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Defining barriers to food systems sustainability: a novel conceptual framework

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The transformation of food systems emerges as a critical challenge necessitating a deep, holistic comprehension of the complex and multifaceted barriers that hinder progress towards sustainability. The existing literature is not consistent in identifying these barriers. Building upon existing work, this paper introduces a comprehensive, integrated, and interdisciplinary framework to dissect the nature and origins of the barriers to food system sustainability. Our framework categorizes these impediments into five domains: political economy, socio-technical, socio-cultural, biophysical, and socio-economic barriers, and highlights their intricate interplay and interconnected nature. We pinpoint the foundational role of political economy barriers as the cornerstone of a “system of barriers” that create or perpetuate unsustainability. This framework not only advances academic knowledge by providing a structured basis for analysing sustainability barriers but also serves as a practical tool for policymakers, researchers, and practitioners, to foster transdisciplinarity and develop targeted interventions. We call for further empirical research, emphasizing the need for comparative analyses, longitudinal studies, and the exploration of feedback loops and non-linear dynamics between barriers, to inform effective and sustainable food system transformation strategies.

KEYWORDS

food system, sustainability, barriers, framework, transdisciplinary

1 Introduction

The transformation of food systems towards sustainability is an urgent and complex global challenge (Webb et al., 2020; Herrero et al., 2021; Fanzo et al., 2021). While food systems possess the potential to bolster human health, provide livelihoods, and support environmental sustainability, their current trajectory poses threats to these very aspects (IPES, 2015; Frison and IPES, 2016; HLPE, 2017). Given the evident sustainability challenges posed by current food systems, transformative changes are imperative. Our starting assumption is that these transformative changes cannot be achieved without a comprehensive and nuanced understanding of the barriers hindering sustainability (De Schutter, 2017; Hoek et al., 2021).

Extensive research has delved into the barriers to sustainable food production (MacRae et al., 1989; Rodriguez et al., 2009; Galli et al., 2020; Hoek et al., 2021) and consumption (Vermeir and Verbeke, 2006; Goryńska-Goldmann, 2019; Dawkins et al., 2019; Hansmann et al., 2020), often through a lens that primarily emphasizes environmental concerns. Investigations into the sustainability of agri-food supply chains have also identified critical barriers (Smith, 2007; Gold et al., 2017; Zhu et al., 2018; Mohseni et al., 2022). However, while the latter often addresses the multiple dimensions of sustainability, it tends to focus on specific barriers, such as technical hurdles or governance, rather than comprehensively addressing all barriers at once.

The existing debate among scholars, practitioners, and policymakers on pathways to achieve food system sustainability (Luederitz et al., 2017; Béné et al., 2019a; Béné, 2022) reflects a wider discord regarding foundational assumptions about the causes and obstacles to food system (un)sustainability. These divergences underscore the importance of not sidelining these crucial discussions in scientific discourse. Instead, there is a need to bring these underlying framing assumptions to the forefront, rather than "*black-boxing*" them (Scoones, 2009), as a critical step in achieving sustainability precisely lies in identifying, characterizing, and hierarchizing these barriers, to enable the design and implementation of suitable and effective measures. The multiplicity of barriers, along with their complex, evolving, and highly intertwined nature, also suggests the need for an overarching framework that transcends ideological divides, reconciles fragmented disciplinary knowledge, and allows for the comprehensive consideration of all barriers simultaneously to design effective strategies towards sustainability.

Against this background, our paper introduces a comprehensive, integrated, and interdisciplinary framework that offers a robust foundation for analysing and gaining a more nuanced understanding of the barriers obstructing food systems sustainability, while simultaneously ensuring clarity and usability. Our approach builds upon an existing framework developed by Conti et al. (2021), which identifies six "*sources of resistance*" to sustainable changes. While this framework provides valuable insights, we argue it does not fully capture the complexity and interconnected nature of barriers to food system sustainability. Expanding on Contis' model, our framework aims to fill this gap by offering a more comprehensive foundation for analysing these barriers in an integrated manner. Our approach aims to advance academic discourse and provides actionable insights for transdisciplinary work, aiding researchers, decision-makers, and practitioners in structuring and framing a nuanced analysis of sustainability barriers and identifying effective strategies for overcoming sustainability challenges.

In the subsequent sections, we introduce pivotal concepts and mechanisms related to food system sustainability barriers. We then present the details of our proposed framework, delineating each barrier and explaining the rationale behind the inclusion of novel elements and the organization into distinct categories. Finally, we discuss the combined effects and interconnectedness of barriers, emphasizing on the paramount importance of political economy barriers.

2 Methods

2.1 Concepts

This section presents key concepts foundational to our analysis, focusing on sustainability and its barriers. We further elucidate the mechanisms underlying these barriers, notably the increasingly recognized phenomena of path-dependency and lock-in.

There is no consensus on the definition of sustainability. The concept initially emerged in the early 1970s as a response to environmental concerns, notably linked with industrialization and the green revolution (Carson, 1962; Meadows et al., 1972). Over time, it expanded to encompass economic and social dimensions, as reflected in initiatives like the United Nations (UN) Sustainable Development Goals. However, an intense scholar debate still surrounds the concept, sparked by the historical association between the terms "sustainable development" and "economic growth" (Mitlin, 1992); some arguing that "*development—understood as economic growth—is incompatible with sustainability because an infinite growth process on a finite planet is impossible*" (Ruggerio, 2021, p. 3). Building on the work of the International Panel of Experts on Sustainable Food Systems (IPES-Food, 2015) Ruggerio (2021), and many others, this paper adopts a broad definition of sustainability, considering food systems sustainable when they (i) avoid doing harm to the natural environment and contributing to climate change, while engaging in regenerative, restorative, and mitigating activities, (ii) ensure universal access to healthy and nutritious food, and (iii) support an inclusive and equitable economy that foster decent livelihoods for all.

A wealth of literature exists that proposes a diverse range of actions for achieving food system sustainability, but very few studies specifically focus on barriers to sustainability (Garnett, 2013; Hinrichs, 2014; Béné et al., 2019a; Weber et al., 2020). We refer to barriers to sustainability as multifaceted constraints, impediments, and resisting factors that hinder deep changes towards more sustainable behaviors, practices, and policies, or perpetuate unsustainable patterns within food systems. These barriers span across multiple dimensions, encompassing social, economic, technical, environmental, and institutional domains. Such barriers notably include institutional inefficiencies, governance dysfunctions, power asymmetries, economic disincentives, technological limitations, entrenched societal norms, and bio-physical constraints. Throughout this paper, we discuss both "barriers" and "sources of resistance" as factors affecting food system sustainability. While "sources of resistance" mostly refer to the inertia or pushback within systems resisting change, we use "barriers" for its broader application, encompassing any impediments that prevent sustainable practices from emerging. This distinction is essential for understanding our framework, and further considerations are detailed in the discussion section.

Contemporary academic discourse increasingly employs terminologies such as path-dependency, lock-in, traps, and inertia (see Table 1) to characterize the underlying mechanisms by which barriers manifest (Oliver et al., 2018; Conti et al., 2021; Goldstein et al., 2023). The succinct definitions provided in Table 1 serve as a reference for the mechanisms discussed in this paper, yet they are not meant to be exhaustive nor systematic. Several papers are entirely dedicated to clarifying the meaning of these concepts, with some contradicting others, thereby highlighting the interpretative nature of such an exercise. Goldstein et al.'s (2023) review paper, for example, provides useful insights on how different disciplines define and use these terms, highlighting the similarities, intricate interconnections, and thin boundaries between these conceptual mechanisms. The use of different terms across disciplines to describe analogous mechanisms contributes to the confusion and ambiguity surrounding these mechanisms (Conti et al., 2021; Goldstein et al., 2023). While recognizing the crucial importance of these mechanisms, and their (potential) utility in delineating cause-consequence relationships among and within barriers, we refrain from extensive utilization or systematization due to disciplinary variations and the interpretative nature of their application.

2.2 Approach

Our research methodology is distinctive in its combination of inductive and deductive approaches (Fereday and Muir-Cochrane,

TABLE 1 Definitions of the mechanisms underlying barriers to sustainability.

