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Framing the Intractable: Comprehensive Success Factor Analysis for Grand Challenges

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ABSTRACT

Complex socio-technical challenges, often referred to as grand challenges or wicked problems, lack a robust method for their holistic framing. Current approaches to framing fall into two primary categories. On one hand, models grounded in reductionist perspectives tend to oversimplify the problems and thus fall short of capturing the true complexity that must be understood to make tangible progress. On the other, notable attempts to achieve holism are more effective at incorporating contextual nuance, but still lack systematicity to identify and drive effective inclusion of critical issues, and also tend to suffer from the inherent bias of select expert input. In this article, we report on an extension of holistic problem framing techniques called comprehensive success factor analysis (CSFA) that makes-sense of web-mined information reflective of both expert and general population perspectives as well as pattern-informed ontological knowledge organization structure, to yield 'richer pictures' of grand challenges. This method has been developed and refined over a seven-year period by application to a variety of distinct socio-technical challenges, and emphasizes that framing complex problems requires one to embrace multiple levels of abstraction, a plurality of perspectives, careful contextualization, and an overarching system view. The CSFA method results in 'success factor trees' that are more comprehensive than seen otherwise and present a holistic view of the essential factors that need to be considered when engaging in large scale socio-technical problems. The success factor trees provide common grounds for meaningful collaboration and discourse on grand challenges, facilitate more informed resource allocation decisions, and provide guidance for designing solutions through careful consideration of system factors that are not always apparent. The paper illustrates CSFA applied to the challenge of 'food security for a nation in a low- to middle-income country context' to ascertain the value of the approach and finds that it results in a robust view of the challenge that greatly exceeds perspectives arrived at in the literature using current framing methods, on dimensions of scope, levels of abstraction, plurality, and context detail.

Abbreviations:

CSFA	Comprehensive Success Factor Analysis
SSM	Soft Systems Methodology
MBSE	Model-based Systems Engineering
USAID	United States Agency for International Development
PSM	Problem Structuring Methods
SCA	Strategic Choice Approach
SODA	Strategic Options Development and Analysis
AHP	Analytical Hierarchy Process
SEO	Search Engine Optimization

1. Introduction

As evident in the National Academy of Engineering's (NAE) call to action on grand challenges [1], the World Economic Forum's Global Risks Report [2], and the UN's millennium sustainable development goals [3], tackling complex socio-technical challenges is one of the more important objectives of our time. Challenges of water availability, food security, management of smart cities, and the future of work in a world involving smart technologies and artificial intelligence serve as prime examples, are studied across disciplines such as public policy, economics, law, engineering, and the social sciences, and lie at the core of the agenda for international development. Complex socio-technical problems of this caliber, which have been variously termed grand challenges, major, complex, and wicked problems in the literature [4–7], tend to defy straightforward examination due to their numerous stakeholders, multi-disciplinary grounding, and obstacle laden context [8]. These challenges typically involve an inhomogeneous environment with multiple problem tiers and varying exchanges of influence, resources, and capabilities among the many involved stakeholders [9]. In addition, the complex system that characterizes these interactions is fraught with uncertainty [10]. A major obstacle to addressing grand challenges is thus their framing, which is an initial step determining the extent of interrelated issues to be covered in any effort to address them.

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Existing techniques employed to address grand challenges implicitly cover this initial framing process but suffer from several critical limitations such as an oversimplification of complex problems rooted in reductionism [11], and an overwhelming reliance on expertise for the framing exercise, thereby leading to less than ideal framing. Herein, we report on Comprehensive Success Factor Analysis (CSFA) - a method to aid in framing complex socio-technical problems using a pattern informed ontology (the CSFA framework), and the mining of publicly available data (populating the CSFA framework) with the goal of developing a holistic perspective on the breadth of factors critical to a successfully operating system [12]. These factors take the form of a 'success factor tree' which organizes critical categories of factors in the system likely to be relevant to address the challenge being studied.

This technique has evolved over a seven-year period involving collaboration between the authors' research team and partner organizations on application of CSFA to an array of grand challenge problems. Specific challenges explored include collaborations to identify means to make medication for infectious diseases available and accessible for those in need in the context of low- to middle-income nations; work with a Purdue University research team pursuing solutions to potable water availability in villages in the Dominican Republic; and an effort with CommonWealth Kitchen - an organization in the greater Boston area that works to help address challenges of poverty and opportunity access among disenfranchised populations in metropolitan areas. These problems were explored longitudinally through multiple annual offerings of a full-semester graduate course called Breakthrough Thinking for Complex Challenges which is administered at Purdue University, and through targeted research and field work. Coupled with extensive review of innovation, design, and systems literature, the above-mentioned activities led to the identification of a repeating pattern of challenge-agnostic elements at the core of grand challenges, which fostered a method to build 'success factor trees' for complex challenges that were more comprehensive than typically obtained. The generalizable nature of the observed pattern elements and repeatability of the process provides confidence to call CSFA a 'method'.

When applied to a specific challenge, CSFA yields a reference point or ideal state system to achieve commonly acceptable outcomes, and thus provides the topical stimuli necessary for dialogue on the specific priorities that might require attention for a system that is not yet functioning desirably. While other techniques such as the SSM recommend painting a 'rich picture' [13–15], the CSFA method helps paint a 'rich*er* picture' at a relatively quick*er* pace. We do not claim that CSFA is a substitute for discussion or expertise, but rather an input dependent method complementing manual techniques and augmenting experts' discussion-based efforts. We observe that employing CSFA alongside traditional discussion-based methods leads to a 'rich*er*' starting point for subsequent stakeholder dialogue. In addition, examining success factors also helps contextualize a problem space so that individual actors and institutions can position their effort within a broader landscape of actors, and potentially make more informed decisions on the set of actions that may be necessary to ensure their specific efforts yield desired outcomes. Thus, CSFA enhances the framing process, fostering a more holistic view of complex challenges.

The CSFA process is currently being used in efforts to assist USAID and its implementation partners in identifying research initiatives that could advance progress on issues of high importance in low- and middle-income countries as part of a USAID cooperative agreement with a Purdue University-led consortium termed LASER (Long-term Assistance and Services for Research) PULSE (Partners for University-Led Solutions Engine).

2. Theory

Complex challenges have been described as 'messes' [16] due to their tendency to involve several interacting components, dynamic nature, and plurality, which create hurdles to solutions [17,18]. Broadly, two distinct approaches have been employed in attempts to manage this complexity.

The first, rooted in a reductionist perspective, seeks to understand the influences of specific variables on the system by placing emphasis on the constituent parts of the system rather than the whole [12]. The rationale behind these strategies is that complex problems can easily become logically intractable, and therefore reducing the scope of the challenge by making logical assumptions about influences could lead to actionable answers, albeit for specific parts of the complex challenge. However, this view falls short of capturing the true breadth of issues affecting the system and therefore inevitably discounts factors that ultimately do affect the functioning of the system, resulting in behavior that was not expected or predicted even for the isolated partial system. Reductionist methods are useful primarily when the abstracted system is highly controlled. Thus, although helpful when a comprehensive understanding of the problem already exists, reductionist methods are not generally effective for the framing exercise itself.

Model-based systems engineering (MBSE) techniques are part of this family of reduction-oriented methods and operate over a wide range of specificity. For instance, Systems Dynamics models, Stock-Flow diagrams, and Fuzzy Cognitive Maps [19,20], operate at a broader level, whereas more quantitative models of processes such as precise stakeholder exchange processes (e.g., of resources) are detailed and narrower in their formulation. Alternatively, modelling systems bottom-up and focusing on the interaction between 'actors/agents' and the 'environment' in which they operate is termed agent-based modelling [21,22]. While this technique has the potential to identify emergence in the system [23], it requires several bounds to keep models computationally tractable. Furthermore, agent behaviors as well as environment behaviors are controlled and often do not accurately capture the breadth of factors that might impact an agent's decision making. As a result, approaches rooted in reductionism tend to only limitedly acknowledge or capture reality, including the characteristic 'deep uncertainty' [24,25] of complex socio-technical challenges, and thereby omit important problem features often resulting in the development of solutions that fail to scale, miss the root cause, or offer only temporary relief [26]. Lastly, MBSEs tend to ignore the 'human' component [20,21] leaving this for another class of systems approaches called 'soft systems methodologies (SSM)'.

As the limitations of reductionist approaches have come to light, others have explored means to achieve greater holism, particularly through enhanced information gathering and the collection of expert input and stakeholder perspectives to "construct meaning" [27] or better define the problem in an ill-defined setting [28]. These methods rooted in the holism school of thought form the second set of useful approaches to manage complexity. Many of the approaches pursued to achieve holism draw on the theory of social constructionism which seeks to achieve shared meaning about the world (in this case the system) through coordinated interpretation of multiple perspectives [29]. To fulfill this objective, a host of problem structuring methods (PSM) [30] and issue prioritization methods have been employed.

Originating in operations research, PSMs have evolved to meet the need for an information-rich problem structuring approach. Soft Systems Methodology (SSM), issue prioritization methods [13,14], Strategic Choice Approach (SCA), Scenario Planning, Strategic Options Development and Analysis (SODA), and Robustness Analysis [17,20] fall into this family and have their distinct strengths and weaknesses [15,31]. Scenario planning frames a problem as a particular set of scenarios to consider, while exploring compatibility with other processes in the decision-making or design-oriented task, but tends to be bound by the spectrum of studied scenarios [19]. Other techniques focus heavily on the thought processes of individuals and the creation of a common language with which to explore problems, but are not intended to foster a holistic view. For instance, SODA draws further on psychology schools of thought, emphasizing subjectivism, to recognize individual personal views of a problem, but again fails to enable comprehensiveness [32].

The Soft Systems Methodology (SSM) - an evolved methodology within Systems Thinking - is said to be able to grasp the breadth of complex challenges and has a role to play in addressing them holistically [13,14]; and while SSM advocates 'problem framing' followed by 'issue generation' to gain this perspective, it does not elaborate on a method to frame a challenge holistically. This is where a comprehensive framing by using CSFA is contributory.

In a complex ambiguous setting like that typically associated with grand challenges, current PSMs to achieve holism in the framing of a problem bring multiple benefits to bear in identifying key features, and developing a deeper understanding of the problem in terms of relevant stakeholder perspectives [17]. However, they remain highly dependent upon the stakeholder perspectives collected. Techniques such as in-depth-interviews, workshop-based methods, and Delphi panels are typically used with the aim of gathering unique inputs that can be integrated to more fully define the problem.

