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Perspective

The imbalance of food and biofuel markets amid Ukraine-Russia crisis: A systems thinking perspective

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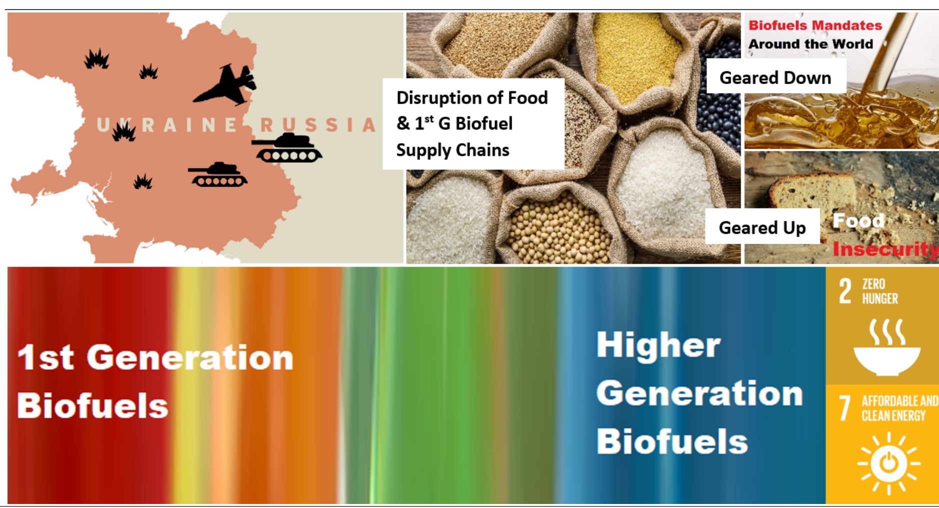
HIGHLIGHTS

- The Ukraine-Russia war has significantly impacted food and energy markets.
- A systemic approach is needed to analyze the war implications for the market.
- Transition from 1st generation biofuels to higher generations is key to balancing the already volatile market.
- The war has directly and adversely influenced achieving the SDG 2 and SDG 7.

GRAPHICAL ABSTRACT



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ABSTRACT

The Ukraine war has immensely affected both food and energy systems due to the significant role of Russia in supplying natural gas and fertilizers globally and the extensive contribution of both Russia and Ukraine in exporting grains and oilseeds to the international markets. Hence, the Ukraine-Russia conflict has resulted in a shortage of crops and grains in the food market, especially in Europe, causing speculations if these resources should still be used for biofuel production (1st Generation). However, the International Energy Agency has warned that lowering biofuel mandates could result in rising petroleum demand and supply concerns. In light of these unfolding events, a systems thinking approach is required to monitor and analyze the implications of this crisis for food and biofuel markets as a whole to alleviate the concerns faced and plan sustainably. In this vein, based on the trade-offs between food system elements and the biofuel supply chain, as well as the potential effects of the war on the food and energy systems worldwide, a causal loop diagram is developed in the present work. According to the insights provided, the key to preventing food insecurity and keeping biofuel mandates on an increasing trend simultaneously amid the Ukraine war is to switch from the 1st Generation biofuels to higher generations. This transition would reduce not only the pressure on the food market to move toward zero hunger (SDG 2) but also pave the way to move towards a circular economy and clean and affordable energy (SDG 7) during the post-war era.

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Contents

1. Introduction

During the past two years, global economies were strongly hit by the COVID-19 pandemic, and the food and energy markets were faced with an imbalance of supply and demand, resulting in an increased cost of living all over the world. Unfortunately, the global community has been shocked again by Russia's invasion of Ukraine in late February 2022, which has brought about huge casualties on both sides and has added to the food and market challenges in the already volatile post-COVID-19 market. These crises have led to increased vulnerability and food insecurity worldwide.

