), which opens the debate on whether the final outcome justifies any strategy to meet the Paris Agreement targets. Moreover, the projections suggested a reduction of the energy generated by biomass in 2025, nearly disappearing by 2040.

2.5. Life Cycle Impact Assessment

For quantifying the potential GHG emissions of the scenarios simulated, the Global Warming Potential, excluding biogenic carbon, was selected from the CML v3.06 methodology [47]. This choice was made considering that the assessment method has enough scientific endorsement and is widely used in the LCA literature [48] and is in the list of recommended models at midpoint of the Product Environmental Footprint Category Rules Guidance [24]. The selection of the Global Warming Potential indicator was done considering climate change as one of the most relevant impacts linked to food production and organic waste generation. It is acknowledged that other assessment methods or impact categories could have been chosen, but in this work, the use of one indicator of one single method for the degrowth assessment was prioritized. The conversion factors used, extracted from GaBi Software [17], were 0.0256 kg of CO_2 equivalents per megajoule of primary energy demand (in the case of food production) or embodied energy loss (in the case of FLW), and 72,700 kg of CO_2 equivalents per ton of ammonium sulphate used (assumed as equivalent to agrochemicals in agricultural production).

2.6. Assessment of Food Production and Food Loss and Waste Generation Scenarios

For determining the reduction of the environmental impacts, total results for summer and winter were added and divided as follows:

$$R_{25} = \frac{\left(EI_{25,s} + EI_{25,w}\right)}{\left(EI_{b,s} + EI_{b,w}\right)} \quad (1)$$

where R_{25} is the reduction of the environmental impacts in D25%, $EI_{25.S}$ are the environmental impacts in D25% in summer (D25%-s), $EI_{25.W}$ are the environmental impacts in D25% in winter (D25%-w), $EI_{b.s}$ are the environmental impacts in BAU in summer (BAU-s), and $EI_{b.w}$ are the environmental impacts in BAU in winter (BAU-w). As the winter and summer plans correspond only to the half of the year, the results in the numerator and denominator of the equation, were multiplied by 0.5.

As a next step, due to the fact that the total GHG emissions from 2015 to 2040 projected by TIAM-UCL are representing the whole production and consumption system in Spain, it was necessary to look for a reference indicator, in order to determine the percentage of GHG emissions in Spain corresponding only to the food sector. In this line, according to the European Commission [49], industrial activities related to food systems require approximately 26% of the European Union´s final energy consumption. As energy production is one of the sectors with higher environmental impacts, a 26% of the reduction needed of the GHG emissions in Spain was assumed as representing the food sector.

This percentage was used to calculate for each year the projected reduction of GHG emissions related to the Spanish food sector in 2015.

The following part of the methodology is based on the combination of the two previously steps. When the assessment of the GHG emissions in the BAU for 2015 to 2040 is done, the percentage of total reduction in GHG emissions in all Spain can be calculated as follows:

$$tR_x = 100 - \frac{(GHG_x \cdot 100)}{GHG_0} \quad (2)$$

where tR_x is the percentage of total reduction in *GHG* emissions in Spain from 2020 to 2040, related to 2015. GHG_0 represents the total GHG emissions in the reference year, i.e., 2015, and GHG_x means the total GHG emissions in the compared year. In parallel, the percentages of the reduction of GHG emissions related to 2015, only for the Spanish food sector, are determined as stated in Equation (3):

$$pR_f = \frac{(GHG_0 - GHG_x) \cdot \alpha \cdot tR_x}{(GHG_0 - GHG_x)} \quad (3)$$

where pR_f is the percentage of the reduction related to 2015 only for the food sector and α the reference for the part of the GHG emissions corresponding to the food sector, i.e., 26%. They have been calculated from 2020 until 2040. Finally, the degrowth needed in the four pillars from 2020 until 2040 was determined by implementing the comparison between BAU and D25% scenarios, and using Equation (4):

$$D_X = \frac{pR_f \cdot D_{25}}{R_{25}} \quad (4)$$

where D_{25} is the degrowth assumed in D25%, i.e., 25%; and R_{25} is the percentage of reduction of the GHG emissions between BAU and D25% scenarios.

