Review

Exploring Grey Systems Theory-Based Methods and Applications in Sustainability Studies: A Systematic Review Approach

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Abstract: In recent years, there have been international movements advocating more sustainable societies, and as a result of such movements, a remarkably important sub-branch has been shaped in systems studies called sustainability. It would be vital to propose methods that could deal with inherent complexities and uncertainties in such systems. Grey systems theory (GST) represents a nascent method that could help to solve complexities in the face of multifaceted problems, uncertainty, and complexity in systems, and the theory could considerably contribute to sustainability studies. The present study sought to fill a gap and provide an updated review of the literature on the roles and impacts of GST-based methods in sustainability studies as one of the most significant areas of exploring economic, social and environmental systems. Primarily, the theoretical foundations of sustainability and GST were briefly reviewed. Next, by categorizing the studies conducted in the literature on sustainability studies, GST-based methods used in such studies were identified. Finally, the advantages, effects and functions of GST-based theories and their applications in sustainability studies were explicated. The papers found in this systematic review were searched on such databases as Scopus, Web of Science, and ScienceDirect, as published from 2010 up to the first three months of 2020, based on these keywords: grey relation or grey relational, grey model, grey system or grey systems, grey prediction, grey control, grey incidence, grey cluster, grey decision, grey input-output. The total number of publications found on all of the databases was 446, although (following a more meticulous investigation of the publications) 145 ones were used for the comprehensive analysis. The 10 different areas in which GST was used to explore sustainability in the publications were: sustainability assessment, industrial sustainability, urban sustainability, energy sustainability, sustainability development, businesses sustainability, agricultural sustainability, sustainable products, tourism sustainability, social sustainability. The results revealed that complexity, uncertainty, and inaccessibility of a large set of data and initial statistical distributions led researchers to rely on GST in sustainability studies, and that the applied areas of GST in terms of sustainability issues had some features in common, including linguistic variables, long-term projects, technological demands, conflicting goals, and uncertainty. Moreover, compared to other methods used to deal with uncertainty, GST did not require the formation of an extensive databank of classified rules and was more practical and efficient in sustainability calculations (as complex systems) with fewer numerical calculations. Ignoring systematic approaches, causal relations, cause-effect loops, and dynamic feedback was the missing link in the application of GST in sustainability studies as complex economic, social and environmental systems.

Keywords: sustainability; grey systems theory; grey model; grey relational analysis (GRA); grey decision making; grey number; grey forecasting; grey incidence; sustainability assessment
1. Introduction

Over the past years, many investigations have addressed sustainability, emphasizing this notion in countries’ economies and various businesses. It has been underscored that pursuing sustainability could accelerate societies’ achievement of (non)economic goals. Although the outcome of the Industrial Revolution brought about positive accomplishments that contributed to the convenience of human life on Earth and considerably increased human control over the planet, the truth is that there are hidden tragedies that represent a serious source of concern. In the past century, it was gradually revealed that “human” or “social” dimensions had been ignored in the traditional paradigm in such a way that the economic development system and increasing modernization turned humans into machines or parts of them while neglecting human dignity and basic rights [1].

Of course, economic development did not reveal a dark side only because of ignoring human or social qualities; in fact, it involved a more tragic aspect: “environmental destruction.” Unidimensional development, only regulated by economic growth, has demanded the continual destruction of natural resources—and after only a short period of time, has caused more extensive environment damaged than any other time in human history. Global warming, water resource pollution, air pollution, a rampant extinction of various animal and plant species, ocean acidification, the destruction of a large proportion of forest cover and Earth’s green belt, water shortage crises, major climate change, storms, floods, seasonal changes, and drought in many parts worldwide are some of the signs of this wide-ranging assault on nature [2].

In the late twentieth century, the emergence of these detrimental consequences gradually revealed “behind the scenes” of economic growth and led to attempts to raise awareness and possibly correct the consequences of modernization. As a result, important international organizations and academic institutions shaped new approaches to development—one of which is known as “sustainability.” Sustainability arose from increasing awareness on a global scale of social, environmental and economic issues, along with poverty, inequity, and concerns about a healthy future for humanity [3]. Sustainability strongly links these issues (social, environmental and economic); studies in this field try to correct the unidimensional path of development taken over the past few centuries, seeking to bring more convenience and satisfaction to human life and future inhabitants of Earth [2]. The issues associated with sustainability actively direct development plans in various regions worldwide and are regarded as essential matters. Although there seems to be a considerable consensus that a sustainable society involves benefits for all its members, definitions of sustainability and ways of achieving it are as diverse as the institutions concerned with it. Sustainability could be viewed as the welfare of succeeding generations, especially if it is achieved through irreplaceable natural resources. Sustainability in development represents a multidimensional measure that can help to reach higher levels of living for all people and future generations [4]. Sustainability, in fact, is an attempt to supply present needs without damaging the ability of future generations to satisfy their needs [5].

According to another view, sustainability is a dynamic balance between a population and environmental carrying capacity; in this relationship, a population must fully realize its potential without engendering detrimental or irrecoverable effects on the carrying capacity of the environment [3]. Obviously, nowadays, this balance has been disturbed due to an exponential increase in human activities, exceeding demands for resources, and the production of waste that moves beyond the recycling and absorption capacity of the planet. Some scholars, too, see sustainability as an approach to the future, a blueprint that concentrates on a set of values and ethical/spiritual principles [5]. Irrespective of the different definitions proposed about sustainability, scholars divide its scope into three areas: economic, social and environmental. This categorization, of course, works according to the principles of systems theory [2]. There are also some subsidiary areas of sustainable development: cultural, technological, and political. Instead of prioritizing only one of these dimensions, sustainability tries to optimize all of them. Otherwise, businesses, global economies, and societies as wholes, would have to pay the price for failing to be sustainable. In the long run, it would not be possible to accomplish one dimension while ignoring others. Without a working economy, the rate of unemployment would rise and bring about major social costs [6].
Meanwhile, due to limitations in financial resources, governments would not be able to solve social problems. On the one hand, without a healthy environment, economic foundations would give way, and numerous social issues would arise. Without a dynamic society, there would be no workforce needed for economic activities, while people may ignore environmental issues as a “luxury” topic [7]. The ultimate purpose of sustainability as a principle regulating the planet is to formulate effective coordination between individuals, society, economy, and the recovery capacity of ecosystems that support life on the planet. Over the past years, the global movement toward more sustainable societies has raised heated debates about various issues such as society, occupation, government, universities, and individuals [1]. Apparently, all these activities seek to create and employ methods, practices, educational programs, and technologies that could meet today’s needs, without harming succeeding generations. Because sustainability is an interdisciplinary topic and is composed of various aspects (e.g., economic, social, environmental), studies in this field are particularly complicated; in fact, sustainability is a notion governed by systems. From a systemic perspective, sustainability refers to the capability of systems to ensure progression, compatibility, transformation, or transition in the face of constantly changing situations [8]. Many scholars view systems thinking as a tool used to better analyze sustainability. Sustainability studies investigate complex structures composed of social, economic and environmental ingredients [9].

Such studies shape a complicated combination of systems that are deeply interwoven from various respects. When dealing with chaotic or perplexing issues like sustainability, one could rely on systems thinking to systematically understand the situation and envisage an ideal framework to resolve problems. A sustainable society would not reduce its social opportunities and ecosystem health for the succeeding generations in the face of shocks and social/environmental changes. Such an approach, of course, demands a forward-looking perspective, one beyond today’s society. Such an approach would include a larger population (either born or unborn, human or nonhuman) [10]. Today’s environmental issues are not detached incidences—they are systematic phenomena that require novel and innovative solutions [11].

Because systems thinking is a comprehensive method that analyzes how parts in a system interact with each other, how a system works over time, and how a system is situated within a larger system, this method could be used to profoundly develop a holistic approach to sustainability. The empirical world in such systems with all their complexities is constantly linked with human life, society, and the environment. The wide spectrum, multidimensionality, and complexities associated with sustainability issues demand specific investigation methods that can prove to be effective and efficient in dealing with such qualities. Given the existence of multifarious elements in sustainability studies, such systems are obviously uncertain. Furthermore, to propose sustainability solutions, one has to predict future impacts and incidents, which would be an uncertain and error-prone process [10]. Therefore, methods, theories and approaches that have been developed to deal with uncertainty could help to increase the efficiency of sustainability studies. Introduced in the 1980s by Chinese scholar Julong Deng, GST is an essential tool for solving today’s complexities and problems in the face of multifaceted problems and uncertainty in systems. Therefore, GST could considerably contribute to sustainability studies [12]. Shortly after it was proposed, GST was regarded as a method for understanding, modeling and incorporating uncertainty into the analysis of complex and uncertain systems, especially for inadequately captured data [13].

