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Exploring the Challenges to Sustainable Development from the Perspective of Grey Systems Theory

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Abstract: Today's challenges to sustainability are explored through a complex combination of interdisciplinary topics that explore various interactions between economic, social, and environmental systems that further contribute to existing uncertainties. Solving complex/dynamic sustainability constraints does not demand exclusively technical and practical methods, as it is equally important to have a profound conceptual understanding of the origins of such challenges. The purpose of this study was to investigate the challenges to the sustainable development process from the perspective of the philosophy of grey systems theory (GST). GST considers inherent defects and shortcomings in human understanding/knowledge and identifies the roots of uncertainty. The study concentrates on the sustainable development process, highlighting the ways in which GST explains the causes and sources of uncertainty in this process. It is emphasized that sustainability cannot be achieved without intentional human intervention, and that international collaboration is vital in solving sustainability problems. Uncertainty and challenges to sustainable development stem from human grey understanding and knowledge. This problem makes it difficult for humans to understand and model dynamicity, to strike a balance between different spheres of science, and to have an objective view of reality due to the dependence of knowledge on thinking paradigms and values. These shortcomings ultimately bring about value conflicts, different understandings of risks, and impediments to international collaboration and agreement. Finally, the study explains that uncertainty arises from incomplete understanding and grey knowledge, and that uncertainty undermines the prediction of outcomes. Furthermore, delays inherent in interactions and the impacts of diverse systems on the world increase uncertainty and complicate decision- and policymaking in improvement projects. In their efforts to implement their decisions and policies, humans also encounter various limitations in terms of their capacities, resources, and facilities. The application of GST-based approaches to the operational area is also discussed.

Keywords: sustainable development; sustainability; philosophy of sustainability; uncertainty; grey systems theory; grey information; sustainability policies

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1. Introduction

Without a doubt, extensive development in human societies has led to a challenging and complex situation in today's world. The past centuries have witnessed vast energy production, economic growth, increased life expectancy, and higher literacy rates [1]. These achievements, however, have brought about many obstacles to sustainability. Increasing globalization has also given rise to sustainability-related crises beyond conventional geographical borders. Sustainability is a result of increasing international awareness of environmental, social, and economic issues, as well as problems such as poverty, inequality, and the life situation of future generations [2].

Sustainability strongly consolidates environmental, social, and economic topics. Studies addressing this area seek to correct the problematic and one-dimensional development trajectory that has been followed over the past centuries. As a result, present and future

generations can live on Earth with higher levels of life satisfaction and prosperity. International organizations have highlighted many concerns to be addressed, although nations do not show the necessary motivation to practice and pursue policies through international collaboration. In fact, worldwide, countries do not seem to share similar concerns. Meanwhile, although people generally agree that sustainable societies provide benefits for all, different institutions have different understandings of the concept of sustainability and the ways in which it should be achieved [3].

Sustainability and sustainable development are concepts that are used interchangeably in many cases today, although they have different meanings. Since this article may sometimes talk about sustainability and sustainable development, it is necessary to point out the difference between these concepts. Sustainable development involves the engagement of the world's educational systems to work for a more sustainable future. We can say briefly that sustainability is thought of as a long-term goal, whereas sustainable development refers to the many processes and pathways necessary to achieve sustainability. In other words, sustainable development is a process to achieve sustainability as the final goal [4].

However, a large number of challenges to sustainability seem to stem from the structure of human knowledge and its inability to perfectly analyze the world's dynamicity and complexity [2]. Sustainability is a concept that is governed by the systems perspective. Clearly, systems that include numerous elements regulated by complex relationships involve a high degree of uncertainty. Explaining, understanding, and improving sustainability goals demands a flexible process of analyzing dynamicity, complexity, and uncertainty. Such a process must rest on interactions between social, economic, and environmental systems. For this reason, approaches to dynamic analytics and uncertainty have come to the fore among sustainability analysis experts [5].

One of the approaches to have recently emerged to the analysis of uncertainty is called grey system theory (GST). This nascent theory, which was proposed only about four decades ago, is an essential approach that can help to solve today's complexities and problems arising from multifaceted issues of uncertainty in systems. After it was introduced, GST was quickly adopted as a method for understanding, modeling, and integrating uncertainty in complex systems analytics, especially for cases in which there is a small set of recorded data [6]. Such efforts have brought about helpful practices, as well as major social, economic, and environmental benefits. Along with the applications of GST to the analysis and solution of uncertainty problems, the philosophical foundations of the theory can also further clarify uncertainty, causality, and cause–effect processes [7]. The philosophy behind GST posits that due to the inherent human inability to completely obtain and understand all information in a system, uncertainty is an indispensable part of the human knowledge of systems [8].

With its emphasis on inherent shortcomings in the process of understanding and on the uncertainty of human knowledge, GST can conceptually help researchers to understand the challenges to sustainable development. Plausibly, understanding and solving sustainability issues does not exclusively demand practical methods. Before any problem can be scientifically solved, a conceptual understanding of the problem's structure can contribute considerably to problem-solving operations [9]. The complex and dynamic character of the world should also be viewed from conceptual and philosophical angles. Providing a clear understanding of the challenges to sustainability and their origins can remarkably enhance the efficiency of programs, policies, and operations regarding sustainability. Therefore, sustainable development demands both conceptual and practical approaches that can not only explain and solve challenges to sustainability but can also clearly link foundational concepts to practical ones. Without a doubt, practical methods cannot generate the results we desire without offering lucid conceptual and foundational approaches [10].

The main purpose of this study is to explore the challenges to sustainable development and to provide a conceptually comprehensive description of such challenges at various sustainable development stages. In doing so, the study relies on the philosophical foundations of GST, especially in terms of uncertain, grey information and knowledge and its

defects. A development process that strives to be sustainable has to analyze the current state, define the ideal state, analyze potential risks and deviations, and finally, formulate improvement scenarios. As such, a set of actions should be taken to maintain the path to sustainable development as an ultimate desired goal or value. This study focuses on the sustainable development process as its basic issue, exploring challenges to sustainability through the principles of GST (e.g., human grey knowledge).

The questions and issues specifically addressed in this study are as follows: What are the challenges that grey and incomplete understanding could cause in relation to sustainable development? How does human grey knowledge complicate the identification and definition of sustainability-related values, desirables, and preferences? Why do individuals and communities react differently to sustainability concerns? Is it possible to have a sustainable world without human intervention? What are the human operational limitations that can negatively affect sustainable development?

The remainder of this study is organized as follows: Section 2 explicates the foundations of sustainable development and the notion of sustainability. Section 3 addresses GST definitions, principles, and theoretical bases. Section 4 explicates the challenges to sustainable development from the perspective of GST. Section 5 discusses the challenges identified and describes how GST-based methods can help solve these sustainability challenges in practice. Section 6 reports the concluding remarks.

2. The Foundations of Sustainable Development and Sustainability

2.1. Sustainable Development

Terminologically speaking, "development" refers to a gradual process of change that results in a different status of quality. Conceptually speaking, development denotes a desired status or goal (an ideal state), the path leading to it (change), and efforts to improve it (activities) [11]. An ideal state is that which human beings try to achieve. As such, development rests on three foundational elements: an ideal state/goal, change, and action.

The development process involves five components. The first component includes a set of variables that human beings value and try to protect, improve, and change. That is, to implement development, human beings should first recognize the objects, conditions, or variables that they value. The first component, then, focuses on the identification of values and desirables [2]. The second component involves a descriptive proposition about the current state of the set of variables in question. This component is concerned with specifying the current state. The third component includes a prescriptive proposition about the *ideal* state of the set of variables. This aspect describes the ideal conditions or the desired goal. The fourth component maps out an expected scenario of change over time. If the current state is incompatible with people's dreams, ideal goals, or desired outcomes, people usually try to introduce changes to the situation. The fourth component describes how the ideal state can be achieved [12]. This component addresses the process of identifying the discrepancies between the current state and the ideal one, focusing on decisions, policies, and changes that could lead to the ideal state. The fifth component encompasses a set of purposeful activities that direct the changes. This component involves human efforts, activities, and practical measures that result in the ideal state [13].

Development includes intentional and intelligent activities that move the current state toward the ideal state. When the goal is to achieve sustainable development, it is important to maintain development in the long run. Sustainable development is a mode of development that should be pursued over time in such a way that negative events/processes do not disturb or halt its progression [14]. Temporary development is not a human ideal. As such, one can argue that sustainable development denotes a process of constant change in quality over time. Sustainable development requires well-informed decision making and intentional measures to reduce any risk that could potentially distance us from the world we wish to have, either in the present or in the future. In its "Our Common Future" report, the World Commission on Environment and Development (the Brundtland Commission) defines sustainable development as a mode of development

that meets existing needs without endangering the ability of future generations to meet their needs [15].

Figure 1 illustrates a summarized version of the process of development and its components. In this process, humans analyze the current state of their set of values and its ideal status, using their knowledge and understanding of the world. Based on the current state, humans can envisage a probable future or forecast future trends in relation to their values or ideals. A probable or potential future shows the outcomes of existing trends. The variance between the potential future and the ideal future can be called "risk", and the understanding of such a risk can be called "risk perception". Risk involves a degree of uncertainty in relation to the outcomes or consequences of activities associated with that which people value (e.g., heath, welfare, wealth, assets, the environment) [16]. As a key notion in sustainable development, risk represents uncertainty in the development process. Risk perception motivates people to search for solutions that reduce the variance between a potential future and an ideal future. Adopting the best solution and implementing it constitute the last stage of the development process [17]. Every sustainable development stage can involve challenges, as explicated in the following sections.

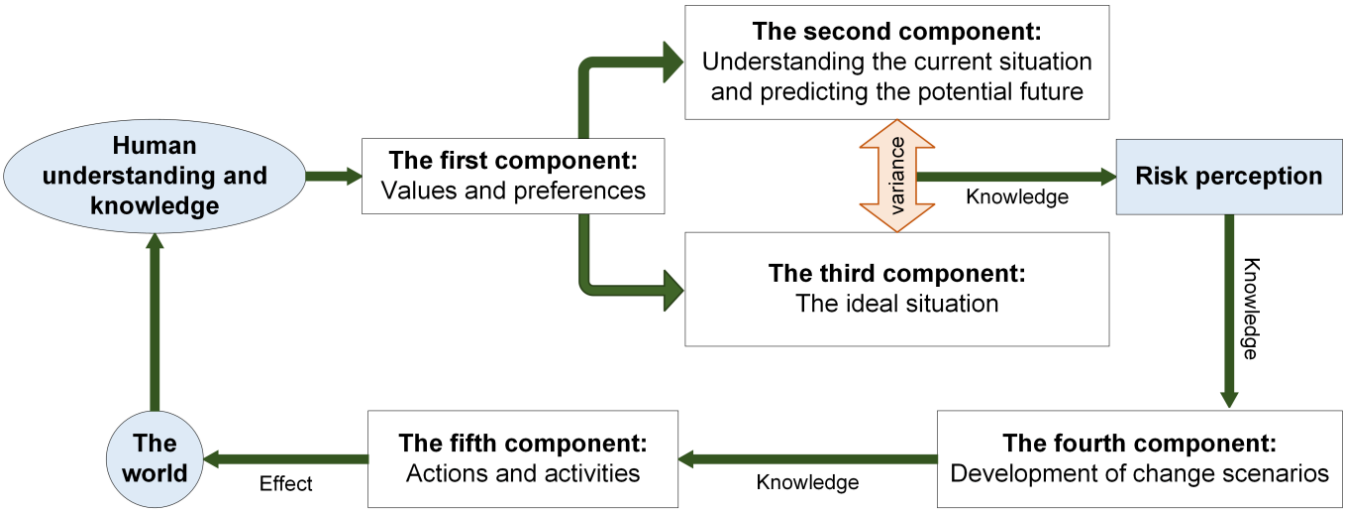

Figure 1. The development process and its components.

2.2. Sustainability

Sustainability could be defined as the protection of that which human beings value in the present or will value in the future [9]. In the twenty-first century, this concept generally refers to the capacity of life on Earth and in human civilizations. In other words, sustainability is the ability to endure and maintain a stable level of wellbeing in different aspects of life over time. Along with homeostasis, sustainability also denotes the process of maintaining change in a stable environment in which resource exploitation, investment directions, technological orientations, and institutional changes are all coordinated and reinforce the present and future potential for meeting human needs. Sustainability, as an economic, social, and environmental process, addresses human values and preferences and seeks to build an ideal world [18].

Sustainability involves decision making and responsible innovation that would minimize negative impacts and strike a balance between ecological resilience, economic welfare, political justice, and cultural vitality. As such, Earth would be an ideal planet for all species in the present and in the future. Sustainability is a futuristic notion, as it emphasizes the future [2]. Sustainability and sustainable development, of course, are different in terms of their goals and their ways of achieving such goals. In short, sustainability is a long-term goal, whereas sustainable development addresses the processes and ways of realizing sustainability. The purpose of sustainable development is to achieve ideal conditions and the desired goal of sustainability in the future and to maintain it over time [14].

Sustainability is accomplished through three interconnected areas (pillars): the environment, economy, and society. Similarly, sustainable development includes such sub-areas as culture, technology, and politics. These pillars are interconnected, and none of them can exist without the other. As such, the notion of sustainable development can be regarded as a holistic concept regulated by systems thinking. This concept involves the coordination and integration of various activities in the sub-systems of the world, including economic, social, political, and ecological systems. Various systems are plausibly interconnected, because human beings do not exist in a vacuum [19].