Further, processes to spur brainstorming and decision making, such as causal influence diagram development [33], the Analytical Hierarchy Process (AHP) [34], and decision tree generation, are often used to assist with decision making under ambiguity. The effectiveness of causal-influence diagrams depends on the completeness of information available [35]. Traditional AHP is straightforward to apply across contexts and is capable of incorporating objective and subjective nuances, but finds its limitations when the variables considered are interdependent [36]. In the case of complex challenges, the intricately interconnected system does not allow for the ready application of this method. Further, it has been recommended that AHP be used in conjunction with other problem structuring methods (PSMs) to develop a hierarchical problem structure [36]. Decision trees, of course, are only as good as the scope of potential considerations that they contain. Thus, again, these techniques rely heavily on expertise or subjective judgement [33,37]. In fact, methods attempting to develop more holistic perspectives informed by expert judgement, all involve a group of experts participating in interactive processes to provide input. While this seems intuitive and is founded on the notion that expertise is earned through years of topical focus, it also carries with it the experts' biases. Unfortunately, methods adopted to extract expertise for use in complex problem framing reinforce the bias [38]. For example, techniques such as in-depth-interviewing, workshop-based methods, and Delphi panels depend critically on the constitution of the panel of experts [31,39].

Experts can base their judgement on heuristics [40], which are built up through their experiences. Heuristic thinking has proven advantages, but it is also known to potentially generate systematic errors in judgment due to pre-existing biases [41]. In addition to underlying assumptions in perspectives that may go unrecorded until they create limitations in the future [42], another challenge that arises here is that experts tend to create problem frames using the tools and language with which they are most familiar [43]. Arriving at a consensus regarding the problem requires alignment of multiple problem frames and resolution of discrepancies among individual perspectives of the problem, and brings in the question of who should be involved [15]. Furthermore, it is evidenced that confidence and consensus among experts are linked to contextual information provided to them. For instance, excess contextual information has been shown to provide better consensus and more confidence in decision-making among experts [44]. Ultimately, existing problem framing approaches profoundly rely upon relatively small sets of interactions to extract what amounts to limited information, rather than the vast sources of documented information that are available in the printed and digital realm [45].

A holistically framed challenge should account for the comprehensive set of issues that act as hurdles to drive tangible impact [46,47]. Without a tool or systematic methodology that guides development of a holistic perspective, framing efforts are likely to fall short of capturing the true breadth of variables that play a role in a given problem space. The CSFA method overcomes these documented limitations of existing framing methods for complex challenges by building on perspectives from various fields of study and providing a means to limit bias while highlighting what could otherswise be unknowns, supporting expert dialog, and providing a holistic perspective to facilitate collaborative efforts toward addressing grand challenges.

2.1. Rethinking grand challenge framing

In light of the above discussion, it is evident that there are several critical limitations to existing approaches to problem structuring. Specifically, they fall into two categories. The first is the inappropriate use of techniques belonging to the reductionist school. As described above, reductionist techniques are useful when applied to controlled sub-systems discovered post comprehensive framing. The second is the overwhelming reliance of PSMs on expertise, and therefore an inevitable expert bias that shapes the framing of challenges. Table 1 below highlights four specific dimensions along which currently used techniques (belonging to the above-mentioned categories) tend to fall short.

The framing process delineates bounds around a subject such that attention can be focused on the components encapsulated within the frame while excluding those outside it [48]. However, as there exists no ideal process for framing complex socio-technical challenges, it must be guided by a philosophical premise. Our approach is guided by the evidence outlined above which suggests that current framing efforts lack holism and their focus is likely to be misguided due to a biased view of the complex challenge either in favor of that which can be modelled or that familiar to the experts. Therefore, in our view, during the framing stage, systems thinkers must lean toward increasing scope rather than reducing scope. In addition, our approach to framing is based on embracing the plurality of the challenge and taking a knowledge/information-based approach to framing. A typical framing exercise should involve experts from various fields whose perspectives would then shape the challenge and its sub-parts to be addressed. In addition to traditional expert opinion, we also advocate inclusion of the perspectives of the general populous, who are critical stakeholders in the socio-technical system. The underlying premise is that society/people build, utilize, and benefit from systems, and are therefore its primary stakeholders. In today's society, people- 'the collective of agents/actors'- generate information including dis/satisfactory sentiments about the system that are expressed in many venues, including social media platforms. With roughly 3.2 billion people having internet access, greater than 1 billion daily active users on major social media platforms and more than 1.2 billion people using major search services daily, digital social input cannot be disregarded, and rather becomes a resource for identifying matters of importance to society. For instance, studies of keyword searches on search engines have been conducted in relation to several socio-technical system level issues ranging from jobs and local economies [49] to the COVID-19 pandemic [50]. Given that systems are built of people, by people, and for people, it is only prudent to utilize their expression through data generated on digital media platforms to inform expert and stakeholder discussion while framing grand challenges. Therefore, our approach informs expertise with inputs gathered from peer-reviewed publications from academic and institutional databases, as well as non-reviewed social trends from a sub-set of digital media platforms.

The CSFA method augments PSM techniques and belongs to the holism school of thought. However, we are of the view that most useful is a constructionist perspective i.e., one which incorporates useful aspects of all methods (and thus perspectives) at appropriate phases of analysis. With regards to problem scope, reductionist methods actively seek to reduce scope whereas holistic methods rely on experts to define coverage of scope. Both these views are problematic from our viewpoint as firstly we think that reducing scope is useful but not until in the later phases of the problem-solving exercise where a cleaner understanding of cross-component effects and accurate and suitable aggregated proxy estimations for effects are known. Secondly, expertise should be augmented with social data such that expert perspective gets further shaped

Table 1
CSFA differentiators relative to traditional framing approaches.

Dimension of advance	Status-quo	Limitation of status-quo	Solution adopted in CSFA
Plurality of perspective	Reductionist: do not intentionally explore plurality	Lack of plurality	CSFA is in favor of information excess rather than information parsimony. CSFA embraces plurality via incorporation of multiple disciplinary views (P^{3}OE^{3}TS), digitally mined insights from literature and in-context stakeholder perspectives, as well as several iterative interactions between participating experts, who are aided by organized presentation of captured perspectives.
	Holistic: consider plurality as a disadvantage, and therefore consolidate perspectives into a 'shared understanding' of the problem. [38]	Attempts to overcome plurality	
Level of abstraction	Reductionist: work at singular levels (System Dynamics at broader level, process models at more discrete levels) [12,23]	Complex socio-technical challenges are multi-level. Singular level solutions are unlikely to succeed.	CSFA explicitly fosters exploration of success factors at multiple abstraction levels. For instance, for socio-technical challenges, CSFA operates at individual, household, community, regional, and national levels.
	Holistic: tend to not explicitly use analysis at multiple abstraction levels	Multiple abstraction levels are required to capture plurality of interconnected systems [51]	
Contextualization	Reductionist: tend to focus on a single, often generalized context	Most complex challenges involve multiple variations of context and thus the transferability of narrowly contextualized solutions is limited	CSFA facilitates robust exploration of contextual variation by a) defining stakeholder sets comprehensively, b) detailing the specific resource availability and barriers to solution development and adoption (skill, wealth, access, time, behavior, attitude and belief) that may vary by context across the problem space, and c) exploring these factors at varying levels of abstraction.
	Holistic: utilize expertise to formulate context. For example, 'rich picture' in SSM.	Require expertise at each stage as contexts vary, 'rich pictures' need to be modified [19,20].	
Scope	Reductionist: actively reduce scope [12].	Reducing scope too early can miss critical aspects of a challenge	Scope is systematically addressed through a structured taxonomy of success factors, and reduction in scope is only considered post-framing of a challenge.
	Holistic: rely on experts to define and capture scope [12].	Experts are a proxy for capturing broad scope and inputs are dependent upon experts involved.	Expert inputs are augmented with data/ digitally mined insights from literature and in-context stakeholder perspectives. Again, CSFA is in favor of information excess rather than information parsimony.

by contextual information, thereby focusing the design of solutions with an understanding of contextual factors. We believe doing so leads to fewer implementation issues and increases the chances of solution success. Thus, in the spirit of holism, we propose that during the framing stage, systems thinkers should lean toward increasing scope rather than reducing it.

In addition to scope expansion, it is important to correctly map interactions between various system elements, as multilevel interactions are characteristic of complex socio-technical challenges. In CSFA, we explicitly perform the framing process at various levels of abstraction to think of potential issue implications between levels as well as stakeholders interacting at the various levels. This is not the case for either reductionist methods, which operate at singular levels, or traditional methods attempting to achieve holism, which do not explicitly call for analysis across levels of abstraction. Plurality of perspective is a closely connected idea. It generally means accepting a range of perspectives of the same system and is often correlated to the multiplicity of stakeholders who use the system in consideration. CSFA embraces the idea of plurality of perspectives and achieves it via both broad digital data gathering, and several iterative interactions between expert participants from a range of vocations, operating at various system levels. This cannot be said for either reductionist approaches or typical approaches targeting holism, which actively seek to contain the plurality of perspectives by being selective (reductionist) or consolidating them into a shared perspective (holism methods). Thus, they seek information parsimony whereas CSFA seeks information excess in the framing process.

3. Method

Building on the identified gaps in problem framing described above, herein we put forward a new approach to problem framing – a method termed CSFA. The CSFA method was developed overtime from theory and practical application, and its components were informed through the discovery of patterns commonly appearing in successful innovation systems, many of which are reinforced in the theoretical schools of thought of design and innovation, as articulated below. In the following sections, we detail the methodological framework at the core of CSFA which prescribes specific viewing lenses through which a complex challenge can be examined (3.1), and the procedure employed to apply this framework to specific complex challenges (3.2). This latter activity increases the depth of problem framing and involves a combination of inputs from experts as well as broader stakeholders that can be discovered in several ways, including from publicly available data. Thus, the method is an iterative process of knowledge (or information) discovery and information organization guided by the overarching CSFA framework.

3.1. A Structure for Grand Challenge Knowledge Representation

Knowledge-based framing of a socio-technical system encounters complexity similar to that witnessed in other domains that require knowledge organization such as language mapping and semantic networks, species categorization, big data organization, and world wide web information organization. One of the classical approaches to knowledge representation is through ontology building [52,53]. Ontologies are relation-defining structures that link pieces of information (a cat 'is a' feline, a tiger and cat 'are both' pathera tigris, and/or 'both possess' a furry tail) based on object feature information, thereby enabling identification of an object of interest without prior knowledge of its existence. Additionally, they aid in future categorization of newly discovered/invented objects. An ontology for characterizing a complex socio-technical system helps to structure seemingly disconnected varied information about numerous sub-systems, reduces the possibility of missing key sub-system components, and increases the possibility of discovering latent interconnections. The CSFA framework is intended to play this role thereby allowing us to capture and organize information rapidly.

The underlying structure of CSFA, which provides guidance of enquiry in the problem framing activity, was informed through the examination of innovations that have had an impact of a scale and significance similar to that likely required to address grand challenges [54–56], and was later reinforced through application over multiple separate real-life framing efforts mentioned above. The integrated fields of design and innovation deal with problems that share characteristics with grand challenges [57]; and the approach typically used to structure ambiguity in these domains involves identifying patterns and themes in a system [58]. A common theme observed in innovation literature indicates that innovation impact is driven by adoption [54,55,59–62]. In other fields that grapple with grand challenges, this process is termed implementation, research translation [46], or closing the "know-do" gap [47]. The adoption process includes multiple stages, is facilitated by communication and the availability of resources, and is motivated by the needs, attitudes and behaviors of the beneficiary population. Additionally, it is influenced by external systemic forces such as political, economic and social factors [63]. Thus, achieving adoption - that is having impact – requires an understanding of the system elements required to realize impact, and insight into these elements can be built upon several key concepts from theories of design and diffusion of innovation.