Over the years, many researchers tried to extend GST, using innumerable ideas and models and offering many practically successful solutions in various fields. Such works brought about applications and evident economic, social and environmental benefits. GST seeks to construct theories, techniques, and ideas for analyzing uncertain and complex systems. GST makes it possible to produce and analyze useful and practical information in systems with uncertain or partial information. Through the help of GST, one could properly define and supervise the operational behavior of a system. Furthermore, the complexities associated with sustainability studies could lead to uncertainty in data and analyses, as a result of which it would be difficult or even impossible to have access to sufficient or certain data [14].
As such, GST, and models regulated by it, provide effective tools for analyzing complexities governing sustainability studies and for improving the results arising from such studies. The problem, however, is that presently there is no specific and organized explication of the outcomes of using GST-based methods as approaches to uncertain systems investigation in sustainability studies [12]. Clearly, there is a shortage of organized and general studies exploring the impact of GST on improving sustainability, as an important sub-branch of systems research.

The purpose of the present study is to fill this gap in the literature and provide an updated literature review of the functions and effects of GST-based methods on sustainability studies, as a research field dealing with economic, social and environmental systems. This review acknowledges the scientific progress emerging from GST since it was introduced up to the present time, by focusing on the sustainability literature. That is, this study tries to detect the diversity of the themes and identify some key GST-based studies conducted in the field of sustainability. As a result, this investigation could pave the way for researchers, inspiring them in their future studies in related areas.

This study, then, seeks to answer these questions: (a) What are the contributions of GST-based methods to sustainability studies? (b) In which areas of sustainability have GST-based methods been used? In this study, the main lines of GST research in terms of sustainability (and its sub-topics) are presented in an informative summary for further research. In doing so, all of the papers published in the field on Web of Science (WoS), Science Direct (SD), and Scopus are taken into account. To highlight the scientific progress in this area, a “scoping review” is provided, which is guided by the following keywords coupled with sustainability: grey systems, grey relational, grey model, grey prediction, grey control, grey incidence, grey cluster, grey decision, grey input-output.

The study primarily explores the theoretical foundations of sustainability, and some definitions proposed by researchers are reviewed. Next, a brief account of the theoretical bases of GST is presented. Following that, the publications in the literature are categorized, through which various sustainability sub-topics as explored through GST are identified. Then, a review of GST-based studies as used in sustainability research is reported. Finally, the advantages, impacts, and functions of GST-based methods in sustainability research are substantially discussed.

2. Theoretical Background

In this section, we give a brief account of the fundamental notions of sustainability, and then review the foundations of GST.

2.1. Sustainability

Today, humanity faces many complex sustainability problems—overpopulation, shortage of resources, ecosystems destroyed by pollution, biodiversity loss, climate changes, and human activities have all undermined the Earth’s capacity to support life [2]. A reduced return on investments in fossil energies, along with environmental harms arising from such energies, are threatening the industrial civilization. Many have emphasized the importance of a transition to sustainable methods, although the prospects of such a transition do not seem to be clear due to logistic issues and the need for new ways of approaching complex problems [15]. The notion of sustainability has been defined differently—supplying needs without destroying future generations’ ability to supply their needs, and having good lives within the limits of nature are some general ideas that describe sustainability. From a systemic perspective, sustainability is a norm-governed notion that points to an ideal state of existence in which humans are able to flourish and survive within the ecological margins of Earth, along with other living creatures [16]. In the twenty-first century, ‘sustainability’ is used to refer to Earth’s biological capacity and the human civilization’s ability to co-exist with other creatures. It seeks to find practices that satisfy existing needs without ignoring the capability of succeeding generations to meet their needs [3].

Sustainability, however, is not a final status to be ultimately accomplished, but a “dynamic goal” that is constantly changing and improving [5]. As such, this dynamic state is defined within the natural margins of the planet or operationally safe spaces to be used by humans. Sustainability is a
condition in which utilities and existing facilities are not degraded over time, focusing on ecosystems’ capacity to continue their functioning in the future without any limitations or without downgrading or exhausting resources [1]. Ecological investigations suggest that sustainability can be achieved by striking a balance between species existing in an environment. To keep this balance, existing resources must not be consumed faster than the generation of natural resources [17].

Sustainability is not exclusively concerned with the environment—most definitions are also concerned with social rights and economic development. Sustainability describes how biological systems remain diverse and fertile over time [7]. The long and healthy life of forests and wetlands are samples of biologically sustainable systems. To humans, sustainability is the potential for realizing long-lasting welfare that includes environmental, economic, and social dimensions. Sustainability as a political notion appeared in Brundtland reports in 1987 [3]. This document was about the dreams of humanity for a better life and natural limitations. As time passed by, the notion was re-interpreted and described as having three basic aspects: social, economic, and environmental [15].

Sustainability issues involve a wide range of interrelated, complex and multifaceted social, economic, and environmental underpinnings. To solve such problems, vital knowledge of all actors (players) and academic disciplines are needed; therefore, sustainability represents a cross-disciplinary field of investigation. Sustainable development cannot be achieved through detached initiatives—rather, it requires a comprehensive effort at various levels, including social, environmental, and economic ones [10]. A hybrid approach to sustainability demands the realization of its main dimensions (e.g., financial, social, and environmental), and at the same time, manage tensions, interactions, and synergy between the dimensions involved [9].

Economically speaking, sustainability refers to available resources and methods of organizing such resources for satisfying human needs and achieving human goals [1]. An economically sustainable system must be capable of continuously producing services/products, retaining a controllable level of governance and external debts, and avoiding radical measures that would damage agricultural or industrial production. From an environmental perspective, a sustainable system must maintain a basic, stable source, and refrain from exhaustive utilization of environmental resources [17]. This process involves preserving biodiversity, atmospheric stability, and ecosystem functions, which are not usually categorized as economic resources. From a societal viewpoint, a sustainable system must fairly distribute opportunities, as in providing sufficient social services (e.g., health, education), gender equality, accountability, and political participation [5]. Sustainability in societies is a significant condition for meeting human needs. Socially relevant criteria are important for sustainability because they describe current life qualities and could constitute the main proportion of the heritage left for future generations [11]. Economic sustainability demands retaining or reinforcing all sources of capital that generate economic production; such sources include production capital, natural capital, human capital, and social capital. Some sources of capital may be converted into each other, although generally speaking, they complement each other; therefore, it would be necessary to retain all of these four sources for long periods of time [7].

It would be essential to preserve ecosystems and natural resources for economically sustainable production and intergenerational justice. Ecologically speaking, both the human population and the demand for resources must be kept to a minimum, and the consistency of ecosystems and diversity of species must be preserved. Social equality, realizing health-related needs, and education, as well as participatory democracy, are the main constituents of sustainability and are associated with environmental sustainability [2]. Over the past years, there have been increasing concerns about climate and environmental changes, poverty, increasing divide between societies, and tensions arising from social iniquity; as a result of such issues, sustainability studies have come to the fore [10]. Moving toward sustainability, of course, involves social challenges that must be addressed through international and national laws, urban transportation planning, supply chain management, local/individual lifestyle, and ethical consumerism. More sustainable lifestyles could generate new ways of life by re-organizing life conditions (e.g., ecovillages, eco-municipalities, and sustainable cities), re-evaluating economic sectors (e.g., surplus cultivation, green buildings, sustainable agriculture) or practices (e.g., sustainable architecture), utilizing science to develop new technologies
(e.g., green technologies, renewable energies, sustainable fission and fusion power), designing flexible and resilient systems, and encouraging individual lifestyles that would preserve natural resources [3].

2.2. GST

GST, which was first introduced by Chinese scholar Julong Deng in 1982, is a nascent theory with a background of fewer than 40 years [13]. In its simple configuration, a grey system is the result of imperfect human understanding and perception, in which “grey” is a term applied to systems that cannot be completely understood by humans [18]. A grey system is better conceived when it is compared with “white systems” and “black systems”. A system that we have no information about regarding its structure, behavior, boundaries, elements, and internal relations is called a black system, while the information used by this system is called black information [19]. In contrast, a white system is a hypothetically-existing system about which we possess every piece of information precisely and completely, without any doubt or ambiguity. Hypothetically speaking, if we had all the information for a white system, the knowledge/information used by this system would be called white information. Because of the imperfect and incomplete human understanding of grey systems, human predictions about such systems remain uncertain—such a system, then, is called an uncertain system [12].

‘Grey understanding’ refers to human incomplete and inadequate understanding of world realities and systems. That is, such a system could not be fully known or perceived. Furthermore, the main characteristic of grey systems (or uncertain systems) is the incompleteness/inadequacy of the information available about them [20]. Liu et al. (2017) attribute this insufficiency of information to the incomplete elements (parameters), structure, boundaries and behaviors of a given system [14]. A grey system results from imperfect human understanding of inputs, outputs, and the internal structure of a system. It is plausible that humans could gain some information about the components of a system, but such human knowledge will always remain completely grey [18].

Presently, GST-based models and methods could be divided into two general groups: First, there are models that were constructed based on limited data and small sets of data about a system; such models include the grey forecasting model and grey relational model. The grey model, working according to limited data, is a novel version of the forecasting model for solving prediction problems through values of finite sequences and it could be compared with traditional linear regression and exponential smoothing [21]. The grey relational model shapes a significant proportion of grey theory, because it tries to determine whether two information curves are closely related considering their geometric similarity. The more similar the curves are, the greater their relation degree is (and vice versa). Because this theory underscores geometric similarity between two curves, there is no need to measure samples or population distribution [14].