Humans are part of nature, and human communities are part of the natural environment. Any change in nature will inevitably impact human communities and various dimensions of human life, such as the economy, politics, and culture. The economy and many industries directly depend on nature. A classic example in this regard is the question raised by environmental economist Herman Daly: "What good is a sawmill without a forest?" [20]. From this perspective, the economy is a sub-system of human society, which is itself a sub-system existing on Earth. Obviously, Daly's idea suggests that extracting something from one area could damage another area.

3. Definitions, Principles, and Foundations of Grey Systems Theory

This section explores the basic concepts and theoretical foundations of uncertainty and GST, along with providing the definitions of some terms related to these concepts as used in this study. Of course, this study does not seek to substantially address human understanding of the world. Previous research has specifically and fundamentally focused on the process of human perception and knowledge generation. For this reason, this study only reports the findings of other investigations, but we address these concepts in relation to sustainable development.

3.1. Uncertainty

Uncertainty points to an epistemic imbalance caused by incomplete or unknown information. Uncertainty may be associated with future events, preexisting physical measurements, or anything unknown. Uncertainty arises from partially observable environments or random environments and is caused by indolence, a lack of knowledge, or both. In its simplest configuration, uncertainty is often associated with a shortage of information or with situations in which the correct response to a problem is unknown [21]. The main specification of uncertain systems lies in the incompleteness and inadequacy of their information. Sources of uncertainty are either subjective or objective [22].

Objective uncertainty is independent of human subjectivity and is caused by objects/entities themselves. For instance, next winter's total precipitation is an unknown variable, and this "unknown" quality is not related to human subjectivity or statements [23]. As such, objective uncertainty is about objects *per se*. This mode of uncertainty can be further divided into epistemological uncertainty and ontological uncertainty [24]. The former arises from a gap in knowledge, whereas the latter emerges from the stochastic properties of a specific condition that usually involves complex technical, biological, or social systems. In contrast to objective uncertainty, there is subjective uncertainty, which results from human interpretations. This type of uncertainty would continue to exit even if, under ideal and basically impossible circumstances, we had complete knowledge of the world. Subjective uncertainty suggests that even if an object in question is assumed to be definite and certain, our subjective interpretations of it would still remain uncertain [25]. Moral uncertainty and rule uncertainty are types of subjective uncertainty. Moral uncertainty (or normative uncertainty) is concerned with human action despite the diversity of ethical and moral teachings [26]. Rule uncertainty addresses the indeterminacy of ethical rules [27]. Subjective uncertainty in sustainable development can lead to relativism and a pluralism of opinions, ideas, values, and preferences. Greyness, which is substantially explored in the next section, results from incomplete information about objects, although in some cases, the models used in GST incorporate objective uncertainty and subjective uncertainty [7].

3.2. Philosophical Foundations of GST and Greyness

GST was first proposed by Chinese scientist Julong Deng in 1982 as an approach to the uncertainty that governs systems using a model for small-scale and incomplete data [6]. From the perspective of this theory, because human beings are inherently incapable of possessing a thorough understanding of and access to all information in a system, uncertainty remains an indispensable aspect of the human knowledge of systems. When it was first proposed, GST viewed "greyness" as the quality of information that is partially known and partially unknown. Afterwards, "grey" was used as an adjective modifying other terms and in novel created ideas such as "grey information", "grey knowledge", etc. in the literature on this topic [7].

In a simple, clear, and basic definition, "grey" as an adjective is synonymous with "incomplete", "inadequate", "multifaceted", and "changeable". As such, "greyness" in this theory means "incomplete", "inadequacy", and "changeability". More specifically, "greyness" in GST literally refers to uncertainty arising from partial, incomplete, and inadequate information. Similarly, the *greyness level*, in its simplest form, is the degree of incompleteness and inadequacy [28]. As such, the higher the greyness level, the more degrees of incompleteness, imperfection, and uncertainty [29]. For instance, higher degrees of greyness being associated with the knowledge of an entity suggest that the knowledge or information in this case is more inadequate, more uncertain, and more incomplete [22].

It must be noted, of course, that although "greyness" and "uncertainty" co-occur and may even appear to be synonymous, technical terms in many contexts, they are conceptually different from each other. "Greyness" in GST refers to "incomplete information" or "inadequate understanding". The result or output of greyness, which is the same as incomplete information and inadequate understanding, is uncertainty as an epistemic issue [7]. The greyness of a given thing means it can be changed or corrected [30]. A grey entity may be changed or corrected some time in the future, even if it is a scientific law that was established centuries ago [28]. The meanings of "grey" and other expressions including this concept can be extended from different perspectives or under different conditions. Some of the terms including the concept of "grey" as used in this research are described as follows:

- Grey dataset: This is a set of incomplete, partial, and inadequate data related to an external reality. As such, this dataset would not include some of the data associated with the reality in question.
- Grey information: This is incomplete and partial information of a reality or an external entity. Data that are incomplete or partial, and in some cases, even wrong or irrelevant, are converted into grey information through imperfect, error-prone, and partial human interpretation.
- Grey knowledge: This is an incomplete, partial, changeable, and error-prone understanding of or familiarity with an object or a person, including facts, information, descriptions, or skills. At any given point in time, grey knowledge may be changed in light of new data or information.
- Grey understanding: This is an incomplete, inadequate, and partial representation of a reality or an external entity. The grey understanding of an object involves the creation of an incomplete/partial mental structure. The grey understanding of an external reality could be modified over time as new observations and new data are obtained or alternative interpretations emerge.
- Grey system: This is a concept or symbol that represents incomplete, partial, and insufficient information, knowledge, and understanding of a system. Such human information, knowledge, and understanding may focus on a system's elements, relationships between such elements, or laws governing elements, as well as other features such as a system's structure, boundaries, functioning, or behaviors [21].

Explaining the notion of "greyness", especially in combination with other terms, can be simplified when it is compared with such notions as "white" or "black". In this comparison, "white" means compete, perfect, flawless, and certain. In contrast, "black" is the total opposite of white [31]. Black, in fact, means utter ignorance and the impossibility

of having access to any information. Grey falls between these two extremes. Julong Deng (1985) identified the following six foundational principles that contain the philosophical bases of GST [6]:

- The principle of informational differences: addresses the existence of information. When object A is thought to be different from object B, we have some information about the former that we do not have about the latter. Differences between natural things, events, and incidents depend on the initial information they provide. Based on such information, they are distinguished.
- The principle of non-uniqueness: a solution proposed based on incomplete information cannot serve as the unique solution to a problem.
- The principle of minimal information: GST tries to make optimal use of "minimal available information". That is, we should not refrain from generating knowledge on the basis that sufficient information is unavailable.
- The principle of recognition base: Information is the foundation based on which humans perceive and understand things (e.g., nature). All cognition works according to information. Without information, humans cannot recognize anything. Incomplete and uncertain information would only provide grey and indeterminate attitudes about phenomena.
- The principle of new information priority: new information is more practical and efficient than old information.

The principle of absolute greyness: Information "incompleteness" is absolute and information uncertainty is universal. That is, information greyness and uncertainty are absolute and will never be eliminated [32]. Further, in the literature, the philosophical paradigm of GST has been investigated and described by researching its six principles. Accordingly, the ontology of GST is introduced as anti-realist, and its epistemology as anti-positivist. The methodology of this system, too, is described as interpretivist. In relation to human nature, GST does not believe in determinism. Given these stances, GST should be regarded as a postmodern theory belonging to the humanist paradigm [7].

Although in the practical field of GST, white systems are generally referred to as part of the basic concepts of GST, in this research, we focus our attention on grey systems, because, as mentioned in the sixth principle, greyness and incompleteness of information are absolute. This means that white systems are only temporary beliefs or certainties that may change in the future with the discovery of newer information. As a result, in this study, we have focused on greyness, which encompasses all the systems we know.

3.3. The Formation of Grey Knowledge

In the literature on grey systems, it is mentioned that due to human epistemic limitations and the ambiguity of "complete knowledge", white or complete knowledge of systems is not possible for humans [22]. Therefore, white systems do not exist in practice. In fact, researchers in this field contend that greyness circumscribes the entire scope of human life [28]. Whiteness or completeness, along with perfect perception, cognition, understanding, and ultimately, perfect knowledge, only represent mere unachievable dreams. We only see parts of reality that are perceivable to us, although no one knows how much of reality they have missed or failed to perceive [7].

As the literature suggests, knowledge is obtained through information, and information is gained through data. Information appears as meaningful and well-formed data. Knowledge is in turn interpreted information that is integrated with other topics, themes, and contents of understanding. The world can be likened to an endless ocean that encompasses an unidentifiable range of data. Humans cannot even delineate the volume of data obtained from parts of the world (e.g., sub-systems) or its phenomena [33]. We can never decide upon the ultimate amount of data in a system or phenomenon. Therefore, from a philosophical perspective, we can never prove whether or not a dataset includes all the data related to a phenomenon or system. The reason for this is that we do not know the total amount of data [7].

Thus, there is no fully complete dataset, as all datasets under any circumstances are grey. At best, humans may manage to recognize the data they perceive, but they cannot verify how much more data is left unperceived or totally lost. In fact, we have no idea how much data we tend to miss. There is no way to prove that our current understanding has taken shape by including all pieces of data related to a phenomenon. As a result, we always interpret the world and anything contained in it through incomplete datasets. Our understanding and perception of the world and its phenomena stem from the data we perceive. Otherwise, no perception and, consequently, no cognition or understanding would be possible. Without perceiving any data of the external world, humans cannot shape any understanding of the world [21].

Due to incomplete data and the dependence of meaning on the subjectivity of an interpreter, information will always remain incomplete and grey. In fact, information itself is derived from an incomplete understanding of the world. Our interpretations of our grey information arise from paradigms, theories, and laws governing science, and they involve elements of understanding, argumentation, induction, and subjective/intellectual processes that are all biased and error-prone [32]. Obviously, definitive/absolute knowledge cannot be generated out of grey information or imperfect processes of interpretation, argumentation, understanding, and judgement [8].

Furthermore, human knowledge reflects the past rather than the future. Knowledge is produced based on prior data. Scientific laws, even if they were established centuries ago, are likely to undergo changes in light of new discoveries. Moreover, humans are not mere observers or interpreters of the world. They are part of the world and interact with its various entities. The interaction between humans or between other sub-systems in the world clarifies that humans are one of the factors that contribute to the dynamicity of the world [34]. Dynamicity means that data in the world are constantly changing. Importantly, constant change in the world's data, the dependence of human knowledge on the past, and possible knowledge modifications through new data all underscore the eternal greyness of human knowledge of the world [35]. As such, humans cannot be optimistic about the possibility of ever achieving definitive, eternal, and error-free knowledge. New data constantly arise in the world, making currently available data obsolete. Figure 2 briefly illustrates why every dataset and, consequently, all human knowledge remain eternally grey and incomplete [21].

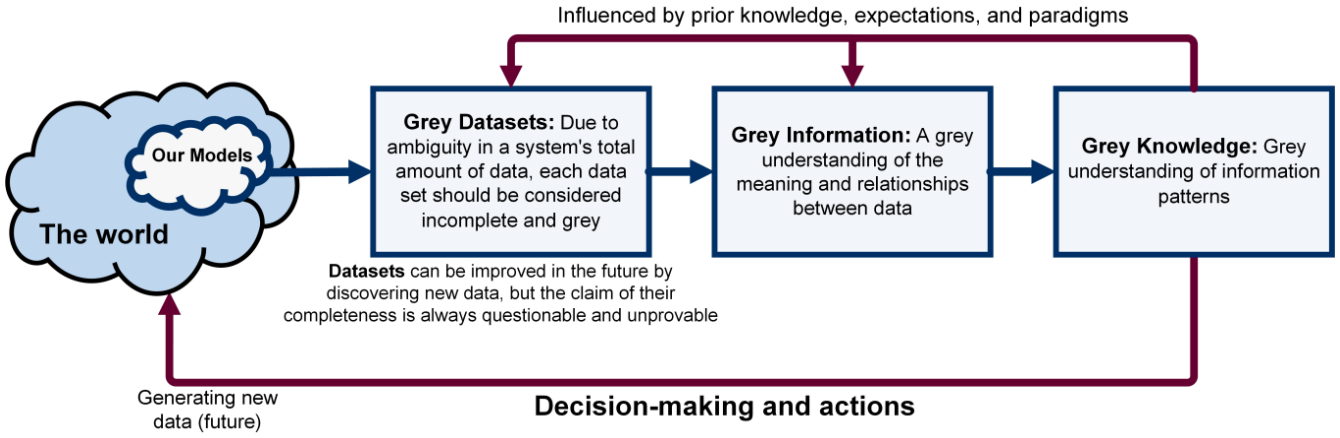

Figure 2. A brief depiction of greyness in data, information, and knowledge achieved by humanity.

The foundational assumption of this research, which appears frequently in the following sections, posits that the human understanding of the world and its phenomena/sub-systems is not complete, and that human knowledge as the product of this understanding remains uncertain. Uncertain knowledge can be transformed as new discoveries are made in the future. No matter how much progress we make, we cannot claim that we have

achieved certain and absolute knowledge. This study explores the uncertainty of human knowledge and its greyness as the roots of challenges to sustainable development.

4. Challenges to Sustainable Development from the Viewpoint of GST

This section investigates the challenges to sustainable development, focusing on the foundational principles of GST and its philosophical principles. The framework of this analysis rests on the process of development, as shown in Figure 1. Incomplete understanding and grey knowledge represent the main roots of challenges in all stages of sustainable development. An ideal future, which is the same as a sustainable future, depends on our understanding of the world. People's different understandings of the world would create different ideals for them. Grey understanding and knowledge point to the inequality of people's perceptions of the world, which accounts for difference preferences that different groups, communities, and societies have [2].