First, as briefly explained in the paragraph above, there is no impact without adoption of a solution by involved stakeholders [54,56,59,62]. Underlying the notion of adoption is an inherent requirement that stakeholders have a true need and acknowledge that that need exists. With the **awareness and acknowledgement of a need**, comes the potential for **motivation** to address it.

Second, changes, both in desired outcome and the environment of solution application, alter the path to solutions. The link between problem space and solution space is well accepted in the design community [64], and highlights the importance of accounting for purpose and context when addressing any challenge, especially those of great complexity. Exploration of context, in particular, typically elucidates barriers that may be faced by intended beneficiaries of a solution, which guide solution design choices that **enable access to a solution**, and often fall into categories of skill, wealth, access, time, behavior, attitude, and belief [65] .

Third, the successful translation of a solution requires a linkage of significant factors that span what is sometimes termed the "translation chain" (or consumption funnel) [66]. Developed solutions must be made context-relevant (overcoming the barriers described above) on a context-by-context basis. Then potential beneficiaries of the solution must be able to gain awareness of the solution, access it, fit the solution into their lives, and help establish the acceptability of the solution, possibly to the level of advocacy [66].

Fourth, addressing grand challenges requires multi-level reform and is predicated on the existence of a **secure and stable context**. If this foundation does not exist, it is likely the major priority, else the solution effort becomes one of acute rather than chronic need falling more aptly in the domain of emergency or crisis response [67]. Similarly, addressing complex challenges at scale typically requires engagement of **supportive and influential leadership** [68]**.** Leadership involvement can take many forms – such as governance, policy, and regulation, and spans individual, household, community, regional, and/or national levels. Importantly, the expressed goals and actions of involved leaders must be **aligned and influential** on the broader set of stakeholders to address a challenge impactfully.

Fifth, the variables of a system give it dynamism and need to be acquired via resource expenditure. At the most fundamental level, resources (which may include money, capabilities, infrastructure, facilities, and relationships) must be available to provide value or a supply chain connecting inputs to outputs that yield value/impact [69,70]. Mobilizing this requires **enabling methods and limited-time resources** [71]. Once functioning, **self-sustaining mechanisms** such as private sector engagement or additional **long-term resources** are required to ensure a sustainable approach encompassing technical, operational, economic, environmental, and cultural factors. The systems must posses properties of resilience and sustainability in a dynamic context [72].

Sixth and finally, the effects of problems as well as impact of solutions at one level are likely to affect the system at other (perhaps not immediately apparent) system levels. Traditionally in policy, levels are abstracted in societal terms such as national, regional, community, household, individual levels, which makes a relatable way to visualize the system. Hence, we include the multilevel representation of issues as a hierarchy for the ontological structure. The design community characterizes macro forces affecting wicked socio-technical challenges and includes the psychology of human behavior and cognition; social, political and economic frameworks; and technical issues [63] as significant forces. We adopt their recommendation and extend it to include 'psychology', 'physiology', 'politics', 'operations', 'education', 'environment', 'economy', 'technology', and 'sociology', as overarching viewing lenses that give us broad perspectives on the state of a variable. For simplicity, we give the overarching view the acronym P^3OE^3TS.

These observed themes give rise to four categories of success factors that can be further sub-divided into 16 total elements which form the base of the CSFA ontological structure. At the highest level, as shown in Figure 1, the system is composed of elements that make up the solution (a combination of organization, operations, and dynamic properties) and another set of elements that characterize the user and actors that are/will be engaged in the management, development, delivery, and use of the solution. The solution consists of fundamental and constant 'organizational' elements as well as in-motion and desired 'operations' elements representing activity within the system. Organizational elements form a foundation for development support - 'security and safety'; 'policy'; 'leadership'; and 'stakeholder interactions'. They are typically present and are necessary regardless of the context of the challenge at hand. The operations elements include desired variables 'infrastructure'; 'equipment and supplies'; 'workforce and talent'; 'capital and finances'; and 'practices and mechanisms'. These are desired but not guaranteed requiring them to be built/accumulated, and therefore, consume resources. Specifically, operational elements require two types of resources a). resources to start-up operations, and b). resources to sustain operations, and these need not (and often are not) the same. The users and actors category contains elements that are important for impactful action, that is for the expansion of the reach and impact of the intended action. It includes measurable and evaluable outcomes and learning; awareness and access; motivation; adoption and habit conversion; and retention, loyalty, and advocacy. Lastly, changes in the system

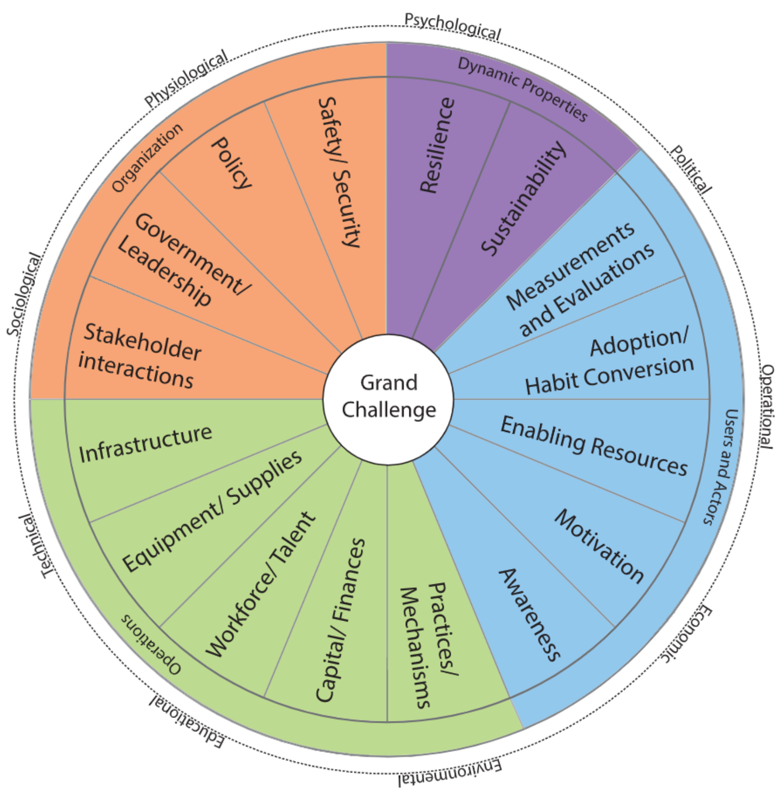

Fig. 1. The CSFA framework contains 16 challenge-agnostic elements that were observed to be shared across mulitple challenges of a nature similar to that of complex socio-technical challenges. They are organized into 4 categories - the organization, operations, users and actors, dynamic properties, along with 9 overarching viewing lenses- P^3OE^3TS, and 5 abstraction levels- national, regional, community, household and individual level- form the ontological structure for the success factor tree building exercise.

overtime are affected by dynamic properties that constitute elements of 'sustainability' and 'resilience'.

In summary, the framework (represented in Fig. 1) can be employed to initiate exploration of a specific challenge with an aim to holistically frame the grand challenge. Each of the challenge-agnostic elements constituting the framework are explained in detail the following paragraphs.

With the above theoretical underpinnings, generalizable views of each of the 16 challenge-agnostic elements are detailed below, noting that these descriptions are provided as guides to exploration in the problem framing exercise. For any given challenge, each of these elements is expounded upon through processes outlined in the methods subsection 3.2 below:

Security and safety: This category covers aspects pertaining to maintenance of the state of security and safety for all actors in the context and to provision of a conducive environment for solution generation. Elements that could fall within this category are safety of vulnerable populations, risk management, conflict resolution mechanisms, crime and corruption mitigation mechanisms, workforce safety concerns, environmental safety, and information safety.

Policy: Policies are a formal set of guidelines that direct operations within a governed region. The policy category, therefore, helps frame the overarching understanding of existing goals and outcomes in the region, and formal guidelines related to governing paths to achieve desired goals.

Government: An engaged and supportive government/leadership is necessary to drive change (at scale) and see to the creation and implementation of policies. This category frames factors such as the legislative, executive, and legal structures of the country; the commitment of the leadership towards solving the challenge at hand, government bodies that need to be in place for management of the system, and the overall government structure (centralized versus decentralized) along with mechanisms of cooperation among different levels.

Stakeholder interactions: The stakeholder interactions section captures internal system interactions. This is characterized by capturing the various types of stakeholders present in the system in terms of roles and responsibilities that they carry out, as well as the types of positive and negative interactions that may take place among them.

Infrastructure: This category includes the different infrastructure capabilities required to support value chain processes and related institutional, organizational and other supporting processes to facilitate solution delivery to the beneficiary population. Infrastructure needs for a solution that may be product-based (e.g., manufacturing infrastructure) would be different than those required to support a digital solution, for example. This category aims to capture these infrastructure facilities to envision a realistic and applicable solution.

Equipment and Supplies: Just as infrastructure needs exist for different demands and types of solutions, on a smaller scale equipment and supplies are required to support the infrastructure and sustain value chain operations. This section delves into the details of types of equipment and supplies required to perform different critical operations within the system.

Workforce and Talent: Here, the workforce development process is highlighted. This includes, for example, the need for a specific workforce to drive system processes, the progression of training the workforce to fulfill these roles, generation of interest in roles that need to be filled in the system, placement of individuals within the system as per their skillset and ability to contribute, and provision of fulfilling and rewarding jobs with benefits that help the workforce meet their needs.

Capital and Finance: Capital and finance mechanisms enable the economics of the system to function. This element category highlights that start-up finances and sustaining finances are distinct and need to be accounted for separately, along with other macro and micro-economic factors.

Practices: To enable the best outcome, tools and facilities provided should be put to their intended use. This category encourages exploration of ideal practices in the operating system that can achieve the required social, economic, health and/or environmental outcomes for the context.

Awareness: A population needs awareness regarding its existing conditions, knowledge of the possibility of improvement, and means to improve. This category contains factors that substantiate the acknowledgement of the existence of a problem as well as awareness building mechanisms that are necessary to drive change.

Motivation: Intrinsic and extrinsic motivators drive populations to adopt desired habits and practices. This section can be used to explore existing attitudes and beliefs towards change and the means to manage it strategically.

Enabling strategies: Barriers to adoption and change are commonplace in development. This section can be employed to explore the different types of barriers that can be encountered during the adoption process, which, if overcome, contribute towards achieving the desired system state.

Adoption/Habit conversion: The last stage in the translation process is related to adoption, retention and advocacy for new solutions, practices, habits and/or processes. Adoption is reflected through progress towards set goals to overcome existing challenges. Achieving this requires that key stakeholders, including beneficiary populations, are encouraged and/or incentivized to accept their roles and responsibilities involving possibly new practices and behaviors in favor of improvement in existing conditions.