Both Russia and Ukraine play key roles in the energy, food, and fertilizers markets. While Russia is the world's largest exporter of wheat, the second largest exporter of sunflower oil, and the largest exporter of fertilizers, Ukraine is the largest exporter of sunflower oil, the fourth largest exporter of maize, and the fifth largest exporter of wheat (Benton et al., 2022). Therefore, the disrupted agricultural production in Ukraine, which is likely to continue even in the post-war era, and the extensive international sanctions imposed on Russia, limiting the country`s trades, are expected to impact both food and fuel markets. As for the latter, in addition to the petroleum price increase, the Ukraine war has disrupted the biofuel feedstock supply chain and, consequently, adversely affected biofuels production. The main culprit is the existing food *vs* fuel competition over agricultural commodities. More specifically, biofuel production has already been criticized for its impact on increasing food/feed commodity prices and the consequent contribution to food insecurity (Koizumi, 2015; Martínez-Jaramillo et al., 2019; Subramaniam et al., 2019). Approximately 10% of all grain supplies worldwide are used for biofuel production (Biofuels International, 2022), which could alternatively be used to reduce food insecurity in many parts of the world. Biofuel production from edible resources is also considered a contributor to land-use change and climate change (Yan et al., 2021).

The decline in crop supply and the resulting rising prices have further intensified the food *vs* fuel conflict encouraging calls by major media outlets for easing biofuel production mandates in favour of food systems amid the Ukraine war to prevent further food insecurity (Grunwald, 2022; Le Page, 2022). On the other hand, the International Energy Agency (IEA) has warned about the consequences of such diversion, highlighting that reducing biofuel mandates could further increase petroleum prices and cause energy supply concerns (Biofuels International, 2022).

The interconnectedness of food and energy markets on the global scale and the food and energy crises triggered by the Ukraine-Russia war highlight the significance of addressing these challenges as interrelated systemic risks rather than in isolation (Benton et al., 2022). Therefore, this research adopts a systems thinking approach to analyze the interconnections among food and biofuels market elements, their role in climate change, and the impact of war on them. In this vein, a causal-loop diagram (CLD) is developed to better address and clarify the existing interconnections and feedback structures. In addition to the 1st Generation (1st G) biofuels that use food/feed crops as their feedstock, the role of shifting from the 1st G biofuels to higher generations is discussed in the presented CLD.

2. Methodology

The complexity of food systems and biofuel production dynamics, which can be translated into food and energy security, is acknowledged in the literature (Pruyt and Sitter, 2008; Koizumi, 2015; Weng et al., 2019). Moreover, the need to study the interlinkages and the system behaviour as a whole has been highlighted (Pruyt and Sitter, 2008; Ansah, 2014; Martínez-Jaramillo et al., 2019). The Ukraine war and sanctions on Russia have further increased this complexity. Therefore, the concerns and challenging aspects discussed in the introduction section can be put together in a systems model and analyzed from a systems thinking perspective, which tries to understand a certain event by seeing things as a whole instead of isolated parts. In better words, systems thinking aims at improving the understanding of the ways through which the performance of an organization/system is related to its internal structure and external operating policies and tries to use that understanding to design policies for success (Sterman, 2000; Forliano et al., 2022). In this context, the system science set of tools, including CLDs, provide a powerful framework to better comprehend the complex interplay of factors affecting the organization's/system's performance (Sterman, 2006). CLDs explicitly present the structural and agent system elements that may endogenously generate the dynamics in the behaviour of the system or organization being studied (Papachristos and Struben, 2020).

Based on the conducted literature review on the interplays of food system elements and biofuel supply chain and investigations on the various potential effects of the Russia and Ukraine war on the food and energy systems worldwide, a CLD is developed in this research. The presented CLD aims to provide a systematic perspective and offer aid to explain the potential challenges in the food, energy, and climate change domains caused by the crisis of Russia's invasion of Ukraine.

In line with the convention of causal diagrams, the presented CLD map consists of variables connected by headed arrows starting from the cause towards the effect, indicating causal links. Positive (+) and negative (-) signs located on the arrows show their polarity (($x\uparrow\rightarrow y\uparrow$) and ($x\uparrow\rightarrow y\downarrow$), respectively). The indicated polarities help identify positive (reinforcing) and negative (balancing) feedback loops within the presented structure.

3. Analyzing the war challenge for food and biofuel markets

The CLD presented in **Figure 1** portrays the challenges caused by the Ukraine-Russia war for food and energy markets. Analyzing the interconnections among the factors in this map provides support for designing appropriate policies to deal with the issue of the food-energy crisis resulting from the war timely.