Meanwhile, human knowledge makes it possible to predict the future. As such, risk identification depends on human knowledge. Risk is identified by calculating the difference between a potential future and the ideal future. As Figure 1 depicts, humans use their knowledge to analyze their state. Predictions, too, arise from knowledge, and thus risk perception depends on knowledge as well. Furthermore, sustainability solutions are contingent on knowledge. Humans identify problems based on their knowledge, find solutions to such problems, and make relevant decisions or take necessary actions. Human knowledge helps to identify solutions that could reduce or eliminate risk. As such, humans can make decisions about the best and most practical solutions. Scenarios of change, as well as proper methods of implementing decisions, also depend on human knowledge. Without knowledge, it is not be possible to take action, solve a problem, or make a decision. Grey knowledge and incomplete understanding can lead to a false idea of sustainability problems. When we fail to understand a problem, how can we propose a proper and optimal solution to it? A wrong understanding of problems and formulating solutions to vaguely defined problems can even give rise to more issues and increased unsustainability. Grey knowledge suggests that errors will take place in the decision-making or implementation process. Grey knowledge can lead to wrong decisions. Higher degrees of greyness engender more uncertainty, which could account for more errors in decisions or practical measures [36].

As a result, incomplete understanding and grey knowledge shape the very foundational challenges to sustainable development. This issue is addressed in the following sections. The other topics explored below are the challenges to the identification and definition of values, challenges to risk perception, challenges to the discovery of improvement solutions and scenario formulation, challenges to implementation, and finally, challenges associated with delay.

4.1. Challenges Caused by Incomplete Understanding and Grey Knowledge

The central issues addressed in this section are the importance of human grey knowledge in sustainable development and the challenges it brings about in the process of development. The challenges engendered by grey knowledge are further explored here from three perspectives: (a) the challenge of the human knowledge imbalance in various domains.; (b) challenges to the identification/definition of values, preferences, and desirables; and (c) the challenge of modeling and understanding sustainability.

4.1.1. Challenges Caused by the Imbalance of Human Knowledge

The first basic challenge caused by grey knowledge is the imbalance of human knowledge in different areas. Human knowledge in some areas may be greyer and more uncertain than in others. In simple words, we know some areas or fields more clearly than others that may appear more ambiguous to us. The reason for this is that humans do not interact equally with all systems. Furthermore, different areas show different levels of objectivity. Different areas of human knowledge involve different levels of uncertainty and, thus, different greyness levels.

Many investigations have focused on the imbalance of human knowledge. For instance, Yackinous (2015) explained that knowledge in the humanities and social sciences is more subjective, more imaginative, more contemplative, and more creative [37]. Of course, such disciplines involve a higher degree of reflective rationality and require less documented evidence. Because social and cultural issues are major parts of sustainability, subjectivity in the humanities and social sciences poses a serious challenge to sustainable development, because subjectivity denotes greyer understanding or more uncertainty.

Meanwhile, Javanmardi and Liu (2020), too, demonstrated that knowledge of different systems is imbalanced and is directly correlated to the level of complexity in a system. The authors used Boulding's systems hierarchy as a criterion for world systems, showing that more levels of complexity in a system in this hierarchy are associated with more levels of greyness and uncertainty [8]. In line with previous research, this study proposes a simple classification of human grey knowledge in various areas, along with their levels of imbalance. Figure 3 illustrates the classification.

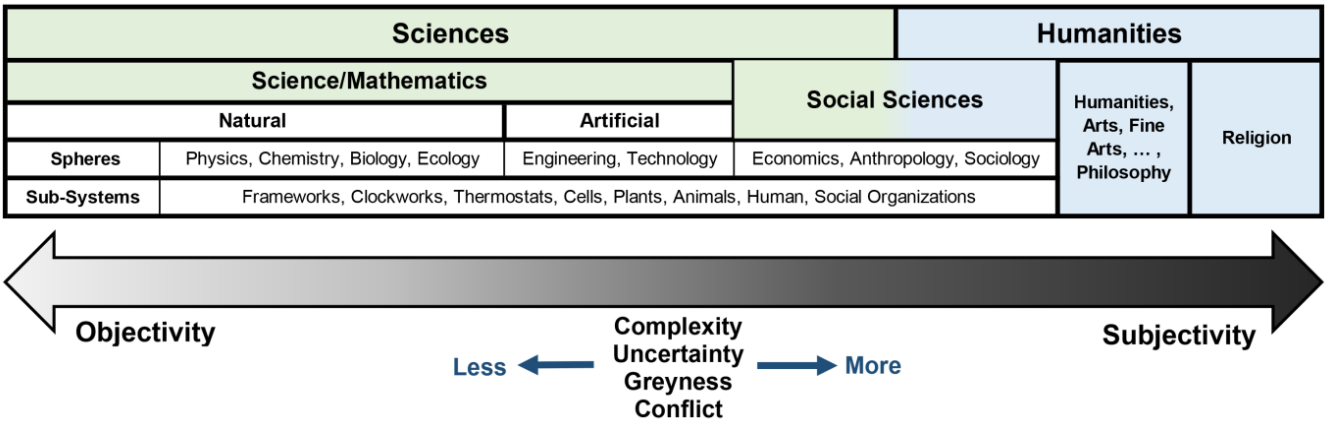

Figure 3. Classification of human knowledge in various areas and their complexity level.

The two major domains in Figure 3 are the sciences and the humanities. Each domain includes categories, spheres, and sub-systems. This is, however, not a comprehensive view, as many other disciplines are not mentioned in it. The purpose of this illustration is to depict a set of disciplines, categories, and academic majors as a sample to better clarify the notion of knowledge imbalance. Consider the "science/mathematics" category, which includes two general systems, namely, natural and artificial. The spheres of the natural sciences range from the least complex system (physics) to the most complex one (ecology). Ecological systems are the most complex natural scientific systems. The spheres of natural systems are physics, chemistry, biology, and ecology [7].

"Artificial" sciences address human-made tools and instruments. Engineering and technology are the main spheres falling under this branch of sciences. The cognitive approach that dominates the sciences is called the "scientific method", which is highly rigorous, well defined, and evidence based. This is why this approach is so convincing. The "social sciences" share some aspects with the sciences and the humanities, because some areas of social science rely on the scientific method. Social organizations account for the main sub-system of the social sciences, and its spheres can include economics, anthropology, and sociology. The "humanities", as an extensive domain, encompass a wide variety of areas such as art, fine arts, philosophy, etc., along with many other disciplines that draw on different methodologies. The sub-systems of the sciences are frameworks, clockworks, thermostats, cells, plants, animals, and human beings. This classification is relatively similar to Boulding's systems hierarchy. The aim is to show the order of their complexity [37].

Meanwhile, there are two aspects, namely, "subjectivity" and "objectivity", represented as the two extremes of a scale. Objectivity is usually a specification of science, whereas subjectivity is often associated with the humanities. Objectivism posits that human knowledge takes shape independently of the human mind, interpretations, emotions,

imagination, and thoughts. Scientific objectivity points to the ability to make judgements without bias or external effects. Human knowledge in scientific areas most often arises from objectivity. In contrast, subjectivism postulates that mental experiences and activity shape the foundations of all laws and criteria. The role of subjectivism is more outstanding in the humanities.

Of course, this division is not as simple as it may seem. Scientific areas are not completely objective, and the branches of the humanities are not utterly subjective. The subjectivity–objectivity range represents a matter of degree. As Figure 3 shows, the areas closer to the left extreme are normally more objective. Yet science always involves a subjective element. For instance, bias may affect scientific activity when a scientist holds onto preferences that are refuted by empirical evidence. The more we move toward the right, the more subjective the areas become. As Figure 3 further illustrates, the more complex/subjective a system or sphere is, the more uncertain it will be (and thus shows a higher greyness level) [36].

However, even in the case of high objectivity and low complexity, human knowledge cannot include all possible existing data, although we expect to gain knowledge from less complex levels. More subjectivity can give rise to different ideas and conflicting theories in a discipline. Subjectivity and objectivity can also serve as criteria for defining complexity. Because objectivity leads to less conflict, more objective systems and spheres may be thought to be less complex. Increasing objectivity can reduce subjectivity, although even in the most objective spheres/sub-systems, no one can claim that complete knowledge is attainable. More objectivity can help to reduce uncertainty. However, even in the case of the most objective spheres/sub-systems, no one can claim to have achieved complete knowledge. More subjectivity can lead to more speculation, theorization, conflict, and complexity. Clearly, more subjective areas tend to internalize newer experiences and, in some cases, less known ones. Knowledge, then, is more uncertain in more subjective areas [38].

As a conclusion, although human knowledge may remain eternally grey and uncertain, it must be acknowledged that human knowledge shows varying degrees of uncertainty in different domains. More complex and subjective areas are greyer and more uncertain. Additionally, in more subjective disciplines, views and opinions abound and make it more difficult to reach a universal consensus. It must be remembered that society, as one of the topics addressed in the sphere of the social sciences, has a foundational role in sustainable development. Like economic aspects, social variables have been approached from numerous perspectives, and there is no universal consensus on them.

It was mentioned earlier that knowledge greyness denotes uncertainty and the possibility of change in scientific theories by virtue of future discoveries and observations. The argument raised in this section has posited that human knowledge is not only grey, but it is also imbalanced. As such, some areas are greyer than others. The greyness of a scientific field is associated with more uncertainty, more conflict, and a greater likelihood that novel theories may replace older ones. Greyness also suggests that more errors and mistakes may happen. That is, uncertainty and possibly wrong understandings of phenomena could be more likely [22].

In light of Figure 3, one can clearly realize that knowledge in social and human disciplines is greyer than that in sciences and mathematics, including their natural/artificial sub-systems. Furthermore, achieving a universal consensus in social and human disciplines is more difficult. Especially today, culture, as an important part of the human sciences, has even been introduced by many researchers as the fourth pillar of sustainability [39]. In this regard, the independent role of culture is recognized as an influential factor on values, which can ultimately affect actions and decisions. Under the umbrella of cultural sustainability, various representations of different political, social, and sociological ideologies articulate solutions to various social and environmental problems associated with sustainable development. It is clear that more subjectivism in these sectors leads to more imbalances and conflicts and can seriously challenge the achievement of global understanding and cooperation [40]. Similarly, in terms of sustainability as a scientific topic, there

is an imbalance between various branches, which could bring about serious challenges. Plausibly, sustainable development itself is a mode of balance. Development per se is not the ultimate goal, as sustainable development and maintaining balance in the world are more important goals. As Forrester (1971) observes in *World Dynamics*, balance is a more significant objective than development, and a global balance is a combination of social, economic, and technical changes [41]. The major challenge, however, is that we do not possess balanced levels of knowledge in all areas to maintain a global balance.

Another problem is that societies must initiate necessary measures on a global scale and implement policies, but the greyness and subjectivity of knowledge in the social sciences, as opposed to physical, biological, and ecological areas, bring about conflicts of opinions and make it difficult to arrive at agreed-upon solutions. In natural, empirical, and technical sciences, in which scientists/researchers unanimously accept many principles and foundations, many scientific theories are rejected over time. In the social sciences, however, there is a spectrum of ideologies, thoughts, and paradigms, which would contribute to conflicts, contradictions, and rapid changes. Such contradictory approaches and conflicts in the humanities (including society, culture, politics, and even economics), as a substantial proportion of sustainability, can affect societies' future preferences and risk perception. Following a specific paradigm or theory in the humanities and social sciences can lead a community to believe in different values and ideals in relation to sustainability [2].

Sustainable development is a global concern. To realize sustainable development and maintain sustainability, humans need effort, collaboration, and agreement on a global scale. However, the imbalance of knowledge across the sciences represents a critical challenge to the achievement of a global agreement, especially in the social and economic arenas. This imbalance can specifically lead to diverse ideas in the social and economic sciences, which would otherwise complicate the achievement of globally accepted ideals. Even if we could arrive at a shared understanding of problems, or we could more easily reach a consensus on solutions in technical and scientific areas, it would still be very improbable for us to achieve a universal and globally acknowledged agreement in terms of the social sciences [15].

The main challenge is that problems/conflicts in one area of sustainability are not exclusively limited to the area in question. Environmental problems can give rise to social unrest or economic difficulties. Similarly, disturbances in social and economic dimensions can endanger environmental issues. More uncertainty, possible wrong theories/beliefs, and more conflicts in the social sciences can result in many environmental or economic disturbances and vice versa. For instance, the Aral Sea, which was formerly the fourth largest lake in the world, turned into a massive barren land due to human interventions. The dried-up Aral Sea did not merely result in environmental or geographical consequences. After the lake dried up, major economic, social, environmental, health, and biological problems arose. Some of these issues appear to be highly complex and may not be resolvable [42].

All humans, regardless of their ideas, worldviews, and socio-economic approaches, must live in the same world, and they must share their environments. Nonetheless, socio-economic conflicts affect collaboration, agreement, and efforts in relation to the environment. In short, the imbalance of knowledge across different disciplines is a serious challenge to the achievement of globally acknowledged agreements in terms of sustainability, as it could lead to conflict. In turn, conflict could result in opposing ideals and contradictory expectations, which pose a basic obstacle to the attainment of a unanimous approach to sustainability problems in the world. The following sections further address the impacts of this knowledge imbalance and the conflicts it causes in terms of sustainability and global sustainable development.

4.1.2. Challenges Caused by the Dynamicity of Knowledge, Paradigms, and Values

Another challenge to sustainable development is the interdependency of human knowledge and values. As Figure 1 shows above, one of the stages of development is value identification. Human understanding/knowledge, along with dominant thinking paradigms, can significantly determine values. In fact, values do not take shape in a

vacuum, as they are decided based on how humans understand and know the world. At the same time, human knowledge rests on dominant thinking paradigms and values. Scientific interpretations always emerge in light of governing paradigms, theories, and scientific laws. The interpretations and meanings given to data do not take place in a vacuum or in an abstract realm [43].

