Towards sustainable dietary patterns under a water-energy-food nexus life cycle thinking approach

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Highlights

- Sustainable food systems should consider production and consumption matters.
- LCA and WEF Nexus approach are powerful tools to assess dietary patterns.
- Nutritional and health aspects could be added to the WEF nexus for dietary patterns

Abstract

The big challenge of the next decades is meeting the global nutritional demand, while reducing the pressure on food resources and the GHG emissions. In this regard, the overall goal consists of re-designing the food systems, and promoting sustainable dietary patterns is a crucial aspect. This article focuses on reviewing the state-of-the-art of the combined Life Cycle Assessment (LCA) and the Water-Energy-Food (WEF) Nexus approach in assessing the effects of diet transitions. Diet LCAs differ in methodology, design and assessed environmental impacts. The WEF nexus, which aims at finding synergies and trade-offs between the water, energy and food resources systems, has been applied to different contexts and levels. However, a limited number of nexus methods has been developed at the food and diet levels, and no commonly recognizable methodology for the nexus assessment has been achieved. An integrated Life Cycle Assessment and WEF Nexus approach can be a decisive tool to improve the understanding of the interconnections in the nexus, as it enables the consideration of entire supply chains.

Keywords

WEF Nexus, food consumption, Life Cycle Assessment, sustainability, diets, food

1. Introduction

Food systems are resource-intensive. They consume globally about 70% and 30% of the total global freshwater and primary energy, respectively. They are also a main driver of climate change, being responsible for 19-29% of global anthropogenic Greenhouse Gas (GHG) emissions [1]. Furthermore, these environmental pressures associated to the food systems may increase dramatically by 2050, if the expected global socioeconomic development occurs [2].

This results in a global challenge on how to re-design food systems without threatening the environment. In most cases, strategies towards sustainable food systems focus on the production side, such as agricultural intensification [3]. However, the consumption side, meaning eating patterns, is a crucial aspect to take into account, since they are the main drivers for food production. For instance, a global transition to a "Western" style diet may increase 80% current global GHG emissions by 2050 [4]. Instead, changing towards a "healthy diet", especially in industrialized countries, together with the reduction of food waste, are crucial to ensure global food security and to avoid land clearing, and higher GHG emissions by 2050 [5].

Facing this significant role of dietary patterns, a growing amount of scientific literature has focused on assessing their environmental impacts, mostly following the Life Cycle Assessment (LCA) approach, and performing diet scenarios [6]. However, a remaining challenge is how to compare the outcomes of these studies. Diet LCAs differ in methodology and design, such as the location, type of alternative diet, system boundaries and functional unit (FU). Moreover, studies may assess different environmental impacts. In Table 1, the reported impacts within 30 comparative LCAs of diets are shown, and carbon footprint (CF) is the most commonly used (80%), followed by Land Use (LU; 53%) and Water Footprint (WF; 47%), while just one article [7] considers the energy use.

To further contribute to the current debate on whether alternative healthier diets are environmentally beneficial or not, here we attempt to give a general overview of the main outcomes of the most recent comparative diet LCAs. Moreover, we aim to investigate the level of application of LCA within the water-energy-food (WEF) nexus framework. The WEF nexus, a relatively recent concept, is based on better understanding the interconnections between water, energy and food, in order to find synergies and trade-offs between these resources systems. This approach has been applied at different contexts and levels; however, a limited number of nexus methods have been published yet [8]. In this regard, this article focusses on reviewing the state-of-the-art of the combined LCA-WEF Nexus approach in assessing the effects of diet transitions.