Among the balancing and reinforcing loops formed in the CLD provided in **Figure 1**, the main identified loops, including two reinforcing and seven balancing loops, are highlighted, and their causality chains are tabulated in **Table 1**. These loops are discussed in detail in the following sub-sections.

3.1. The imbalances caused to food and energy markets

As *Loop B1* in **Figure 2** shows, the rise of fertilizer prices and the reduction in the production and export of crops and grain by the two conflicting countries have negatively affected the supply of crops and grain and, consequently, have led to a shortage of crops and grain in their customer countries. A potential solution to deal with the shortage of farm-based products could be their domestic production. However, this solution is not feasible within a short period and might even be infeasible because of economic reasons or resource depletion that has originally provided the ground for importing these products. Due to time restrictions for production, export, and import planning, finding immediate replacements for Ukraine and Russia also seems infeasible, resulting in a shortage of crops and grains in the food market, especially in Europe.

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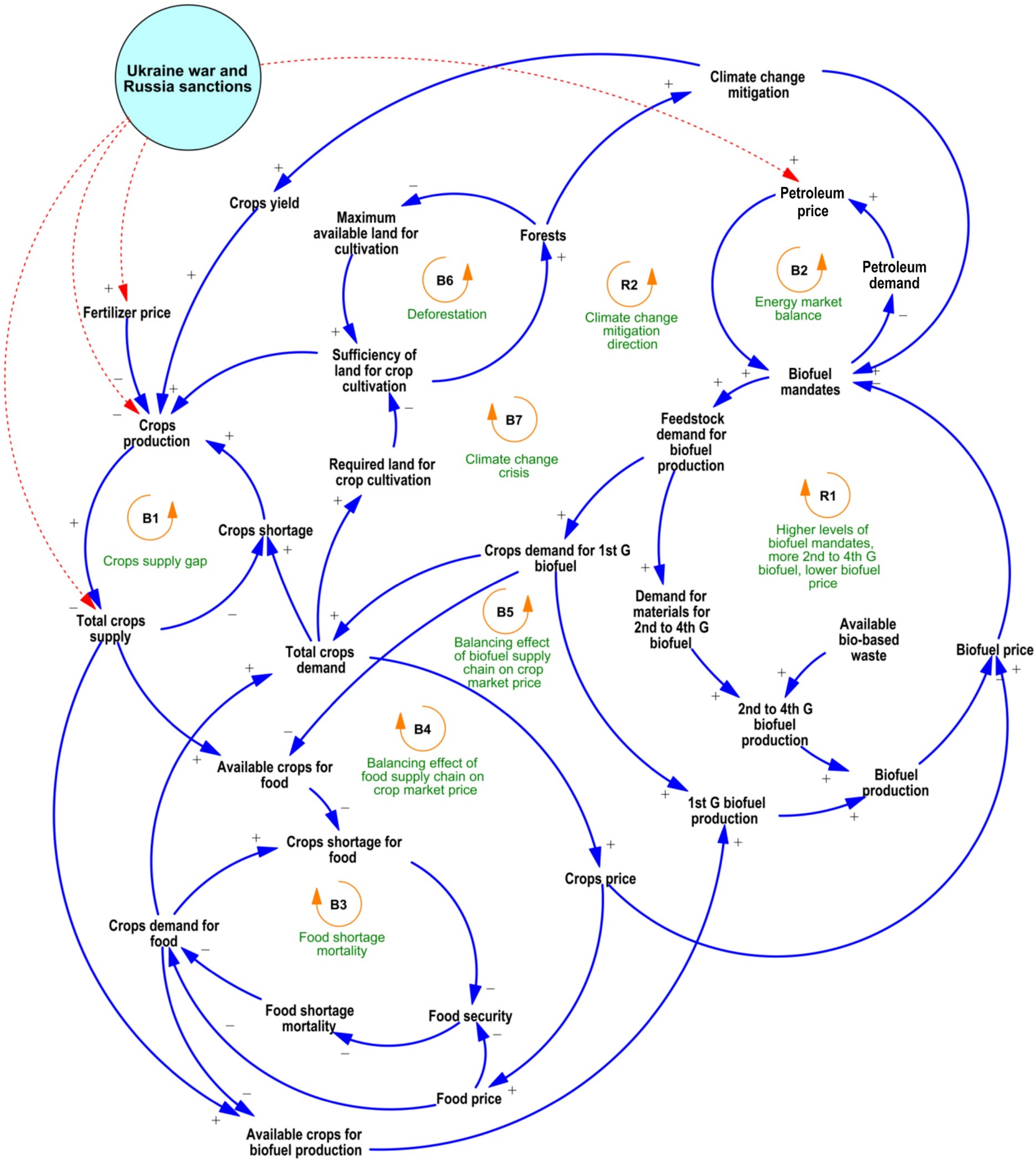