As explained in the case of Figure 2, humans do not encounter the world with an empty mind or a "blank slate" (*Tabula Rasa*). Instead, people always rely on their prior thoughts, experiences, and values to deal with new experiences. People can even choose their experiences and select that which they want to see or know. A governing thinking paradigm guides its followers as to how to see the world. It is as though each individual cuts the world into their own frame of understanding. Humans do not observe things passively, as observations are affected by the human perception of the way the world works. Individuals view the world in line with their own imagination, but not in line with reality [44]. Processes such as thinking, argumentation, contemplation, and judgement are always influenced by multilayered and complex biological, technical, economic, and cultural domains, a phenomena otherwise called "knowledge ecology". Knowledge generation and cognitive activities do not exist or even have any meaning outside of this technological, economic, and cultural sphere. Personal assumptions, hypotheses, prejudices, and preferences have a major function in scientific knowledge generation. Science always operates under specific conditions decided by methodological abstraction. Modern scientific achievements are realized because this abstraction conceals other possibilities. Thomas Kuhn contended that paradigms would remarkably affect knowledge formation, and that when paradigms changed, previously unseen possibilities would reveal themselves to scientists [43].

As such, in the initial stages of sustainable development, we face a feedback loop, which involves an interaction between human knowledge, thinking paradigms, and human values and preferences, which ultimately affects human actions and decisions. Figure 4 depicts this mutual interaction and dynamic relationship. As can be seen, human understanding of the world, new discoveries, and knowledge transformation gradually lead to changes in paradigms and values. A change in paradigms and values could in turn result in alterations to our approach to the world, transformation, and knowledge development.

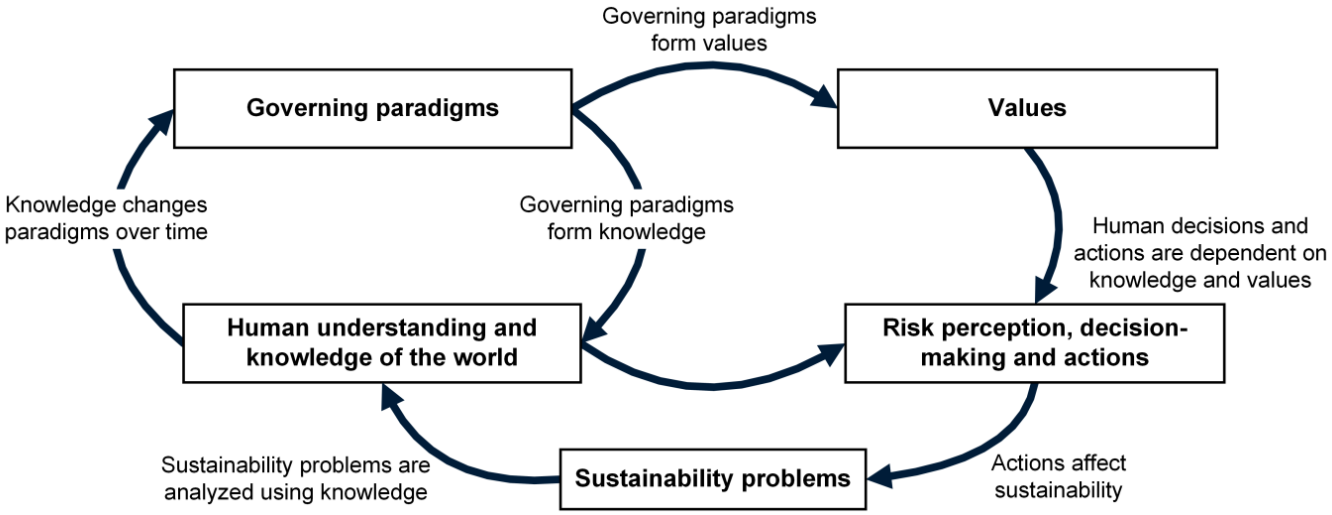

Figure 4. The dynamic interaction between human knowledge, governing paradigms, and values.

Yet what are the problems that these interdependencies can cause in practice, and what challenges do they pose to sustainable development? The major problem is that most currently existing issues stem from human thinking paradigms, decisions, and values. What is known as unsustainability today has partially emerged from human thinking and actions, which were assumed to be true and desirable based on previously existing governing paradigms. For instance, people could not predict that a specific measure or

value would turn out to be detrimental or lead to unsustainability. Today, however, the consequences of those actions have contributed to crises or unsustainability. As an example, most types of fertilizers that were previously used for farming served one specific value, such as agricultural development or increasing productivity. Today, we have realized that most chemicals degrade the environment and account for many existing problems [2].

Plausibly, human understanding and knowledge are grey. We cannot readily, accurately, and certainly determine which paradigms and values have caused problems. The reason for this is that we use the same governing paradigms to investigate the situation, and we use the same paradigms, theories, and frameworks that gave rise to the problems in the first place. Such a tendency, however, cannot propose new knowledge or solutions. We tend to rely on causes of unsustainability to create sustainability, which leads to a paradox. This mutual interaction between knowledge, governing paradigms, and values represents a basic challenge to sustainable development.

4.1.3. Challenge of Comprehensive Modeling of the Problems

The next challenge that human grey knowledge poses to sustainable development stems from the human inability to build comprehensive models. Hosting numerous sub-systems, the world is a complex system composed of living organisms and the environment. Sustainable development necessitates an understanding and management of dependencies, interactions, impacts, and relationships that exist among these sub-systems. To understand sustainability, analyze existing conditions, and predict the future, we have to devise mental models of this complex world. The models we construct reflect some parts of the world that we seek to understand or improve [45].

The problem, however, is that our models only represent part of the world, not all of it. We are unable to create a fully consistent and comprehensive model of the whole world and its sub-systems. Our knowledge is grey, which means most sub-systems have remained undiscovered, let alone unmodeled. Meanwhile, the parts that we have already discovered may be incompletely recognized. Therefore, even if we built a complete model of all identified sub-systems in this world, we still could not claim that the model would contain all the sub-systems in the world or that it would provide a comprehensive image of the real world. The black part of the world, which is utterly unknown to us, would not be reflected in this hypothetical model. How could we model a system we have not yet discovered and of whose existence we have no knowledge? We have no idea how much data exist in the entirety of the world and its sub-systems to be able to build a universal model of the world. Therefore, humans are not capable of creating a comprehensive model of the world and its sub-systems. Therefore, all of the models we construct for the purpose of analysis are incomplete cuts and do not represent the whole of reality [46].

The science of sustainability necessitates a multifaceted understanding of the sub-systems existing in the world, including biological, social, and economic ones. By modeling only portions of the world, we miss many complexities. Complexity denotes that a behavior or measure may be locally compatible but globally incompatible. Minor changes in a system, a place, or a point in time may leave considerable impacts on other systems, places, or points of time. The models we build cannot reflect all of the elements of a system, its relationships, and its external interactions. Our models only represent a small part of the world. They do not encompass the broadness, expanse, and outlook of complexities inside of systems or between them.

Therefore, a major impediment to sustainable development stems from humans' limited ability to model the world, its sub-systems, and its dynamic complexities. A thorough understanding of the challenges to sustainability demands constructing universal models, which is a task that is beyond human capacity. Additionally, challenges to sustainability are dynamic, which further contributes to complexity. Dynamicity suggests that environmental, social, and economic systems are in a state of constant flux due to both human intervention and natural causes. These constant changes will require us to develop knowledge dynamics. The problem, however, is that knowledge always represents the past. That is, we generate

knowledge through previously obtained data. The knowledge gained in the past must be used to analyze future problems. Nonetheless, knowledge of the past and a static mindset cannot properly solve the dynamic issues of sustainability [47].

In short, we deal with multifaceted and dynamic phenomena and integrated complex systems in the environment, society, and economy. Human understanding and grey knowledge are insufficient for a profound and comprehensive processing of all aspects, elements, and relationships in highly complex, dynamic systems. We exclusively model slices of systems, phenomena, and issues in relation to sustainability, while failing to understand or even discover many sustainability problems. Figure 5 illustrates an image that summarizes the challenge of the human capacity to model sustainability problems. The central problem is that we cannot verify how much of reality and sustainability-related phenomena have remained undiscovered. The knowledge obtained through modeling slices, separate regions, or cross-sections is uncertain/grey. This uncertain/grey knowledge may contain some errors that should be corrected in the future. Analyses, predictions, and scenarios in subsequent stages of development stem from grey understanding or knowledge.

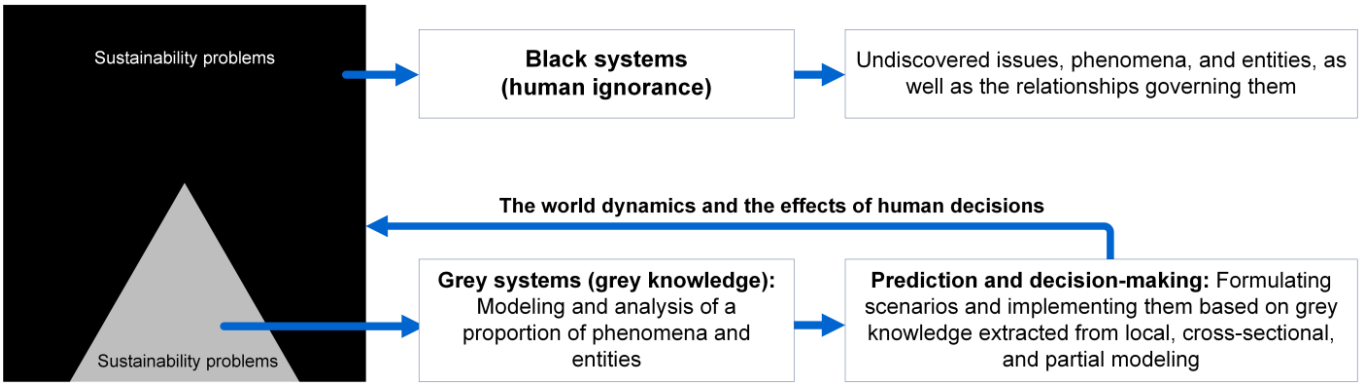

Figure 5. Challenges caused by the human inability to model sustainability problems. Sustainability problems can be black or grey. They are complex and multifaceted environmental, social, and economic phenomena.

4.2. Challenges to the Identification/Definition of Values, Preferences, and Desirables

As Figure 1 shows, the second stage of development is the "identification and definition" phase. The main question addressed in this section is: what are the impacts of imperfect grey understanding/knowledge of human values and desirables, and what challenges do these impacts pose to sustainability on a global scale?

4.2.1. Complexity of Reaching a Universal Consensus on Sustainability Values

From the perceptive of a systems approach, the material world is a network of interconnected patterns in a planet as a self-regulating and living whole. The most important insight in a systems-based understanding is that networks fundamentally organize all living systems. Wherever there is life, networks exist as well. A systems viewpoint believes in the mutual interaction and interrelationship of all sub-systems in the world. An action in one side of the world could slightly or majorly affect other sub-systems on the other side of the world, regardless of their distance from each other. The systems perspective suggests that the pressing problems of this era, such as energy, pollution, climate change, poverty, inequality, war, etc., cannot be solved in isolation from each other. Moreover, these problems will not exclusively affect one specific region, as they are systemic issues. That is, they are all interconnected, continuous, and interdependent. A problem, a mistake, or an unsustainable decision in one part of the world could lead to unsustainability in other parts of the world [48].

Therefore, the systems viewpoint regards sustainability as a global issue. Problems in one particular part of the world can affect another part of the world. Unsustainability is a global concern that, if left unaddressed, can consume the whole world. To achieve

a sustainable world, the efforts and collaborations of a group of people or countries will not suffice. The future of the world is the product of the decisions/actions of all its inhabitants. The world is built by all humans, not by a limited group of them. To accomplish sustainability and an ideal world, people, communities, and countries must cooperate with each other. Sustainable development cannot be achieved through the collaboration of some countries or classes of people. Sustainable development is not a local or regional concern, as global sustainability depends on the participation of people at local levels. One cannot decide to dry up a lake or sea in one part of the world and then expect to limit the effects of such decisions to that part of the world only. Ozone depletion, for instance, demands the unanimous decision of all countries to stop the production of chlorofluorocarbons (CFCs). It would not be effective if some countries were to halt the production of CFCs while others still produced and consumed them. Sustainable development cannot be achieved in a vacuum or in an isolated space somewhere in the world. Sustainability-related concerns and problems are trans-local, transnational, systemic, global, and interconnected [11].

It would not be possible to manipulate nature and the environment on the assumption that they fall within one specific territorial border, as sustainability problems will not be limited to one specific border. Examples of this problem abound, ranging from dried-up rivers/lakes in different countries and water-related conflicts caused by local policies to the Cold War political competition that most notoriously led to the Chernobyl incidence. The world will be sustainable when a large proportion of its inhabitants abide by the values and goals of sustainability. A sustainable world cannot be achieved when groups of people have no intention of finding a unanimous solution. Global sustainable development demands participation, partnership, collaboration, and an understanding of problems as global, and not local, concerns [1].

It is exactly for this reason that the seventh sustainable development goal (SDG), as stipulated by the UN, directly addresses "partnerships for the goals". This goal specifically states that an SDG requires partnerships between governments, private sectors, and civil societies. Such wide-ranging partnerships demand common principles, values, goals, and outlooks that would concentrate on people and the Earth at global, regional, national, and local levels [49]. The central issue, however, is that people can reach an agreement and participate in a given activity when they have identical or very similar priorities, goals, and values. How would it be possible to achieve agreements and have long-term partnerships when groups of people follow opposing values, have different concerns, and prioritize contradictory preferences? Consider a sports team; such a team is only successful when its players have a sense of belonging and commitment, which can only be realized when they pursue common values, desirables, and preferences. A team in which each member follows their own values and preferences can hardly be successful.