Measurement and Evaluation: The effective functioning of the system depends on careful monitoring of its operations. Various indicators need to be defined and monitored to gather information for learning and improvement where necessary. This section can be used to frame details on the indicators that are required for these purposes.

Sustainability: The overall system needs to be able to sustain functions and processes in the long-term. This section probes key areas to assess system sustainability measures without which long-term plans may face limitations.

Resilience: Sudden shocks and long-term stressors, which can vary in intensity, duration, frequency of occurrence, and scope, can cause large impacts on progress. This section studies elements of resilience that help protect the system and overcome negative impacts, which are categorized into 'sensing' as planning and anticipation; 'response' as implementation and performance measurement; and 'learning' as feedback, and adaptation.

Collectively, the 16 elements, P^3OE^3TS and abstraction levels form the bases of our ontological structure- the CSFA framework. Figuratively speaking, they can be viewed as the roots of the resultant success factor trees. This ontology serves as a methodological guide to iteratively organize information gathered from multiple sources when performing CSFA on a particular challenge.

3.2. Populating the ontological structure to build a holistic success factor tree

The next step in building a comprehensive view of the system is populating the ontological structure with relevant, current and historical, and context-specific information which forms the branches and leaves of the success factor tree. To do this, we employ digital search. Keywords are at the core of information search and retrieval programs that help connect users to relevant information on both academic as well as commercial data platforms. Academic perspectives on the challenge can be curated by searching for keywords 'related' to the 16 pattern elements that surface from theory and in-field observations in well-established academic databases. The resulting set of related words would typically include synonyms, hypernyms, hyponyms, associations as well as keyword suggestions by academic journal curators. Next, we iterate over this set of words to create word pairs of the structure 'root word' + 'related word' (e.g.- infrastructure sector, infrastructure modernization, infrastructure deterioration, infrastructure costs and so on for the root success factor 'infrastructure'). The new set of keyword pairs are then viewed in the context of the challenge at hand and used to drive searches of a broad array of literature (e.g., peer-reviewed journals, institution/agency reports, professional publications) to gather and include the plurality of perspectives. In addition, for relevant information retrieval from commercial data platforms, we apply the logic that regionally popular keywords as provided by search engine optimization (SEO) tools are a fair approximation of the trending searches of the region. This is justified because the goal of an SEO provider is to generate the top trending keywords and related keywords through studying web traffic and user search patterns. Our approach thus is to utilize this information, along with historically accumulated knowledge, to populate our ontological structure with contextually relevant issues, thereby supporting (or refuting) long held knowledge and insights with current information.

The information categorization is aided by semantic relationships between the information and the nodes of the ontology. Relations mostly belong to the 'verb' part of speech and their main role is in helping establish links between the subject/s, object/s and their features as shown in Table S1 of the supplementary materials. The enlisted 40 relations are chosen based on digital dictionaries and broader open-source work in representational knowledge in the field of computational linguistics [73] in order to build a link to data-mining as a method to populate the ontology. Fig. 2 is a conceptual representation of the CSFA method.

4. Results

4.1. Application of the method to frame a grand challenge

The ontology-driven method described above was applied to the grand challenge of achieving 'food security for a nation in a low- to middle-income country context'.

4.1.1. Incorporation of plurality in problem-framing

In the context of food security, P^3OE^3TS was used to systematically identify and frame interconnected variables. For instance, considering workforce in the food system - the political and economic lenses speak to the importance of having policies to incentivize availability of jobs for the workforce, the operations and technology lenses provide scope for framing employment within the system, the education lens indicates the need for training programs, and the psychology lens provides insight into to the need to motivate the workforce to engage in the system. Similar processes were applied to other categories and variables throughout the framing process. In addition, keyword search processes that were employed to gather information further enhanced the incorporation of perspectives of various stakeholders and experts that operate within the system.

4.1.2. Encompassing levels of abstraction

The challenge of food security was examined at individual, household, community, region, and national population levels. When applied in the framing process, this gave rise to different practices and disparate food value chains based on subsistence farming practices [74] that cater to individuals and households, small-holder farming [75] that can cater to the community level, and commercial farming [76] that caters to regional and national populations. Among the operations elements, these levels enabled the framing of food value chains to include different segments based on the scale of demand and type of food (crop-based, animal-based, aquatic or marine-based). It also highlighted the important interconnections between levels of the system that link to labor, economics, and policy decisions.

4.1.3. Contextualizing the ontology

While framing the complex challenge of food security at a country level, the process began by using academic databases to curate a list of 'related' words to the 16 elements of the grand challenge knowledge representation framework. Table S2 presents the obtained curated list of keywords.

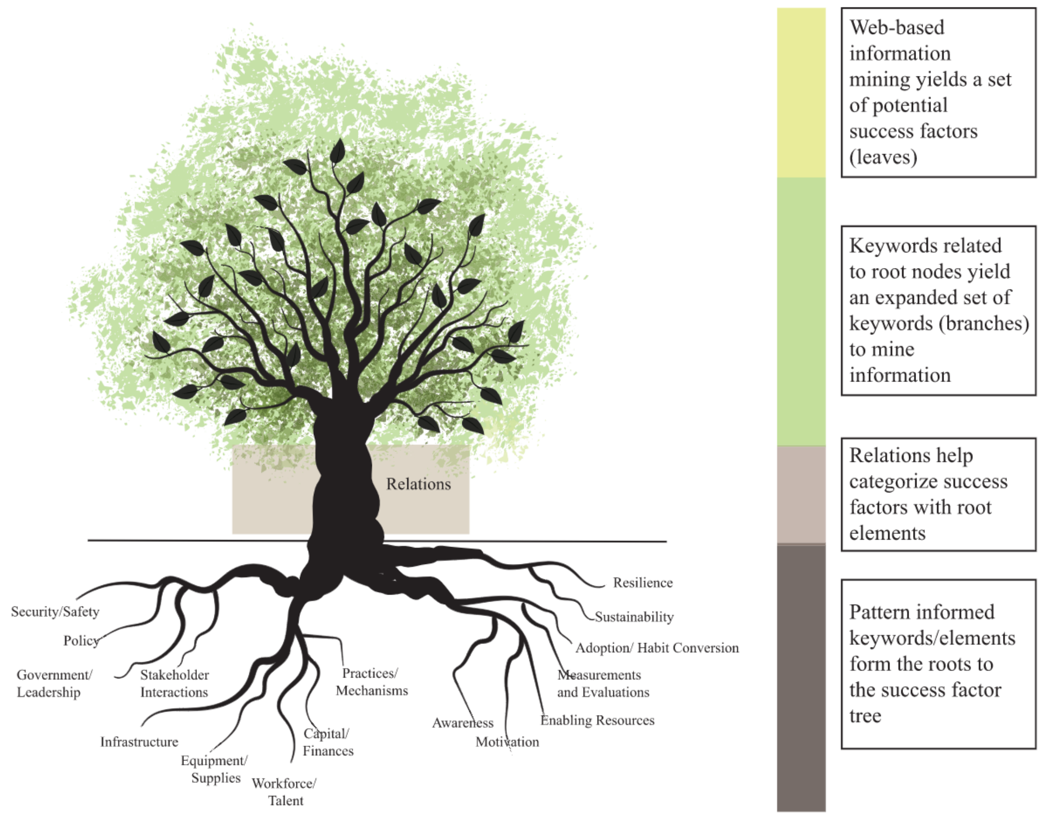

Fig. 2. A conceptual representation of the CSFA method. The tree roots are input nodes of the ontology. The relations trunk (explained in Fig. S1.) provides organizing rules. The branches, sub-branches and leaves for the tree are expanded success factors obtained after recursive organization. The corresponding process components are shown.

Next, simple searches relevant to this topic such as “food security”, “food delivery”, “food ecosystem”, “food process” and about 100 more were performed. As expected, each of these led to numerous results. We then scanned the results and added linked keywords from both academic databases as well as popular trends, thereby beginning to populate the ontological structure leading to a first draft of the multilevel success factors that relate to the food security grand challenge. This was done recursively and each time, the reordering of terms led to one of three states: 1). Information that fit well into a node of the ontology, 2). Validation or contradiction of previously discovered and arranged information, which led to rearrangement if necessary, or 3). Information that did not fit well in any node and prompted us to create a ‘new home’ for the information in the ontology. Multiple iterations were carried out to develop a strong ontological structure contextualized to food security in a low- to middle-income nation context.

4.1.4. Achieving scope

A description of variables that were encountered and classified among individual factor categories of the CSFA knowledge representation framework is provided below to highlight the scope of the analysis:

Security and Safety: This section covers aspects of risk management in the food system, such as risks associated with climate variability, economic variability, and perishable food items [77]; Standard Operating Procedures related to hygienic handling of consumable products to maintain quality [78]; corruption and conflict mitigation mechanisms where necessary to overcome negative societal influences on the functioning of food system [79,80]; and safety of the workforce through provision of benefits such as health coverage and labor protections.

Policy: The policy section of the success factor tree frames the need to understand food security in the low- to middle-income nation context in terms of pre-defined goals and outcomes [81]; guidelines specific to food value chain entities [78] guidelines on import, export and trade to meet food demands within the nation [78]; health and nutrition aspects for consumers [82]; partnerships within the food system [83]; and general implementation as well as degree of flexibility in updating these existing polices [82].

Government: In the context of food security, this category frames factors such as the commitment of the leadership in generating equitable access to food; budget allocations towards creating food security; government bodies that need to be in place for management of the food system; and collaborative efforts across different levels of the government structure, both horizontally and vertically, to allow for the unhindered operation of the food system [84].

Stakeholder Interactions: The stakeholder interactions section maps required stakeholders that enable food security such as formal and informal local and national leaders (e.g., government, influencers of change) [47,84]; the workforce which plays critical roles in the food value chain (agriculturists, food processors and distributors) as well as those that support activities that enhance food security (technology providers, healthcare workers, researchers, NGOs and other partners); and drivers of food demand (i.e., consumers); stabilizers or stakeholders who are experts at managing variability in the system (climate predictors, economy assessment agents, emergency response personnel) [85]. Beyond this, interactions between these multi-tiered entities have also been outlined in terms of positive and negative interactions, wherein positive interactions (such as cooperation, partnerships and healthy market competition) are encouraged in the food system and measures to mitigate negative interactions (such as conflicts or disputes) are framed to bring out the best outcome in connection with achieving food security in the nation [86,87].

Infrastructure: This category frames the different infrastructure capabilities required along separate value chain segments (food sourcing, food processing, storage, distribution and waste management) to meet the demands of different food types such that their quality and nutrition value may be preserved when delivered to a consumer [88–90]. Further, it also showcases the dependencies of the food system on supporting infrastructure such as communication, water, electricity, and education infrastructure, that can help strengthen food systems in parallel [91].