Fig. 1. The CLD designed to analyze the challenges of food and biofuel markets amid the Ukraine-Russia war. G: Generation; "+" sign on arrows indicates ($x \uparrow \rightarrow y \uparrow$); and "-" sign on arrows indicates ($x \uparrow \rightarrow y \downarrow$).

Based on *Loop B2* in **Figure 2**, the rise in the petroleum price since the onset of the war in Ukraine has also affected the biofuel market. The main mechanism in a market is switching towards using an alternative (such as biofuel) when there is an increase in the price of the original commodity (such as petroleum in this case), which consequently results in the reduction of demand for the original commodity, followed by a decrease in its price. This mechanism is reflected in *Loop B2*, which is then affected by other feedback structures.

However, despite the rise in the petroleum price, the increases in food and feedstock prices amid the Ukraine war have increased the biofuels price, leading to the adjustment of biofuel blending mandates in some the European countries (Biofuels International, 2022). In this regard, the IEA has warned that lowering biofuel mandates could result in rising petroleum demands and, subsequently, supply concerns (Biofuels International, 2022).

Table 1.
Selected main identified balancing and reinforcing loops in the designed CLD.

Loop name		Type of loop	Chain of causalities
B1	Crops supply gap	Balancing	Crops production + → Total crops supply + → Crops shortage - → Crops production -
B2	Energy market balancing	Balancing	Oil price +→ Biofuel mandates + → Oil demand - → Oil price -
B3	Food shortage mortality	Balancing	Crops shortage for food + → Food security - → Food shortage mortality + → Required crops for food supply - → Crops shortage for food -
B4	Balancing effect of food supply chain on crop market price	Balancing	Total crops demand + → Crops price + → Food price + → Crops demand for food - → Total crops demand -
B5	Balancing effect of biofuel supply chain on crop market price	Balancing	Total crops demand + → Crops price + → Biofuel price + → Biofuel mandates - → Feedstock demand for biofuel production - → Crops demand for 1st G biofuels - → Total crops demand -
R1	Higher levels of biofuel mandates, more 2nd to 4th G biofuel, lower biofuel price	Reinforcing	Biofuel mandate+ → Feedstock demand for biofuel production + → Demand for materials for 2nd to 4th G biofuel production + → Biofuel production + → Biofuel price - → Biofuel mandates +
B6	Deforestation	Balancing	Maximum available land for cultivation - → Forests - → Maximum available land for cultivation +
B7	Climate change crisis	Balancing	Climate change mitigation + → Biofuel mandates - → Feedstock demand for biofuel production - → Crops demand for 1st G biofuel - → Available crops for food + → Crops shortage for food - → Food security + → Food shortage mortality - → Crops demand for food + → Total crops demand + → Required land for crop cultivation + → Sufficiency of land for crop cultivation - → Forests - → Climate change mitigation -
R2	Climate change mitigation direction	Reinforcing	Climate change mitigation + → Biofuel mandates - → Feedstock demand for biofuel production - → Crops demand for 1st G biofuel - → Total crops demand - → Required land for crop cultivation - → Sufficiency of land for crop cultivation + → Forests + → Climate change mitigation +