"*Path-dependency*" expresses the enduring influence of historical choices on contemporary decisions and institutional arrangements, emphasizing that initial movements in one direction tend to prompt subsequent movements along the same trajectory (Mahoney, 2000; Kay, 2003). It is often used to explain sub-optimal decisions, of both public and private actors, regarding technologies, infrastructures, regulatory systems, etc. (Arthur, 1988; Goldstein et al., 2023).
"*Lock-in*" refers to a situation where a particular state or set of conditions becomes difficult to change (David, 1985; Arthur, 1989). It is extensively used to describe any kind of blockages leading to sub-optimal outcomes (Goldstein et al., 2023). It is often seen as a result of path-dependency mechanisms, and sometimes used in lieu of path-dependence. Lock-ins result in maintaining inferior and sub-optimal technologies, practices, regulations, etc. (David, 1985; Mahoney, 2000; Barnes et al., 2004) and excluding competing perspectives and practices. They render systems impervious to alternative pathways, maintaining their established trajectory (Conti et al., 2021). The perpetuation of these lock-ins is reinforced by mutually supportive components within systems (Kuokkanen et al., 2017).
"*Trap*", similar to lock-ins, is commonly referred as a self-reinforcing situation leading to negative outcomes. Specifically, the term "poverty traps" has been extensively used to describe the persistence of poverty and inequalities (Haider et al., 2018). The concept of "*productivity trap*," or "*intensification trap*," has also been used to describe scenarios where endeavours to boost agricultural or economic productivity, ultimately lead to diminishing returns, or adverse social and environmental consequences (Ferguson, 2016; Lade et al., 2017). "*Maladaptive rigidity trap*" refers to situations where an organization becomes excessively rigid in its structures, processes, or practices, leading to negative consequences (Holling and Gunderson, 2002). For instance, in an institutional context, "*political-economic interests, and prevailing discourses and power*," can create a maladaptive rigidity trap, limiting innovation and responsiveness to emerging (un)sustainability issues (Méndez et al., 2019).
"*Inertia*" is often employed in relation to institutions, to denote a reluctance to implement necessary changes (Stål, 2015). At the system level, inertia is frequently used interchangeably with path-dependency, illustrating how entrenched routines, social habits, infrastructure, and organizational logics can impede or delay shifts in direction within agri-food systems (Leach et al., 2020; Conti et al., 2021). Stål (2015, p. 362), warns that "*inertia cannot only be understood as non-change, but also as the pursuit of change in an unfruitful direction.*"

2006; Proudfoot, 2023). Initially motivated by the need to analyse a dataset (see below), we undertook a non-systematic thematic literature review on barriers to sustainability within food systems, particularly looking for existing frameworks. Amongst the nine identified papers which present or discuss frameworks, one was deemed particularly relevant for our analysis. This framework, elaborated by Conti et al. (2021), delineates six "*sources of resistance*" impeding the transformation of agri-food systems towards desirable outcomes. These six sources of resistance are: the persistence of inappropriate technologies; misaligned institutional settings; actors' aversion to change; political economy dynamics; infrastructural rigidities; and misaligned research and innovation priorities (Table 2).

Using Conti et al. (2021) framework, we first employed a structured deductive approach to investigate local stakeholders' perceptions, perspectives, and discourses, on a range of issues affecting food systems in Vietnam—with findings to be detailed in a forthcoming manuscript (unpublished). Specifically, we intended to analyse interview transcripts with food system stakeholders using Conti's six "*sources of resistance*." This phase involved an immersive exploration of real-world scenarios and perceptions, allowing us to test the applicability of the theoretical constructs proposed by Conti within a practical context. Using an iterative approach, we engaged in a back-and-forth dialogue between theory and practice. Initial deductions from applying Conti's framework were scrutinized against the actual narratives revealed by our primary data. This unveiled limitations in Conti's framework. We realized that strictly applying Conti's framework to our data would overlook certain issues raised by local stakeholders. This prompted us to revisit Conti's framework in the light of this empirical dataset, thus inducing a shift from a deductive to an inductive approach. As patterns and emergent themes surfaced from the empirical data, we used these insights to shape and inform the creation of a new, more comprehensive framework. This paper presents this framework, incorporating interpretive analysis of academic literature and leveraging the authors' practical experiences to discuss the refined framework critically. While we aimed to cover a broad spectrum of the literature on food system sustainability, we acknowledge potential oversights. Additionally, certain assertions in this paper may face inevitable contestations due to diverse interpretations in the appropriate pathways to sustainable changes in food systems.

3 The new framework

This framework is not intended to be an extensive and long-winded list of barriers and concepts. While our goal is to achieve comprehensiveness, our objective is also to maintain clarity and ensure practicality and applicability to real-world food systems. Our key additions to Conti's framework involve the inclusion of previously overlooked barriers, and the clustering of these barriers into five distinct groups. Figure 1 visually outlines our framework, highlighting the connections with Conti's original work. Our proposition suggests a hierarchical relationship among barriers, where certain barriers are deemed to "precede" others, indicating their deeper-rooted nature. These core barriers may catalyse the emergence of subsequent barriers. Consequently, we posit that these foundational barriers play a more pivotal role in hindering sustainability.

3.1 Political economy barriers

One of the primary shortfalls of Conti's framework stems from its definition of political economy, which we consider somewhat restrictive, failing to encapsulate the intricate dynamics between incumbent economic actors', policies, and institutions. While insightful, Conti's framework is limited in addressing the multifaceted interplay among influential actors, their agendas, and the broader political and institutional landscape. Specifically, their framework posits two distinct sources of resistance, namely "*political economy factors*" related to "*powerful actors, power imbalances and corporate power*," impeding food system trajectories towards sustainability, and an "*institutional setting*" comprising "*policies, regulations, and norms*" hindering transformative changes within the food system. Given the intricacy of these factors (IPES, 2015; De Schutter, 2017; Béné, 2022), we advocate for the adoption of a broader definition of political economy that considers both power dynamics and institutional

TABLE 2 Overview and definition of the sources of resistance proposed by Conti et al. (2021).

Sources of resistance	Explanations	Key references
Dominant and persistent technologies	Dominant technologies often persist, eclipsing potentially superior alternatives due to their social entrenchment. This signifies that once a technology establishes itself, it impedes the adoption of alternative technologies and development pathways.	Ruttan (1996); Wilson and Tisdell (2001); Barnes et al. (2016); Magrini et al. (2019); Farstad et al. (2021)
Misaligned institutional settings	Institutions and policies inadvertently create incentives misaligned with new directions for change. The institutional setting, comprising of policies, regulations, norms, informal rules, and practices molds individual and organizational behavior, locking food systems into existing trajectories.	Kay (2003); IPES (2015, 2017); Frison and IPES (2016); Turner et al. (2016); van Bers et al. (2019); Russell et al. (2020)
Attitudinal and cultural aversion to change	The persistence of certain production and consumption modes is often attributed to values, attitudes, and cultures. Deeply ingrained cultural elements can hinder actors from embracing change, maintaining the status quo in food systems.	Reenberg et al. (2012); Gonçalves et al. (2015); Frison and IPES (2016); Barnes et al. (2016)
Political economy dynamics	Political economy dynamics play a crucial role in skewing the direction of change within food systems. Powerful actors influence the trajectory of change, often aligning with their interests and values, and perpetuating the status quo.	Barnes et al. (2016); De Schutter (2017); Frison and IPES (2016); IPES (2017); IPES (2015); Oliver et al. (2018); Swinburn (2019)
Infrastructural rigidities	The inherent logistics and established infrastructure for the collection, processing, storage, and marketing of certain crops impede the diversification of agricultural products.	Thompson and Scoones (2009); Kimmich (2016); Meynard et al. (2017); Magrini et al. (2019)
Misaligned research and innovation priorities	Agricultural research priorities, practices, and dominant innovation narratives are misaligned with sustainability changes. The institutional setting, particularly within public agricultural research, support research trajectories that are path-dependent and misaligned with the overarching goal of transforming food systems.	Vanloqueren and Baret (2009); Frison and IPES (2016); Hall et al. (2016); Turner et al. (2016); Klerkx and Rose (2020); Herrero et al. (2021)

aspects, and how market power translates into political power. We therefore propose to conceive political economy as the interrelation between political and economic structures, encompassing how institutions, policies, and power dynamics shape food systems and influence the trajectories taken by these systems. At the core of this political economy lens lies the reciprocal impact of the economic sphere on political processes, resulting in convoluted interactions that deeply shape the production, distribution, and consumption of foods. We suggest introducing a group of barriers called "political economy barriers," under which we identify two specific barriers: one related to the economic dominance of powerful incumbent actors over decisions, actions, and processes governing food systems, and another linked to the deficiencies of existing institutions and policies. These are numbered *#1* and *#2*, respectively, in Figure 1 and are discussed further below.