Equipment and Supplies: This section speaks to the technological and raw material requirements to perform different critical operations within the food system for different demand scales and types of food, such as farming equipment for agricultural practices; raw materials (e.g., fertilizer, seeds, water), and other similar requirements for pastoral farming or aquaculture practices, as well as equipment and supplies necessary for harvest processing, storage and distribution [88–90].

Workforce and Talent: The food system workforce may be classified according to skill or based on capacities at which they work [86,87]. Training or education facilities to impart specific skillsets vital to the food system workforce in addition to availability of employment opportunities and mechanisms to place trained individuals in a contributing position in the food value chain are identified as key factors for workforce development. Further, supporting workforce members such as researchers or private sector and non-profit entities also have a role to play and are included here [92].

Capital and Finance: With a start-up versus sustaining finances lens, this section explores adequate access to finances and other assets such as land, machinery and labor to smoothly run operations along the food value chain segments so that food demand across the nation is met. In addition to delving into the various types of financial requirements in the food system, this section outlines protection measures that can be taken for different stakeholders in the system to manage financial risks [75,81,93,94].

Practices: This section of the success factor tree frames ideal practices in the food system that can help achieve progress towards the desired outcome of food security and adequate nutrition in the country. For example, ideal agricultural practices involving climate adaptation techniques [75,95] (when performed in combination with other ideal external factors like high quality seeds, fertile land, skilled labor) can yield a good crop. Similarly, ideal practices exist for processing, storage and distribution of different food types such as drying practices for grains [96] or cold storage practices for meat, fish and dairy [97]. These factors are captured in detail in this section.

Awareness: To bring about food security with adequate nutrition, the population needs to be made aware of different factors related to food. Downstream, beneficiary populations or consumers, in general, need to be aware of safe consumption practices (e.g., the best techniques to cook certain foods to preserve their nutrients or how to check for adulteration or food that may have perished before purchase) along with nutritional benefits of different foods (e.g., avoid foods with excess salt or sugar content) and the importance of a balanced diet in order to make informed decisions about the types of food they consume [98,99]. Leadership needs to be aware of the functioning of the food system to drive policy development or implementation, and quality assessments as necessary [100]. The workforce needs to be aware of best practices, guidelines for food quality standards, and requirements charted for the regions and scales at which they operate [83,101]. These elements have been described in this section along with those factors, such as appropriate communication channels and content for specific audiences, that can enable generation of awareness among them [85,102,103].

Motivation: To achieve food security and nutrition in the country, the population needs to be motivated to make the right choices that ultimately enable adoption of desired practices and achievement of food security [66,67,98,104]. Once they are informed about their choices, a study of their prevailing internal attitudes and beliefs towards desired food-related practices and habits [105] can provide insight into the need for and type of interventions to extrinsically motivate the population to adopt healthy habits and practices [103]. This section frames assessment mechanisms and strategies to facilitate the adoption process.

Enabling Resources: Barriers to adoption of practices that can facilitate food security when encountered are placed in this category. Several barriers such as those faced in farming practices [106], or the economics of the food system [107,108], cultural ideals [109] or social inequalities [110] that prevent access to adequate food for all are framed in this section. These often are the underlying bottlenecks to adoption and impact development in food security contexts.

Adoption and Habit Conversion: Successful adoption of desired habits and practices in the food system generates measurable impact in the form of a healthy, well-fed population with lower mortality rates caused by malnutrition or hunger apart from other dimensions. The adoption/habit conversion section of the tree has been framed to depict this positive shift in the functioning of the food system that drives the system to continue to improve and maintain food security across the country through technology adoptions and improvement in agriculture practices [111], evidence-based government decisions [112], access to and consumption of adequate nutritious food by beneficiary populations [113] and upholding of quality and hygiene standards by food system workforce [114].

Measurement and Evaluation: Monitoring of the food system has been structured based on sets of indicators that measure different aspects of the system outputs as well as outcomes in terms of health and mortality rates among children and adults. The major branches of this section describe indicators to measure improvements in nutritional consumption, food accessibility, stability in food security, uptake of nutritious food, indicators of the existence of double burden, and indicators of impact [112,115,116].

Sustainability: Sustainability in the food system has been framed across the five population levels such that all system functions and processes beginning with sourcing food, through processing, storage, distribution of food, and waste management are sustainable so that they target and achieve food security across the country by planning for long term demand. This further includes that organizations and institutions that play crucial roles in the food system are sustainable [86,89,117,118].

Resilience: This section indicates the need for sensing, response, and learning mechanisms specific to the adaptation process including planning, anticipation, implementation, performance measurement, feedback, and transformation, which play an important role in managing short and long-term shocks and stressors that impact the food system [75,117].

4.2. Resulting success factor tree

The result of applying the above described method is a success factor tree constructed to frame the challenge of food security in the context of a developing nation and is provided in Table S3 supplementary to this paper. The tree encompasses 1000+ success factors that detail various features of the challenge under scrutiny in the form of branches and leaves rooted in the 16 elements depicted in Figure 1. To enable ease of navigation for readers, each section of the success factor tree (Table S3) is accompanied by a dendrogram that provides a brief overview of its contents. The individual dendrograms highlight branches within each section (text provided in color) followed by a list of keywords found within each branch (text provided within parentheses). Figure 3 below consolidates all of the dendrograms in the supplemented tree to provide readers with an overview of the substantial array of factors and perspectives generated through this method.

The resulting success factor tree is framed such that when oriented bottom-up, all factors listed within a branch typically need to be true for the main branch to hold true. Further, the success factors have been framed in a positive light so as to depict an ideal system state where the challenge of food insecurity has been overcome, i.e., food security exists across the nation. Therefore, when viewed top-down, the tree is structured such that for the condition of food security in the nation to be true, a list of factors that contribute to its success are featured in detail.

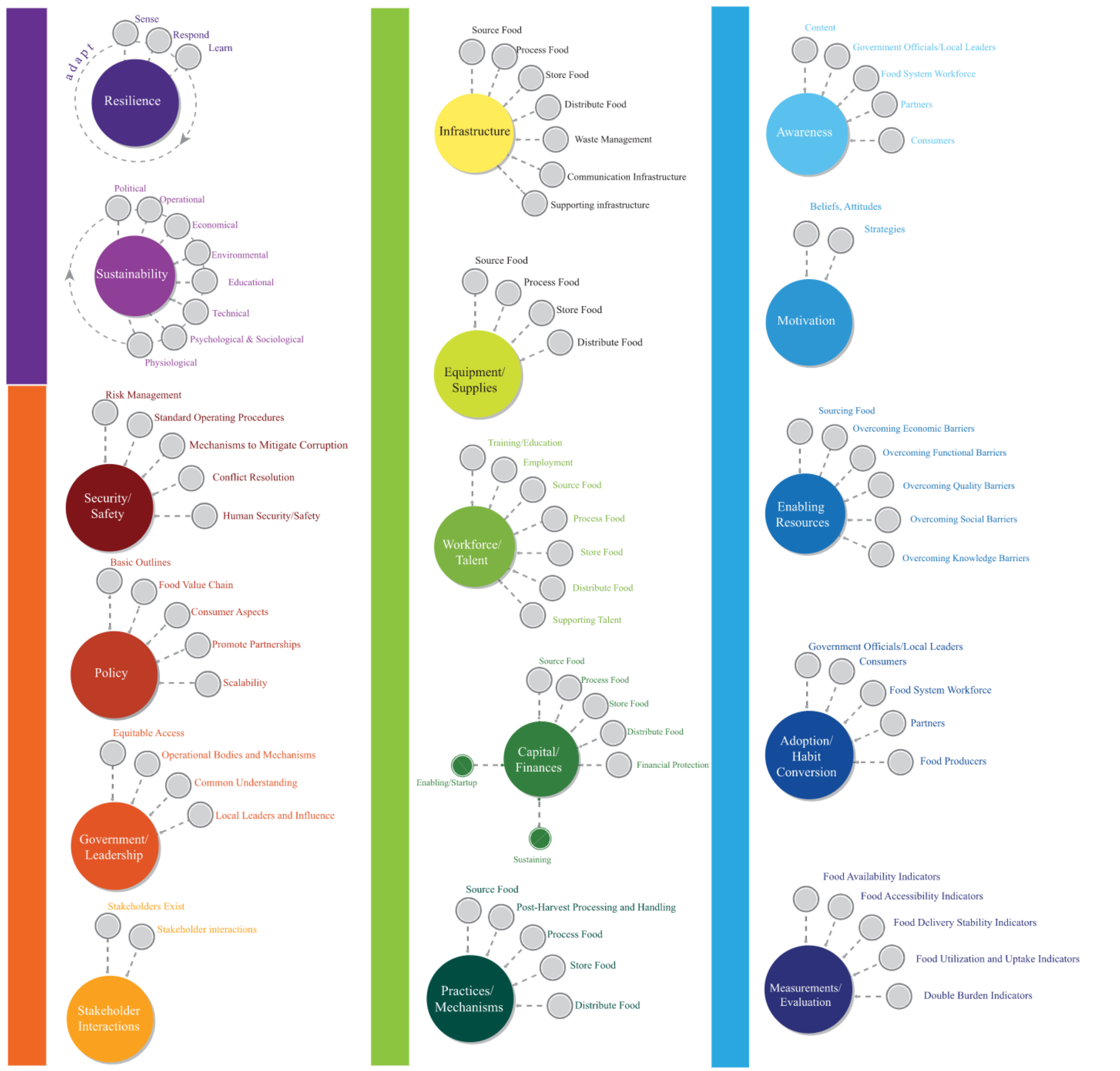

Fig. 3. Navigation Diagram. This figure illustrates application of the grand challenge knowledge representation framework and is an overview of the major success factor categories captured in the tree on food security illustrated in Table S3 in the supplementary materials. This diagram is to be used to navigate the success factor tree.

5. Discussion

We broadly searched the literature on the topic of 'national food security' and discovered studies that covered a single or a few parts of the CSFA ontology. For instance, the bulk of the focus in the literature was laid on system level elements – Policy [85,117,119,120], Security [74,121], Sustainability [121,122], Resilience [75,117,120,122], and Leadership [120,121,123,124]. Furthermore, another strong focus was on operational elements - Resources [95,100,120], Economics [74,121], and Supply-chain and distribution [95,117,124,125]. Lastly, only a limited number of studies focused on the social side of the socio-technical challenge [87,104,126,127]. All studies investigated covered individual elements or small groups of connected elements, at one or two levels of abstraction, and no study connected all of these critical elements [128–131]. This also highlights the disparate manner in which grand challenges are addressed in scholarly conversations. CSFA in contrast, is constructionist by property and in approach, and thus logically links all elements into one broad and encompassing framework. As demonstrated by the success factor tree, grand challenge elements cannot be addressed in isolation. The CSFA framework intentionally aggregates these disparate elements into one holistic lens.

The process of using a pattern initiated ontological structure, relevant information retrieval from databases, and manual synthesis helped us generate a 'rich*er* picture' and be more holistic than typically possible in framing a complex challenge. This is because rich picture development in traditional problem solving methods leads to identification of interrelated issues that typically number in the double-digits, whereas CSFA applied to the national food security challenge leads to a success factor tree with 1000+ interrelated and critical factors. Therefore, CSFA provides a robust means to develop a more comprehensively framed and less biased framing of a grand challenge.