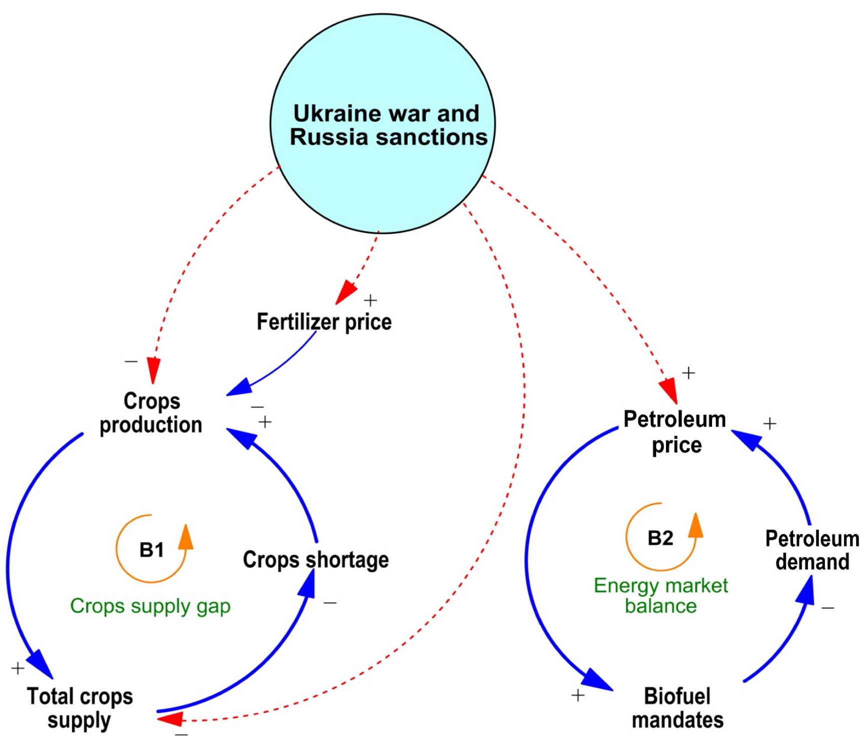

Fig. 2. Causal loops of the food and energy markets directly affected by the Ukraine-Russia war. "+" sign on arrows indicates ($x\uparrow\rightarrow y\uparrow$), and "-" sign on arrows indicates ($x\uparrow\rightarrow y\downarrow$).

3.2. Food insecurity and the risk of stepping away from SDG 2

Food security and the second Sustainable Development Goal (SDG 2), referred to as "Zero Hunger", have already been affected by the COVID-19 pandemic (Ranjbari et al., 2021a and b; Ameli et al., 2022) and the climate change challenges (Chen et al., 2021; Shams Esfandabadi et al., 2022). The Ukraine-Russia crisis has also intensified the current food availability and price challenges. Reduction of crop supply resulting from the military conflict in Ukraine, on the one hand, and using parts of crops supply for biofuel production, on the other hand, have lowered the available crops for food consumption. Biofuels produced are mainly farm-grown energies, and their main feedstock is agricultural commodities (i.e., 1st G biofuel). Therefore, they compete for natural and agricultural resources with food. The reduced available crops for food and food-related use causes a shortage of crops, and a feedback structure, as reflected in *Loop B3* (**Fig. 3**), is formed.