3.1.1 Dominance of powerful incumbent actors

We designate incumbent actors within food systems as multinational corporations with substantial economic and financial resources, accumulated essentially through increased financialization, market concentration, and integration of agri-food chains (Murphy, 2006; Clapp, 2022), commonly referred to as *Big Ag* and *Big Food* (Stuckler and Nestle, 2012; Ashwood et al., 2022). They are active across all segments of the chains, particularly in agro-inputs supply, trade, processing, and distribution (IPES, 2017; Gura and Meienberg, 2013). The dominance of these incumbent actors originates from, and is reinforced by, economic power asymmetry, allowing them to exert substantial influence over the entire food system (Murphy, 2006; Clapp and Scrinis, 2017). Leveraging their structural power, they use both instrumental power (such as lobbying and financing of political campaigns (IPES, 2015; Clapp and Scrinis, 2017), intellectual property strategies, etc.), and discursive power (such as knowledge production and dissemination (Loughnane, 2022), marketing, etc.) to shape and influence policies, regulations, resource distribution, and consumers' perceptions and choices (Stigler, 1971; Hajer and Versteeg, 2005; Wiist, 2011).

This influence serves to advance their own agenda, typically reflecting economic interests and financial motives, such as "*generating shareholder value and adhering to short term financial targets*" (Keenan et al., 2023, p. 3). Because the rational economic choice for incumbent actors often leans towards maintaining existing practices, regardless of their sustainability (Wackernage and Rees, 1997), one can easily comprehend the potential detrimental impact of such mechanisms. An extensive body of research demonstrates the pervasive contribution of these incumbent actors to unsustainability, spanning socio-economic, environmental and health dimensions (Stuckler and Nestle, 2012; Lang and Heasman, 2015; IPES, 2017; Clapp, 2021) even if a large number of political institutions and international development partners still fail to recognize the problem (Clapp et al., 2021).

3.1.2 Deficient institutions and policies

The second component of these political economy barriers relates to the deficiency of institutions and policies, reflecting the growing dominance of corporate entities and the concurrent erosion of political institutions (Canfield et al., 2021). This shift of power and decision-making in food systems from governments to corporations is well-documented (Strange, 1996; Murphy, 2006; IPES, 2015). The deficiency of institutions and policies emerges in several forms, which we have identified as "inaction", "ineffectiveness", "fragmentation", and "dilution".

Inaction refers to a situation where policymakers, public organizations, governments, or policy networks fail to intervene on issues within their realm, despite having viable policy options (McConnell and 't Hart, 2019). Inaction can be (i) deliberate, to serve

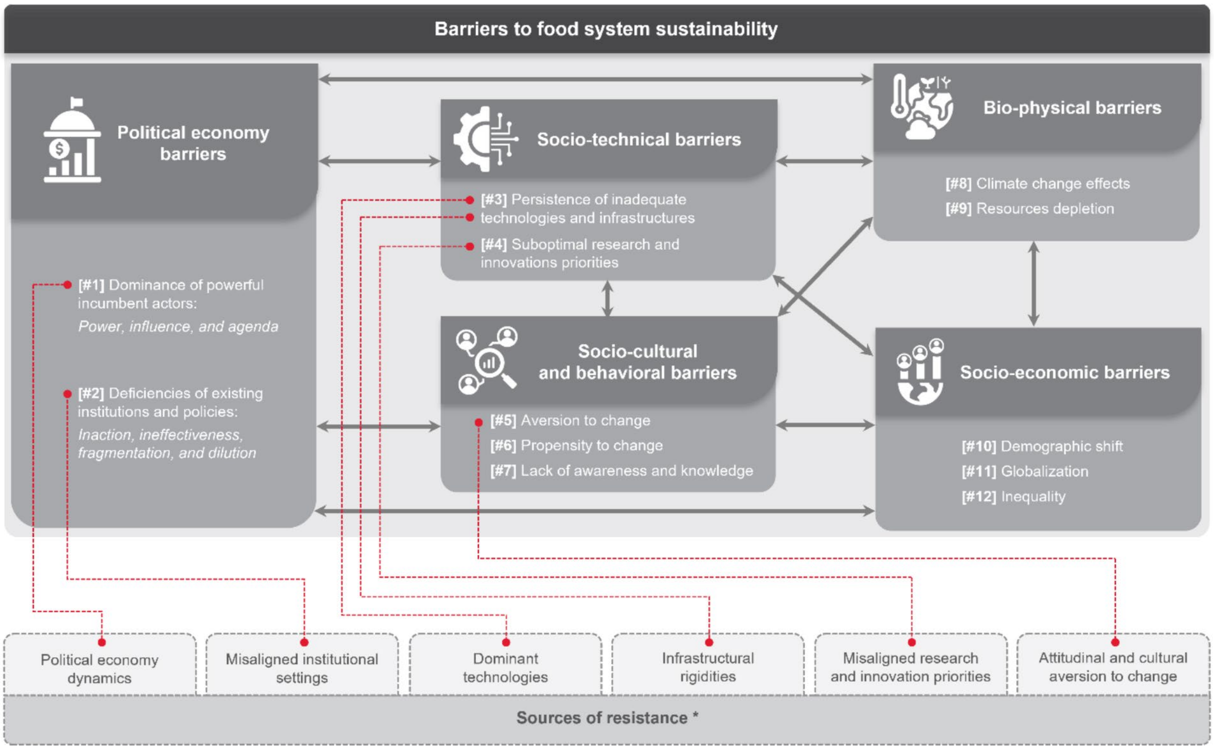

FIGURE 1
Correspondences between the newly proposed framework (upper part) and the sources of resistances defined by Conti et al. (2021) (bottom part). * "Sources of resistance" from Conti et al. (2021).

political strategies and/or ideologies and values, (ii) imposed by power dynamics, election cycles, and/or the lack of available tools and resources, or (iii) inadvertent, due to cognitive biases and/or "generational priorities" leading to some issues being neglected (Pierson, 2004; Vries, 2010; McConnell and 't Hart, 2019). Overall, it indicates a systemic inability to adapt and respond to emerging challenges or changing conditions within the food system. A case in point is a recent study by Mackay et al. (2022) from New Zealand, which reveals a persistent "*nine years of inaction*" over three electoral terms concerning the adoption of policies for a healthier food environment. Despite the availability of prioritized, actionable recommendations from a panel of experts, including academics, practitioners, and government officials, institutional inertia prevailed.

Ineffectiveness refers to the failure of institutions and policies to achieve their intended goals and outcomes within the food system (Bali et al., 2019). It often relates to the inappropriateness of policy tools, not well-suited to address the specific challenges that they were designed for (Peters et al., 2018). This can be due to outdated frameworks (Abdulai et al., 2024), mismatched regulations, or a lack of understanding and anticipation of the complex and dynamic interactions within the food system (DeLeo, 2015). Multiple studies revealed the ineffectiveness of existing policies to tackle issues such as food security, or equitable access to resources (Edwards et al., 2006; Klümper et al., 2018). Roberto et al. (2015), for example, showed that policies that emphasize individual responsibility as the primary approach to behavior change often overlook the structural and systemic factors that shape food systems. While individual behavior does play a role, framing solutions predominantly around personal choice ignores the collective and structural dimensions of sustainability challenges. Without structural reforms and coordinated actions to shift the system at a higher level, policies focusing solely on individual agency will continue falling short of creating meaningful, sustainable change. The role of incumbent actors in maintaining or promoting ineffective policies is also pointed out by scholars and civil society. For example, Capewell and Lloyd-Williams (2018, p. 131) showed how "*food industries continue to promote weak or ineffective policies such as voluntary reformulation, and resist regulation and taxation.*" This concept of ineffectiveness is closely linked with fragmentation and dilution of policies. Several studies (Torres and Muchnik, 2012; Giles et al., 2021; Elkharouf et al., 2021) point at policy ***fragmentation*** as the presence of disconnected elements within the food system's institutional and policy framework. They suggest a lack of coordination and integration among different components, related to maladaptive rigidity traps, leading to inefficiencies, gaps, and difficulties in implementing cohesive and comprehensive strategies.