We wish to emphasize that the CSFA technique is not a fully automated method that yields a perfectly framed grand challenge, nor can it substitute the thought process necessary to formulate the critical parts of an acceptably functioning system. However, it aids systems designers and experts in being considerably more comprehensive while muddling through [38] the process of building a holistic understaning of a challenge. It does so by firstly filling data holes in the framed challenge; secondly, by giving the system designer starting points (a branch) that may be used to begin the search for (leaves) via an iterative organizing process; and/or thirdly (and often), by providing leaves (success factors) themselves. In addition, it enables the unearthing of potential interconnections between seemingly disjointed system components, and the process highlights potential gaps where either missing information or insights can initiate a direction to call for research. Clearly, there are overlaps while organizing information into the ontological structure, but the objective here is to ensure information capture and not perfect organization - i.e., if unavoidable, we trade-off mutual exclusivity for collective exhaustivity.

5.1. Limitations

The limitations of utilizing the CSFA method for problem framing are quite apparent: a). the approach does not eliminate the need for manual observation and thought processes, rather it simply helps organize it, b). adding objects to an ontology may lead to an exponential increase in interconnections, and c). bounding an ontology necessitates trade-offs that might make it less than perfect. However, beyond these limitations, this approach still yields improvements over an unstructured pursuit of information that would require later coordination. Arguing specifically, a). the latest of machine general intelligence has not evolved enough to capture contextual nuances in an unsupervised manner. Hence, a manual process is unavoidable, but a computer aided manual process is better than an unaided one, b). interconnections grow rapidly as objects increase and hence, in our method, we rely on patterns observed in the mentioned exercises that form a limited set of core ontological components as described above, and c). a perfect and/or complete ontology does not exist, but an ontology that satisfices its purpose may be created such that it captures adequate breadth of information given a maintained level of organizational clarity, capturing obvious interconnections while leaving room to build non-obvious ones, thereby providing a structure to which information can be added easily.

5.2. Applications

This method has been applied in problem framing processes to analyze the multi-tiered and interconnected scope of issues related to region-specific development challenges. Challenges explored to date encompass a). working with small volunteer efforts with non-profits in well-defined settings, b). experiential learning work at the community scale in developing contexts, and c). rigorous examination of issues of national and/or multi-national importance for numerous countries around the globe [132]. In all of these activities, the framework has broadened analysis perspectives, helped identify critical research questions, and facilitated decision-making and resource allocation.

In addition to those applications listed above, the method has found value in educational contexts to teach complex problem analysis to more than one hundred graduate students across multiple colleges through course work at a university level, and has informed capacity-building workshops to impart training to approximately three hundred development actors working in international development to facilitate the use of systems thinking approaches and identification of potential collaborators to address challenges in their specific fields of work.

The true value of the method is in its scalability across levels of abstraction, in contextualization to specific in-field situations, and in elevating the viewpoint of development actors to realize their interdependencies, which are natural to grand challenges.

6. Conclusion

This paper highlights gaps in the traditional methods to address complex socio technical challenges which often fall short of completeness. Specifically, current methods lack comprehensiveness in framing exercises. This is because complex challenges are inherently difficult to navigate with their numerous stakeholders and interconnections. Herein, we explain the need for a more comprehensive framing of such problems so as to accurately understand the breadth of stakeholders and the diversity of interconnectedness of the complex system being addressed. CSFA achieves this by comprehensively capturing factors along the dimensions of scope, levels of abstraction, plurality, and context detail. In addition, we offer a method, based in a broad framework supported by data mining and knowledge structuring, that leads to a more comprehensive framing exercise. The CSFA method involves application of a 16 element framework that is generalized and applicable to frame any socio-technical grand challenge. When used in conjunction with data and information, the CSFA method results in success factor trees that can inform dialogue among experts/teams addressing grand challenges. We show that success factor trees are extensive in their framing of the breadth of interdependent stakeholder issues and their interactions offering the potential for a more robust effort to address them.

We demonstrate the application of CSFA to the challenge of achieving a system for food security in a nation. Traditional problem structuring techniques similar to the Soft Systems Methodology are likely to depend heavily on workshop-type interactions and discussions among a group of experts who will develop a ‘rich picture’ of the challenge. These traditional methods will inevitably suffer from expert bias. While expertise is necessary, effort must be dedicated to reduce the expert bias as much as possible. Utilizing the CSFA method is likely to reduce this expert bias by offering inputs from a broader set of perspectives that will enrich the interaction of engaged parties and thereby lead to a ‘rich*er* picture’. In addition, we believe the method provides researchers and practitioners with a greater sense of their role and contribution in the space of a challenge, helps expose the full expanse of activities required to address grand challenges, and serves as a starting point for dialogue on means to address grand challenges holistically. At the same time, we hope that this comprehensive view reinforces the call for convergent efforts expounded by many agencies that foster research, and encourages deep collaboration among all too often siloed disciplines, as the CSFA readily highlights the merit and necessity for multiple perspectives to address complex socio-technical problems.

In conclusion, we reiterate that there is limited value in efforts that hope to solve grand challenges without first holistically framing them. The CSFA method is a new approach to aid the research and practitioner communities in comprehensively framing a grand challenge. We describe the class of problems for which CSFA is suited as a framing technique. By using CSFA, researchers can develop a more complete understanding of the parts of a complex socio technical system that need to be considered to achieve desired outcomes.

Declaration of Competing Interest

The authors declare no competing interest.