2.7. Main Limitations and Assumptions of the Study

This study deals with a field where there are important gaps in the clarity of the reported data, both in terms of the generated quantities of FLW, and in terms of the relative importance of different recovery or disposal options [50]. Moreover, it is difficult to link FLW generation and management, as the whole process takes time and in the meantime, a fraction of the weight might be lost (e.g., due to drying). Differences can occur also due to import and export of waste, as well as unaccounted fractions. Moreover, existing statistics generally refer to the generation of biodegradable municipal waste, not to the generation of bio-waste or FLW [46]. Biodegradable municipal waste also includes paper, cardboard, and biodegradable textiles. Additionally, in the more advanced stages of the food supply chain, FLW is usually mixed with general waste, which complicates the determination of the percentage that corresponds to FLW exclusively. The amount of FLW also depends on factors such as the time of the year and the region. Therefore, the main limitations are the uncertainty in the data used.

Another important discussion point is the fact that this work has suggested the TIAM-UCL results as a reference, in combination with the assumption of a 26% of representatively of the food sector, as LCA is able to compare scenarios but it may not be enough to determine if a scenario is improved enough [51]. Thus, an analysis of sensitivity using the same methodology but considering other different reference indexes would be an important point for further discussion and development of the presented methodology. Moreover, the evolution in a compliance framework, suggesting an increase of nuclear energy, reaching 55% of the total electricity mix in 2040, is surprising and contradictory to what the actual information is, which is that in 2019 just over 4% of global primary energy came from nuclear power. The reason for this high value in the model is due to the fact that the model was updated in 2015, when several nuclear power plants were planned, e.g., UK was going to double its nuclear capacity from 9 to 18 GW installed (100% increase). Since the price of wind and solar energy has fallen dramatically in the last 3 years, finally the UK decided not to go ahead. It is assumed that the same happened in other countries.

Regarding the P3, there are many arguments for using food miles for measuring sustainability of food production (e.g., GHG emissions), but some arguments against using only food miles as a unique measure of sustainability of local production of food have also been cited. Among them stands out the fact that if there is a growth in business for smaller producers and retailers, there could be an increase in energy consumption or congestion as smaller vehicles are used and economies of scale in production are lost [36]. Due to all this, it is often suggested that only through combining spatially explicit life cycle assessment with analysis of social issues can the benefits of local food be assessed [52].

According to the Product Environmental Footprint Category Rules Guidance, at least three relevant impact categories shall be considered in a LCA, or covering at least 80% of the total impacts [24]. Therefore, future works should consider including more indicators to assess if results would differ considerably. Additionally, in this study, only the GHG emissions related to energy consumption and the production and use of fertilizers in agricultural processes are considered. On-farm emissions were not included as a source of emissions, and neither were outputs of the productions systems such as products demand and nutrient values of the food. These could be a considerable underestimation.

Finally, the method used and the data assumed when building the model may have considerably conditioned the results. Furthermore, it is important to highlight that this paper represents an exercise, which is purely theoretical, with multiple assumptions, simulating scenarios to obtain results, any scenario simulation being a simplification of reality.

3. Results and Discussion

Within this section, results from the whole methodology are represented, focusing, first, in Section 3.1. on the reduction of GHG emissions regarding the food categories and the reduction of the GHG emissions at the different stages of the food supply chain. Second, in Section 3.2. the degrowth needed in the Spanish food sector from 2020 until 2040 in order to achieve the Paris Agreement targets is determined, assessing also the influence of each of the four pillars when thinking of strategies for degrowth towards a circular bioeconomy.

3.1. Percentage of Greenhouse Gas Emissions Reduction Regarding the Food Categories and Stages of the Food Supply Chain

When carrying out this analysis of the reduction of GHG emissions between the BAU and D25% scenarios, due to the way the LCA model is built to shape the pillars (as explained in Section 2.6.), the categories representing a reduction in the *GHG* emissions (as seen in Table 4) are meat, fish and seafood (both above 26% of reduction), vegetables (11.6% reduction), and fruits (12.8% reduction). Derived from the construction of the model and the energies associated with the food categories, the remaining seven categories increased their percentage of *GHG* emissions, the categories of pulses (+68.3%) and vegetable oils (+16.6%) reaching the highest increases. The lowest increase was shown by sweets (+0.4%) and dairy products (+0.8%).

Table 4. Percentage of reduction of greenhouse gas emissions achieved between business as usual (BAU) and 25% degrowth (D25%) scenarios. Positive values mean a reduction and negative values mean an increase in the emissions.