Dilution occurs when the excessive addition of new policies, through processes known as "*policy stretching*" or "*policy layering*," paradoxically undermines or even dismantles existing policies and regulations (Barnett et al., 2020). This may occur due to shifts in goals, compromises, conflicting interests, or the influence of powerful stakeholders, resulting in measures that can be less robust or effective in addressing the underlying issues. For example, Feindt and Flynn (2009, p. 411) showed how policy stretching and layering in the UK explain why "*despite apparently sweeping institutional reform, food policy and the closely related agriculture policies have not undergone radical but rather incremental change at best.*" Policy reforms were diluted over time, not due to the direct intention of policymakers but as a consequence of policy layering. They also claim that new layers of policy can, rather than radically transforming a policy landscape, reinforce or even revert to older paradigms, in that case to a productivist approach. Another instance of policy dilution can be seen in the implementation of food labeling standards. As governments and international bodies introduce various labeling requirements to promote healthy eating and inform consumers (e.g., nutritional information, organic certification, GMO labeling), the proliferation of (sometimes misleading) labels can overwhelm consumers. This overabundance of information might weaken the effectiveness of each label's intended message, leading to confusion rather than informed decision-making. Such a scenario illustrates how the well-intended addition of policies to enhance consumer knowledge and support sustainable eating habits can paradoxically dilute the overall impact of these measures, complicating consumers' ability to make health-conscious choices.

3.2 Socio-technical barriers

We conceive socio-technical barriers as the sum of technical choices, practices, and routines made by food system actors that impede sustainability of food systems. The preference for the term "socio-technical barriers" over "technical barriers" stems from the imperative to recognize the interdependencies between technical and technological elements and the tethered social and human underlying determinants impeding the adoption of more sustainable choices and practices. It is indeed the nuanced interplay of social and technical factors that underpins the enduring prevalence of unsustainable technical choices. In contrast to still prevailing "*productivist discourses constantly circulated through the disciplinary power–knowledge network of science, technology and economics*" (Anderson, 2008, p. 122), we posit that the current main focus of science and research on technological innovation—resulting from the simultaneous manifestations of lock-in, path-dependency, and inertia mechanisms—actually contributes to maintaining food systems on unsustainable trajectories. The development of technologies and infrastructure for production, storage, processing, and distribution has indeed primarily served the production of major commodities, meant as inputs for the food manufacturing industry and large domestic or export markets (De Schutter, 2017). Concurrently, agricultural research has predominantly concentrated on the varietal development of a restricted subset of crops, including wheat, maize, soybean, and rice, while the optimization of farming methods has been largely directed towards monocropping and input-intensive systems (Haddad, 2020). This focus has resulted in the relative neglect of numerous other crops, particularly those grown for local consumption, as well as of more integrated farming systems, such as agroecology (Frison and IPES, 2016; Kumar et al., 2024). We identify three sources of resistance from Conti's framework that fall under what we call socio-technical barriers to sustainability, namely "*infrastructure rigidities*," "*dominant and persistent technology*," and "*misaligned research and innovation priorities*" (see Figure 1).

3.2.1 Persistent technologies and infrastructures

Despite operating at different scales, sources of resistance related to infrastructures and technologies have analogous impact pathways that contribute to create rigidity and persistence and share common mechanisms—cognitive routines reinforcing lock-ins, sunk costs reinforcing path dependency, and institutional support. Although their manifestations differ within the varying scales of food systems, we propose to merge them together under a single barrier called "persistence of inadequate technologies and infrastructures" [*#3* in Figure 1].

Infrastructure rigidities, exemplified by entrenched infrastructural arrangements around specific crops or by the extensive infrastructure supporting and optimized for the production, distribution, and marketing of ultra-processed foods, manifest as lock-ins hindering agricultural practice diversification or the development of healthier food options (Thompson and Scoones, 2009; Meynard et al., 2017; Magrini et al., 2019). Sunk costs, both financial and resource-related, associated with these longstanding infrastructure choices, give rise to a path dependency phenomenon. Past decisions embedded in the existing infrastructure persistently influence current practices, rendering deviations from the established path challenging and impeding the emergence of alternatives with distinct production and distribution requirements. As actors within food systems align their practices with this existing infrastructure, the system remains entrenched on a particular trajectory.

Technology persistence operates at a more granular scale, focusing on individual, farm-level, or business-level technology choices influencing daily practices, but follows the same logic as infrastructure rigidities. Once a technology is adopted, users (farmers, processing factories, retailers, etc.) invest not only in the technology itself but also in the skills and knowledge required for its effective utilization, creating cognitive lock-ins that reinforce the use of that particular technology over potentially more sustainable alternatives (David, 1985; Arthur, 1989). The persistence of unsustainable technology is thus emphasized by diverse sunk costs as well as some form of individual "*aversion to change*" (see below), making it difficult to deviate from the initial technology choices and fostering a path-dependency phenomenon.

The commonalities between these two types of socio-technical barriers extend to the institutional (and corporate) support that maintain the status quo. Institutions, encompassing public policies, regulations, and organizational structures play a pivotal role in shaping the trajectory of technological adoption and infrastructural arrangements (Bijker et al., 2012). In most cases, these institutional frameworks first guide, support and later align themselves with established infrastructures or technologies, creating mutually reinforcing lock-ins that sustains prevailing practices. This alignment not only reinforces the current state but also introduces inertia into the system, complicating the emergence of alternative options, as regulatory frameworks favor the continuity of existing practices (Kim et al., 2006).

3.2.2 Suboptimal research and innovation priorities

In line with Conti et al. (2021) and others, we contend that ***suboptimal research and innovation practices*** [*#4* in Figure 1] are a prominent barrier to sustainability, revealing a complex interplay of individual, institutional, historical, and economic factors that constrict the emergence of alternative and sustainable solutions. A large part of food systems incumbent actors, such as corporations but also governments, donors, and international organizations still consider technological innovation, enhanced productivity, and economic growth as fundamental to reduce poverty, alleviate hunger and cope with environmental and climate challenges (see, e.g., European Commission, 2023; Grow Asia, 2022; Schroeder et al., 2021; World Bank, 2021). This perspective is mirrored not only by major publicly funded international research organizations and philanthropic foundations dedicated to food and agriculture research (Beintema et al., 2020; Stads et al., 2022), but also by private-led research endeavours, which channel substantial efforts towards crop-centric and technology-oriented approaches (Baranski and Ollenburger, 2020). In contrast, fewer resources are allocated to comprehensive, transdisciplinary, and socio-political approaches (ASTI, 2020). The alignment of public research strategies with the productivist and technology-driven narrative of incumbent actors' is notably guided by a funding imperative (Thelwall et al., 2023), creating an institutional lock-in (Abdulai et al., 2024). However, it also stems from deeper impediments such as researchers' reluctance and inability to explore novel topics (Vanloqueren and Baret, 2009), disciplinary fragmentation (van Bers et al., 2019), the disconnection of researchers with societal stakeholders, real-world realities, and transformational challenges (FEC, 2018; Baranski and Ollenburger, 2020), or their connections to and dependence on private corporations' fundings, which can introduce biases in research outcomes (Massougbodji et al., 2014; Mandrioli et al., 2016). Such factors, mutually reinforcing one another, contribute to a research-endogenous lock-in that combines with a more exogenous institutional lock-in.