On a global scale, too, countries, like sports team members, have to establish transnational and global agreements to be able to realize sustainability. Accomplishing comprehensive and global partnerships demands appreciation from a huge number of people. Plausibly, we can be optimistic about collaboration between people when we prioritize identical or similar goals, desirables, preferences, and ideals. The next section explains why reaching agreements on values on a global scale is a basic challenge.

4.2.2. Value Conflicts and Their Origins

Sociologically speaking, a "value" refers to a belief that individuals or communities have about an appropriate and desirable thing. In some cases, a value describes the significance of different actions. Generally speaking, the things that are important to a group of people and their common ideals are values. Values affect people's behaviors and attitudes, accounting for their intentional actions [50]. In Section 4.1.2 and Figure 4, it was mentioned that humans encounter a dynamic cycle of understandings and values. The dynamic interaction between grey knowledge and values leads to two major challenges to sustainability, as briefly shown in Figure 6. First, our grey knowledge/understanding could sometimes define the wrong values. Theoretically speaking, "wrong" describes any

value that clashes with sustainability. That is, in some cases, wrong beliefs/values can undermine sustainable development. Instead of directing us toward a more sustainable world, such values can further disturb su stainability dimensions. For instance, one can think of the beliefs of extremist or fundamentalist groups. Some of these groups consider gender inequality to be an established belief. Similarly, massacring innocent people for one's religious beliefs is an ideologically valuable action for such groups. Some may even seize power in countries.

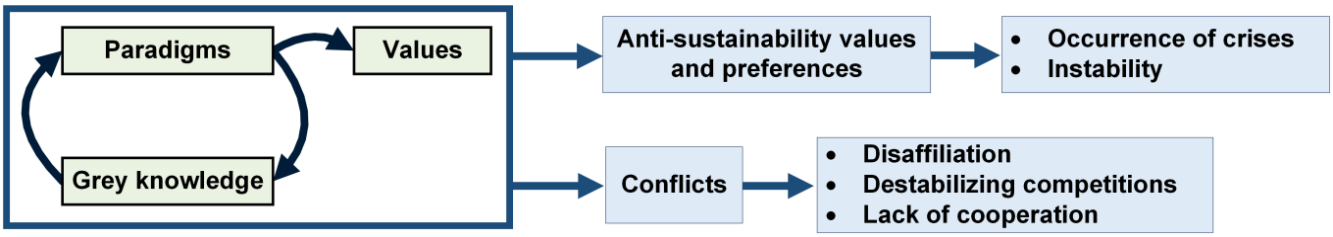

Figure 6. Major challenges to sustainability in the dynamic interaction of grey knowledge, paradigms, and values.

Without a doubt, humans, due to their incomplete and grey understanding/knowledge, may pursue values, beliefs, and attitudes that contradict sustainability. Just like wrong scientific beliefs that change over time, values, ideologies, and preferences can be transformed when people gain novel understandings of the world. The second obstacle addressed in this section is "value conflict", which means disagreement over beliefs and preferences. To reach an actual agreement on common values and preferences, people must handle deep challenges. Naturally, when there are different values and priorities, people will have different understandings of risks, dangers, decision-making, and actions. Value conflicts ultimately lead to incongruous decisions/actions. The world is characterized by various types of inequality in terms of the economy, education, gender, race, security, health, welfare, freedom, etc. Inequalities give rise to value conflicts.

In wealthy countries, people are healthier, live longer, and receive quality education. They have access to a variety of facilities and options ranging from vacations to career paths, which appear like dreams to people in poor countries [51]. According to Oxfam's statistics, in 2020, the ten richest men in the world collectively possessed wealth and assets that were worth more the wealth of 3.1 billion people. More interestingly, estimates suggest that the 20 richest billionaires produce 8000 times more CO_2 than billions of average poor people in the world [52]. Inequalities contribute to conflicts and could make the world collapse. In in unequal world, people tend to have different values and preferences. A world of inequality will contribute to more value conflicts [17].

The relativity of values and value conflicts account for the differences that individuals and communities display when participating in sustainability programs. Individuals, communities, groups, or societies focus on their specific understandings, interpretations, and concerns. This situation will urge them to make decisions based on personal or local criteria and interests. As a result, it would be very difficult to mobilize people globally in line with sustainability policies. A critic, however, may raise the objection that governments and countries have reached a consensus on many values and goals. For instance, the 17 SDGs proposed by the UN exemplify an international agreement over values [53]. The question, however, is whether the UN's approval would necessarily lead to a practical, universal, and common agreement among all nations, groups, or communities living on Earth. Will the SDGs be implemented perfectly in all countries across the world? A glance at available news and statistics clarifies that some countries and governments are not even superficially committed to these goals, let alone in practice.

Now, the question is why defining and abiding by "common values across the world" is such a demanding task. Where does this conflict stem from? Such conflicts arise from the human process of understanding and knowledge generation. Because knowledge is

created in social contexts and is based on thinking paradigms and individuals' beliefs, it is unsurprising to see relativism, divergent interpretations, and conflicts of opinion among people. In more subjective areas (see Figure 3), such as the social sciences and the humanities, beliefs and values are more entangled with local understandings and knowledge. In such domains, society and governing paradigms leave a profound impact on human understanding. Children born into war-stricken and poor communities or those who receive extremist teachings are very unlikely to think like those who have lived in advanced countries. Because knowledge, which is already grey and incomplete, dynamically interacts with relative and error-prone values, it gives rise to value conflicts.

For instance, even the 17 SDGs involve many relative values that are not equally prioritized for all groups. Even some evident and simple SDGs, such as gender equality or peace, are not priorities for some nations, and some even try to negate such values. Today, many governments firmly believe in gender inequality, deprive women of their basic rights in their communities, and subordinate groups by virtue of their approved laws. In many areas in the world, women are not allowed to receive a higher education or to choose their spouses. Such tendencies may appear as laws in a country or as socially held beliefs in different layers of communities, including families. Meanwhile, the different priorities followed by nations may distract them from considering the 17 SDGs. As such, communities do not equally give weight and significance to all the SDGs. For example, a society may focus on economics and overcoming poverty or hunger in any way possible, even by degrading the environment and nature [54].

Today, "power" represents a foundational aspect of value construction and definition. Power can be gained through membership in a social class, wealth, weapons, or political positions or roles. Personal, partisan, or group interests, along with conflicts in terms of interest and competition, contribute to value conflicts and majorly challenge sustainable development. Apart from competing with each other, powerful people pursue personal, partisan, or group goals, not necessarily global ones [51]. Under such circumstances, they follow values and desirables that are not compatible with those of the general public, and at the same time, they possess enough power and resources to realize their own values and wants. For such groups, it is more important to maintain their own power than to strengthen sustainable development for their subordinates. More problematically, superordinate or powerful people not only find their interests incompatible with those of the general public, but they also try to project their own values onto their subordinates in different ways. The media can serve as a channel for distorting reality and manipulating public opinion. Powerful people communicate their values to other people through propaganda [55].

Even if a group of responsible and competent scientists who are interested in today's world issues gathered together and properly specified the values and priorities of global sustainable development, it would still be difficult to resolve conflicts over these values and to reach a global agreement. The reason for this is that people, especially ordinary people who are not scientists, researchers, investors, or powerful politicians, learn many things through the media and formal education systems. In fact, the output of the media is the input that most people receive. Plausibly, not every citizen is sophisticated in the field of sustainability or able to conduct independent research. People often understand the world through the mediation or filter of the media or formal education. The media communicate data to audiences who cannot explore the world themselves. Mass media or education systems shape information for people and even generate knowledge. Ordinary people, then, do not directly experience the realities of the world, but rather, in many cases, they accept the information that is provided for them via the media and education systems [56].

The media are even able to represent an anti-value topic, such as war, as a value. Unfortunately, a huge proportion of people do not receive their information and knowledge from independent resources, as they rely on the media and other sources that are controlled by powerful people. The fact that human understanding is constituted by such resources as the media is a major challenge to sustainable development, especially at the stage of

value definition. This issue can seriously affect the participation of people, groups, and communities on a global scale.

The problem here is that when groups of people shape their opinions through cognitive biases, they tend to further reenforce and internalize such biases. Cognitive biases are deviations that undermine sound judgement that can contribute massively to value conflicts. For instance, cognitive dissonance is a cognitive bias that can intensify conflicts and prejudices. Cognitive dissonance occurs when people organize and select the information they receive based on their beliefs and preferences. As such, people tend to welcome information that is compatible with their beliefs [57]. A person holding a particular ideology tends to follow the media, content, and topics that corroborate their opinions. Such a selective perception of data only encourages a reinforcement of people's beliefs and ideologies as they are. However, what if such beliefs are incompatible with the SDGs?

Another basic issue is that people usually understand short-term goals better than long-term ones. Irrespective of thinking paradigms and social values, many people tend to see short-term effects while ignoring long-term ones. Parties, politicians, investors, and wealthy people focus on short-term goals and benefits [58]. For instance, they may try to capture public opinion for the next elections or maintain their power or economic revenue. In such conditions, sustainability goals, which are usually long-term projects, do not appear interesting to such groups of people. Because the media serve as an influential filter used by powerful people to shape others' opinions, the media can promote a short-term approach among people. As sustainability goals/values usually need a long-term outlook, a reenforced short-term approach represents a basic challenge to the agreement upon long-term sustainability values [59].

Figure 7 illustrates a summarized version of the process leading to value conflicts among people around the world. As can be seen, value conflicts majorly challenge participation in sustainable development on a global scale. Conflicting values and priorities may ultimately distract people from considering sustainability concerns. Many statistics also suggest that people in many communities have not reached a consensus on the importance of sustainable development, and global participation in this area is characterized by tension. Investigations reveal that the awareness of climate change in developed countries is greater than that in developing countries, as the majority of people in developing territories have no information about climate change [60]. As some surveys show, since the 2009 Copenhagen Conference, wealthy countries have not been as concerned as they were before with climate change. Finally, sustainable development needs worldwide awareness-raising activities to address concerns and common values and unify nations. Although this study emphasizes that human understanding/knowledge is incomplete and grey, people should not let forces against sustainability manipulate their understanding, knowledge, and beliefs. Value distortion is unhealthy, because values can contribute to union, global participation, and actions fostering sustainability. In fact, sustainability must be a unifying and common concern among people [61].

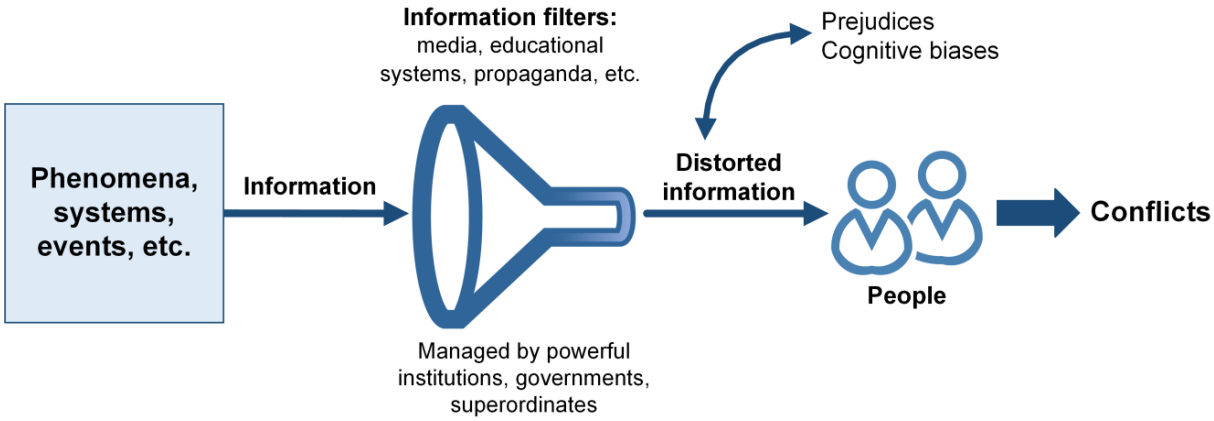

Figure 7. The biased process of receiving information that can lead to conflicts of values and preferences.

4.3. Challenges to Risk Perception

Sustainability underscores the future and the importance of maintaining values or achieving ideals (either tangible or intangible) over time. The problem is that the future is uncertain and is affected by a wide range of human activities, interactions between environmental systems, and even unknown (black) systems. We can never be certain that the future will unfold according to our desires. Uncertainty gives rise to risk [62].

The risk here is the likelihood of variance in a future ideal/desired outcome. Risk perception focuses on the potential variance from an ideal or desired future. Risk, then, suggests that we may not achieve what we wish to achieve in the future. Risk perception predicts the potential variance that current events may undergo in relation to ideals and desirables. Variance can mean deviation, divergence, or difference. As such, risk perception involves an understanding of the deviation, divergence, or difference from the ideal or desired state. Risk perception, which warns us that the future may not turn out to be what we desire, urges us to find solutions. It fundamentally helps people to make decisions and take action [2].

Sustainable development depends on how much we can manage risk and increase resilience. Risk analysis addresses three questions: What are the deviations or incidents that may occur in the future? How probable is each deviation or incident? What are the consequences of each deviation or incident? Risk perception and analysis basically depend on two categories: (a) values, ideals, and preferences, which account for the desired state; and (b) our understanding of the current state, along with our predictions and estimates. By comparing the items in the second category (our understanding of the current state, predictions and estimates) with those if the first category (values and ideals), we can gain an understanding of risks and variance [17]. Figure 8 briefly describes the risk dimensions and challenges to understanding risk in the sustainable development process [63].