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Supplementary materials

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References

[1] National Academy of Engineering. NAE Grand Challenges for Engineering, http://www.engineeringchallenges.org/14500.aspx; 2017, [accessed 26 August 2020].
[2] World Economic Forum, The Global Risks Report 2018, 13th Edition, World Economic Forum, Geneva, Switzerland, 2018. http://www3.weforum.org/docs/WEF_GRR18_Report.pdf.
[3] United Nations. Sustainable Development GOALS. United Nations. https://www.un.org/development/desa/disabilities/envision2030.html; 2015, [accessed 26 August 2020]
[4] WA Wulf, Great achievements and grand challenges. Natl. Acad. Eng. Bridg. 30:3&4 (2000) 5–10.
[5] H Varmus, R Klausner, E Zerhouni, T Acharya, AS Daar, PA Singer, Public health. Grand challenges in global health, Science 302 (2003) 398–399, doi:10.1126/science.1091769.
[6] V Marchal, R Dellink, D Van Vuuren, C Clapp, J Chateau, B.M é, et al., Environmental Outlook to 2050, OECD, 2011.
[7] E Uehara, M Flynn, R Fong, J Brekke, RP Barth, C Coulton, et al., Grand challenges for social work, J. Soc. Soc. Work Res. 4 (2013) 165–170, doi:10.5243/jsswr.2013.11.
[8] USAIDGrand Challenges for Development, USAID, 2018.
[9] A Monk, Howard S. Methods & tools: the rich picture: a tool for reasoning about work context, Interactions 5 (1998) 21–30, doi:10.1145/274430.274434.
[10] V Marchau, WE Walker, P Bloemen, S Popper, Decision Making under Deep Uncertainty, Decision Making under Deep Uncertainty, 1st ed, Springer, 2019.
[11] HHQ Heng, The conflict between complex systems and reductionism, JAMA 300 (2008) 1580, doi:10.1001/jama.300.13.1580.
[12] FC Fang, A Casadevall, Reductionistic and holistic science, Infect. Immun. 79 (2011) 1401–1404, doi:10.1128/IAI.01343-10.
[13] PB Checkland, Soft systems methodology: a thirty year retrospective, Syst. Res. Behav. Sci. 17 (2000) S11–S58, doi:10.1002/1099-1743(200011)17:1+<::AID-SRES374>3.0.CO;2-O.
[14] Checkland PB. Soft Systems Methodology. Hum. Syst. Manag. 1989;8:273–89. 10.3233/HSM-1989-8405
[15] M Marttunen, J Lienert, V Belton, Structuring problems for Multi-criteria decision analysis in practice: a literature review of method combinations, Eur. J. Oper. Res. 263 (2017) 1–17, doi:10.1016/j.ejor.2017.04.041.
[16] R Ackoff, Redesigning the Future: a Systems Approach to Societal Problems, Redesigning the Future: a Systems Approach to Societal Problems, Wiley, New York, 1974.
[17] J Rosenhead, Encyclopedia of operations research and management science, Encycl. Oper. Res. Manag. Sci (2013) Published Online First, doi:10.1007/978-1-4419-1153-7.
[18] HWJ Rittel, MM Webber, Dilemmas in a General Theory of Planning*, Policy Sci 4 (1973) 155–169, doi:10.1007/BF01405730.
[19] A Wilkinson, R Kupers, D Mangalagiu, How plausibility-based scenario practices are grappling with complexity to appreciate and address 21st century challenges, Technol. Forecast Soc. Change 80 (2013) 699–710, doi:10.1016/j.techfore.2012.10.031.
[20] CM Smith, D Shaw, The characteristics of problem structuring methods: a literature review, Eur. J. Oper. Res. 274 (2019) 403–416, doi:10.1016/j.ejor.2018.05.003.
[21] E Bonabeau, Agent-based modeling: methods and techniques for simulating human systems, Proc. Natl. Acad. Sci. 99 (2002) 7280–7287.
[22] A Sheth, JV Sinfield, Simulating Self-Organization during Strategic Change: Implications for Organizational Design. In: ACM SIGCHI - Collective Intelligence, 2019. Pittsburgh: ArXiV, 2019. Retrieved from https://arxiv.org/pdf/2007.08521.pdf.
[23] R Gallagher, T Appenzeller, Beyond reductionism, Science 284 (80) (1999) 79 79, doi:10.1126/science.284.5411.79.
[24] WE Walker, RJ Lempert, JH Kwakkel, Deep uncertainty: uncertainty in model-based decision support, Encycl. Oper. Res. Manag. Sci. 1 (2013) 395–402.
[25] JH Kwakkel, WE Walker, M Haasnoot, Coping with the wickedness of public policy problems: approaches for decision making under deep uncertainty, J. Water Resour. Plan Manag 142 (2016) 01816001, doi:10.1061/(ASCE)WR.1943-5452.0000626.
[26] BW Dunn, Problem Structuring in Public Policy Analysis. Available at: http://www.ippapublicpolicy.org/file/paper/5aeff35b03d17.pdf. (Accessed on 14 September 2018).
[27] F Glock, Design tools and framing practices, Comput. Support Coop. Work CSCW Int. J. 12 (2003) 221–239, doi:10.1023/A:1023984313005.
[28] T Kvan, S Gao, A comparative study of problem framing in multiple settings, Des. Comput. Cogn. (2006) 245–263 06.
[29] V Burr, P Dick, Social Constructionism, Palgrave Macmillan, 2017, doi:10.1057/978-1-137-51018-1_4.
[30] J Rosenhead, J Mingers, A new paradigm of analysis., in: Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty and Conflict, 2nd Edition, Wiley, Chichester, 2001, p. 386.
[31] R Giordano, I Pluchinotta, D Zikos, T Krueger, A Tsoukiàs, L White, et al., Behavioral Operational Research, Springer International Publishing, 2020, doi:10.1007/978-3-030-25405-6.
[32] C Sanderson, R Gruen, Analytical Models for Decision Making. Birkshire UK, Open University Press, 2006.
[33] H Auvinen, S Ruutu, A Tuominen, T Ahlqvist, J Oksanen, Process supporting strategic decision-making in systemic transitions, Technol. Forecast Soc. Change 94 (2015) 97–114, doi:10.1016/j.techfore.2014.07.011.
[34] EH Forman, SI Gass, The analytic hierarchy process - An exposition, Oper. Res. 49 (2001) 469–486, doi:10.1287/opre.49.4.469.11231.
[35] A McLucas, Improving causal mapping practice using the System Dynamics 'Front-End'Tool, in: Proceedings of the International Conference of the System Dynamics Society, 2002 Published Online First:.
[36] A Ishizaka, A Labib, Analytic hierarchy process and expert choice: benefits and limitations, OR Insight 22 (2009) 201–220, doi:10.1057/ori.2009.10.
[37] ST Liu, Clemen RT.Making Hard Decisions, an introduction to decision analysis, Technometrics 34 (1992) 365, doi:10.2307/1270059.
[38] R Giordano, M Brugnach, I Pluchinotta, Ambiguity in problem framing as a barrier to collective actions: some hints from groundwater protection policy in the Apulia region, Gr. Decis. Negot. 26 (2017) 911–932, doi:10.1007/s10726-016-9519-1.
[39] Pontius J, McIntosh A. Critical skills for environmental professionals, 2020. 10.1007/978-3-030-28542-5
[40] A Tversky, D Kahneman, Judgment under Uncertainty: Heuristics and Biases, Science 185 (80) (1974) 1124–1131, doi:10.1126/science.185.4157.1124.
[41] SM Kassin, IE Dror, J Kukucka, The forensic confirmation bias: problems, perspectives, and proposed solutions, J. Appl. Res. Mem. Cogn. 2 (2013) 42–52, doi:10.1016/j.jarmac.2013.01.001.
[42] JF Sowa, Knowledge representation: logical, philosophical and computational foundations, 1st ed., Brooks/Cole Publishing Co, 1999.
[43] J Euchner, Problem Framing, Res. Technol. Manag. 62 (2019) 11–13, doi:10.1080/08956308.2019.1563433.
[44] IE Dror, J Kukucka, SM Kassin, PA Zapf, When expert decision making goes wrong: concensus, bias, the role of experts, and accuracy, J. Appl. Res. 7 (2018) 162–163.
[45] AM Maier, M Kleinsmann, Studying and supporting design communication, Artif. Intell. Eng. Des. Anal. Manuf. 27 (2013) 87–90, doi:10.1017/S0890060413000139.
[46] RE Glasgow, C Vinson, D Chambers, MJ Khoury, RM Kaplan, C Hunter, National Institutes of Health approaches to dissemination and implementation science: current and future directions, Am. J. Public Health 102 (2012) 1274–1281, doi:10.2105/AJPH.2012.300755.
[47] G Bennett, N Jessani (Eds.), The knowledge translation toolkit. Bridging the know-do gap: A resource for researchers, International Development Research Center, Ottawa, 2011.
[48] Entman RM Framing, Toward Clarification of a Fractured Paradigm, J. Commun. 43 (1993) 51–58, doi:10.1111/j.1460-2466.1993.tb01304.x.
[49] S Chancellor, S Counts, Measuring employment demand using internet search data., in: Proceedings of the Conference on Human Factors in Computing Systems - Proceedings, New York, New York, USA, Association for Computing Machinery, 2018, pp. 1–14, doi:10.1145/3173574.3173696.
[50] EO Nsoesie, B Rader, YL Barnoon, L Goodwin, J Brownstein, Analysis of hospital traffic and search engine data in Wuhan China indicates early disease activity in the Fall of 2019, (2020), http://nrs.harvard.edu/urn-3:HUL.InstRepos:42669767.
[51] Geels FW Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective, Res. Policy 39 (2010) 495–510, doi:10.1016/j.respol.2010.01.022.
[52] Fensel D Ontologies, in: Ontologies, Springer Berlin Heidelberg, Berlin, Heidelberg, 2001, pp. 11–18, doi:10.1007/978-3-662-04396-7_2.
[53] TR Gruber, Toward principles for the design of ontologies used for knowledge sharing, Int. J. Hum. - Comput. Stud. 43 (1995) 907–928, doi:10.1006/ijhc.1995.1081.
[54] JV Sinfield, F Solis, Finding a lower-risk path to high-impact innovationsAM3, MIT Sloan Manag. Rev. 57 (4) (2016). http://mitsmr.com/1S2UAM3.
[55] V Sinfield J, F Solis, Thinking big to address major challenges: design and problem-solving patterns for high-impact innovation, Natl. Acad. Eng. Bridg. 46 (2016) 11–18.
[56] F Solis, V Sinfield J, Rethinking innovation: characterizing dimensions of impact, J. Eng. Entrep. 6 (2015) 83–96.
[57] V Goel, P Pirolli, The structure of design problem spaces, Cogn. Sci. 16 (1992) 395–429, doi:10.1207/s15516709cog1603_3.
[58] N Cross, Designerly ways of knowing: design discipline versus design science, Des. Issues 17 (2001) 49–55, doi:10.1162/074793601750357196.
[59] EM Rogers, Diffusion of Innovations, 1st ed, Simon and Schuster, 1962.
[60] TF Bresnahan, M Trajtenberg, General purpose technologies 'Engines of growth'? J. Econometrics. 65 (1) (1995) 83–108.
[61] JP Wisdom, KHB Chor, KE Hoagwood, SM Horwitz, Innovation adoption: a review of theories and constructs, Adm. Policy Ment. Health Ment. Health Serv. Res. 41 (2014) 480–502, doi:10.1007/s10488-013-0486-4.
[62] FG Solis, V Sinfield J, Designing for big X: Characterizing design for major challenges, Int. J. Eng. Educ. 34 (2018) 801–823.
[63] D Norman, P Stappers, DesignX: complex sociotechnical systems, J. Des. Econ. Innov. 1 (2016) 83–106.
[64] C Kruger, N Cross, Solution driven versus problem driven design: strategies and outcomes, Des. Stud. 27 (2006) 527–548.
[65] S Anthony, M Johnson, J Sinfield, E Altman, The innovator's guide to growth: Putting disruptive innovation to work, 1st ed., Harvard Business Press, Cambridge, 2008.
[66] A Colicev, A Kumar, P O'Connor, Modeling the relationship between firm and user generated content and the stages of the marketing funnel, Int. J. Res. Mark. 36 (2019) 100–116, doi:10.1016/j.ijresmar.2018.09.005.
[67] USAID, Service UF.Field Operations Guide For Disaster Assessment and Response, 4th ed, USAID, 2005.