The enduring influence of the green revolution, and its associated mechanization, chemicalization, and plant breeding programs, also exemplifies the power of path dependency mechanisms. Despite the well-documented adverse effects on sustainability (Evenson and Gollin, 2003; Horlings and Marsden, 2011; Erick et al., 2013), these historical pathways persist in shaping contemporary research agendas and discourses (Baranski and Ollenburger, 2020). Furthermore, the increasing importance of private sector research (Fuglie, 2016), prioritizing economic returns over environmental and socio-economic outcomes (Beintema and Stads, 2017), suggests limited prospects for a significant shift of the agri-food research landscape toward more sustainable trajectories.

3.3 Socio-cultural and behavior barriers

Sustainability efforts face barriers rooted in societal norms, cultural values, individual behaviors, and societal patterns shaping production and consumption (Kates et al., 2001). Socio-cultural barriers tend to be collective and revolve around social norms and cultural values (Stern, 2000; Rhodes et al., 2020). Meanwhile, behavioral barriers rather manifest in individual choices and practices, shaped by knowledge, habits, perception and cognitive factors (Sawitri et al., 2015; Gumber et al., 2023).

The concept of ***aversion to change*** [*#5* in Figure 1], described by Conti et al. (2021), features prominently among these socio-cultural and behavior barriers towards sustainability. Individuals often resist changes that disrupt their established habitus, routines, and lifestyles, with factors such as fear of the unknown and preference for the familiar playing significant roles (Bourdieu, 1990; Coghlan, 1993). Societal norms and cultural values can also create resistance to change when stakeholders' practices are deeply rooted in culture and traditions.

There is, however, a flip side to aversion to change towards sustainability that Conti and her colleagues did not explicitly address: the ***propensity to change*** towards unsustainability [*#6* in Figure 1]. This refers to the tendency of individuals and society to engage in practices and behaviors that may not be sustainable. There is indeed a tendency for individuals or society to prioritize short-term interests over long-term ones (Carrington et al., 2010; Miniero et al., 2014). This unsustainable propensity to change is crucial to consider when exploring dynamic and transient food systems (i.e., constantly moving), where challenges reside not only in the resistance to change towards more sustainability but also in the current trajectories towards less environmentally-friendly, equity and healthy outcomes that are at play in many countries. This is particularly acute in cases such as the intensification of chemical inputs use, or the increased consumption of ultra-processed food. For instance, the prevailing paradigm of unlimited economic growth has historically promoted a continuous shift towards production practices that yield immediate profits but have adverse effects on the environment over time (Meadows et al., 1972). Another dimension of this unsustainable propensity to change is reflected in modern lifestyles, which are often characterized by a quest for convenience, with a preference for products and services that offer immediate reward (e.g., ready-to-eat ultra-processed food) but are detrimental to long-term sustainability (Hawkes et al., 2024). Socio-economic and institutional factors, such as poverty, inequity, or insecure land tenure, reinforce these behaviors (Brundtland, 1987), whether they manifest as aversion or propensity to change.

Another aspect missing in Conti's framework is the ***lack of awareness and knowledge*** [*#7* in Figure 1], often mentioned as a cause of food systems unsustainability (Ingram, 2008; Oliver et al., 2018). Certain stakeholders do not fully grasp the environmental impact as well as social or health implications of their actions and behaviors (Kronrod et al., 2012). When the negative consequences of unsustainable behaviors are not immediately visible or directly affecting individuals, there might be less motivation to change (Sanchez-Sabate and Sabaté, 2019). Some stakeholders interested in sustainability also simply lack the necessary knowledge and skills to switch towards more sustainable practices (de Paiva Duarte, 2015). Uncertainty about the costs and benefits of more sustainable practices, due to unreliable and/or unavailable information, further reinforce the aversion to change towards more sustainability.

Finally, while some stakeholders possess knowledge and awareness, they may still face barriers rooted in psychosocial factors and in particular in self-efficacy (i.e., the belief in one's ability to act effectively). As highlighted by Plechatá et al. (2022) low self-efficacy can prevent individuals from translating their knowledge into action, as they may doubt their capacity to make a meaningful impact or feel overwhelmed by the complexity of navigating sustainable choices. This psychological barrier underscores that knowledge alone is not enough; confidence to act is equally critical. As Foucault's (1969, pp. 44–45) aptly stated: "*it is not enough for us to open our eyes, to pay attention, or to be aware, for new objects suddenly to light up and emerge out of the ground.*"

3.4 Biophysical barriers

Biophysical barriers are often less controllable and primarily arise as long-term unintentional consequences of various choices made by individuals and societies. They manifest as global phenomena widely acknowledged and documented in academic literature and the media, often as ***drivers*** (HLPE, 2017; Béné et al., 2019b), but are not acknowledged as sources of resistance to change in Conti's framework. Among those bio-physical barriers, one of the most prominent is certainly ***climate change*** and its detrimental effects [*#8* in Figure 1]. Human activities (e.g., fossil fuel, deforestation) contribute to the alteration of the climate (e.g., increased temperatures, increased frequency, intensity, and severity of extreme weather events), posing severe challenges to ecosystems, agriculture, and overall environmental stability, and making sustainability efforts more complex and difficult to achieve (Lobell et al., 2011; IPCC, 2012; HLPE, 2017). The ***depletion of natural resources*** [*#9* in Figure 1], such as water, minerals, and arable land, is another significant bio-physical constraint. As populations grow and consumption patterns intensify, the depletion of these resources accelerates and hampers sustainable development efforts (Rockström et al., 2009; Kuokkanen et al., 2017). The loss of biodiversity, consequence of climate change and resource degradation, has also profound implications for sustainability. Habitat destruction and pollution of ecosystems contribute to the decline of various species, disrupting ecosystems balance and diminishing the resilience of natural systems (Cardinale et al., 2012), which are crucial for food production.

Importantly, while climate change, depletion of natural resources and loss of biodiversity may initially result from unsustainable practices, they also become reinforcing constraints to adopting more sustainable practices due to feedback loops within the system. Thus, even if individuals or communities seek to adopt more sustainable practices, they may be limited by the pre-existing unsustainable state of the system. For example, if climate change and/or overuse of water resources leads to reduced surface water availability for agriculture, farmers may be forced to resort to unsustainable irrigation practices, such as excessive pumping and surpassing aquifer renewal limits, to avoid decreased crop yields. Similarly, the loss of biodiversity can lead to increased vulnerability to pests and diseases, further diminishing agricultural productivity and forcing farmers to rely on chemical inputs, exacerbating the cycle of resource depletion and environmental degradation.

3.5 Socio-economic barriers

Similarly to biophysical barriers, socio-economic barriers are often considered as drivers (HLPE, 2017; FAO et al., 2023). They materialize in several ways, including rapid urbanization, population growth, globalization, and socio-economic inequality.

We propose integrating rapid urbanization and population growth together under a single barrier named ***demographic shift*** [*#10* in Figure 1]. The rapid *urbanization* currently at play, is a trend that cannot be ignored (FAO et al., 2023). From a food system perspective, it involves changes from food production, through food processing and food distribution to consumer behavior, and inadvertently lead to the rise of unsustainable practices. The increase in consumers' income, often associated with urbanization and change in lifestyle, has also been recognized as a driver of major shifts in dietary patterns, particularly increasing demand for animal-sourced protein and ultra-processed food, with significant environmental and health consequences (Popkin, 2006; Kearney, 2010). Additionally, the increased participation of women in the labour force has contributed to reshape food consumption patterns, shifting to more "convenient" and ready-to-eat foods, to manage time constraints, and potentially leading to unsustainable practices (Devine et al., 2009; Hawkes et al., 2024). In some countries with limited resources and territory, *population growth* can also be an issue (e.g., increased demand for food, pressure on natural resources, access to land, etc.); it can damage ecosystems and exacerbate socio-economic inequalities (Tilman and Clark, 2014; UNEP, 2016). Balancing the needs of a growing population with sustainable resource management becomes increasingly complex.