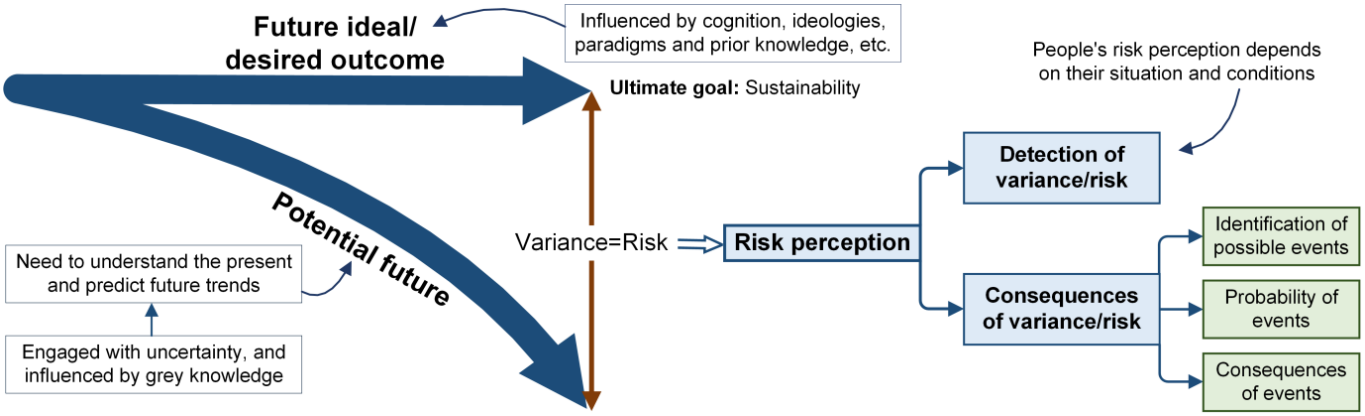

Figure 8. Risk dimensions and challenges to understanding risk in the sustainable development process.

The first category in Figure 8 includes values, ideals, and preferences, which are the ultimate goals of sustainable development and lay the foundations of risk perception/analysis. Risk is identified as a deviation from an ideal future. Values and ideals (e.g., welfare, equality, health, the environment, order, wealth) constitute the idea of a desired future, which is decided by values. The ideal and desired future shapes the very criteria of risk perception, because a deviation from such a future represents a risky condition. Therefore, the first step in understanding a risk is to determine and identify its main criteria, which are decided through values. However, if we fail to have a lucid understanding of values and desirables, how can we identify the potential variance? [16].

In this case, values serve as the criterion against which present and future conditions should be compared, so that a deviation can be identified. Even if, under hypothetical conditions, we could perfectly identify, understand, and measure deviations without any

error, we would still need a criterion for defining our true preferences. The failure to specify an ideal condition would make it extremely difficult to identify the hazard or risk in a situation. This is a natural condition for almost all activities that seek to bring about desired results. Nonetheless, values and desirables are heavily dependent on cognition, experiences, paradigms, ideologies, and thinking trends. As such, reaching a global agreement on values can be a highly challenging and complex process. When there is a lack of agreement on values and preferences, deviation and risk may be meaningful to one group and meaningless to another. That is, outcomes that represent risk to one group may be viewed as desirable and risk-free to another group, because groups may follow different criteria for identifying deviation [2]. Without delineating a robust criterion for desirability and without agreeing with it, how can we define deviation and risk? The chaos and disagreement over globally shared desirables would encourage different individuals and groups to develop different ideas of risky situations, as some view a situation as a risky, and some see it as an opportunity to realize a value or desire.

The second fundamental category in risk perception/analysis addresses our understanding of the current state, along with our predictions and estimates of future events. Sustainable development rests on an understanding of the past and the present to forecast future trends. However, as explained earlier, humans face undeniable weaknesses in all of these activities, especially in the case of predicting the future [16]. Our predictions rest on experiences and knowledge that were gained in the past. Yet if humans fail to have specific experiences and knowledge of a given topic, they cannot identify risks or measures to overcome such risks. In many cases, we have no knowledge of entities, phenomena, and systems. That is, we may have no information of the existence and possible occurrences of such things. When we have no knowledge of an existing phenomenon, we cannot make any prediction of its occurrence. Without making predictions, it would not be possible to identify variance [7].

For instance, how was it possible for industries to assess the risk of using CFCs for industrial mass production before they were able to analyze the effects of CFCs on the ozone layer in the 1970s? Had any scientist identified the risky effects of CFCs on ozone depletion in the 1950s or 1960s? For several decades, people used such substances in ventilation systems and thermodynamic cycles without realizing the risk they posed to sustainability. Without experience, information, and knowledge, it would be impossible to understand and analyze risk. Risk perception depends on knowledge of risk; yet, because human knowledge is imbalanced and uncertain, no one can claim to identify all deviations and risks [64]. Furthermore, although we may have some knowledge of things, the number of things unknown to us remains a mystery. We do not know what we might have missed or failed to see. In the 1950s and 1960s, no one was aware that we had no knowledge of the ongoing problem of ozone depletion. Risk perception only works in the case of things we have some prior knowledge of [64].

As Figure 8 shows, the different dimensions of risk analysis involve the problem of grey and incomplete knowledge and its impact on predictions. The first and most important step in risk analysis is the identification of deviation. If we fail to detect a risk due to our grey and incomplete understanding, we cannot analyze the risk at all. Therefore, risk analysis is very strongly dependent on the identification of deviation. If a possible deviation or risk is detected, efforts should be made to understand its consequences. In doing so, three basic questions must be answered: What are the events that will follow the occurrence of a deviation? How probable is each event or outcome? What are the consequences of the events? Due to our grey and incomplete knowledge, even if we find a risk or deviation, we still cannot identify all the possible events or outcomes. Sometimes we may detect deviations, but we cannot precisely measure their size or intensity. That is, the understanding we have of the magnitude of events and occurrences may be incomplete, wrong, or inaccurate [16].

Naturally, a wrong idea of the intensity of events can leave detrimental impacts on human measures and decisions. For instance, the Fukushima nuclear disaster caused by

a tsunami in 2011 is an objective example of faulty risk analysis, especially in relation to the identification of a deviation's consequences and intensity. Another issue is that social, economic, educational, and even gender-specific factors can affect people's understanding of and worries about risks. People with different backgrounds may have different understandings of the same risk. As a result, an identified risk is a source of concern to some people but is unimportant to others. Hallegatte et al. (2020), for instance, demonstrated that the risk of unsustainability may be different for people depending on their conditions. Similarly, people's understandings depend on the situations in which they find themselves. Because people may understand a risk or challenge differently or associate varying degrees of concern with it, risk assessment can pose a major challenge to global collaboration or agreement regarding sustainability problems [65].

In short, risk perception involves an understanding of sustainability problems and provides a standard for taking action and implementing improvements. Any obstacle to this perception will directly affect nations' efforts to solve sustainability problems. Our actions stem from our risk perception/analysis. Many environmental disasters or humanitarian crises have resulted from people's unintentional actions when they had no proper understanding of the risks or hazards involved. Such uninformed actions can lead to accidents and disasters. The failure to have a perception of risks or to identify challenges to sustainability will prevent nations from taking appropriate action or from improving the situation. When no problem is identified, no solution will be proposed for it.

4.4. Challenges to Decision Making and Taking Action

Today, human activities are becoming increasingly important determining factors that can change the future of the world. We have "conquered" this planet; of course, here, "conquer" does not mean that Earth is exclusively populated by the human species, but rather that humans are increasingly affecting vital systems on the planet. Therefore, investigations into the challenges to sustainable development must plausibly address human decisions and actions that can affect sustainability. As mentioned earlier, determining values and desirables and reaching agreements on them are major challenges for nations. Even if it were possible to achieve a global consensus on truly relevant values and desirables, it would still be difficult to predict their deviations and risks.

Meanwhile, even if deviations and risks could be perfectly and meticulously identified, it would be yet another challenge to find proper, complex, and functional solutions to such problems. More problematically, identifying and formulating proper solutions would not solve the problem of prefect solution implementation, because humans face operational limitations in their tools, instruments, and resources. This section primarily explains the significance of human actions in the achievement of sustainability. Next, it answers the question of whether sustainability is attainable without intentional and premeditated human intervention. Then, this section tries to explain whether it is possible for humans to construct proper and precise solutions to the problems and challenges associated with sustainability. It is also explains the obstacles people have to overcome to be able to effectively implement possible solutions in this area. This section also introduces the phenomenon of "competition" as a challenge to sustainability, emphasizing the importance of global collaboration in achieving sustainability.

4.4.1. The Importance of Achieving Sustainability through Human Intervention

There is no doubt that human action can cause many social, environmental, and economic disasters. Intentionally or inadvertently, humans can create crises or even major catastrophes. When humans intentionally manufacture a crisis, they are aware of its negative consequences and risks. That is, they realize a given action can endanger the environment, economy, or society. Of course, considering the assumption that knowledge is grey, humans may not be able to completely predict the consequences of an action [66]. For instance, chemical weapons, which were used many times in the past century, can cause premeditated disasters and unsustainability. In contrast to intentionally destructive actions,

there are unintentional measures that can contribute to massive disasters or a high degree of unsustainability. In the case of such unintended disasters, people do not seek to damage the environment, economy, or society, as they are unaware of the consequences of their actions. That is, they neither intend to cause damage, nor do they have any knowledge of possibly negative outcomes associated with an action. Some of the disasters that have undermined sustainability that were unintentionally committed by people are as follows: the Great Pacific Garbage Patch, soil salinity and dryland salinity in Australia, the salinization of the Fertile Crescent in the Middle East, the Dust Bowl disaster in the USA and Canada in the 1930s, the Four Pests campaign in the 1960s in China, the rabbit problem in Australia, Romania's population control policy in the 1960s, the gully erosion crisis in Nigeria, the Goiânia accident in Brazil, and the Hong Kong plastic disaster in 2012 [67].

These examples reveal how humans are transforming the Earth, bringing about long-term or wide-ranging consequences in relation to the environment, society, and economy. Most environmental disasters have not exclusively affected the environment, as in retrospect, they have undermined agriculture, biodiversity, the economy, and human health. Furthermore, such disasters' tragic impacts will be long term and will persist for many decades. Analyzing the samples mentioned above abundantly clarifies that human actions leave a considerable degree of impact on sustainability and the future of the world. Humans and their actions are a massive force that can transform the world's natural trends. Obviously, in the case of many disasters, people's unawareness of the consequences of their actions was the main reason the disasters occurred. Perhaps, if there had been sufficient awareness of the potential problems, many such disasters would not have occurred. For instance, if people had realized how negative the effects of CFCs are, they would have never used them so extensively. Human agents were responsible for all these disasters without realizing what they were exactly doing at first [68].

In a world in which humans take actions based on their grey knowledge, at any given moment, an unexpected problem may occur due to humans' unwarranted decisions or actions. With millions of human decisions and actions every day, the world dynamically undergoes impacts created by the human population. Intentionally or inadvertently, we affect the world, as we part of it, and we create much instability and unsustainability. For this reason, it would not be possible to achieve sustainable development and preserve sustainability without human intervention. This world is ultimately affected by human actions, whether humans want to admit it or not. Living on Earth, humans are constantly and incessantly engaged in different activities. This cumulative human impact is unstoppable, because activity is part of human nature [69].

Even simple everyday activities, such as eating, drinking, or traveling, affect the world and the environment. Billions of people make immeasurable (un)intentional impacts on the world each day. Considering the impact of almost every human action on the world, it would be necessary to formulate policies to direct human measures and activities toward sustainability. Even if we ignored the intentionally destructive effects of human activities and assumed that humans would not willfully disturb normal environmental, social, and economic processes (which is not the case in reality), we still cannot overlook the negative consequences of their unintentional and uninformed actions. Therefore, overcoming these (un)intentional negative outcomes demands human intervention.

Sometimes we need to correct wrong decisions/actions, either intentional or unintentional ones, that led to or might lead to disasters. We need to take measures to contribute to sustainability. For instance, is it possible to undo ozone depletion without human intervention and decision making? Should we not make some decisions and take some actions (e.g., banning some activities) to protect the ozone layer? Will the ozone layer be protected if we simply follow our old way of living and take no protective action? To maintain or attain sustainability, and even to prevent major disasters, we must decide to practice some activities and stop others. Admittedly, by living on this planet, we are constantly affecting it. As we gain more information and knowledge over time, we must re-consider some wrong actions, correct them, or even change our way of living. Although

we leave unintentional impacts on the world, we must correct our mistakes through new information and knowledge. Without human intervention or the adoption of some policies, sustainability will remain unachievable. Passivity and simply observing things as they happen in the world will not contribute to a sustainable world, as in some cases, seemingly harmless everyday activities can lead to instability and unsustainability.

4.4.2. Challenges to Decision Making and the Formulation of Solutions/Policies

Problem solving involves problem analysis, the formulation of possible solutions, and decision making. All these elements must rest upon knowledge. Yet, as already explained in this study, human grey knowledge remains necessarily incomplete and uncertain, which is a situation that poses challenges to decision making and solution development in relation to sustainability [68]. Grey knowledge, which means incomplete knowledge, brings about two obstacles to the process of discovering optimal solutions to sustainability risks. First, incomplete/grey knowledge suggests that decision makers cannot identify all possible solutions or scenarios and may miss some of them. As such, the set of all possible solutions is itself incomplete, lacking some possible solutions or scenarios. Second, grey knowledge, due to its imperfections, cannot determine the best approach and solution it has identified. That is, grey knowledge neither helps us to identify all possible solutions, nor does it reveal the best alternative among existing polices. Therefore, our solutions are not necessarily the best ones, may not prove to be successful, and may even generate more complex problems in the future [2].