***Table 1**: List of comparative diet LCA studies, published in the last 3 years. HIC: High Income Country; UMIC: Upper-medium Income Country, LMIC: Low-Medium Income Country; LIC: Low income country. NDG-based: National Dietary Guidelines-based; E&N-based: Energy- and nutritional-based; C-: Cradle-; FLW: Food Loss and Waste; CF: Carbon Footprint; WF: Water Footprint; LU: Land Use; E: Energy Demand.*

Articles	**Country**	**Type of country**				**Dietary Scenarios**			**Functional Unit**			**System boundaries**				**FLW**	**Nutritional Assessment**	**Environmental Assessment**					**WEF-Nexus Appoach**
		HIC	UMIC	LMIC	LIC	Other current	NDG-based	Optimization-based	mass-based	energy-based	E&N-based	C-to-FARM	C-to-RETAIL	C-to-FORK	C-to-GRAVE			CF	WF	LU	E	Others	
Aleksandrowicza et al. [9]	IN			X			X		X					X				X	X	X			
Arrieta e tal. [10]	AR		X				X			X		X						X					
Batlle-Bayer et al. [11]	ES	X					X			X				X		X	X	X					
Batlle-Bayer et al. [12]	ES	X					X				X			X		X	X	X					
Behrens et al. [13]	GLO	X	X	X	X		X		X			X						X		X		X	
Birney e tal. [7]	US	X					X		X						X	X		X	X	X	x		
Blackstone et al. [14]	US	X					X			X		X						X		X			
Blas et al. [15]	ES	X					X		X			X							X				
Bozeman et al. [16]	US	X				X			X			X						X	X	X			x
Bruno et al. [17]	DK	X					X			X				X		X		X					
Chen et al. [18]	CH	X					X		X			X					X	X	X	X			
Corrado et al. [19]	IT	X					X		X						X	X		X					
He et al. [20]	CN			X		X			X			X					X	X	X	X			
He et al. [21]	CN			X			X		X			X						X	X	X			
Mekonnen et al. [22]	US	X					X		X			X				X			X				
Milner et al. [23]	IN			X				X	X			X							X				
Perignon et al. [24]	TN			X				X	X											X		X	
Reynolds et al. [25]	UK	X						X	X			X						X					
Ritchie et al. [26]	IN, DE, CA,CN, AU,US	X		X			X		X			X						X					
Rizvi et al. [27]	GLO						X		X			X								X			
Rosi et al [28]	IT	X				X			X						X		X	X	X	X			
Song et al. [29]	CN			X				X	X				X					X					
Song et al. [30]	CN			X				X	X				X					X	X	X			
Springmann et al. [31]	GLO	X	X	X	X		X		X			X				X	X	X	X	X			
Treu et al. [32]	DE	X				X			X				X			X	X	X		X			
Ulaszewska et al. [33]*	-	X					X			X			X			X		X		X			
Vanham et al. [34]	DE,FR,UK	X					X		X			X							X				
van de kamp et al. [35]	NL	X					X			X				X				X					
Veeramani et al. [36]	CA	X				X				X					X	X		X					

*Not related to a specific country consumption patterns

2. Environmental impacts of diet transitions

The effect of diet transitions differ among the country income level, diet composition and the scale of the study.

In high-income (HI) countries, dietary transitions towards reduced meat consumption, generally, decrease the CF [11–13,17–19,25,28,35,36] (Table 2), LU [7,13,18,28,32] (Table 3), and WF [15,18,28] (Table 4). Nevertheless, these results can vary depending on the amount and type of food groups recommended within the diet. For example, following the US dietary guidelines increases the CF, WF and energy use by 7%, 15% and 35%, respectively [7]. This occurs because the environmental benefits of cutting down meat intake do not compensate the larger impact of the recommended higher consumption of dairy products. This is in line with findings in previous studies [37].

The same happens to upper and lower middle-income (UMI, LMI) countries. As explained by Behrens [13], the National Dietary Guidelines (NDGs) of UMI countries are similar to the ones of HI countries, in regard to reducing meat, dairy, oils and sugars intakes. However, the NDGs of LMI countries recommend less reduction in meat, and even some countries, such as India, Indonesia, and Romania, suggest higher meat intake than currently consumed, most probably due to protein energy malnutrition. This results in reductions of CF [13,38] and LU [9,13,20,21,30] when following the NDGs in UMI countries, while the opposite outcomes are found for LMI countries [9,13,20,21]. For example, adhering to the 2016 Chinese Dietary Guidelines increases the CF, LU and WF of Chinese diets by 7.5%, 54.2% and 53.5%, respectively [21]. This is due to, first, the higher impacts of increased intake of recommended products (such as dairy products, nuts, fruits and seafood) than the environmental benefits of reduced meat consumption, and, second, the larger amount of food waste of the recommended products. The waste ratio of fruit and vegetables at the consumer level is 15% versus the 8% for meat products. Environmental benefits for LMI countries have been just reported for optimized diets [23,29,30]. Hence, optimization of diets might be a useful tool to design better environmental performing diets.