Then, the grey relational model measures the degree of correlation between similarities and differences of vital variables [20]. The grey incidence analysis investigates the association between the features of a system and other factors based on their observed similarities through the development of the factors. Such an analysis is used with several data points (normally less than three ones) and does not require data to satisfy a pre-determined distribution. Grey clustering, too, is a method for categorizing observation indicators or observation objects into definite classes through the grey incidence matrix or grey possibility functions [14]. The second group of grey models are regulated by grey numbers, which normally focus on system analysis, decision-making, evaluation, control and optimization. Such models rely on grey numbers, while ignoring whether the scope of data is limited or not [22]. Such methods include grey clustering models, grey control models, and grey decision-making models that includes combined GST-based methods and multi-criteria decision-making methods (MCDM), including the technique for order of preference by similarity to ideal solution (TOPSIS), analytic hierarchy process (AHP), decision making trial and evaluation laboratory (DEMATEL), etc. [21]. Grey numbers constitute one of the elemental components of quantitative studies in grey systems. A grey number is a real number, the exact value of which is not known, although the set of its values or potential values could be partially determined [22]. Set D is
a value-covered set or information background of a grey number \( (\mathcal{O}) \); \( d' \) is the real or exact value of \( \mathcal{O} \). Generally, a grey number is represented as follows:

\[
\forall \mathcal{O} \Rightarrow d' \in D.
\]  

(1)

where set \( D \) could include continuity on intervals, discrete values, or even a combination of continuous or discrete values [21]. If the determined values only involve a continuous set with upper and lower boundaries, the grey number is called an interval grey number and is formulated as follows:

\[
\mathcal{O} \in [\bar{a}, \bar{a}], \quad \bar{a} < \bar{a}
\]  

(2)

where \( \bar{a} \) and \( \bar{a} \) are the upper and lower limits of separate pieces of information. Moreover, the greyness level of a number reflects the uncertainty level of the thing represented by the grey number (and its value falls between 1 and zero) [22]. An interval grey number involves upper and lower boundaries, although the status between the boundaries remains unknown [23]. Obviously, a grey number should not be confused with an “interval number” or “interval fuzzy number”, because although grey numbers have operations similar to those numbers, they are inherently different [24]. First, grey numbers are defined based on their information background, and secondly, a grey number is a set formed when it is not possible to determine real values, while its intervals could be continuous, discrete and a combination of the two modes [21].

It should also be noted that the greyness level is not the same as probability and should not be confused with it. Probability is normally a prediction about events that have not happened yet; moreover, probability works according to a universal model that assumes every element involved is known [25]. In contrast, GST does not follow such assumptions. Upon closer scrutiny, GST claims that the world is an integrated system—which is neither black or white, but grey [26]. The relatively known sub-systems in the world shape part of the grey world [27]. Black systems are the undiscovered parts of the world, while white systems represent perfect human knowledge; of course, as explained earlier, having access to white systems is a dream that will never be realized because human knowledge cannot be absolute or perfect. From the viewpoint of GST, any piece of new knowledge or novel discovery only exhibits a partial truth that remains uncertain [13].

3. Methodology

This literature review was conducted to investigate the role of GST-based methods in sustainability studies and its various sub-topics. The specific purpose of this study was to explore diverse GST-based approaches in different sub-topics of sustainability and their impacts on sustainability studies. Furthermore, this study focused on the mainstream research lines according to GST methods and applications as used in the field of sustainability, trying to propose a select and informative set of research works that could inspire future investigations.

In this study, an attempt was made to review the publications in the literature, detecting the most common GST-based methods as applied to various fields of sustainability studies. To investigate the impact of GST methods as used in the sub-fields of sustainability, a four-phase study was conducted in the light of the literature: (a) Search and select the relevant publications; (b) revisit the publications selected; (c) include or exclude the publications with a full-text through an evaluation; and (d) re-inspect 40 publications meeting the inclusion criteria thoroughly and meticulously.

3.1. Search Procedure and Inclusion Criteria

The literature of the topic was searched on such databases as ScienceDirect, Scopus, and Web of Science (WoS) within a period starting from January 2020 to March 2020, during which the publications indexed from 2010 up to the first three months of 2020 were investigated. The keywords guiding the search procedure were: Grey Relation OR grey Relational, grey model, grey system OR grey systems, grey prediction, grey control, grey incidence, grey cluster, grey decision, grey input-
output. These keywords were used because they could lead to better search results and more optimally detect the relevant publications. The keywords were encapsulated in quotation marks to precisely conduct the search procedure because without quotation marks, there would be a huge number of papers that could reduce the accuracy of the investigation.

In the initial search, all types of documents were included—although in the final analysis, only two types of publications were considered for this literature review: papers (articles) and reviews. Following the search procedure, a total number of 446 publications were found, although after further filtering the results by articles and reviews, this number was reduced to 421. Out of this figure, 105 publications were indexed on ScienceDirect. On this database, the searches explored the keywords in such sections as “keywords”, “abstracts”, and “titles.” Meanwhile, 127 publications were indexed on Scopus as found through the keywords used. On this database, too, “keywords”, “abstracts”, and “titles” were included in the searches. Finally, a total number of 175 publications were found on WoS; the searches focused on “TOPIC” and “all databases.” Table 1 lists the statistics of the keywords searched on the databases.

### Table 1. Statistics of the number of publications in the databases.

| Keywords                                                                 | 2010–2019 |
|--------------------------------------------------------------------------|-----------|
|                                                                           | Sciedirect| Web of Science| Scopus |
| Sustainability AND (“Grey Relation” OR “Grey Relational”)                | 65        | 82           | 88     |
| Sustainability AND “Grey Model”                                          | 21        | 22           | 24     |
| Sustainability AND (“Grey System” OR “Grey Systems”)                     | 10        | 106          | 17     |
| Sustainability AND (“Grey Prediction” OR “Grey forecasting”)             | 11        | 13           | 10     |
| Sustainability AND “Grey Control”                                        | 0         | 1            | 2      |
| Sustainability AND “Grey incidence”                                      | 3         | 8            | 6      |
| Sustainability AND (“Grey cluster” OR “Grey clustering”)                 | 2         | 2            | 2      |
| Sustainability AND “Grey decision”                                       | 11        | 15           | 12     |
| Sustainability AND “Grey number”                                         | 2         | 5            | 8      |
| Sustainability AND “Grey programming”                                     | 0         | 0            | 0      |
| Sustainability AND “Grey planning”                                        | 0         | 0            | 0      |
| Sustainability AND “Grey input-output”                                    | 0         | 1            | 1      |
| **Total publications**                                                    | 125       | 255          | 170    |
| **Total publications after removing duplicates**                          | 111       | 185          | 150    |
| **Total publications limited to article and review**                      | 109       | 179          | 133    |

The findings revealed that the use of GST-based methods over the past ten years followed a rising trend, while more researchers relied on such methods in recent years. Figure 1 reports the number of the publications (according to publication year) as found on the databases between 2010 and the first three months of 2020. Clearly, the number of the publications showed a continuously increasing trend, which clarified that more researchers drew on GST-based methods in addressing/analyzing sustainability issues. In this study, bibliographical tools were utilized based on the keywords; after the initial search, the repetitive records were removed, as a result of which the number of the publications was cut down to 325 ones. Next, the “titles”, “keywords”, and “abstracts” of all remaining publications were meticulously investigated by the research team so that they would be compatible with the research objectives. Although some of the publications appeared to be relevant considering their “titles” and “keywords”, they were accordingly found irrelevant to the topic when their “abstracts” and “full texts” were closely studied. As a result, because they lacked the criteria sought after in this research, they were eliminated. For instance, some publications mentioned sustainability in their abstracts, although upon further scrutiny, it was revealed they did not directly address sustainability or its various sub-topics. The research team inspected the papers very carefully to find those specifically relevant to the field of sustainability.
Moreover, a total number of 145 publications remained for further investigation, and their full texts were deeply perused through manual and semi-manual inspections, in accordance with the criteria in Section 3.2. Once more, another set of the papers not compatible with the purposes of the study were screened. This final process of screening revealed 40 publications that were selected following the in-depth and full-text investigations. These 40 carefully selected works shaped the very core of the analyses in this systematic literature review; Figure 2 illustrates the different stages in the screening the publications found.