According to the philosophical foundations of GST, especially the six principles proposed by Deng, knowledge is contingent upon information. The fourth principle, namely, the "principle of recognition base", clearly states that information constitutes the basis of knowledge. Information itself stems from prior experience. Knowledge is retrospective and is updated as new experiences and consequently new information are gained. Deng's fifth principle, the "principle of new information priority", explains that new information should replace old information, and that knowledge is a time-sensitive concept (it can change over time). Knowledge rests upon information, and new information can generate new knowledge over time [6].

The information we use to build our knowledge is retrospective; that is, our information represents past events (whether they occurred one moment ago or several years ago). The greyness or incompleteness of prior knowledge can have two aspects. The first issue is related to the incomplete data/information obtained from past events. The second aspect involves our dependence on one and only one idea of the past. We have no idea how many alternative scenarios could have potentially occurred in the past. In our experience, past events occurred according to one specific scenario [70].

Today's world conditions are the outcome of past events and are the result of a complex combination of numerous choices and practical decisions humans made in the past, coupled with the interactions among various sub-systems in the world. We do not know what today's world and its phenomena/events would be like if any player in the system had made a different decision at any given moment in the past. That is, we have missed a huge proportion of potential information about past events. For instance, how would we know what today's world would be like if the Dunkirk evacuation (Operation Dynamo) had failed during World War II? What would be the fate of the war exactly? As such, we can only wonder what today's world would look like if the Dunkirk evacuation in World War II had failed. The reason for this is that we do not know what other actions or reactions would have been made with regard to such a hypothetical failure, not only in the short run, but also 80 years after the event happened. This lack of knowledge is an informational defect [2].

Here, we can also refer to the theory of path dependence. Path dependence is a concept in economics and social science that refers to processes in which past events or decisions constrain future events or decisions. This theory emphasizes the idea that "history matters". Accordingly, the future development of an economic or social system is influenced by the

path it has traced in the past, and it is claimed that certain events in the past can have vital effects in the future [71]. We must acknowledge that we keep record of only one line of past events while missing other potential scenarios. Such defects pose a serious challenge to sustainability, which is a future-oriented concept. In this complex world, in which sub-systems experience multitudes of interactions with each other, the future involves numerous potential scenarios. However, we have no idea which scenario will finally occur and what exactly will happen if a given scenario occurs. Our models only reflect part of reality and not its entirety. Based on some proportion of reality, we make decisions, build scenarios, and take action [17].

Understanding and predicting the consequences of actions/decisions represents an overriding aspect of decision making and the formulation of solutions in the process of achieving sustainability. Because sustainability is a vital dimension of human life, we need to have a clear image of how our actions affect the world before making decisions [3]. The major problem here is that it would be impossible to have an accurate and comprehensive understanding of human decisions and measures, and that is why predicting the impacts of human decisions involves uncertainty. Human decisions and actions do not exclusively affect one aspect of the world. Human actions leave impacts on numerous sub-systems, creating multifaceted and interwoven outcomes. There are many examples reported from different parts of the world in which environmental crises led to economic, social, and political upheavals and vice versa [69].

For instance, consider drought and water crises. Some of these crises are caused by human factors and are exacerbated by human activities. Social and economic activities and even political decisions can worsen droughts and give rise to them. Today, social development and human activities have hugely increased water consumption, causing greenhouse gas emissions that can change precipitation patterns in the long run. Furthermore, traditional water management, dam construction, energy production, increased foodstuff production, and land use change are some other human activities that have either led to drought or intensified existing water crises [12].

Drought can degrade agriculture and husbandry, halt economic activities, or engender many social problems such as despair, depression, unemployment, and migration. Another consequence of drought is food insecurity, which can deteriorate social integration. Amid unemployment and food shortages, anything can happen. Drought also destructively affects health systems. Respiratory, eye, skin, and gustatory diseases are directly caused by drought. As a result of reduced moisture, soil becomes more vulnerable to different risks, such as floods and earthquakes. Today, there are many lakes and wetlands under climate stress due to extensive water extraction and drought caused by human factors. For instance, Lake Urmia, located in the northwest of Iran, was once the second largest salt lake in the world. Human activities over the past 40 years have reduced about 80% of the area of Lake Urmia. This is a classic case of drought caused by human activities that has considerably degraded the environment, which could negatively affect social and economic systems in a feedback loop [72].

Therefore, it would be naïve to assume that a problem or crisis would only and exclusively affect its place of origin. The world and its sub-systems encompass an immeasurable number of interacting feedback loops.If we truly intended to understand the impacts of human decisions on various sub-systems, we would have to explore an infinity of interacting feedback loops [37].

The other challenge that we encounter in terms of our decisions/actions is the temporal or spatial distance between causes and effects in the world. One of the reasons the world is so dynamic and complex is because effects do not necessarily occur in a temporal or spatial sequences close to their causes. Consider the Great Pacific garbage patch as an instance. Some of the plastic substances in the patch were generated more than 50 years before it was shaped, and many substances were obviously abandoned on land, which finally ended up in the ocean as particulates. Did the people who consumed such plastic substances 50 years ago in a place far from the current location of the patch ever think such substances

would create an agglomeration in the ocean and cause many environmental problems? The existence of time and space intervals between actions and their consequences could further complicate the analysis of decisions and outcomes [2,17].

Another challenge is the irreversibility of most actions and policies. Human choices, decisions, and measures in many areas, especially in the case of the environment or culture, cannot be corrected or undone. Even if some are irreversible, the correction process might be very demanding and time consuming. That is, after decisions are made and implemented and outcomes are observed, it would be very difficult, and sometimes impossible, to go back to the original situation and make corrections. For instance, how would it be possible to remove the Great Pacific garbage patch? How much time would it take to rebuild the ozone layer, and how should it be achieved? Is it possible to recover the Aral Sea or Lake Urmia, which have dried up due to the wrong government policies, and how much time or cost would such a probable recovery require? Humans do not have the opportunity to examine a strategy and observe its outcomes and then go back to the starting point if the strategy fails. The irreversibility of human life choices and their repercussions pose a major challenge to the process of decisions on sustainability.

4.4.3. Challenges to the Implementation of Decisions and Policies

To achieve sustainability, it would not suffice to adopt decisions and policies, as it is also important to properly and completely implement policies. However, can people fully actualize every decision they make? In fact, human knowledge, analysis, and decisions are not the only conditions for realizing sustainability. Rather, to achieve sustainability, people must thoroughly implement related policies and solutions. The problem, however, is that humans possess a limited range of resources, opportunities, and capacities they can use to practice their decisions. That is, apart from human incomplete/grey knowledge and understanding, humans have to deal with limited resources to realize their ideas.

Even if we could hypothetically make correct decisions and formulate perfect, flawless, and comprehensive policies for achieving sustainability (which is not the case in reality), we would still face basic challenges and shortages in implementing decisions and policies. We are unable to fully implement our decisions. Human capabilities are limited. People cannot enjoy infinite power, capacity, or resources that might realize just any change in the world. Such limitations have always existed and will continue to exist [73]. The concept of sustainability rests on the foundational assumption that human resources for development are limited. Now, how can we ever claim that we face no limitations in the implementation of our solutions? If we encountered no limitations, then we would not be concerned with sustainable development. Sustainability per se and sustainable development are founded on an idea of limited resources. We cannot put any idea we develop into practice.

Apart from implementation limitations, nations should cooperate or at least have an international agreement on how policies should be practiced. Yet, as established earlier, nations not only find it difficult to achieve mutual agreement on their values and ideals, but they also face policy implementation problems in terms of securing thorough and global collaboration. The world is affected by the collective actions of all its inhabitants. Obviously, the decisions individuals make may differ in terms of their weight and significance. For instance, the decisions of a CEO of a large multinational company may be different from the decisions made by a politician or an ordinary citizen. Yet, all inhabitants of Earth will affect its future to a greater or lesser extent. Will we ever achieve sustainability if a proportion of people on Earth try to realize sustainability goals while others make every effort to destroy the environment? Attaining sustainability depends on the international collaboration of all nations, not just some [17].

Another obstacle to international collaboration in the case of sustainability is *competition*. Sometimes countries, nations, companies, groups, individuals, organizations, and governments endanger sustainability because they try to maintain their competitiveness. Although jeopardizing sustainability may appear to be a risky behavior at first, it turns into a habit, routine, and paradigm over time. As people engage in more competition, they

find it more acceptable to push the boundaries of sustainability to its limit in an attempt to outdo other competitors. In some cases, competitors shatter such boundaries to such an extent that the situation becomes unmanageable. For instance, one can think of the Cold War and some of its disastrous results or economic warfare today [53].

Because the long-terms impacts of decision makers' assault on sustainability may reveal themselves somewhere else or at some time in the future, such impacts often remain intangible and imperceptible [74]. The core problem of debates over competition is that they do not clearly delineate the borders of sustainability. We cannot precisely identify the boundaries of sustainability and unsustainability to know to what extent we can exploit resources and the environment. The boundaries of sustainability remain undefined. In practice, we may even violate these boundaries without knowing it. Years from now, we may realize that we have broken these boundaries. The uncertainty of identifying the boundaries of sustainability prevents us from realizing how much instability or damage our decisions/actions have caused. In some cases, people might have long violated sustainability standards for the sake of competition. This inability to perfectly define the scope of sustainability is itself another challenge to sustainability-related measures and policies [2].

4.5. Challenges Arising from Delay

Delay, as an inherent character of the human–world interaction, is another impediment to sustainable development. One of the best ways of understanding delay and its importance can be found in a proposition in Miguel de Cervantes' *Don Quixote*, *Book IV*: "Delay always breeds danger" [75]. Delay is a considerable source of dynamicity in almost all systems and is an effective factor in incidents and crises leading to unsustainability. Terminologically speaking, delay refers to the time duration by which something is late or postponed. In systems science, too, delay is the length of time between action and reaction. Systems science views delay as a process in which the output lags behind the input for some reason. In another definition, delay is the temporal and/or spatial distance between causes and effects. As such, when an effect occurs somewhere or at some time remote from its cause, a delay takes place. Uncertainty, complexity, and delay are positively and directly correlated. More delay leads to more uncertainty and complexity, and vice versa.

As Figure 9 depicts, delay is an indispensable part of and a ubiquitous factor in sustainable development. Humans perceive phenomena with a lag. Similarly, the process of knowledge generation and formulation also involves delay. We need time to analyze and interpret our perceptions and information. Humans are unable to generate knowledge as soon as they observe a phenomenon or gain information. Knowledge generation requires analytical and interpretive processes. Delay, whether short or long, will occur in the knowledge generation process. Furthermore, the risk perception process is delayed, as we cannot immediately or readily determine risks [45].

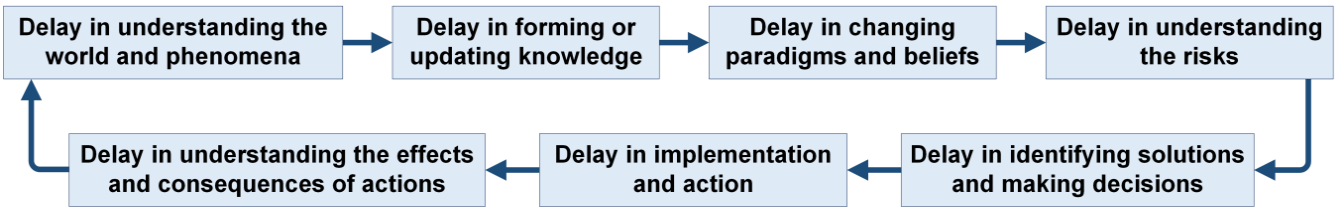

Figure 9. The effect of delay in different stages of the sustainable development process.

In some cases, years may pass by before we identify a risk or a deviation from the ideal or desirable status. For instance, people used CFCs extensively for several decades without realizing the negative impacts and risks of such substances. It was only in 1974 that scientists Sherwood (Sherry) Rowland and Mario Molina co-authorized an academic article published in a nature journal that warned people that using CFCs damages the ozone layer. This warning, however, came after several decades of delay. Furthermore, even after perceiving a risk, humans may not be able to immediately react. People need

time to discover solutions and policies that can resolve a problem and an identified risk. Implementing such policies also takes time. We cannot readily and immediately respond to risks. We need time to analyze risks, formulating and implementing solutions to them. We are slow to read signals, and we gradually build knowledge. Even practicing our knowledge may require much time. It is noteworthy that although the destructive impacts of CFCs on the ozone layer were discovered in 1974, the Montreal Protocol was approved in 1987, about 13 years later (that is, 13 years of delay). More problematically, this move did not ban or put an end to the consumption of CFCs, because such substances had been extensively produced and used for many years after the Protocol was approved [64].

Of course, the problem of delay has a broader scope. The consequences of human decisions, actions, and policies affect the world. Normally, the impacts of human actions do not appear instantly. The world does not work like a machine that can readily solve problems by pushing some buttons. Our decision to solve a problem does not work like an automatic process that yields immediate results. In fact, human decisions and actions will take time to actually affect the world and will involve both temporal and spatial delays. The outcomes of human actions may appear long after such actions are completed. An Outcome may even appear somewhere far from the place in which the original action was taken. Therefore, human actions involve delay, both in terms of time and space [48].