	% Reduction
Eggs	−8.1
Meat	26.7
Fish and seafood	26.1
Dairy products	−0.8
Cereals	−1.2
Sweets	−0.4
Pulses	−68.3
Vegetable oils	−16.6
Vegetables	11.6
Fruits	12.8
Roots	−5.0

If the four considered stages of the food supply chain are analyzed separately, the stage of processing and packaging showed the highest reduction in GHG emissions (14.1%), followed by distribution (10.4%), agricultural production (8.2%), and consumption (7.7%). All of these are partial values on the specific emissions at each stage. In this sense, while processing and packaging energy demand was much less compared to the stages of distribution and agricultural production, a higher reduction was obtained since the assumed reduction in transatlantic boat transportation (reducing the primary energy used in imports by 25%) was included in the processing and packaging stage. These results reflect the fact that the analysis includes food production in addition to FLW generation. In terms of primary energy demand, which is associated with highest GHG emissions, these results are in line with those achieved in a previous work [34]. Nevertheless, if only the FLW and its embodied energy loss are considered, the stages with the highest potentially rates of GHG emissions related the embodied energy loss, would be potentially the stages of consumption and distribution.

3.2. Percentage of Degrowth Needed in the Spanish Food Supply Chain

As represented in Table 5, the TIAM-UCL projections reflected a reduction needed in the GHG emissions in Spain between 41.9% in 2020 and 93.2% in 2040 in order to achieve compliance with the Paris Agreement targets (including all the Spanish sectors). From those rates of total GHG emissions reduction needed in Spain, following the equations presented in Section 2.6., the food sector will need to reduce their emissions between 10.9% in 2020 and 24.2% in 2040.

Table 5. Reduction of greenhouse gas emissions in Spain according to TIAM-UCL projections, and the corresponding percentage of the Spanish food sector, assuming a 28% of all.

	2020	2025	2030	2035	2040
% Reduction from 2015 (Spain)	41.9	58.4	66.8	77.1	93.2
% Reduction from 2015 (only food sector)	10.9	15.2	17.4	20.1	24.2
Degrowth needed in the 4 pillars	26.8	37.3	42.5	49.0	58.9

On the other hand, after performing the analysis between the four scenarios, the reduction in D25% reached percentages of 10.2% and 10.6% from 2015 until 2040 (as seen in Figure 5). Therefore, using the Equation (4), the degrowth needed in the 4 pillars for achieving the levels of GHG emissions reduction, in order to accomplish the climate targets, was calculated, reaching values between 26.8% (in 2020) and 58.9% (in 2040).

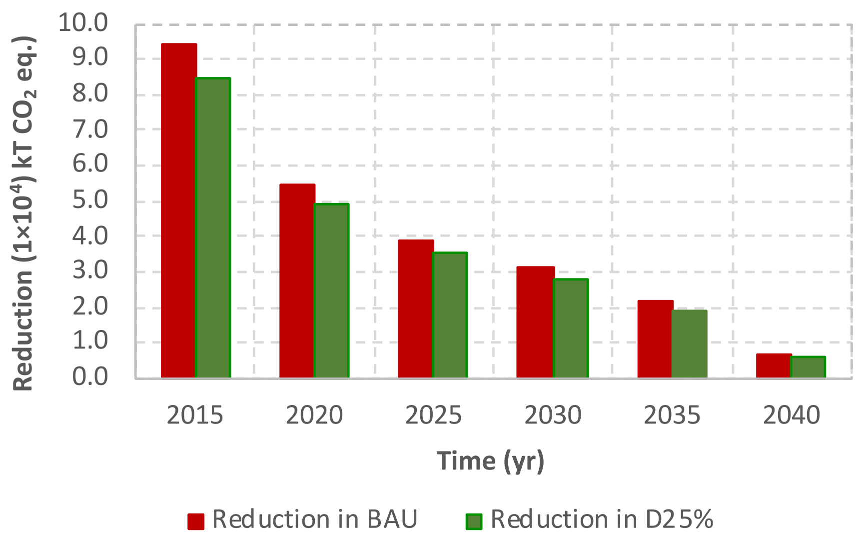

Figure 5. Representation of the greenhouse gas emissions in the baseline (BAU) and the 25% degrowth (D25%) scenarios from 2015 until 2040 (in kilograms of CO_2 equivalent).

If the four pillars are analyzed separately (as highlighted in Figure 6) in order to see the influence in the comparison between BAU and D25% scenarios, P2 represented the greatest influence, with a 78.5% from the total. That result suggests the fact that reducing the consumption of meat and fish and seafood products seems to be clearly the strategy with the highest potential of influence when searching for degrowth through a spiral bioeconomy path until the achievement of the Paris Agreement targets. With much less influence, the second pillar in terms of its importance was P4 (14.9%), followed by P3 (6.3%) and P1 (0.3%). In this way, a more seasonal diet and more local consumption had a considerable influence as well, but the increase in organic farming would be a pillar with very low relevance in terms of degrowth in the Spanish food system towards the compliance with the Paris Agreement targets. As P2, P3, and P4 are strictly related, according to the results, a mixed scenario could be formulated to drive future food policies in Spain, promoting more plant-based food production and consumption, firstly, made up of seasonal plants as much as possible, and secondly, based on locally produced products. Organic production, in terms of degrowth needed, according to the results obtained, would occupy a secondary role. As a reference for developing national strategies, the EU Farm to Form Strategy [27] would be the most suitable, since it mentioned the three highlighted pillars.