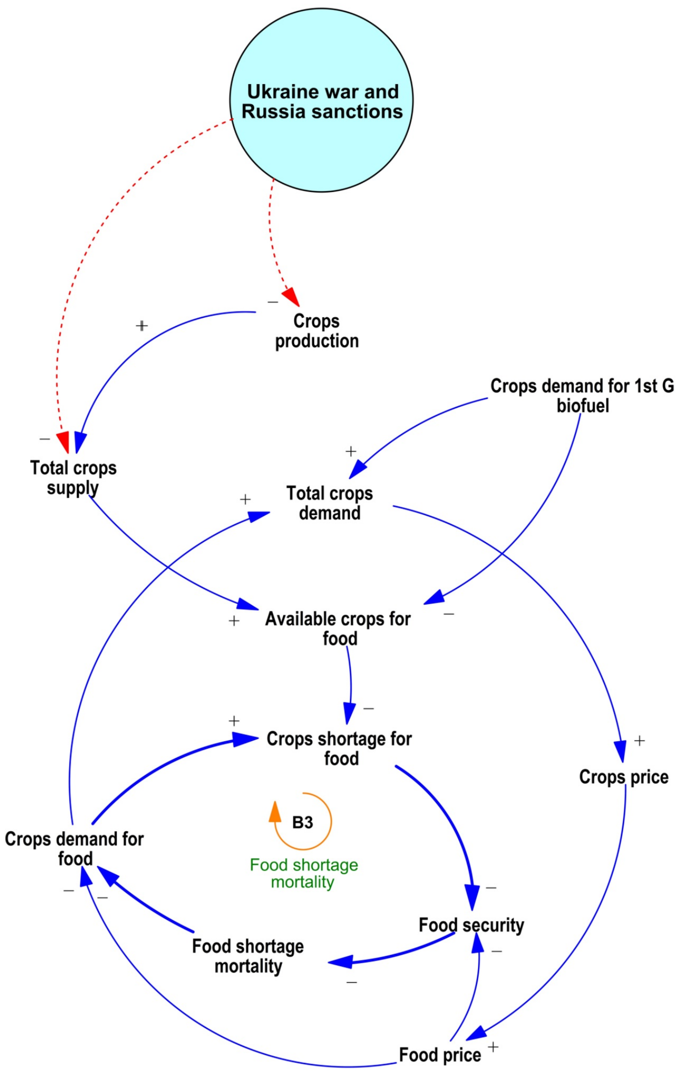

Fig. 3. Causal Feedback structure addressing food insecurity as a result of the Ukraine-Russia war. G: Generation; "+" sign on arrows indicates ($x\uparrow\rightarrow y\uparrow$); and "-" sign on arrows indicates ($x\uparrow\rightarrow y\downarrow$).

Shortage of crop supply for food consumption could result in famine and affect food security. According to the Food and Agriculture Organization of the United Nations (FAO), "food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life", and availability, access, utilization, and stability constitute the pillars of food security (FAO, 2009). Thus, the "availability" pillar of food security is affected by the shortage of crops supply for food, leading to food insecurity. If the food market is not managed properly, food insecurity might turn into food shortage mortality, principally reducing the global population and the overall demand for food, leading to a lower food shortage.

Moreover, the demand for crops by both food and biofuel markets leads to increases in crop prices and, therefore, rises in food prices. Rising food prices threaten at first the food security of the poor by limiting their "access" to food, highlighting the disruption of another pillar of food security. If the crop's market is not effectively managed, the food insecurity could affect other income groups, especially in the countries that are heavily dependent on food imports.

3.3. Pricing in food and biofuel markets

Figure 4 illustrates 3 main loops. *Loop B4*, indirectly explained in *Section 3.2*, addresses the balancing of crop prices in the food market. Based on this loop, when the total demand for crops by the food and energy markets rises, the resulting increment in the crops price increases the food price. Consequently, higher prices lower the demand for crops to be used as food, and the total demand decreases.

Loop B5, sharing two variables with *Loop B4*, highlights the role of the biofuel market in crop prices. This loop focuses on the 1st G biofuel production, which is a competitor for the food market in terms of crop consumption. As depicted in **Figure 4**, the biofuel mandates set by the countries affect the demand for the feedstock required for biofuel production. In the case of 1st G biofuel production, the demand for crops increases due to higher mandates. Consequently, the total demand formed for crops increases the crop prices and, therefore, the price of biofuels. The higher the biofuel price, the lower the interest in setting high levels of biofuel mandates. In this vein, some European countries have reported interest in reducing or freezing the biofuel mandates and adjusting biofuel-blending mandates after the biofuel prices increased due to the Ukraine-Russia war (Biofuels International, 2022).

The only reinforcing loop in **Figure 4**, i.e., *Loop R1*, tries to highlight the role of other biofuel generations in reducing the biofuel price and helping countries set higher biofuel mandates with the least possible effect on the food market. Based on this loop, if the demand for feedstock to address the biofuel mandates is satisfied by the supply of bio-based waste, algae, or genetically engineered feedstocks to produce 2nd, 3rd, or 4th G biofuels (Ranjbari et al., 2022), biofuel prices would fall as they would not be any longer affected by the prices of the crops. Using feedstock other than food crops not only helps mitigate the adverse effect of war on the food price and food security but also helps move toward building a more circular economy (Ranjbari et al., 2021c) and prevent deforestation. Research on the sustainability assessment and economic evaluation of using other feedstock than food crops indicates their economic viability (Jin et al., 2019) and lower climate change impacts (Agarwal and Sharma, 2020; Hosseinzadeh-Bandbafha et al., 2022).