At a global scale, the composition of the alternative diet is crucial when assessing the environmental effects of a dietary shift. For example, Rizvi et al [27] estimated that 1 Gha of additional land would be required globally, if population was adhering to the USDA Guidelines [39]. Springmann et al [31] evaluated what type of dietary-shift strategies would result in the best environmental effects. They designed three types of strategies: one based on reducing animal-based products, another one based on improving the energy intake, and the third one adopting healthier dietary patterns. The last approach showed, at the global scale, the best results by significantly reducing the CF, and, in less extent, LU and WF. Nevertheless, large differences among countries were found. For low income (LI) and LMI countries, CF had lower reductions than for HI countries, and LU and WF even increased with dietary shift. This was related to the lower yields of legumes and vegetables, and, hence, the authors suggested the need to combine strategies for dietary shifts as well as technological improvements in LI countries.

Table 2: Effects on GHG emissions by diet shifts to alternative diets. HIST: historical; NDG: National Dietary Guidelines; MED: Mediterranean diet; NDG-NM: National Dietary Guidelines with no meat; PESC: Pescetarian; FLX: Flexitarian; VEG: Vegetarian; VGN: Vegan; OPT: Optimized diets. Red: Increase of GHG emissions by changing to the alternative diet. Green: Decrease of GHG emissions

		DIET SCENARIOS								
		HIST	**NDG**	**MED**	**NDG-NM**	**PESC**	**FLX**	**VEG**	**VGN**	**OPT**
HIC										
Batlle-Bayer et al. [11]	ES		-17%	-11%						
Batlle-Bayer et al. [12]	ES		-58%							
Behrens et al. [13]			-13%							
Birney e tal. [7]	US		7%							
Bruno et al. [17]	DK							-14%	-44%	
Chen et al. [18]	CH		-54%			-66%	-45%	-65%	-83%	
Corrado et al. [19]	IT							-90%	-90%	
Reynolds et al. [25]	UK									-57%
Rosi et al. [28]	IT							-34%	-41%	
Springmann et al. [31]						-82%	-74%	-82%	-89%	
van de kamp et al. [35]	NL		-7%		-37%					
Veeramani et al. [36]	CA					-37%		-54%	-58%	
UMIC										
Arrieta e tal. [10]	AR		-28%		-62%			-68%	-73%	
Behrens et al. [13]	RO, CN, MX,RU, TK, BR,ZA		-1%							
Springmann et al. [31]						-85%	-73%	-85%	-93%	
LMIC										
Aleksandrowicza et al. [9]	IN		4%							
Behrens et al. [13]	LMIC		17%							
He et al. [21]	CN	1%								
He et al. [22]	CN		7,50%							
Song et al. [29]	CN									-12
Song et al. [30]	CN									-24%
Springmann et al. [31]						-71%	-45%	-71%	-84%	
LIC										
Springmann et al. [31]						-70%	-39%	-70%	-86%	
GLOBAL										
Springmann et al. [31]	GLO					-75%	-54%	-75%	-87%	

Table 3: Effect of diet shifts to alternative diets on the Land Use (LU). ORG-NM: Organic diet without meat. Red: Increase of LU by changing to the alternative diet. Green: Decrease of LU when shifting to the alternative diet.