Globalization [*#11* in Figure 1], as a combined effect of liberalization, technological progress, and cheap fossil-based energy, and characterized by the interconnectedness of economies and the global movement of goods (e.g., inputs) and food products, also promotes unsustainable practices. While it contributes to economic growth, it also leads to environmental, social and health externalities, posing challenges to food system sustainability (Hawkes, 2006; Stuckler et al., 2012; Sabir and Gorus, 2019; Heimberger, 2020).

Finally, an essential socio-economic barrier influencing sustainability across the economic spectrum is ***inequality*** [*#12* in Figure 1]. On one end of the inequality spectrum, low-income households face significant constraints that hinder their capacity to adopt sustainable practices. Limited financial resources and cognitive bandwidth often force these groups to prioritize short-term survival over long-term sustainability (Mullainathan and Shafir, 2013; Fielding-Singh, 2017). For instance, smallholder farmers may struggle to invest in sustainable methods due to immediate economic pressures and the need for quick returns. Similarly, individuals with low incomes often find their food choices constrained by their limited financial resources, which can prevent them from adopting sustainable purchasing behavior. Conversely, wealthier individuals and communities contribute disproportionately to unsustainability through higher consumption levels and larger carbon footprints (Wiedmann et al., 2020; Chancel et al., 2022). Greater purchasing power drives unsustainable dietary patterns, including higher meat consumption for example (Godfray et al., 2018), and supports the use of resource-intensive technologies (e.g., chemical fertilizers and pesticides) that can degrade the environment (Tilman et al., 2011). Addressing socio-economic inequality as a barrier to sustainability requires a balanced approach that recognizes how both poverty and affluence can impact food systems sustainability, thus ensuring that the proposed solutions do not unfairly focus on and stigmatize vulnerable populations while addressing the underlying, structural issues perpetuating these inequalities.

4 Discussion

Barriers to sustainability of food systems are multiple and complex. Expanding on Conti et al. (2021), our study proposes a comprehensive framework that incorporates additional elements, resulting in the identification of 12 distinct barriers clustered into five overarching domains (see Figure 1). Such a framework is useful in providing clarity while translating theory into practice. If we consider for example the rising rates of obesity, extensively documented in the media and literature, it becomes evident that the inability to halt the obesity epidemic results not just from one but from a combination of several barriers. These include, but are not limited to, the increased availability and promotion of ultra-processed foods, sedentary lifestyles exacerbated by urbanization, and consumption patterns that prioritize convenience over nutritious choices (Kennedy et al., 2004; Stuckler and Nestle, 2012; Monteiro et al., 2013; FAO et al., 2023). This highlights the interconnected and mutually reinforcing nature of these barriers, leading to negative and unsustainable outcomes. In the absence of a structured framework to acknowledge, unpack, and address these interconnected barriers, the formulation of effective strategies to tackle specific issues, such as obesity in this case, becomes significantly more complex.

Several additional points emerge from the construction of the framework.

4.1 Sources of resistance, drivers, or barriers?

It appears unwise to solely focus on ***sources of resistance*** when looking at evolving and dynamic objects such as food systems. While we understand that Conti refers to sources of resistance "*towards new directions of change*," we find the term "sources of resistance" potentially confusing and prefer the term "barriers". Some would argue that it is "*the resistance of agri-food systems to detach themselves from the past and change in new directions that is the concern*" (De Schutter, 2017, as cited in Conti et al., 2021); we posit that the current changes at play, especially in the global South, are as concerning as the absence of change in industrialized countries. Furthermore, we favor the expression "barriers to sustainability" over "new direction of changes" as it is more explicit and avoids misinterpretations.

One major improvement offered by our framework is the incorporation of socio-economic and biophysical factors—often categorized as "drivers" (HLPE, 2017)—within the analysis, as barriers to sustainability. In existing theories, barriers and drivers are often considered separately, though in practice, they sometimes correspond to the same influencing factors. Barriers are considered as forces opposing change, maintaining a hypothetical status quo, whereas drivers are seen as catalysts propelling change forward. However, because both barriers and drivers may prevent us from reaching the ultimate outcome of interest (that is, sustainability of the system), drivers may become barriers especially when they move us away from sustainability, thus justifying that the two terms may be used interchangeably when referring to the same factor. For example, the socio-cultural and behavioral dynamics underlying the overconsumption of meat can be considered either as barriers or drivers, depending on the context or perspective. Hansen (2018, p. 57) points out that in Vietnam, the "*positive social connotations attached to meat as a symbol of development and progress*" act as a "*driver*", boosting meat consumption. Conversely, recent research in Northern Europe (Hielkema and Lund, 2021; Collier et al., 2021) underscores how "*social norms*" and "*habits*" serve as "*barriers*", impeding efforts to reduce meat consumption. Although drivers and barriers are intuitively perceived as fundamentally distinct, our analysis demonstrates that in the context of sustainability, drivers can paradoxically manifest as barriers—a notion that challenges conventional understanding.

4.2 The particular role of crises on food system (un)sustainability

Crises, including local and global events such as wars, civil unrest, and pandemics, pose significant challenges to food system sustainability. These external shocks disrupt food production and supply chains, exacerbate market volatility, affect food security, and ultimately destabilize food systems (Martin-Shields and Stojetz, 2019; Clapp, 2023). Armed conflicts, such as the ongoing war in Gaza, have devastating impacts on food systems by disrupting food production, distribution, and access, leading to acute food insecurity (Hassoun et al., 2024). Such disruptions also extend beyond conflict zones, as displaced populations place additional pressure on neighbouring regions, further destabilizing food systems in these areas (Béné et al., 2024). Similarly, the COVID-19 pandemic exposed critical vulnerabilities within global food systems, with widespread supply chain interruptions, labour shortages, and economic downturns exacerbating existing food system flaws (Love et al., 2021; Kubatko et al., 2023). However, while their detrimental effect on food system sustainability in unquestionable, we consider them as separate from the structural barriers constituting our framework.

The main reason is that our 12 barriers are primarily structural, meaning they are deeply embedded in politico-institutional, economic, socio-cultural, and biophysical settings characterizing human societies. While dynamic, they arise from foundational characteristics of the system and persist over time. Conflicts and crises, however, are conjunctural, meaning they are temporary disruptive events that impact food systems but do not form an inherent or permanent part of the system's structure. In other words, structural barriers persist over long periods, often requiring foundational shifts to address them. In contrast, crises are time-bounded (even if protracted), meaning their impacts might be severe but are not permanent features of the system.

Distinguishing between structural barriers and external shocks allows for more accurate analysis and targeted interventions, addressing root causes for structural sustainability issues and building response capacities for crises. Béné et al. (2021) notably highlighted that the threats posed to food systems by crises, such as COVID-19, stem not solely from the shocks themselves but from political and institutional status and responses (such as lockdowns and business closures) which produced secondary effects, including reduced food availability, affordability and accessibility. By acknowledging and treating conflicts and crises as situational stressors, we want to underscore the importance of adaptive capacity and resilience, and subtly bridge the concepts of sustainability and resilience, highlighting that while sustainability focuses on long-term stability and resource management, resilience addresses a system's ability to endure, adapt to, and recover from disruptions. A sustainable food system, therefore, is one that is not only able to tackle its structural barriers but also builds robust resilience to withstand and adapt to both anticipated and unforeseen crises.

4.3 Combined effects and interdependency of barriers in complex systems

We contend that barriers do not function in isolation but are rather interconnected and interact to produce combined effects on food systems and their actors. This suggests that rather than focusing on food systems interventions targeting a single barrier, it is crucial to design comprehensive approaches and strategies that transcend disciplinary divides and address simultaneously multiple barriers.