3.4. The climate change challenge

Figure 5 presents three loops reflecting the challenge of climate change mitigation considering both food and biofuel supply chains. In the current worldwide situation, one of the main drivers of biofuel development is climate change (Hassan and Kalam, 2013). On this basis, worsening climate change pushes countries towards setting higher levels of biofuel mandates. Consequently, as *Loop R2* indicates, the demand for feedstock would rise, translating into a growth in crop demand for 1st G biofuels production. The increased demand for crops requires more land for cultivation, leading to deforestation based on *Loop B6*, and hence, higher levels of climate change would be expected. *Loop B6* is activated when the required land for crop cultivation is more than the maximum available land for cultivation. In this case, more forests would be destroyed and changed to farmlands to support both food and biofuel markets, posing additional risks to the ecosystem, including loss of biodiversity.

As mentioned earlier, due to the competition between 1st G biofuels and the food market, the demand for crops to be used as biofuel feedstock affects the available crops for food. Therefore, based on *Loop B7*, which includes all the variables present in *Loop R2*, setting higher biofuel mandates by the decision-makers due to the worsening climate change, increases the crop demand in the biofuel production system. This increase in demand is followed by the reduction in the available crops to be consumed in the food systems, increased food shortage, food insecurity, and increased mortality rate due to food shortage. Hypothetically, a shrinking global population would be expected to lower the demand for crops, reducing the need for cultivation lands and deforestation. In this case, the outcome would be an improvement in climate change mitigation.

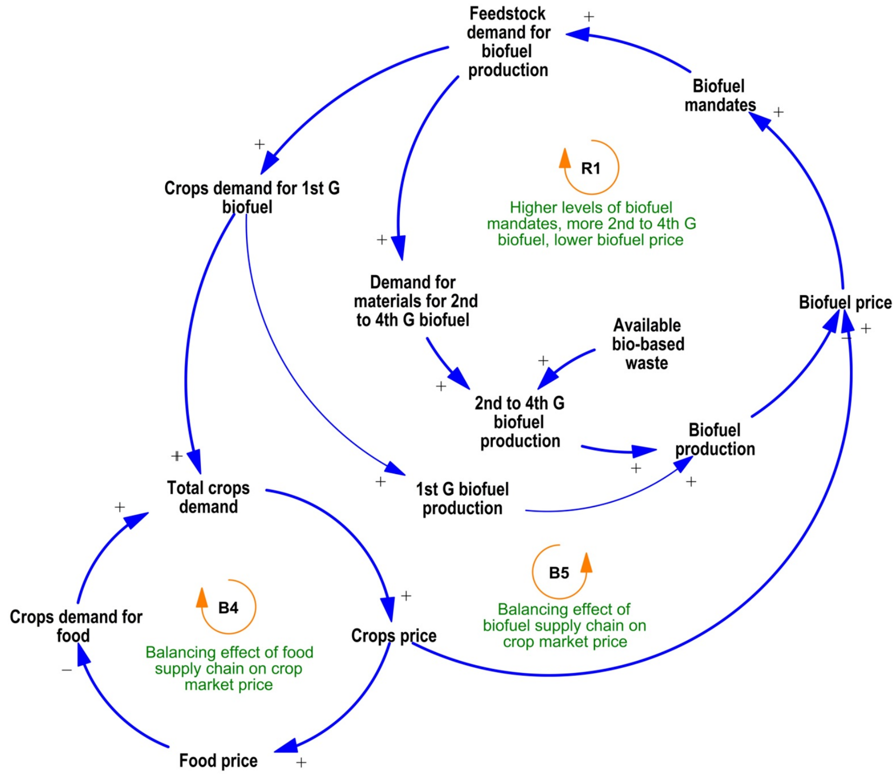

Fig. 4. Feedback structure of price formation in the food and biofuel markets. G: Generation; "+" sign on arrows indicates ($x\uparrow \rightarrow y\uparrow$); and "-" sign on arrows indicates ($x\uparrow \rightarrow y\downarrow$).