3.2. Extracting the Data and Evaluating the Quality of the Study

From each of the publications selected, the following data were extracted: title, objectives, methods and main findings, fields under investigation, and publication year. Primarily, the publications that relied on GST in addressing sustainability studies were filtered. As another filter, the publications that drew on GST as a practical method for investigating sustainability were separated. Next among the remaining publications, their titles and abstracts were considered, and again, some of the remaining publications were removed. Meanwhile, the texts of some publications that appeared to be suspicious were also re-inspected. As a result of such filtering procedures, only publications were selected that were close to the objectives of the present study, through a systemic and holistic approach. Furthermore, a paper would be included in the investigation, if it—

- was published in 2010 or later;
- was a research paper (article)
- directly concentrated on various issues of sustainability and the problems in this area;
- drew on a GST-based method;
- addressed practical matters and a real case study;
- was written in English

Moreover, a publication would be excluded if it—

- only described a theoretical model or explicated an algorithm as a specific mathematical model or tool;
- only addressed one element or dimension of sustainability, while lacking a comprehensive investigation;
- did not use a GST-based method clearly and accurately;
- focused on other aspects of an economic or social system instead of sustainability;
- focused on a technical description or a solution;
- addressed issues beyond the scope of sustainability;
• did not have an available full text;
• presented a comment letter or was a book chapter;

The study utilized the process of search, selection, and analysis based on PRISMA, as a criterion and framework acknowledged by the scientific community. The reason PRISMA was used in the study as the guiding framework for the research was its popularity as an evidence-based minimum set of items tool for preparing systematic reports and meta-analysis. Figure 2 schematically depicts the process of search, selection, and analysis of the publications following PRISMA block diagram [28].

![Figure 2. Publication search process based on PRISMA 2009 block diagram.](image)

4. Results

Given the inclusion criteria and screenings conducted on the publications, it was revealed that 40 publications could meet the inclusion criteria and could be used for further investigation. Table 2 lists the publications and the information related to each one, including methods, objectives, and key findings. The publications selected are sorted according to publication year, and they addressed a wide range of notions associated with sustainability. Through scrutiny of the publications selected, 10 different areas explored through GST-based methods were observed: sustainability assessment, industrial sustainability, urban sustainability, energy sustainability, sustainability development, businesses sustainability, agricultural sustainability, sustainable products, tourism sustainability, and social sustainability.
Table 2. Summary of studies.

| Title                                                                 | Objective                                                                 | Methods   | Results                                                                 |
|----------------------------------------------------------------------|---------------------------------------------------------------------------|-----------|-------------------------------------------------------------------------|
| An Extended GRA Method Integrated with Fuzzy AHP to Construct a Multidimensional Index for Ranking Overall Energy Sustainability Performances [29] | Developing a new composite index for comparing energy sustainability performances | GRA       | flexible nature model can be used in different applications of sustainability |
| Key factors shaping the interactions between environment and cities in megalopolis area of north China [30] | Identifying the interaction effects between urbanization and environment | GRA       | Nine key factors are identified                                         |
| Urban Sustainability Evaluation under the Modified TOPSIS Based on Grey Relational Analysis [31] | Evaluating of urban sustainability | GRA       | Ranking the sustainability level of cities                              |
| The Dynamic Analysis and Comparison of Emergy Ecological Footprint for the Qinghai–Tibet Plateau: A Case Study of Qinghai Province and Tibet [32] | Analyze the sustainability | Grey model | Suggestions for protecting the local environment and restore ecological functions |
| A five-dimensional approach to sustainability for prioritizing energy production systems using a revised GRA method: A case study [33] | Determining the most appropriate energy producers | GRA       | Energy producers have been assessed by a five-dimensional approach to sustainability |
| Developing A Sustainable Urban-Environmental Quality Evaluation System in China Based on A Hybrid Model [34] | Establishing a system for evaluating urban sustainability | GRA       | Finding the three most important dimensions                              |
| Analysis model of the sustainability development of manufacturing small and medium-sized enterprises in Taiwan [35] | Developing a model to evaluate the sustainability development | GRA       | Identifying key sustainability indicators                               |
| Sustainable modeling in reverse logistics strategies using fuzzy MCDM Case of China Pakistan Economic Corridor [36] | investigating the impact of sustainable practices | GRA       | Negligible work has been done regarding sustainable modeling in reverse logistics strategies |
| Estimation of electronic waste using optimized multivariate grey models [37] | presenting a novel forecasting technique for e-waste predictions with multiple inputs | Grey prediction | A nonlinear multivariate grey Bernoulli model with convolutional integral is presented |
| A Hybrid Fuzzy BWM-COPRAS Method for Analyzing Key Factors of Sustainable Architecture [38] | Identifying the key factors of sustainable architecture | Grey MCDM | The key factors of creating engagement between buildings and other urban systems |
| An Integrated Multi-Criteria Decision Making Model and AHP Weighting Uncertainty Analysis for Sustainability Assessment of Coal-Fired Power Units [39] | Assessing the sustainability levels | GRA       | Expanding a novel hybrid MCDM method to the sustainability assessment |
| Integrating Environmental and Social Sustainability Into Performance Evaluation: A Balanced Scorecard-Based Grey-DANP Approach for the Food Industry [40] | Integrating environmental and social sustainability in performance evaluations | Grey MCDM | A case study is conducted on a U.S.-based food franchise                |
| Sustainable Venture Capital Investments: An Enabler Investigation [41] | Identifying enablers for sustainable venture capital investments | Grey MCDM | Presenting the government Policy                                         |
| Extracting key factors for sustainable development of enterprises: Case study of SMEs in Taiwan [42] | Investigating the sustainable development and innovation for developing a business model | GRA       | Finding the key factor for competitive advantages                        |
| Sustainability Evaluation of Power Grid Construction Projects Using Improved TOPSIS and Least Square Support Vector Machine with Modified Fly Optimization Algorithm [43] | Effectively evaluate the sustainability | Grey incidence | Providing a model for sustainability Evaluation                           |
| Assessment of the Sustainability Social Dimension in Machining through Grey Relational Analysis [44] | Assessing the performance of industrial sustainability indicators | GRA       | Analyzed the activities in order to encourage a sustainability culture |
| Title                                                                 | Methodology | Use Case                                                                 |
|----------------------------------------------------------------------|-------------|-------------------------------------------------------------------------|
| Modelling critical success factors for sustainability initiatives in supply chains in Indian context using Grey-DEMATEL [45] | Uncovering the Critical Success Factors for effective adoption of sustainability initiatives | 'Government Legalization' 'Community Welfare and Development' are most easily influenced factor. |
| Multi-attribute sustainability evaluation of alternative aviation fuels based on fuzzy ANP and fuzzy grey relational analysis [46] | Developing a multi-attribute sustainability evaluation model | Four alternative aviation fuels were studied by the model |
| Measurement and Prediction of Regional Tourism Sustainability: An Analysis of the Yangtze River Economic Zone, China [47] | Constructing a more comprehensive and scientific index system | Providing a reference to the study on the sustainable development of tourism |
| Structural model for sustainable consumption and production adoption—A grey-DEMATEL based approach [48] | Developing a structural model to evaluate the sustainable consumption and production adoption drivers | Providing a structural support to the managers |
| Integrating sustainability into supplier selection with analytical hierarchy process and improved grey relational analysis: a case of telecom industry [49] | Evaluating sustainable suppliers in the context of telecom industry | Solving the sustainable supplier selection problem of the telecom industry |
| Decision Mechanism for Supplier Selection Under Sustainability [50] | Sustainable supplier selection in sustainable supply chain | A new evaluation system for supplier selection was presented |
| Enlightening grey portions of energy security towards sustainability [51] | Determining priority order on investments and strategic dimension angles | Renewable energy projects are preferred over the conventional projects |
| Green material selection for sustainability: A hybrid MCDM approach [52] | Proposing a hybrid approach to select the optimal green material for sustainability | Providing a more accurate and effective decision support tool for alternative evaluation |
| A Grey Forecasting Approach for the Sustainability Performance of Logistics Companies [53] | Calculating corporate efficiency to forecast future sustainability values | Helping logistics companies develop operation strategies in the future |
| Multi-criteria group decision-making method for optimal selection of sustainable industrial building options focused on petrochemical projects [54] | Focus on sustainability aspects of industrial buildings to evaluate the sustainable indicators | The developed framework considers uncertainty alongside various preference orders and risk |
| Improving sustainable supply chain management using a novel hierarchical grey-DEMATEL approach [55] | Proposing a hierarchical grey decision-making trial to identify and analyze criteria | Applying the proposed hierarchical structure for supplier prioritization |
| Commercially Available Materials Selection in Sustainable Design: An Integrated Multi-Attribute Decision Making Approach [56] | Presenting an approach for selection of commercially available materials | Ranking alternative materials |
| Using a Hybrid Decision-Making Model to Evaluate the Sustainable Development Performance of High-Tech Listed Companies [57] | Sustainable development performance evaluation | Presenting a triple bottom-line concept as the sustainable development performance |
| Identification of critical success factors for sustainable development of biofuel industry in China based on grey decision-making trial and evaluation laboratory (DEMATEL) [58] | Identifying the critical success factors for promoting the sustainable development | The three factors, including government support degree, competitiveness, and local acceptability are identified |
| An Assessment of Sustainability for Turning Process in an Automobile Firm [59] | Presenting a sustainability assessment framework for turning process | A sustainability assessment framework has been proposed |
| An integrated sustainability assessment framework: a case of turning process [60] | Presenting an integrated sustainability assessment framework | Presenting an illustration of sustainability assessment framework |
| Grey decision Making as a tool for the classification of the sustainability level of remanufacturing companies [61] | Providing a new tool for decision making and the assessment of manufacturing operational excellence | Classifying the current state of remanufacturing operations |
| Title                                                                 | Method                                                                 | GRA | Description                                                                                       |
|----------------------------------------------------------------------|------------------------------------------------------------------------|-----|--------------------------------------------------------------------------------------------------|
| External Benefit Evaluation of Renewable Energy Power in China for Sustainability [62] | Evaluating the external benefits of China’s renewable energy power | GRA | PV, wind and biomass power have the greatest external benefit                                    |
| A systems thinking-based grey model for sustainability evaluation of urban tourism [63] | Establishing an index system and a grey comprehensive evaluation model | GRA | Supplements the evaluation modelling methods widely used in the area of tourism management         |
| General sustainability indicator of renewable energy system based on grey relational analysis [64] | Measuring the sustainability of a renewable energy systems              | GRA | Developing a general sustainability indicator                                                     |
| Assessing secondary soil salinization risk based on the PSR sustainability framework [65] | Developing a soil salinity risk assessment methodology                  | GRA | The salinity risk was strongly influenced by the subsoil and groundwater salinity and other factors, |
| A grey-based group decision-making methodology for the selection of hydrogen technologies in life cycle sustainability perspective [66] | Developing a grey-based decision-making for the selection of the best renewable energy technology | GRA | Twelve hydrogen production technologies have been assessed                                       |
| The grey relational degree measurement of city’s S&T input and sustainable economic development based on the data from Hunan province [67] | Discussing the correlation of S&T input and sustainable economic development | GRA | The correlation of S&T personnel and economic development is stronger than S&T expenditure and economic development |
| Application of improved grey relational projection method to evaluate sustainable building envelope performance [68] | Evaluating the building envelope systems for reducing energy losses    | GRA | Grey relational projection method is simple, practical, powerful tool in building envelope evaluation |