4.3.1 Incomplete assumptions and strategic misalignment overlooking the combined effects of barriers

When addressing food system sustainability, McInnes and Mount (2017, p. 133) astutely delineate existing approaches ranging from "*Amend*" strategies that leverage technological innovation, through "*Transition*" strategies emphasizing alternative market structures, to "*Transform*" strategies that call for radical systemic changes. Each strategy, however, primarily targets specific barriers—technological, behavioral, or political economy respectively—without fully embracing the complex interplay and compounded effects of barriers. The examination of the rationale behind these distinct strategies is particularly insightful as it reveals their limitations, often resting on incomplete assumptions and overlooking the combined and interconnected nature of those barriers. These distinct strategies, though logically grounded, fall short of comprehensively embracing the multiple barriers that challenge food systems sustainability. While we are inclined to endorse the "*Transform*" strategy, and the need for radical transformations of the political economy of food systems, we argue that other barriers, such as socio-technical and socio-cultural factors, cannot be ignored. On the contrary, we posit (and develop in the example below) that this is the combined effect of barriers that generate the complexity around unsustainability.

4.3.2 Interdependency of barriers: beyond single-solution approaches

In addition to the combined effects of barriers, we postulate that the intricate interactions and interdependencies between these barriers also reinforce their detrimental effect on food system (un) sustainability. Food systems components are indeed characterized by multi-level interconnections and interdependencies, with multiple non-linear feedback loops effects (Ericksen, 2008; Ingram, 2011; Baker and Demaio, 2019). The same applies for barriers to sustainability (Liu et al., 2021; Sanga et al., 2021), as interactions between barriers give rise to non-linear feedback loops, amplifying the impact of individual barriers, and intensifying their combined effect on food system sustainability. For example, bio-physical barriers like climate change can exacerbate the impact of socio-technical barriers, such as the persistence of unsustainable technologies, which in return further intensify climate change, leading to compromised agricultural productivity and food insecurity. We highlight this interdependency not solely as a matter of being conceptually right, but also for practical reasons in relation to the design and implementation of policies, and interventions. There is a critical need to identify and characterize all barriers at play, and to understand how these barriers interact with one another to accurately characterize the root causes of the problems. This understanding is paramount for devising appropriate, integrated, and holistic solutions rather than concentrating more narrowly on specific technical remedies (e.g., front-of-pack labeling) or on sectoral policies.

Multiple instances from the literature help illustrate the combined effects and interdependencies of barriers. For example, the examination of contemporary food environments reveals the complex interplay of political economy, socio-economic, socio-cultural, and socio-technical barriers and drivers contributing to dietary-related diseases such as obesity, diabetes, and cardiovascular diseases. Corporate dominance of Big Food wields substantial control over production, distribution, and marketing of food, prioritizing the mass production and promotion of ultra-processed and nutritionally poor food products (Monteiro et al., 2013; Clapp, 2021). This dominance fosters the widespread availability of such products, thereby contributing to suboptimal dietary behaviors and augmenting susceptibility to diet-related diseases (Monteiro et al., 2018; Lee et al., 2019). Concurrently, globalization exacerbates this phenomenon by facilitating the importation and consumption of processed and ultra-processed foods, undermining local food systems, and eroding cultural dietary norms (Kennedy et al., 2004; Pingali, 2007). Rapid urbanization—as a result of poverty and socio-economic inequalities fuelling rural–urban migrations (Nef, 1995; Sachs et al., 2004)—further compounds dietary shifts (Kennedy et al., 2004). Insufficient awareness and nutritional knowledge among consumers worsen the issue, as individuals may lack the understanding of the health implications associated with these dietary choices (Shimokawa, 2013), which is also reinforced by the failure of public institutions to engage in nutrition education, alongside misleading advertising and communications from Big Food corporations (Clapp and Scrinis, 2017). Additionally, in some contexts, inadequate food-related infrastructure development—deriving from public institutions deficiencies—notably in urban areas, limit access to fresh and nutritious food options (Figuié and Moustier, 2009; Wertheim-Heck et al., 2015). Income disparities further impede consumers' ability to procure and afford healthy food alternatives (Drewnowski and Eichelsdoerfer, 2009; Penne and Goedemé, 2021), resulting in increase in the demand for cheap and ready-to-eat food products which further encourages food corporations to produce and market such products. We could enumerate numerous other interdependencies and feedback loops among barriers that exacerbate diet-related health issues, but it goes beyond the scope of this paper. The aforementioned example serves to elucidate the intricate interplay of multiple barriers in perpetuating issues of unsustainability. Consistent with Glanville's (2007) analysis, it shows that addressing any single barrier in isolation is most likely to be ineffective and inefficient, leading to resource fragmentation and overlooking of potential synergies.

4.4 Political economy at the core of the barriers

It is the interaction, interdependence, and combined effects of the barriers—notably through path-dependency, inertia, and lock-in mechanisms—rather than one or two specific barriers, that maintain (and foster) unhealthy outcomes of food systems. While it would be extremely useful to feed the debate on food systems sustainability pathways, achieving a comprehensive, global, and quantitative assessment of the relative importance of each barrier presents evident challenges. Furthermore, the diversity of the food systems adds some additional layer of complexity, as the interdependency of barriers mentioned above might manifest differently from one system to another. The global food system is actually composed by a constellation of interconnected systems, spanning global, regional, national, and sub-national levels, and ranging from industrialized modern (e.g., the United States) through transitioning (e.g., Vietnam, Brazil) to more traditional and rural (e.g., Madagascar, Cambodia) food systems (HLPE, 2017). The exact role and contributions of specific barriers in shaping food systems is therefore highly context-specific and can hardly be generalized. While the interconnectedness of barriers applies across all food systems, the nature, direction, and intensity of the interactions and feedback loops differ among them—calling for context-specific research, as priority interventions might differ according to the considered food system. However, complexity and knowledge gaps should not serve as excuses for inaction. We argue that some barriers consistently "precede" others in all systems, and therefore constitute key entry points for advancing food system sustainability.

Expanding on our understanding of food systems, we consider that the limitations inherent in Conti's framework extend beyond the nature and quantity of identified barriers and encompass the hierarchical arrangement of these barriers. Indeed, Conti's framework places all "*sources of resistances*" on the same level, yet our research suggests that some of these resistances have more foundational implications, affecting other barriers through spill-over and cascading effects. We also posit that political economy barriers, which we characterize as deeply rooted in the system, often serve as the cornerstone of an intricate "system of barriers". Specifically, we suggest that corporate power and agency, along with politic and institutional deficiencies,—grouped under political economy barriers—serve as the foundational underpinnings of socio-technical, socio-cultural, behavioral, and biophysical barriers. While a comprehensive analysis of all causal relationships between barriers goes beyond the scope of this paper, our focus in the following paragraphs is to expose the significant influence exerted by political economy dynamics on socio-technical, socio-cultural, and behavioral barriers.

4.4.1 Political economy dynamics shape socio-technical choices and practices

Multiple studies underscore how corporate agribusiness strategies, often supported by national policies, international organizations and philanthropic foundations, shape food systems to align with their narratives and vested interests, thereby promoting innovations and capital-intensive technologies tailored to large-scale, industrial, and specialized farming practices (Murphy et al., 2012; IPES, 2015; Clapp, 2021). For instance, the intensification and ultra-specialization of smallholder farming systems, facilitated by agricultural biotechnology and synthetic inputs, exemplify how farmers and farming systems can become entrenched in socio-technical models built around and for corporate agribusiness (Holt-Giménez and Shattuck, 2011; IPES, 2017). The development of genetically modified seeds, sometimes engineered to function exclusively with specific chemical herbicides, and its support by governmental policies (Lapegna and Perelmuter, 2020), is a clear manifestation of this phenomenon. It illustrates how the adoption and persistence of inadequate technological innovations can be closely linked to corporate interests, as well as to rural and industrial development policies.

The current trend towards digitalization of agriculture, championed by corporate agribusiness as a panacea to solve climate change and food insecurity, further reveals the sway of political economy dynamics on socio-technical choices and practices. Corporate agribusinesses leverage their discursive power to propagate the narrative that digital technologies are the solution to sustainability issues. Despite the contested potential impacts of widescale digitalization on sustainability (Leroux, 2021; Beste, 2021; Forney and Epiney, 2022), these narratives are adopted by influential international organizations such as UN agencies and the European Union. Notably, precision farming, sometimes described as "*pseudo-sustainable techniques which help to maintain the (…) model of intensive industrial agriculture*" (Beste, 2021, p. 8), has now been embraced as an "*eco-scheme*" by the EU Commission, rendering it eligible for funding alongside agroforestry and agroecology initiatives (Hackfort, 2023). This illustrates how incumbent's discursive agency leads to narrative co-optation by other food system stakeholders (Simoens et al., 2022), reflecting the interplay of power and knowledge, and how this shape what is deemed conceivable, actionable, and achievable (Foucault, 1969).