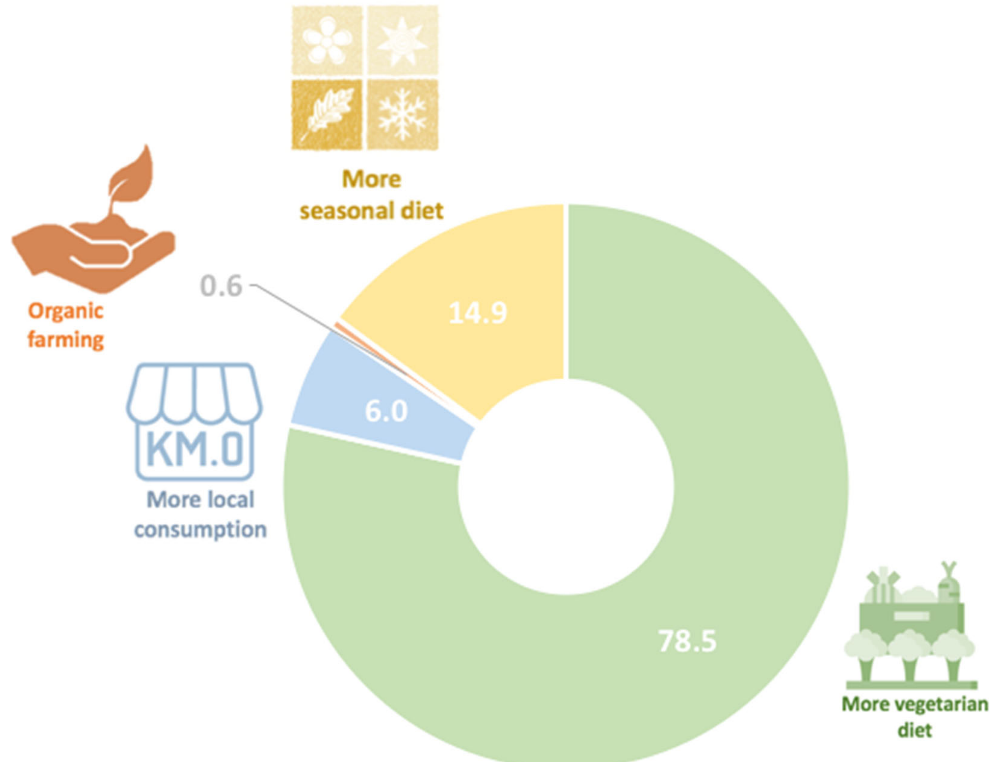

Figure 6. Representation of the influence of the four pillars in the degrowth needed in the Spanish food sector, showing the targets of P1 (organic farming), P2 (more vegetarian diet), P3 (more local consumption), and P4 (more seasonal diet).

In line with the results highlighting the reduction of meat and fish and seafood consumption (P2), i.e., a more ovolactic diet, as the most useful path for the degrowth transition to a framework of real sustainability, there is a growing trend on publishing research assessing the environmental impacts of diets and dietary shifts [53]. More concretely, the fact that a new dietary culture which endorses plant-based foods is required, to contribute to better nutrition, food security, and achievement of global sustainable development goals is often highlighted [54]. In the same framework, a general consensus is shown, regarding the fact that dietary changes can play an important role in reaching environmental goals, the highest reduction potential being mainly on lowering the amount and type of meat included in the diet, but also on the environmental performance of the food substituting meat [55]. This reduction would be also translated in health benefits, as in high-income Western countries, large prospective studies and meta-analyses generally show that total mortality rates are modestly higher in participants who have high intakes of both red and processed meat than in those with low meat intakes [56]. Moreover, different works [57,58] stated that, to reach environmental sustainability as well as to increase the nutritional quality of diets, animal-based food products, as well as sweets, should be partially replaced with fruits, vegetables, legumes, and cereals. However, it is important to think not only in terms of dietary groups, but also of individual dietary habits, irrespective of dietary choice.