[68] J Antonakis, GC Banks, N Bastardoz, MS Cole, DV Day, AH Eagly, et al., State of the journal, Leadersh Q 30 (1) (2019) 1–9, doi:10.1016/j.leaqua.2019.01.001.
[69] RS Russell, BW Taylor, Operations Management: Creating Value Along the Supply Chain, 4th ed., Jersey:PrenticeHall, New, 2011.
[70] JB Barney, Firm resources and sustained competitive advantage, Econ. Meets Sociol. Strateg. Manag. (Adv. Strat. Manag.) 17 (2000) 203–227, doi:10.1016/S0742-3322(00)17018-4.
[71] JJD Sachs, The End of Poverty: Economic Possibilities for our Time, Penguin, 2006.
[72] J Liu, TW Tong, JV Sinfield, Toward a resilient complex adaptive system view of business models, Long Range Planning (2020) 102030, doi:10.1016/j.lrp.2020.102030.
[73] RR Speer, J Lowry-Duda, ConceptNet at SemEval-2017 Task 2: Extending Word Embeddings with Multilingual Relational Knowledge. arXiv preprint arXiv:1704.03560 (2017). doi: 10.18653/v1/S17-2008.
[74] KT Sibhatu, M Qaim, Rural food security, subsistence agriculture, and seasonality, PLoS One (2017) 12, doi:10.1371/journal.pone.0186406.
[75] H Eakin, S Sweeney, AM Lerner, K Appendini, H Perales, DG Steigerwald, et al., Agricultural change and resilience: agricultural policy, climate trends and market integration in the Mexican maize system, Anthropocene 23 (2018) 43–52, doi:10.1016/j.ancene.2018.08.002.
[76] A Spring, Women farmers and commercial ventures: Increasing food security in developing countries, 1st ed., Lynne Rienner Publishers, Colorado, 2000.
[77] PK Thornton, PW Wilkens, Risk assessment and food security, in: Understanding Options for Agricultural, Springer, 1998, pp. 329–345, doi:10.1007/978-94-017-3624-4_16.
[78] B Mahmoud, Guidelines for developing countries to modernize their food safety systems, Food Saf. Mag. (2019). https://www.foodsafetymagazine.com/enewsletter/guidelines-for-developing-countries-to-modernize-their-food-safety-systems/, [accessed 26 August 2020].
[79] FN Uchendu, TO Abolarin, Corrupt practices negatively influenced food security and live expectancy in developing countries, Pan. Afr. Med. J. 20 (2015) 110, doi:10.11604/pamj.2015.20.110.5311.
[80] T Brück, M d'Errico, Food security and violent conflict: Introduction to the special issue, World Dev. 117 (2019) 167–171, doi:10.1016/j.worlddev.2019.01.007.
[81] a abdulai, c kuhlgatz, food security policy in developing countries., The Oxford Handbook of the Economics of Food Consumption and Policy, 2012, doi:10.1093/oxfordhb/9780199569441.013.0014.
[82] AM Thow, S Greenberg, M Hara, S Friel, A duToit, D Sanders, Improving policy coherence for food security and nutrition in South Africa: a qualitative policy analysis, Food Secur. 10 (2018) 1105–1130, doi:10.1007/s12571-018-0813-4.
[83] E Raidimi, H Kabiti, Agricultural extension, research, and development for increased food security: the need for public-private sector partnerships in South Africa, South African J Agric Ext 45 (2017) 49–63, doi:10.17159/2413-3221/2017/v45n1a414.
[84] J Wegener, KD Raine, RM Hanning, Insights into the government's role in food system policy making: improving access to healthy, local food alongside other priorities, OPEN ACCESS Int. J. Environ. Res. Public Health 9 (2012) 9, doi:10.3390/ijerph9114103.
[85] KA Stave, B Kopainsky, A system dynamics approach for examining mechanisms and pathways of food supply vulnerability, J. Environ. Stud. Sci. 5 (2015) 321–336, doi:10.1007/s13412-015-0289-x.
[86] G Breeman, J Dijkman, C Termeer, Enhancing food security through a multi-stakeholder process: the global agenda for sustainable livestock, Food Secur. 7 (2015) 425–435, doi:10.1007/s12571-015-0430-4.
[87] AS Saint Ville, GM Hickey, LE Phillip, How do stakeholder interactions influence national food security policy in the Caribbean? The case of Saint Lucia, Food Policy 68 (2017) 53–64, doi:10.1016/j.foodpol.2017.01.002.
[88] JD Bloom, CC Hinrichs, Moving local food through conventional food system infrastructure: value chain framework comparisons and insights, Renew. Agric. Food Syst. 26 (2011) 13–23, doi:10.1017/S1742170510000384.
[89] A Fearne, M Garcia Martinez, B Dent, Dimensions of sustainable value chains: Implications for value chain analysis, Supply Chain Manag. Int. J. 17 (2012) 575–581, doi:10.1108/13598541211269193.
[90] V Salin, RM Nayga, A cold chain network for food exports to developing countries, Int. J. Phys. Distrib. Logist. Manag. 33 (2003) 918–933, doi:10.1108/09600030310508717.
[91] M Bazilian, H Rogner, M Howells, S Hermann, D Arent, D Gielen, et al., Considering the energy, water and food nexus: towards an integrated modelling approach, Energy Policy 39 (2011) 7896–7906, doi:10.1016/j.enpol.2011.09.039.
[92] Value chains and the development path, in: Aid for Trade At a Glance 2013 Connecting to Value Chains, OECD, WTO, 2013, pp. 89–118, doi:10.1787/aid_glance-2013-7-en.
[93] Huddleston B, Johnson D, Reutlinger S, Valdes A. International finance for food security, 1982.
[94] A Valdes (Ed.), Food security for developing countries, Westview Press, New York, 1981.
[95] T Reardon, L Lu, D Zilberman, Links among innovation, food system transformation, and technology adoption, with implications for food policy: Overview of a special issue, Food Policy 83 (2019) 285–288, doi:10.1016/j.foodpol.2017.10.003.
[96] J Leslie, R Bandyopadhyay, A Visconti, Mycotoxins detection methods, management, public health and agricultural trade, Public Health Agric. Trade. (2008). https://books.google.com/books?hl=en&lr=&id=15uD7bddmCAC&oi=fnd&pg=PR5&dq=Mycotoxins+detection+methods,+management&ots=1m4ee1dFLU&sig=MreaGb0btVXVQCFS0QvLz94SjeM#v=onepage&q=Mycotoxins%20detection%20methods%2C%20management&f=false.
[97] L Kitinoja, Use of cold chains for reducing food losses in developing countries. Population 6(1.23) (2013) 5–60.
[98] BA Alimi, TS Workneh, Consumer awareness and willingness to pay for safety of street foods in developing countries: a review, Int. J. Consum. Stud. 40 (2016) 242–248, doi:10.1111/ijcs.12248.
[99] KA Brown, L Timotijevic, J Barnett, R Shepherd, L Lähteenmäki, MM Raats, A review of consumer awareness, understanding and use of food-based dietary guidelines, cambridge.org (2018) Published Online First:, doi:10.1017/S0007114511000250.
[100] RM Welch, RD Graham, A new paradigm for world agriculture: Productive, sustainable, nutritious, healthful food systems, Food Nutr. Bull. 21 (2000) 361–366, doi:10.1177/156482650002100404.
[101] N Scialabba, Factors influencing organic agriculture policies with a focus on developing countries., in: Proceedings of the IFOAM 2000 Scientific Conference, Basel, Switzerland, 2000, pp. 28–31.
[102] G Lee, A Suzuki, VH Nam, Effect of network-based targeting on the diffusion of good aquaculture practices among shrimp producers in Vietnam, World Dev. (2019) 124, doi:10.1016/j.worlddev.2019.104641.
[103] JF Carriger, BE Dyson, WH Benson, Representing causal knowledge in environmental policy interventions: advantages and opportunities for qualitative influence diagram applications, Integr. Environ. Assess. Manag. 14 (2018) 381–394, doi:10.1002/ieam.2027.
[104] Chakrabarti S, (0304-0941) RB-D Undefined. purchase motivations and attitudes of organic food buyers, 2007.
[105] JA Mello, KM Gans, PM Risica, U Kirtania, LO Strolla, L Fournier, How is food insecurity associated with dietary behaviors? An analysis with low-income, ethnically diverse participants in a nutrition intervention study, J. Am. Diet. Assoc. 110 (2010) 1906–1911, doi:10.1016/j.jada.2010.09.011.
[106] H Bjornlund, A van Rooyen, R Stirzaker, Profitability and productivity barriers and opportunities in small-scale irrigation schemes, Int. J. Water Resour. Dev. 33 (2017) 690–704, doi:10.1080/07900627.2016.1263552.
[107] A Mwaniki, Achieving Food Security in Africa: Challenges and Issues, Cornell University, New York, 2006 http://www.wageningenportals.nl/sites/default/files/resource/achieving_food_security_in_africa.pdf (Accessed date: 26 August 2020).
[108] M Rutten, L Shutes, G Meijerink, Sit down at the ball game: How trade barriers make the world less food secure, Food Policy 38 (2013) 1–10, doi:10.1016/j.foodpol.2012.09.002.
[109] EB Alonso, L Cockx, J Swinnen, Culture and food security, Glob. Food Sec. 17 (2018) 113–127, doi:10.1016/j.gfs.2018.02.002.
[110] TD Beuchelt, L Badstue, Gender, nutrition- and climate-smart food production: opportunities and trade-offs, Food Secur. 5 (2013) 709–721, doi:10.1007/s12571-013-0290-8.
[111] M Zeller, A Diagne, C Mataya, Market access by smallholder farmers in Malawi: Implications for technology adoption, agricultural productivity and crop income, Agric. Econ. 19 (1998) 219–229, doi:10.1016/S0169-5150(98)00027-9.
[112] VJ Quinn, E Kennedy, Food security and nutrition monitoring systems in Africa. A review of country experiences and lessons learned, Food Policy 19 (1994) 234–254, doi:10.1016/0306-9192(94)90073-6.
[113] E Birol, V Meenakshi J, A Oparinde, S Perez, K Tomlins, Developing country consumers' acceptance of biofortified foods: a synthesis, Food Secur. 7 (2015) 555–568, doi:10.1007/s12571-015-0464-7.
[114] D Umali-Deininger, M Sur, Food safety in a globalizing world: opportunities and challenges for India, Agric. Econ. 37 (2007) 135–147, doi:10.1111/j.1574-0862.2007.00240.x.
[115] V Bini, Food security and food sovereignty in West Africa, African Geogr. Rev. 37 (2018) 1–13, doi:10.1080/19376812.2016.1140586.
[116] Y Zhu, International trade and food security: conceptual discussion, WTO and the case of China, China Agric. Econ. Rev. 8 (2016) 399–411, doi:10.1108/CAER-09-2015-0127.
[117] A Chaudhary, D Gustafson, A Mathys, Multi-indicator sustainability assessment of global food systems, Nat. Commun. (2018) 9, doi:10.1038/s41467-018-03308-7.
[118] COR Okpala, Toward sustaining global food systems for the future, Front Sustain. Food Syst. (2020) 4, doi:10.3389/fsufs.2020.00003.
[119] GS Garrett, CL Luthringer, EA Yetley, LM Neufeld, Food Fortification Policy, in: Encyclopedia of Food Security and Sustainability, Elsevier, 2018, pp. 336–343, doi:10.1016/B978-0-08-100596-5.22068-4.
[120] D Gashu, MW Demment, BJ Stoecker, Borlaug LEAP Paper Challenges and opportunities to the African agriculture and food systems, Afr. J. Food Agric. Nutr. Dev. 19 (2019) 14190–14217, doi:10.18697/ajfand.84.BLFB2000.
[121] COR Okpala, Toward Sustaining Global Food Systems for the Future, Front Sustain. Food Syst. 4 (2020) 3, doi:10.3389/fsufs.2020.00003.
[122] MF Ramadan, Underutilized plant species and agricultural sustainability in Egypt., in: Handbook of Environmental Chemistry, Springer Verlag, 2019, pp. 189–212, doi:10.1007/698_2017_195.
[123] M Koniordos, G Matvienko-Bilyaeva, S Strapchuk, Strategic scenario of an open source of sustainable development for the food system, Econ. Ann. 165 (2017) 56–59, doi:10.21003/ea.V165-12.
[124] RW Cotterill, The food distribution system of the future: convergence towards the US or UK model? Agribusiness 13 (1997) 123–135, doi:10.1002/(SICI)1520-6297(199703/04)13:2<123::AID-AGR3>3.0.CO;2-4.
[125] A Hoflund, J Jones, M Pautz (Eds.), The intersection of food and public health: current policy challenges and solutions, Routledge, New York, 2018. https://books.google.com/books?hl=en&lr=&id=nmE1DwAAQBAJ&oi=fnd&pg=PT16&dq=The+intersection+of+food+and+public+health:+

current + policy + challenges + and + solutions&ots=hWAaQkviBy&sig=WsK5UfRCoUvHw-kHObytGK_dn2g#v=onepage&q=The%20intersection%20of%20food%20and%20public%20health%3A%20current%20policy%20challenges%20and%20solutions&f=false, [accessed 26 August 2020].
[126] AL Savage, GW Auld, Development and evaluation of educational materials promoting local Colorado foods, J. Nutr. Educ. Behav. 38 (2006) 61–62, doi:10.1016/j.jneb.2005.11.015.
[127] F Cappa, F Rosso, L Giustiniano, M Porfiri, Nudging and citizen science: the effectiveness of feedback in energy-demand management, J. Environ. Manag. (2020) 269, doi:10.1016/j.jenvman.2020.110759.
[128] P Teng, A Darvin, Food Reserves: a Comparative Study on Food Reserve Management and Policies in Southeast Asia, Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), 2019.
[129] V Armendariz, S Armenia, AS Atzori, A Romano, V Armendàriz, S Armenia, et al., Analyzing food supply and distribution Systems using complex systems methodologies., in: Proceedings in Food System Dynamics, 36–58, 2015, doi:10.18461/pfsd.2015.1504.
[130] M van Dijk, G Meijerink, A review of global food security scenario and assessment studies: Results, gaps and research priorities, Glob. Food Secur. 3 (2014) 227–238.
[131] J Sobal, LK Khan, C Bisogni, A conceptual model of the food and nutrition system, Soc. Sci. Med. 47 (1998) 853–863, doi:10.1016/S0277-9536(98)00104-X.
[132] Sinfield J V, Kotian RR, Busse MM. Application of comprehensive issue analysis to inform development research in East Africa, Part 1: Basic Education (BE), Maternal/Child Healthcare (MCH). LASER PULSE R4D Innovative Science Frameworks Tools Technical Report Series Innovative Leadership Students Program, Purdue University West Lafayette. 2019.