The impacts of human actions on the world should not imply that humans can observe results right after such actions are taken. Even understanding and identifying the outcomes of our actions in the world involves some lag time. That is, we notice the effects of our actions when time passes by. Thus, most of the things we do will not reveal their effects to us immediately without any delay. For instance, actions and policies that try to eliminate the use of CFCs will not have instantaneous effects on the ozone layer. Our actions affect the world with a lag, and we notice them with a lag as well. Meanwhile, effects are not all necessarily physical. People pursue numerous policies and take many actions in economic, cultural, or social areas. Such policies and actions affect people's mentality, thoughts, beliefs, or perceptions. People, however, cannot readily "update" their mental models when they receive new information, as this process of change is delayed and will need time to take place. Generally speaking, changing a belief or assumption will take time, which is called "information delay" in some references in systems science [45].

Delay functions as a major factor of uncertainty in the world and represents a huge obstacle to sustainable development. Delay can contribute to complexity. As a result of delay, we notice risks and problems at a later time and fail to ascertain exactly when or where the outcomes of a decision/action may reveal themselves. The delayed occurrence of effects and the delayed human perception of such effects can both lead to high levels of complexity. It should be remembered that humans recognize entities in the world based on their differences. The first principle of the six principles proposed by Deng, namely, the principle of informational differences, explicitly states that difference points to the existence of different information. For instance, we identify drought because we can recognize the difference between drought and an abundance of water and prosperity. As such, we differentiate phenomena by considering their informational differences [32].

Delay, however, is part of the dynamic and complex structure of the world, making it more difficult for humans to notice differences. Furthermore, differences may be realized gradually over time. In most cases, a difference may not occur immediately, as it needs time to take shape. For instance, the ozone layer was not damaged overnight; several decades of accumulated effect gradually depleted the ozone layer. This gradual process, otherwise called delay, is a major impediment to sustainable development, as the effects of environmental changes will appear gradually and slowly over time, and humans cannot perceive them or react to them in real time [76].

5. Discussion

In this section, by summarizing sustainable development challenges, we will examine the applications and effects of GST-based methods to analyze and solve these challenges

in practice. One of the major knowledge-related difficulties humans face is their inability to have a unified and consistent understanding of the world and its phenomena. We create partial models of the world, and even our analyses of such incomplete models involve biases and errors. More specifically, partial models fail to include some impacts, relationships, interactions, and phenomena that fall outside the scope of such models.

Another problem addressed above is related to human epistemic imbalance. Human knowledge encompasses a wide spectrum of spheres and domains. People, however, do not have equal levels of knowledge in each area. Some domains offer more objective, tangible, and transparent information, whereas others appear to be more subjective, intangible, and grey. Subjectivity gives rise to a multitude of theories, opinions, and views, which increases conflicts. A higher degree of conflict and a lower level of agreement in more subjective areas represent a serious challenge to international collaboration. It should be emphasized that establishing collaboration and reaching am agreement on the achievement of sustainability are such important issues that the UN's SDG 17 explicitly mentions them.

Another challenge is that a huge part of human knowledge and thinking paradigms is obtained through already existing mediated sources. Powerful agents (e.g., governments, politicians, wealthy people), who usually control means of information, can manipulate the information/knowledge people receive and advocate that which they want to instead of that which might contribute to global sustainability. To realize the effects that mediation has on people's knowledge, it would suffice to take a look at the level of concern among people with regard to climate change in different countries with different revenue levels, development levels, and political systems. For instance, according to the 2021 report of the Yale Program on Climate Change Communication, although more than 75% of the respondents in Australia and Germany claimed they knew a lot about climate change, people in Nigeria and Indonesia said they had never heard anything about climate change. The same report stated that although 60% of people in Italy and Spain attributed climate change to human activities, 16% and less than 25% of people in Nigeria and Indonesia found such a factor responsible, respectively [61].

Opposing paradigms, incomplete information, and epistemic imbalance will ultimately leave their impacts on people's risk perception and the extent to which they are willing to collaborate with each other. Achieving sustainability ultimately depends on human intervention. People are constantly affecting the world while performing their everyday activities. Some of their actions, either intentional or unintentional, can leave detrimental impacts on the social, economic, and environmental dimensions of sustainability. To achieve sustainability, then, people must consciously intervene to correct the negative effects of their (un)intentional actions. Human intervention, however, does not mean that only a specific group of people or countries should take action, as all countries have to participate. Global sustainability will not be attainable as long as some countries continue to rely on unsustainable approaches. The slogan to "Think globally, act locally" can also be emphasized, because it encourages people to consider the health of the entire planet and to work in their local communities and cities to improve the world's health. This means that a sustainable world requires local communities' efforts, attention, and actions. [77].

International collaboration, however, may remain unachievable when people around the world have not yet sufficiently raised their awareness of the dangers of unsustainability. Encouraging people worldwide to contribute to sustainability and to undertake responsibility in this regard will depend on how much information and knowledge they receive about these issues. However, as mentioned earlier, knowledge is usually mediated. As a result, different intermediatory entities (e.g., governments, the media, the education system) must pledge themselves to raise the awareness of sustainability and international concerns about it. An awareness of mutual values and reaching an agreement over them can set the stage for practical collaborations. Collaborations occur when there are agreements, and agreements arise from awareness. Without awareness and agreement, no collaboration can be initiated. Such a situation, however, can be realized when all societies shape common

understandings of existing worries, dangers, and risks. Mutual concerns and risks that threaten all nations can ultimately serve as unifying factors.

Finally, GST-based methods as an approach to analyzing and solving uncertainty caused by incomplete and grey information can be helpful in many stages of sustainable development in practice. First, developing and promoting the conceptual and philosophical approach that governs GST, which has a postmodern view of systemic concepts and the uncertainty of knowledge, can help improve processes, attitudes, worldviews, and of course, the development and flexibility of paradigms [7].

Further, practical methods based on GST can have many applications in analyzing and solving challenges in practice. Grey numbers are one of the essential bases in GST that can help to analyze ambiguities and uncertainties in the field of systems analysis and especially risk analysis and forecasts. A grey system is described with grey numbers, sequences, equations, or matrices. Here, grey numbers are the elementary atoms or cells, and their exact values are unknown. This means that the grey number can play a decisive role in the analysis of sustainability issues, such as uncertain systems. Among others, we can mention [78–80]. Sequence operators and grey data-mining methods can be useful in the sustainability processes and phenomena analysis phase, especially in the "discovery of knowledge in databases" [81].

Any given system, such as a social, economic, agricultural, ecological, or educational system, includes various factors. It is the result of the mutual interaction of these factors that determines the tendency and behavior of system development. It often happens that among all factors, researchers need to know which ones are primary and which ones are secondary. Primary factors have a dominant influence on the development of systems. Such factors positively guide the development of systems and should be strengthened. On the contrary, secondary factors have less influence on the development of systems. They usually create barriers to the development of systems and, therefore, should be weakened. For example, many factors generally influence an economic system's overall performance. Systems analysis must be performed carefully to realize the production of additional output with less input [32]. A key part of this analysis is identifying primary and secondary factors. When the available data are few, it is very difficult to use traditional statistical methods to analyze such data. This is because a small amount of data does not meet the modeling requirements of traditional methods, which contain relatively large amounts of grey information and do not follow any normal probability distribution. Grey Incidence Analysis models have shown their utility here. They are a way to analyze systems for which conventional statistical methods do not seem suitable. The analysis can be applied to large or small samples and has no normal distribution requirements. In addition, the amount of computation involved is small and can be performed easily and without disagreement between quantitative and qualitative conclusions [82].

In addition, one of the main tasks of GST is to uncover the mathematical relationships between different system variables and the laws of change of certain system variables themselves based on the available data of characteristic behaviors of social, economic, and ecological systems, for example. When investigating practical sustainability problems, it is often the case that each observation object has a small number of characteristic indicators that are difficult to classify accurately. Grey clustering is a method that has application in these problems [83]. It was developed for classifying observation indices or observation objects into definable classes using grey incidence matrices or grey possibility functions. Further, a series of grey prediction models (GM), such as GM (1, 1) and others, also enable the correct description of a system's running behavior and its evolution law and thus generate quantitative predictions of future system changes [84,85].

In addition, hybrid methods based on GST, including grey econometric models, grey regression hybrid models, the grey Cobb–Douglas model, grey artificial neural network models, and grey Markov models, are widely used in the analysis of sustainability issues [86]. These methods have achieved more efficient results with the help of grey data. Additionally, in the decision-making stage of the development process, grey decision-

making methods can be an ideal option for analyzing and solving problems. Grey decision making is about making decisions using decision models that involve grey elements or that combine general and grey systems models [87].

Further, dynamics can be studied and analyzed from the perspective of grey control systems. Control systems are systems that are formed based on closed feedback loops and are a tool for analyzing the dynamics of systems. The closed-loop control system materializes its control through the combined effect of the input and output feedback. A grey control system stands for such a system whose control information is only partially known; it is referred to as a grey system for short. The control of grey systems is different from that of general white systems, mainly due to grey elements in such systems. Under such conditions, one first needs to understand the possible connection between the systems' behaviors and the parametric matrices of the grey elements, how the systems' dynamics differ from one moment to the next, and in particular, how to obtain a white control function to alter the characteristics of the systems and to materialize control of the process of change of the systems. Grey control contains the general situation of systems involving grey parameters and the construction of controls based on grey systems analysis, modeling, prediction, and decision making. Grey control thinking can reveal the essence of the problems at hand and help to materialize the purpose of control [32].

Finally, since GST is not just a practical approach in a specific sector and is based on a philosophical concept, the practical methods based on this theory have the advantage of always being further developed to analyze sustainability issues.

6. Conclusions

Extensive developments in sciences, technologies, and industries have given rise to unprecedented levels of complexity and difficulty in human societies. In turn, this situation has contributed considerably to the complexity, dynamicity, and breadth of challenges to sustainability. As such, it is of paramount importance to explore the causes and sources of these challenges, especially from a philosophical and conceptual perspective. Given these issues, this study has sought to substantially investigate the challenges to sustainability by relying on the philosophical and conceptual foundations of GST, particularly notions related to the inherent defects and uncertainty of human knowledge. Without a doubt, outlining a clear image of the basic factors that are causing obstacles to sustainability at various stages of the development process can enhance the efficiency of programs and policies that contribute to sustainability.

This study has probed the challenges that can affect the different stages of the development process. At each stage, the most basic challenges have been explored from the viewpoint of greyness in terms of both human understanding and knowledge. Development is a process that is composed of five basic components: values, the current state of values, an ideal state, change scenarios, and goal-driven activities to realize change. Human grey understanding and knowledge are the very roots of the challenges at all stages of the sustainable development process. Human grey knowledge brings about major challenges to sustainability. Knowledge may not suffice to construct models of dynamicity and to properly discern it. There are also knowledge imbalances across various academic/scientific domains, and knowledge is partially influenced by biased thinking paradigms and values.

Formulating ideals depends on how humans understand the world. Different understandings lead to the prioritization of different ideals, which is a problem that engenders deviations from sustainability goals and prevents nations from collaborating with each other. Furthermore, people rely on their knowledge to predict the future. Grey knowledge, however, would always generate inherently uncertain predictions. Different ideals, coupled with imprecise predictions, lead to biases and deviations in risk perception and to errors in decision making.

The study has explained that the first step in risk perception should be to address the identification of "values" as the central criteria. However, because of value conflicts and a multitude of preferences and ideals, it is difficult to define the main criteria in risk

perception. The second step in risk perception/analysis has to focus on specifying the current state and anticipating possible future states. Obviously, grey knowledge would increase the likelihood of errors and deviations in understanding the current state or predicating future possibilities. Risk perception, then, involves the biases, deviations, errors, and conflicts that motivate different individuals or societies to behave differently.

Decisions and practical solutions also depend on human knowledge and understanding. Different ways of perceiving the same risk prompt people to devise different solutions or make conflicting decisions. Grey, imbalanced, and imperfect knowledge cannot help to implement error-free and precise plans. Equally important, people cannot always have a clear idea of the outcomes of their actions. Due to their incomplete understanding and grey knowledge, humans experience two major deviations: First, they cannot properly identify their ideals, values, and deviations from them. Second, they fail to adopt flawless decisions and to put them perfectly into action. As a result, incomplete understanding and grey knowledge account for many challenges to the process of sustainable development.

This study has also explained that humans analyze the world by drawing on partial and limited models, which can represent only part of the world. As such, these models cannot comprehensively reflect the dynamicity and complexity in existing interactions and relationships. Human knowledge is also encapsulated in a paradigm-dependent closed loop. Of course, paradigms change over time as new knowledge is acquired. Values, too, are also affected by knowledge and paradigms. As a result, a closed loop of interacting values, knowledge, and paradigms makes it difficult and time consuming to identify the real causes of problems and to discover solutions to them.

It has also been emphasized that imbalances across different spheres and domains of human knowledge pose a major challenge to the achievement of global agreements on sustainability. Knowledge in more subjective areas involves more divergent theories and views, which can further increase conflicts and limit the possibility of cooperation in such areas. The relativity and diversity of ideas that clash with each other urge people to adopt different levels and types of partnerships in terms of sustainability programs. Human grey knowledge, then, makes it difficult for people to have a proper, equal, balanced, precise, and comprehensive understanding of the risks threatening sustainability. This issue can delay their responses and, in some cases, worsen crises.

This study has also explained that delays, either in time or space, are an inherent aspect of world events and human knowledge, and they pose a major impediment to making decisions and taking action in relation to sustainability. Delay contributes to further complexity, dynamicity, and uncertainty. Finally, the study has underscored that the world needs intentional human intervention to reach sustainability, and that an ideal future cannot be realized without human intervention. However, intervention only works through international collaboration and depends heavily on people's awareness and readiness on a global scale. It is not possible for only one specific group of people to build a sustainable and desirable future; rather, all nations must cooperate with each other.

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