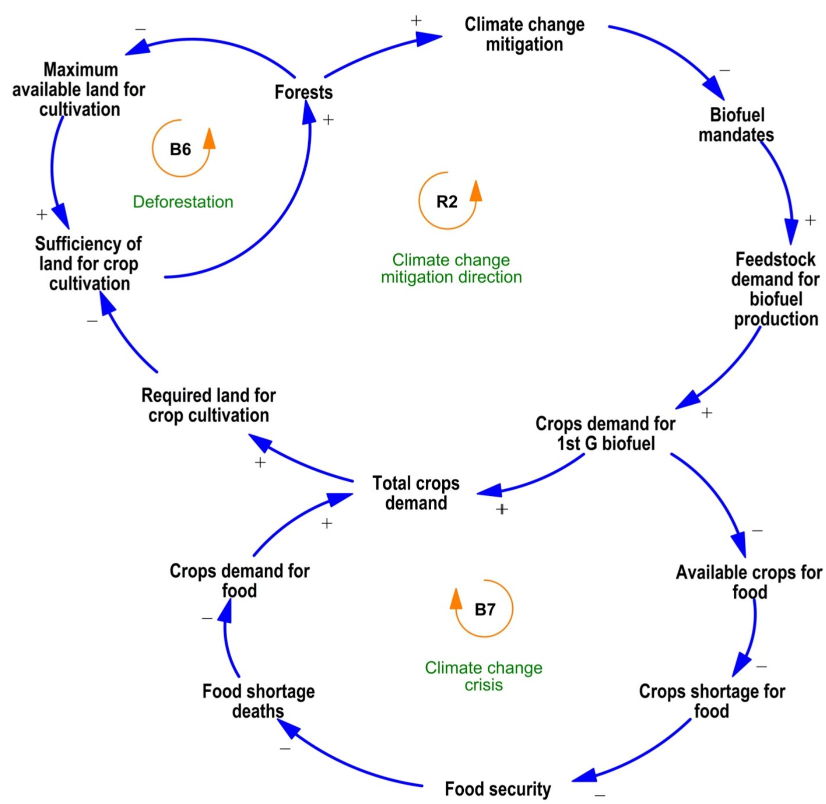

Fig. 5. Feedback structure of the challenge of climate change linked with food and biofuel markets. G: Generation; "+" sign on arrows indicates ($x\uparrow \rightarrow y\uparrow$); and "-" sign on arrows indicates ($x\uparrow \rightarrow y\downarrow$).

Nevertheless, if the decision-makers focus on biofuel generations other than the 1st G, the biofuel market would, to a great extent, be decoupled from the food market, and therefore, the land-use change would not be such a challenging issue.

4. Concluding remarks

The effect of the Ukraine-Russia war on food and biofuel markets requires a systems thinking approach to better analyze the challenges and find solutions to lower the unfavourable outcomes. In line with Pruyt and Sitter (2008), now that the world is close to a food crisis -if not managed properly-, the food sector should be prioritized over the biofuel sector for receiving crops supply. However, based on the CLD presented in this research, the key to preventing food insecurity and keeping biofuel mandates on an increasing trend simultaneously amid the Ukraine war is accelerating the transition from the 1st G biofuels to the higher generations. In fact, using bio-based wastes, algae, and genetically engineered feedstocks to produce biofuel removes the competition between food and biofuel markets in consuming the available agricultural commodities, whose supply has already been compromised by the onset of the Ukraine-Russia war. Regardless of the result of this military conflict, the transition towards the production of 2nd, 3rd, and 4th G biofuels seems like an inevitable option by the decision-makers to control the food supply and food prices, save the environment, intensify climate mitigation, and support providing affordable and clean energy for all as mandated by the SDG 7.

To the best of our knowledge, the present research was the first to address the effects of the Ukraine-Russia war on the food and biofuel markets simultaneously from the lens of systems thinking. Hence, the presented CLD is an initial sketch, yet a comprehensive one, which can be further extended and analyzed in more detail by future studies. Since simulations can better portray the outcome of the feedback structures, future research should also focus on developing a quantitative System Dynamics simulation model based on the CLD presented in this research.

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