It is important to remark that the results of this work could be influenced by the way of constructing the model, and the considered or not considered elements. Regarding P3, the promotion of local food is a complex problem, where transportation is not the only factor that determines how efficient it is to consume local food. The dialogue over food miles has been largely centered not on its complex reality, but on a single variable, but local eating is about much more than distances of transport [59]. Other factors as recycling of nutrients, freshness/taste/nutritional content, technologies used for agricultural production, integration between producers and consumers (i.e., support local or rural economies and small-scale business), or knowing where food comes from, would be important to be considered in future works in order to adopt a more holistic overview of the impacts of local consumption [60]. Additionally, local production does not always mean lower emissions of environmental impacts [61]. Regarding the seasonality of food consumption (P4), it has been also highlighted in the literature as an important variable when defining the best choice of food consumption from an environmental point of view [62]. The results showing the lowest importance of P1 from the four pillars may indicate an argument in favor of those voices denoting that the production from organic systems is equal to or less than conventional yields due to the currently technological limitations [63], being therefore, the ability to feed the world population through organic food production questioned. Nevertheless, the presented results of P1 could also be affected by the way of constructing the scenarios, and the fact of only considering the Global Warming Potential as a reference. In this line, many authors have criticized that conventional agriculture, developed through the Green Revolution, generates high rates of pollution of the environment by the use of agrochemicals and fossil fuels, which produce many other problems in addition to hunger in the world. These other pollutants were not included in the analysis carried out in the present study. Additionally, they are studies suggesting that the world already produces enough food to feed nine to ten billion people, the population peak expected by 2050, and consequently the problem is not to produce more, but to better manage what is produced [35]. In this sense, increasing investment in organic production seems to be important for many other environmental and social aspects that have not been addressed in this work.

Finally, as highlighted in Section 2.4, where TIAM-UCL projections showed a potential tendency of increase in the use of nuclear power, the search for a degrowth in the food production and FLW generation system in order to achieve a reduction of GHG emissions, should be combined with other complementary strategies together with climate policies, existing previous experiences such as the ban of nuclear power developed in 1978 in Austria [64].

4. Conclusions

The methodology presented in this work, implemented in the case study of the food production and FLW management in Spain, highlighted a need for degrowth in GHG emissions between 26.8% in 2020 and 58.9% in 2040. From the four pillars suggested, following the 4 R´s strategy, the reduction in the consumption of the categories of meat and fish and seafood (P2) seems to be the most useful path, as it could achieve the 78.5% reduction of the total GHG emissions between the BAU and the D25% scenarios, much higher than the increase of seasonal products consumption in winter (P4), the reduction in transport distances (P3), and the reduction in the use of agrochemicals (P1). Moreover, results highlighted the stages of processing and packaging (14.1%) and distribution (10.4%) as the ones with more reduction potential in the GHG emissions if the pillars for degrowing are implemented.

If future strategies would focus on achieving this degrowth needed, once right-sizing has been achieved through the progress of degrowth, the aim should be to maintain a so-called steady state economy, with a relatively stable, mildly fluctuating level of environmental impacts and resource consumption in any context of the Global North. In this line, a key research question to be answered is which countries should follow degrowth, which countries can still benefit from an economic growth, and which countries are closest to a steady state economy. It is clear that many countries in Western Europe and North America, the so-called Global North, need to degrow their resource use and environmental impacts before establishing a steady state economy. It is also clear that most of the countries in sub-Saharan Africa can still benefit substantially from economic growth, and that many countries in the Global South should follow a path of decelerating growth. Nevertheless, this leaves a vast gray area in between where the appropriate development paths are unclear and future works on this field should try to clarify.

As in this work the CML method has been assumed as representative for the analysis of the Global Warming Potential, future works could use other methods and impact categories in order to assess the robustness of the methodology and the results presented in this work. In this sense, Section 2.4 highlighted the controversial fact of an enormous increase in nuclear energy, which bears another danger, which is not really covered by available LCA indicators.

On the other hand, when developing strategies for improving the environmental performance of food supply chains and FLW management options, it is also necessary to define the degrowth at least at regional level, as it may change considerably between different regions. This would be another path of study for which different reference indicators would be needed, adapted to more local contexts.

Finally, this methodology aimed to be interesting for policy makers in order to be implemented at any other food supply chain at a national level if the TIAM-UCL projections are used, or at any regional or local level if other targets would be used. Future work should also include social aspects in order to expand this methodology, considering them elements which should not be substituted for one another, i.e., more environmental sustainability cannot substitute social aspects, and vice versa.

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