Table 3 shows the domains and topics probed into in each of the publications; the findings demonstrated that “sustainability assessment” was the sub-topic that was more explored through GST than other topics; 19 publications, out of the 40 ones selected, utilized GST-based methods for “sustainability assessment.” Meanwhile, 13 publications used GST to look into “industrial sustainability”; “urban sustainability” and “energy sustainability” as the areas that more frequently relied on GST than the other areas. Moreover, the top-10 areas most frequently addressed on Scopus were as follows in order of importance: environmental science, engineering, energy, social sciences, business, management and accounting, computer science, agricultural and biological sciences, mathematics, medicine, decision sciences. The frequency of each of these areas is shown in Figure 3.

![Figure 3. The top-10 areas most frequently addressed on Scopus](image-url)
Table 3. The domains and topics probed into in each of the publications. (The * sign in each column means the research area of the article)

| Papers (Authors, Year) | Urban Sustainability | Energy Sustainability | Sustainability Assessment | Sustainability Development | Businesses Sustainability | Social Sustainability | Agricultural Sustainability | Industrial Sustainability | Sustainable Products | Tourism Sustainability |
|------------------------|----------------------|-----------------------|--------------------------|---------------------------|-------------------------|-----------------------|-----------------------------|------------------------|----------------------|--------------------------|
| (Altintas et al., 2020) | [29] *               |                       |                          |                           |                         |                       |                             |                         |                     |                          |
| (Sun et al., 2020) [30] |                      | *                     |                          |                           |                         |                       |                             |                         |                     |                          |
| (Tang et al., 2019) [31] |                      |                       | *                        |                           |                         |                       |                             |                         |                     |                          |
| (Wei et al., 2019) [32] |                      |                       |                          | *                         |                         |                       |                             |                         |                     |                          |
| (Ebrahimi et al., 2019) [33] |                  |                       |                          |                           |                         |                       |                             |                         |                     |                          |
| (Shao et al., 2019) [34] |                      |                       |                          |                           |                         |                       |                             |                         |                     |                          |
| (Chang et al., 2019) [35] |                      |                       |                          | *                         |                         |                       |                             |                         |                     |                          |
| (Awan et al., 2019) [36] |                      |                       |                          |                           | *                       |                       |                             |                         |                     |                          |
| (Duman et al., 2019) [37] |                      |                       |                          | *                         |                         |                       |                             |                         |                     |                          |
| (Mahdiraji et al., 2018) [38] |                |                       |                          |                           |                         |                       |                             |                         |                     |                          |
| (Wu et al., 2018) [39] |                      | *                     |                          |                           |                         |                       |                             |                         |                     |                          |
| (Duman et al., 2018) [40] |                      |                       |                          | *                         |                         |                       |                             |                         |                     |                          |
| (Antarciuc et al., 2018) [41] |               |                       |                          |                           | *                       |                       |                             |                         |                     |                          |
| (Matinaro et al., 2018) [42] |                      |                       |                          | *                         |                         | *                     |                             |                         |                     |                          |
| (Niu et al., 2018) [43] |                      |                       |                          | *                         |                         |                       |                             |                         |                     |                          |
| (Sarria et al., 2018) [44] |                      |                       |                          | *                         |                         | *                     |                             |                         |                     |                          |
| (Luthra et al., 2018) [45] |                      |                       |                          | *                         |                         |                       |                             |                         |                     |                          |
| (Chen et al., 2018) [46] |                      |                       |                          | *                         |                         |                       |                             |                         |                     |                          |
| (Liu et al., 2018) [47] |                      |                       |                          | *                         |                         |                       |                             |                         |                     |                          |
| (Luthra et al., 2017) [48] |                      |                       |                          | *                         |                         |                       |                             |                         |                     |                          |
| Reference                                    | 2017 | 2016 | 2015 | 2014 | 2013 | 2012 | 2011 | 2010 | Total |
|----------------------------------------------|------|------|------|------|------|------|------|------|-------|
| Ahmadi et al., 2017                          |      |      |      |      |      |      |      |      |       |
| Rao et al., 2017                             |      |      |      |      |      |      |      |      |       |
| Singh et al., 2017                           |      |      |      |      |      |      |      |      |       |
| Zhang et al., 2017                           |      |      |      |      |      |      |      |      |       |
| Yu et al., 2016                              |      |      |      |      |      |      |      |      |       |
| Heravi et al., 2016                          |      |      |      |      |      |      |      |      |       |
| Su et al., 2016                              |      |      |      |      |      |      |      |      |       |
| Zhao et al., 2016                            |      |      |      |      |      |      |      |      |       |
| Chang et al., 2016                           |      |      |      |      |      |      |      |      |       |
| Liang et al., 2016                           |      |      |      |      |      |      |      |      |       |
| Bhanot et al., 2016                          |      |      |      |      |      |      |      |      |       |
| Bhanot et al., 2016                          |      |      |      |      |      |      |      |      |       |
| Golinska et al., 2015                        |      |      |      |      |      |      |      |      |       |
| Zhao et al., 2015                            |      |      |      |      |      |      |      |      |       |
| Wang et al., 2014                            |      |      |      |      |      |      |      |      |       |
| Liu et al., 2013                             |      |      |      |      |      |      |      |      |       |
| Zhou et al., 2013                            |      |      |      |      |      |      |      |      |       |
| Manzardo et al., 2012                        |      |      |      |      |      |      |      |      |       |
| Sun et al., 2011                             |      |      |      |      |      |      |      |      |       |
| Zheng et al., 2010                           |      |      |      |      |      |      |      |      |       |
| **Total**                                    | 7    | 9    | 19   | 6    | 3    | 1    | 1    | 13   | 4     |

* Note: The table above represents the number of times each reference was cited in the document.
WoS also showed 10 highly frequent areas as follows: environmental sciences, ecology, engineering, business economics, mathematics, science technology and other topics, computer science, energy fuels, geography, social issues, computational mathematical biology. The frequency of each of these areas is listed in Figure 4. The findings suggested that GST-based methods had various applications in different academic fields and were not limited to one specific sustainability sub-topic. In addition, among the GST-based methods, a grey relational analysis was the most frequently used method in the papers.

![Figure 4. The top-10 areas most frequently addressed on WoS.](image)

Among the 40 publications, 26 ones directly relied on this method or an extended variation of it to analyze sustainability; this observation revealed that grey relational analysis was a well-established approach among researchers. Following that method, grey decision-making methods were the second prominent approaches, as about 10 papers drew on various grey decision-making methods to look into different sustainability sub-topics. In the following sections, the 10 sustainability sub-topics, as addressed in the publications are further explained.

4.1. Sustainability Assessment

Issues related to sustainability have come to the fore as highly significant problems in modern management, given considerable climate change, a rapid reduction of natural resources, and the increasing frequency of natural disasters. Presently, it would be very important for governments, people, investors, and financial institutions to use a comprehensive model as a basis for evaluating the sustainable performance of systems. One of the overriding issues addressed in the papers selected was sustainability assessment; 19 publications clearly focused on various approaches and problems associated with sustainability assessment, and in practice the majority of the publications explored this particular area.