		DIET SCENARIOS									
		HIST	NDG	MED	NDG-NM	PESC	FLX	VEG	VGN	OPT	ORG-NM
HIC											
Behrens et al. [13]			-6%								
Birney e tal. [7]	US		-19%								
Chen et al. [18]	CH		-32%			-4%	-5%	-3%	-7%		
Treu et al. [32]	DE										-45%
Rosi et al. [28]	IT							-38%	-44%		
Springmann et al. [31]						-32%	-27%	-31%	-36%		
UMIC											
Behrens et al. [13]	RO, CN, MX,RU, TK, BR,ZA		-7%								
Springmann et al. [31]						-26%	-21%	-23%	-24%		
LMIC											
Aleksandrowicza et al. [9]	IN		4%								
He et al. [20]	CN	2%									
He et al. [21]	CN		54%								
Behrens et al. [13]	IN, ID		17%								
Song et al. [30]	CN									-23%	
Springmann et al. [31]						-7%	-6%	-7%	-7%		
LIC											
Springmann et al. [31]						9%	11%	13%	14%		
GLOBAL											
Rizvi et al. [27]	GLO		22%								
Springmann et al. [31]	GLO					-11%	-8%	-10%	-11%		

Table 4: Effect of diet shifts to alternative diets on water footprint (WF). Red: Increase of WF by changing to the alternative diet. Green: Decrease of WF when shifting to the alternative diet.

		DIET SCENARIOS								
		HIST	NDG	MED	NDG-NM	PESC	FLX	VEG	VGN	OPT
HIC										
Birney e tal. [7]	US		15%							
Blas et al. [15]	ES			-20%						
Chen et al. [18]	CH		-26%			3%	0%	4%	2%	
Mekonnen et al. [22]	US		7%	5%		-20%		-37%		
Rosi et al. [28]	IT							-27%	-22%	
Springmann et al. [31]						-11%	-12%	-7%	1%	
UMIC										
Springmann et al. [31]						-15%	-17%	-11%	-2%	
LMIC										
Aleksandrowicza et al. [9]	IN		5%							
He et al. [20]	CN	2%								
He et al. [21]	CN		54%							
Milner et al. [23]	IN									-18%
Song et al. [30]	CN									-17%
Springmann et al. [31]						-15%	-15%	-13%	-8%	
LIC										
Springmann et al. [31]						29%	27%	34%	44%	
GLOBAL										
Springmann et al. [31]	GLO					-10%	-11%	-8%	-2%	

3. WEF Nexus approach at the dietary level

LCA has a large potential to be used in the context of WEF nexus [12]. However, it is seldom mentioned within diet LCAs. Bozeman et al. [16] are the first ones that attempt to combine LCA and the WEF nexus framework for the US diets of three main demographic groups. However, they do not propose a new methodology to integrate both approaches. Instead they rather rename LCA impacts to WEF impacts. In addition, they do not consider the energy use, which is one of the three systems within the WEF nexus. Some other diet LCA studies [21,30] refer shortly to the food-health-environment nexus, although not using it,.

At the food product level, the development of methodologies integrating both approaches are also scarce. Only two published articles [40,41] were found. Frankowska et al [40] propose to group LCA impacts into the three pillars of the WEF nexus, and to transform those impacts into a dimensionless scores, by equally weighting the impacts by each nexus system. Regardless the improvements this method might require, it is a useful tool to show the environmental impacts within the WEF nexus framework.

4. Concluding remarks & recommendations

A new approach to assess the lifecycle impacts of dietary patterns must be based on the nexus of water-energy-food (WEF) systems. The term "nexus" implies that the action in one of the systems affects the others. Therefore, any strategy that focuses on one system without considering its influences to the others may lead to unintended consequences. In this regard, within the context of transitioning to a sustainable dietary patterns, it is required a "nexus thinking" that adopts a lifecycle approach to the water-energy-food connections. This is essentially a transformative approach to the dietary pattern decision-making, and it also requires extensive changes in the assessment methodology. The WEF nexus approach allows assessing the lifecycle of dietary-patterns under a holistic manner considering the whole supply chain. Currently, there is no universally recognised methodology for nexus analysis. However, Life Cycle Assessment is particularly important for understanding the interconnections in the nexus.

The need to shift to more environmentally sustainable dietary patterns is increasingly evident but certainly not simple to achieve. Seeing that healthy dietary guidelines can be a good strategy for diet transitions, we suggest that NDGs incorporate the integrated LCA and WEF nexus approach. In this sense, we might argue the need to add a forth system to the WEF nexus, which would be the nutrition/health aspect of diets.

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