Instrumental power of incumbent actors is also at play to create a wide range of technology-related lock-ins associated with digitalization, as highlighted in a recent study by Hackfort (2023). Innovations are tailored for large-scale monocultural farming practices, rendering them less suitable for small-scale or agroecological approaches, and discouraging the adoption of such practices. Additionally, the "*interoperability and incompatibility*" features inherent in digital innovations may create new dependencies and increased bureaucracy, exacerbating the disempowerment of small-scale producers with regards to technology (Forney and Epiney, 2022; Hackfort, 2023). The fragmentation of data policy regulations, allowing companies to dictate the rules, further contributes to reinforce corporate structural power and influence over technological choices. Hackfort (2023, p. 2) reminds the importance of rejecting any form of "*technological determinism*"; despite appearances, technological lock-ins are in fact deeply rooted in political and societal choices, which "*recall the power of progressive political action*" to foster alternative pathways.

4.4.2 Influence on socio-cultural and behavior barriers

The technological-related lock-ins emerging from incumbents' discursive agency extend to behavioral lock-in (Barnes et al., 2004), creating systemic interlock-in effects (Simoens et al., 2022) that foster aversion to change among food system actors, and hinder the adoption of more sustainable practices. Similarly, political economy dynamics exert a strong influence on food environments, shaping consumers behaviors and, often, driving behavioral changes towards unsustainable and unhealthy diets. Indeed, cultural norms and preferences, though deeply rooted in historical contexts and social interactions, undergo dynamic shifts in response to alterations in food environments. As most dimensions of these food environments—such as availability, price, marketing and labelling, and intrinsic properties of food products—are in fact largely under the control of corporate food companies (Clapp and Scrinis, 2017), partly because of the ineffectiveness and fragmented nature of food environment regulations, it becomes evident that incumbent actors play a pivotal role in (re)shaping cultural norms and individual behaviors. Marketing and advertising strategies, in particular, influence individual behaviors, impacting how people perceive and choose their food and shaping dietary preferences (Larson and Story, 2009). Unregulated advertising of processed and convenience foods, especially towards children (Wilks, 2009), is of great concern as it contributes to dietary shifts, often at the expense of healthier dietary habits (Stuckler et al., 2012). In Mexico for instance, aggressive marketing tactics employed by food corporates have contributed to the escalation of consumption of ultra-processed foods, thereby exacerbating public health concerns associated with diet-related non-communicable diseases (Barquera et al., 2018).

In response to mounting health concerns, *Big Food* corporations have engaged in "nutritionism" strategies (Clapp and Scrinis, 2017)—defined as strategies employed to capitalize on the growing consumer interest in nutrition and health. Positioning themselves as providers of solutions to nutritional issues, corporations gain consumer trust and loyalty, ultimately contributing to the adoption and perpetuation of unhealthy dietary habits. These strategies involve various tactics aimed at enhancing the nutritional profile of processed and ultra-processed food products, such as "*the reformulation of foods to reduce levels of harmful food components, the micronutrient fortification of products to address micronutrient deficiencies, and the functionalization of products that claim to provide optimal nutrition and health benefits*" (Scrinis, 2016, p. 1). As rightfully highlighted by Clapp and Scrinis (2017), by focusing on isolated nutrients or health claims, these tactics serve to divert attention from the broader health implications of processed ultra-processed foods.

Furthermore, corporate food processors employ discursive tactics such as product differentiation, portion sizing, and the promotion of physical activity (rather than dietary shift) to shape public perceptions regarding the causes of obesity (Frye and Bruner, 2012; Scrinis, 2016). Communication from these firms often emphasizes the responsibility of consumers to moderate their consumption of unhealthy foods, while downplaying their own responsibility, or the failure of governments, to limit the production, distribution, advertising, and accessibility of such products (Simon, 2006). Large food retailers and distributors employ analogous discursive strategies to position themselves as advocates for consumers' interests, to gain their trust and *in-fine* influence consumer behaviors. Such discursive tactics, contribute to ingrain incumbent actors' narratives that later become normalized through behaviors and practices, accepted as common sense and new norms, and remain largely unquestioned by the public.

Achieving food system sustainability is therefore inherently political (Swinburn, 2019; Leach et al., 2020; Béné, 2022). Due to the complex interplay of power dynamics, interests, and values that shape food production, distribution, and consumption, the identification of root causes is not always straightforward. While we recognize the importance of socio-technical, socio-cultural, and behavioral barriers, these are deeply rooted in the political economy configuration set by corporations and institutions. Technological and behavioral lock-ins are not unavoidable outcomes but rather the consequences of strategies and interests of incumbent actors. As government policies, international trade agreements, and corporate interests often align to prioritize economic growth and profit over environmental sustainability and social justice in food systems (Baudish et al., 2024), there is a pressing need for more inclusive governance structures to ensure that the interests and needs of all are taken into account.

5 Conclusions and implications for future research

Addressing food system sustainability requires a holistic approach that transcends disciplinary and ideological divides. In this paper, we have presented a comprehensive framework identifying the multifaceted barriers to food system transformation towards sustainability. Building upon existing literature and empirical knowledge, we identified a series of barriers, which we categorized into five overarching domains: *Political economy, Socio-technical, Socio-cultural and behavioral, Biophysical,* and *Socio-economic barriers*. Our framework highlights the complex interplay and interconnectedness of these barriers, leading to food system unsustainability. We suggest that only by recognizing and better understanding the combined and interdependent nature of these barriers, decision-makers and other stakeholders can develop more effective strategies to promote sustainability. Moreover, we stress the inherent political nature of food system (un) sustainability, with corporate power and institutional deficiencies creating foundational barriers. While other barriers play crucial roles, we suggest these are deeply rooted in, and derived from, inherent political economy dynamics.

We envision our framework as a valuable tool for researchers, policymakers, and practitioners striving to engage in transdisciplinary approaches to advance food system sustainability. We invite scholars to refine this framework and to include and account for additional nuances and complexities that might have been overlooked in this first iteration. We believe the framework can stimulate further research and discussion among scholars, contributing to improving narratives about the fundamental causes of unsustainability in food systems and the associated sustainability pathways. Ultimately, we hope this integrated framework can be a catalyst for enhancing communication among stakeholders from diverse backgrounds, fostering collaboration, and facilitating the development of consensus to inform and guide effective decision-making processes toward more sustainability.

Moving forward, we call for further research to deepen common understanding of food system barriers. While discussing the framework we underscored the critical importance of investigating the feedback loops and non-linear dynamics that occur between barriers. Further empirical investigation would be necessary, however, to assess the relative importance and significance of these different barriers, and to better characterize the interconnections and feedback loops between them. Future studies should delve deeper into these mechanisms to help confirm the fundamental root causes of food system unsustainability in the political economy spheres. Additionally, these analyses should explore how specific interventions addressing one barrier may impact (positively or negatively) other barriers and the broader system. Conducting cross-contextual comparative analyses would also help to understand how barriers' manifestations vary and impact differently food systems in different contexts. Such comparative approaches could provide valuable insights to discern universal from context-specific patterns and inform the design of more effective and tailored interventions. Finally, conducting longitudinal studies to track changes in food systems over time and assess the effectiveness of interventions aimed at addressing barriers would also be extremely useful. It would enable food system stakeholders to monitor temporal trends, potentially creating learning and accountability mechanisms around barrier-targeted interventions, and eventually redirect sustainability efforts towards the most relevant and efficient interventions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was obtained from the Institutional Review Board of the Alliance of Bioversity and CIAT (#2022-IRB30).

Author contributions

BE: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. HT: Formal analysis, Investigation, Writing – review & editing. HP: Formal analysis, Investigation, Writing – review & editing. CB: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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