There were also remarkably integrated discussions that has, for instance, considered with sustainability in other fields (e.g., urban sustainability, sustainable energy). Using hybrid models or methods, especially multi-criteria decisions making (MCDM) coupled with grey relational analysis, proved to be one of the most commonly used approaches in the publications under study. For instance, Guo and Zhao (2015) utilized an MCDM method to evaluate the external advantages of renewable energy powers in China. They also used a hybrid grey fuzzy relational analysis framework
to overcome the decision-makers’ mental limitations and problems arising from incomplete data or an unknown distribution of data [62]. Among the publications selected, grey MCDM, which relied on grey relational analysis, was conceptually used to assess sustainable building envelope performance [68]. There was also an MCDM, combined with grey relational analysis, used to evaluate sustainability levels in coal-fire power units in China [39]. To reduce subjectivity and reach a comprehensive urban sustainability assessment, Tang et al. (2019) proposed a technique to prioritize orders through TOPSIS. Given decision-makers’ subjectivity and objective causes (e.g., defective data), there was a degree of uncertainty in the evaluation process, which could affect urban sustainability assessment; therefore, the authors used grey relational analysis to reduce uncertainty [31]. Furthermore, Wei et al. (2019) drew on the grey model to forecast sustainability in the future and simulate/predict ecological status based on environmental thermodynamics and long-term sustainability assessment.

Wei et al. (2019) explained that among all forecasting tools, the grey model, despite its simplicity, showed the highest level of acceptance with a certain degree of validity and it could remarkably forecast a system’s development with limited information in many areas, such as CO2, electricity consumption, and stock exchange prices. The corrected version proposed in their study could increase the reliability of findings [32]. Using grey models to evaluate sustainable energy was also a remarkable topic among the publications; for instance, an improved TOPSIS working according to grey incidence analysis was proposed by Niu et al. (2018) to effectively assess sustainability in power grid construction projects [43]. In another study, the sustainability of renewable energy systems, as a physical parameter, was evaluated through grey relational analysis and fuzzy set theory [64].

Manzardo et al. (2012) constructed a grey group decision-making method to select the best renewable energy technology (including hydrogen), by considering the lifecycle sustainability perspective. To overcome uncertainty in lifecycle sustainability assessment, the study relied on improved grey relational analysis. This method would enable decision-makers to make linguistic assessments of renewable energy technologies [66]. There was also an investigation that framed a multiple-trait sustainability assessment model in the case of alternative aviation flues. In this study, to determine the weights, fuzzy ANP was used, which could process interdependencies and interactions between the criteria. In addition, a fuzzy grey relational analysis was used to prioritize each alternative fuel for aerial transport. The study also drew on fuzzy grey logical analysis to reach a sustainability measurement for aerial transport under uncertainty and limited information [46].

4.2. Industrial Sustainability

Among the publications, after sustainability assessment, the notion of industrial sustainability was the second most important field of investigation; 12 publications used GST-based methods to explore industrial sustainability. In this field, sustainable supply chain and other issues were addressed by the researchers. As far as a sustainable supply chain is concerned, Luthra et al. (2017) used grey decision-making to construct a structural model for assessing sustainable consumption, drivers of production, and improvement of sustainability elements in a supply chain scenario in indeterminate environments. This approach not only identified causal relations between the drivers, but evaluated the strength of their mutual relationships. From the perspective of conceptual development, the study sought to evaluate the adoption of the drivers in sustainable consumption and production through the supply chain, which was itself an MCDM problem; to evaluate the drivers, they used a grey-based decision-making technique.

Luthra and colleagues’ (2017) model helped to figure out causal relationships between drivers, while clarifying the strength between such drivers under uncertain environments. Grey decision-making model was used because it could better determine the mutual relationships between the drivers identified in successfully implementing sustainable consumption/production trends in the supply chain. In fact, grey set theory could handle ambiguities resulting from human decision-makers [48]. Although sustainable supply chain has already been addressed by researchers, Mei Su et al. (2016) believe the studies in the literature lack a plausible justification for MCDM in the case of mutual hierarchical relationships with incomplete information; to fill this gap, they proposed a grey
hierarchical decision-making model to identify and analyze criteria and alternatives with incomplete information. By converting qualitative and quantitative information into a comparable measure, using grey theory to evaluate incomplete information, and using DEMATEL to measure mutual relationships between criteria, they built a comprehensive, hierarchical model for incomplete information in the analysis process. This new approach incorporated qualitative and quantitative criteria, while combining grey theory and DEMATEL [55].

Working on the data collected from financial statements of leading logistic firms in the world, Yu et al. (2016) constructed a data envelopment analysis (DEA) model to compute firms’ returns using a grey predication method that forecasted sustainability values in the future. In industrial logistics, the important predicator was operational performance, and the authors argued that using a grey model to predict performance with quantitative data could yield better predictable results compared to other methods [53]. In the area of industrial sustainability and sustainable supply chains, the problem of selecting suppliers is one of the thorniest issues; the reason for this is that over the past decades, with the emergence of sustainability, firms moved toward sustainable development to reinforce the sustainability of their suppliers. Initiatives in sustainable supply chains, such as suppliers’ environmental and social cooperation, could have a visible function in reaching the advantages of the triple bottom line and in contributing to a society’s sustainable development.

Considering this issue, Ahmadi et al. (2017) created an integrated, structural decision-making model to assess sustainable suppliers in the field of telecommunication industry, by combining analytical hierarchy process (AHP) and improved grey relational analysis. This model employed AHP to calculate the weights of sustainability criteria and used improved grey relational analysis to rank suppliers. The authors believed that grey relational analysis could resolve complicated decision problems, which encapsulated numerous variables, ambiguities, and individual subjectivity. In the integrated method proposed, the grey relational whitening process was delayed until the last stage, and it was ensured that anonymity and ambiguity were maintained throughout the computations. Such a process would make the method more flexible than other methods as they require the addition of opinions at the beginning of the process [49].

In the case of selecting suppliers in a sustainable supply chain, Rao et al. (2017) introduced a linguistic 2-tuple grey correlation degree; this mechanism could enhance efficiency, and operationally it could prevent loss and information distortion in the information collection process; it could, therefore, implement the advantage of grey relational analysis for all suppliers [50]. Sustainable production, too, was another area of interest in the field of industrial sustainability, which was dealt with in some publications through GST-based methods. Zhang et al. (2017) investigated an optimal selection of green materials via a grey MCDM method; they stated the method could provide a more accurate and effective decision-making support tool for evaluating alternatives or selecting strategies. The method used DEMATEL to analyze mutual relationships and the effect of each criterion, utilized ANP to compute final weights, and evaluated optimal green materials offered by each alternative using grey-TOPSIS [52].

Another area of industrial sustainability exploration, as observed in the publications, was sustainable manufacturing; two papers compared sustainability in different machining scenarios, in which grey relational analysis was used to assess the sustainability of the methods utilized. In these papers, a grey relational analysis was extensively used in machining to take into account the mutual impacts of various parameters in economic, social and environmental dimensions [59,60]. In another study, Golinska et al. (2015) configured a new tool working according to grey decision-making that could help entrepreneurs to analyze their product lifespan, engineering approach, and manufacturing process; through this tool, entrepreneurs could make decisions about improving operations in line with the requirements of sustainable policies [61]. This tool categorizes the current status of the re-manufacturing operation and then contributes to the identification and prioritization operations undertaken by companies. The authors demonstrated how the decision-making process in re-manufacturing companies could rely on grey decision-making to reach a higher degree of sustainability in their performance. The model proposed conditions characterized by incomplete and
indefinite data, while the mechanisms governing the modeled phenomena were only partially known [61].

4.3. Urban Sustainability

With expansive urbanism, today people pay more attention to the urban environment; air pollution, loss of greenery, water loss, contamination, and waste management difficulties have restricted sustainable development in cities and have encouraged many researchers to delve into urban sustainability; among the papers under investigation, seven (out of 40) addressed this issue. Because assessing environmental concerns effectively serves as a prerequisite for implementing an urban sustainability policy, assessing such a mode of sustainability has been one of the areas of interest explored by researchers in the publications under study. Tang et al. (2019) devised an urban sustainability system composed of 39 indicators falling under three categories (economic, social, environmental development), using an improved version of TOPSIS that relied on entropy to determine the weights of the indicators through assessment scores. They also utilized grey relational analysis to alleviate uncertainty in the assessment process. Grey relational analysis in this system could effectively reduce subjectivity in determining the criteria [31].

In another survey, Shao et al. (2019) sought to construct a system to assess the quality of urban sustainability in China, using grey possibility values [34]. Zheng et al. (2010), too, in their assessment of the quality of urban sustainability devised a hybrid MCDM and improved grey relational framework to assess envelope performance and optimize construction in the conceptual stage. They claimed the method could serve as a powerful tool for assessing envelopes and optimizing construction for building owners, manufacturers, designers, and assessors, because in determining the weights of the assessment indicators weights would be usually decided through subjective or objective methods in most MCDM problems. However, due to the ambiguities of commonly used methods, accurate results would not be observed, although GST-based approaches could handle such uncertainty and ambiguity [68].

In another investigation, the interaction between urbanism and the environment, along with effective factors and interrelationships between the two entities, was explored through grey relational analysis, two-way variance analysis, and simple effect analysis. This study used grey relational analysis to find the initial correlations between environmental variables and urbanism level [30]. Furthermore, another study using GST-based methods was employed to identify and prioritize the main sustainability indicators in contemporary Iranian architecture [38].

4.4. Energy Sustainability

In this era of expansive technological advancement, there is an increasing need for energy and services associated with it; such technologies could contribute to economic and social development, as one of the serious concerns of governments worldwide. Changing consumption patterns, demand volume, and other dynamic processes governing the international energy market have all underscored energy as a trending topic for research, especially in sustainability studies. Evidently, due to the same reason, energy sustainability represented one of the issues addressed in the publications under study; nine papers (out of 40 ones) explored this sub-topic.

In the publications in this area, MCDM methods were used to cope with the multidimensional and complex nature of energy sustainability, while incorporating it into grey approaches was a popular tendency among the researchers. For instance, Altintas et al. (2020) provided a substantial and revised version of grey relational analysis integrated with fuzzy AHP, creating a new composite index for comparing total sustainable energy performance in 35 OECD member countries. In this method, a grey relational analysis was used to rank the alternatives, and the authors believed that their integrated grey method, due to its flexible nature, could have various applications in sustainability [29]. In another study, Wu et al. (2018) utilized an MCDM combined with areal grey relational analysis to assess the sustainability level of units existing in coal-fired power units in China. The advantage of areal grey relational analysis proposed in this study, compared to common methods, lies in its lack of sensitivity to raw data (which normally involve incomplete and poor
information) and in its capability of determining the relationships between sequences of data, making neutral estimates, and even measuring the relationships between indicators [39]. Moreover, a grey incidence analysis, integrated with TOPSIS and its improved version, could create a grey complex proportional assessment to assess effective sustainability in electricity network construction projects in India; this method could offer a grey group decision-making approach used to select the best renewable energy technology (e.g., hydrogen) through lifecycle sustainability perspective [66]. Another hybrid method drew on a decision-making model of fuzzy grey relational analysis for assessing the external advantages of renewable energies in China [62].

A review of the publications under study and the ways their suggested methods affected their analysis samples revealed that using GST-based techniques had a significant function in strategic decision-making in energy and sustainability, and their applications could contribute to the organization of energy and larger systems. Of course, the application of GST in energy sustainability was not limited to integrated grey decision-making. The revised version of grey relational analysis technique (regulated by grey numbers) was used to rank energy producers, as a method to overcome ambiguity in linguistic values and subjective preferences [33]; it also measured sustainability in renewable energy systems as a psychical parameter through grey regression analysis [64], which could be another grey method in energy sustainability.

Liu et al. (2013) contended that uncertainties were the main challenge to sustainability indicators, and as such, they could be considered grey systems. GST not only considers uncertainties in sustainability indicators assessment, but also it processes the grey relationships among the components and degrees in sustainability assessment. Therefore, uncertainties in developing the sustainability index for renewable energy systems could be solved via grey relational analysis [64].

### 4.5. Sustainability Development

*Sustainability development* was also another topic of interest in the publications; six papers (out of the 40 ones) focused on this area. Sustainability development is a foundational notion in sustainability because to create a sustainable society, it would be necessary to first identify infrastructural indicators and adopt effectively sustainable policies. For instance, Chang Ou (2016) proposed a decision-making tool for assessing sustainability development performance in a company, using a hybrid grey DEMATEL model. He believed that GST could help to assess secondary data and determine the correlation between two sequences, while solving common problems in decision-making models. This hybrid model proposed measures the correlation between the criteria and can serve as a basis for assessing sustainable development performance of companies and as reference for sustainable development [57]. Following such an approach, Liang et al. (2016) used grey DEMATEL to identify vital success factors in sustainable development in the biofuel industry, prioritizing effective factors in this industry and recognizing cause-effective relationships between them. They relied on a general method in which decision-makers were allowed to use linguistic statements to express their opinions and alternatives, and numerous decision-makers were engaged in the process. Due to the ambiguity of real-world situations and incorrect human judgments, GST was situated in DEMATEL in their study.

Liang et al. (2016) observed that investigating complex problems in developing the biofuel industry and the effective relationships among the sustainability factors in the industry would make it difficult or even impossible to use accurate quantitative functions. Therefore, in ordinary decision-making models, relationships are not perfectly clarified due to subjectivity, ambiguity, and the immeasurability of values. Linguistic statements are normally used to describe beneficiaries’ opinions; GST, however, can efficiently combine such linguistic variables and is capable of solving problems associated with uncertainty and incorrect information. Thus, GST converts ambiguous linguistic conceptions into quantities [58]. For the very same reason, Heravi et al. (2017) introduced a new grey decision-making method called grey-utility-ELECTRE, which could encounter the challenge of inherent “uncertainty” in judgments by using grey numbers in ranking preferences. The authors stated that this extended framework would be more compatible with ambiguities in real world conditions [54].
4.6. Business Sustainability

Among the publications under study, three ones focused on sustainability in businesses. Out of these, two utilized hybrid grey decision-making methods. Antarciuc et al. (2018) used a grey-based DEMATEL approach and the opinions of investment experts in Saudi Arabia to identify the most important factors affecting investment in sustainable projects and possible cause-effect relationships between them. Because the traditional DEMATEL method would exhibit problems in the case of incomplete information, subjective judgment, and uncertainty, incorporating the method into the grey approach could reduce such problems. Grey-based DEMATEL, introduced in the literature on investment and business, could help decision-makers figure out which investment factors had a main function in the sustainability of businesses in the entrepreneurship environment and which combinations could leave the highest impact [41].

In another publication, Duman et al. (2018) explored sustainability in businesses and the effects of internal/external processes; they drew on a hybrid method composed of balanced scorecards and DEMATEL, in which GST was used to capture ambiguity and uncertainty. Through this hybrid method, they concentrated on the criteria of environmental and social sustainability in jobs performance assessment. Taking into account uncertainty and ambiguity, the approach suggested in this paper measured the impact of each criterion on other criteria; therefore, it could yield more certain and accurate assessments [40]. Matinaro et al. (2018), too, employed grey relational analysis and probed into how a business model could be constructed to contribute to small- and medium-sized enterprises; they focused on a concise set of major factors of sustainable development in the enterprises, to implement a more sustainable and compatible method in relation to the environment. Through grey relational analysis, the differences between the factors of sustainable development could be detected in the operational environments of enterprises. These differences emerged from market size, differences in management practices, and resource consumption [42].

4.7. Agricultural Sustainability

Another field of GST-based research that was concerned with sustainability was agricultural sustainability. Only one publication was found in this field, and it focused on building a method for soil salinity risk assessment through selecting a consistent set of risk factors. This study applied a hybrid approach that consisted of grey relational analysis and the AHP. Grey relational analysis was employed to compute the coefficients of grey relations between individual risk factors and soil salinity through locational observations. Although a causal relationship between the risk factors selected and soil salinity is sometimes evident, in this case, quantitative estimates attributed this causal relationship to other factors. The coefficients of data-driven grey relations displayed a “grey” relationship between the risk factors and soil salinity. In this case, the lack of transparency of data-driven grey relational analysis could be mitigated by the knowledge-based AHP method, which considered expertise and knowledge in the soil salinity problem. As a result, this hybrid method used to investigate agricultural sustainability could strike a balance between a data-driven approach and a knowledge-based approach [65].

4.8. Sustainable Products

Sustainable products represent another area scrutinized by four papers; globalization encourages production companies to utilize sustainable products through sustainably engineered technologies that could increase companies’ competitive advantage in the market. All of the four papers drew on integrated methods, including various decision-making techniques with multiple criteria, along with grey relational analysis. All of the papers clearly stated that applying grey relational analysis, besides offering simplicity and accuracy, made it possible to convert qualitative assessment factors to be used in quantitative analysis, while providing a thorough evaluation of multi-trait decision-making problems [36]. From the viewpoint of practical applications, hybrid grey decision-making methods for sustainability, particularly in the field of sustainable products decision-making, are very easy to
use and do not require any program or software package (they could be conveniently processed in Microsoft Excel where needed) [35].

Moreover, some hybrid grey decision-making methods and grey relational analysis (e.g., grey-DEMATEL) not only control uncertain judgments but also more flexibly deal with the ambiguity of cause-effective relationships between effective factors in decision-making for sustainable production; such methods could even determine causal relationships. Based on the surveys conducted, GST could be simply integrated into various decision-making methods to verify the validity of judgments, while the grey DEMATEL approach could discover cause-effect relationships among measures affecting key success factors in production processes and sustainable products supply [45]. Furthermore, in sustainable production, in the actual materials selection process, some variables must be naturally considered, while decision-making methods, coupled with grey relational analysis, would help designers determine the best materials [56].

4.9. Tourism Sustainability

Among the studies investigated, two papers addressed tourism sustainability; Wang and Pei (2014) tried to formulate an index system and a grey comprehensive evaluation model for analyzing urban tourism. Assessing the sustainability of urban tourism was regarded as a multi-layered problem with multiple indicators. Through a grey correlational analysis, they devised a new model to effectively solve complex and indeterminate problems in an urban tourism assessment system. In this study, the index system for assessing urban tourism development was created through a holistic and systemic view. The authors stated that the comprehensive grey model could effectively convert complex indicators into optimal membership degrees that are easily understandable [63].

Liu et al. (2018), too, constructed a comprehensive and scientific index system composed of economic, social, and environmental dimensions of tourism, and evaluated the sustainable and comprehensive level of tourism in 11 provinces and cities in Yangtze River area. Trying to probe into sustainable development in regional tourism, they focused on the relationships and connections between tourism, economy, society, resources, and the environment in this field through a grey model called GM(1,1). They used GM(1,1) to forecast coordinated tourism development in the next few years. They believed that forecasting coordination in sustainable tourism in the future of the economic zone of Yangtze River through GM(1,1) could help to understand the relationships between development, coordinated connections, and regional differences in the economic zone of Yangtze River, while providing a decision-making basis for regulating the regional, economic structure, preserving the ecological environment, and transforming the tourism industry [47].

4.10. Social Sustainability

Finally, social sustainability was the topic of one paper that specifically addressed this field. Sarria and Pastor (2018), in this paper, assessed the performance of industrial sustainability indicators in machining operations, by focusing on the social dimension. They used the Deming cycle as a tool for improvement, while the indicators were assessed through grey relational analysis as a suggested plan for improvement [44].

5. Discussion

As the publications under investigation revealed, the functions of GST in solving sustainability studies problems could be divided into a number of categories. Moreover, the applied areas of GST in sustainability studies showed some common specifications, including linguistic variables, long-term projects, technical demands, conflicting objectives, and uncertainty. One could claim that GST was seen as an approach used to analyze and model sustainability issues that are characterized by incomplete/limited information and random uncertainty. A review of the publications selected and scrutinized in the field of sustainability clarified that GST could most basically contribute to the improvement of decision-making methods, predication, and uncertainty-based analyses.
Soni et al. (2017), as an instance, observed that GST-based MCDM methods had a major role in decision-making and GST applications could help to organize energy and larger systems so that strategic associations can be developed for sustainable energy planning [51]. Uncertainty and incomplete information are two issues that appear in a decision-making situation, particularly when various objectives and different criteria are involved in decision-making. The majority of the publications under study pointed out that GST was a powerful tool for sustainability-related decision-making because issues in this field are characterized by a shortage of information. Furthermore, verifying results through various methods to overcome uncertain data could further enhance the application and capacities of GST.

Meanwhile, using hybrid GST-based methods, instead of common statistical methods (e.g., regression, fuzzy approaches, neural networks, and rough sets) was an interesting trend observed in the papers. In sustainability issues, as multifaceted systems, dealing with defective data is a common problem, and the most important advantage of GST in sustainability studies lies in its lack of sensitivity to raw data values. GST-based methods, under conditions, including incomplete and poor information, could make neutral estimates by determining data sequences [39]. In addition to the capability to make calculations under uncertainty and with incomplete information, another advantage of GST is that it can offer methods that do not require a very large sample size or sample distribution for ranking alternatives. Grey relational analysis, which uses existing data, determines the links between sequences.

Altintas et al. (2020) observed that hybrid grey relational analysis methods could every effectively solve the problem of ranking alternatives in sustainability problems [29]. Another specification of GST-based approaches, which distinguishes them from other methods (especially common statistical analyses), is that such approaches could assess relationships between variables/factors through a relatively limited amount of data without needing a definite statistical distribution. For instance, the difference between GST and other methods (e.g., regression analysis or factor analysis) directly lies in the validity of datasets, as these methods, contrary to grey relational analysis, particularly emphasize sampling styles and numbers.

Grey relational analysis does not require a definite number of samples, a normal distribution, or hypotheses for analysis. Grey relational analysis could help address processes with indeterminate inputs, multiple variables, discrete data, and dishonesty while compensating for the weaknesses of regression analysis. GST-based models provide sequences with simple calculations. They could be applied to a limited amount of data that do not need to be compatible with normal distributions; this feature would yield a better analysis of systems in sustainability studies [42]. Moreover, a grey relational analysis could process both linear and non-linear relations [30]. In sustainability studies, due to the uncertainty of systems, complexity, and non-linearity, investigating systems without considering a specific sample distribution through a non-linear approach would be more practical and closer to reality. Furthermore, in most sustainability studies that rely on GST, some tools are used to assess weights or linguistic preferences. That is, GST is associated with studies where some of the information is presented by a specialized board. In various sub-fields of sustainability, using precise, quantitative functions to illustrate relationships between factors affecting sustainability is a thorny or even impossible procedure. Additionally, in assessment and decision-making processes, and in cases where there is a shortage or lack of numerical values for comparison, decision-makers normally tend to express preferences through linguistic values. However, these linguistic preferences usually involve uncertainty and ambiguity in decision-making processes. GST is usually used to deal with such linguistic variables because it is able to handle uncertainty and incorrect information issues.

Transforming ambiguous linguistic values into quantities could be accomplished through GST. As a result, GST is usually included in decision-making models associated with sustainability [40]. Broadly speaking, judgments in sustainability-related decision-making models are normally uncertain and cannot be realized through a precise value. The advantage that highlight GST as a decision-making framework in sustainability is its ability to deal with any ambiguous and incomplete data. GST-based models, generally speaking, require fewer data points than other models [54]. Manzardo et al. (2012) observed that GST enabled decision-makers to perform linguistic assessments
in terms of renewable energy technologies, including hydrogen. In their investigation, linguistic statements were improved as connections between decision-makers’ judgments and grey relational analysis [66].

Shao et al. (2019) found out that grey possibility values in assessing the quality of sustainable environment could reduce experts’ uncertainty and increase the accuracy of results [34]. Hybrid grey decision-making methods, then, allow beneficiaries to use linguistic statements and express their opinions in various areas of sustainability. As such, critical success factors in sustainable development could be identified through preferences and collective wisdom. Most decision-making techniques can be successfully incorporated into grey theory, thus enhancing judgments [49]. Extended grey decision-making models enable beneficiaries and decision-makers to use linguistic expressions, through which ambiguity and incorrect judgments in human decision-making could be overcome. Such models also make it possible for different groups of beneficiaries and decision-makers to participate in decision-making processes. Users of such methods could invite more groups of beneficiaries and decision-makers for participation in analyzing the relationships between factors affecting sustainability, thus providing a more complete investigation [58].

Meanwhile, most multi-trait decision-making approaches assume that criteria are independent of each other, although this is not a realistic assumption for real-life situations. In practical conditions in sustainability, too, the unpredictable environment could give false impressions to human decision-makers and lead to flawed judgments; ordinary decision-making methods are not able to cope with this uncertainty. Combining GST with common decision-making methods, such as DEMATEL, could help to predict and understand the complex, causal relationships between various factors affecting sustainability, and to categorize them into cause-effect sets with varying intensities of association.

Luthra et al. (2018) believe that a grey DEMATEL method could not only control indeterminate judgments, but also it could flexibly handle ambiguities in cause-effect relationships. However, other modeling methods are not able to confirm cause-effect relationships, although a causal technique (grey-DEMATEL) could accurately determine the strength of causal relationships and measure a lack of transparency in data [45]. Another advantage of GST in improving sustainability models is the balance it strikes between data-driven through GST and knowledge-based approaches. For instance, the lack of transparency in data-driven grey relational analysis could be compensated by the knowledge-based AHP, which is an interesting method used to consider expertise and knowledge in sustainability issues. Therefore, one could assert that hybrid grey MCDM methods could establish a balance between data-driven and knowledge-based approaches [65]. Generally, GST-based methods could serve the analysis of both qualitative and qualitative data [36].

Cheng and Cheng (2019) found that grey relational analysis, besides such advantages as simplicity and accuracy, provided the option of converting qualitative assessment factors into quantitative ones for analysis, while generating a thorough evaluation in multi-trait decision-making. The advantages of this method include its ease of use as a facile technique helping managers to make decisions about complex criteria. Grey relational analysis could be used to analyze or construct a model of an indeterminate/incomplete information system.

Additionally, through predication and decision-making methods, one could use a grey relational analysis to detect and understand a system’s status. As such, a grey relational analysis can effectively serve the analysis of uncertainty, multiple inputs, discrete data, and incomplete data. From a practical perspective, such methods can be easily implemented and do not require any program or software package; they could be simply processed in Microsoft Excel [35]. Compared to other methods (e.g., fuzzy logic), GST-based methods do not need extensive databanks of classified rules. Creating a databank of rules usually involves time-consuming procedures to reach an appropriate change compatible with experts’ knowledge. This advantage of GST could relatively reduce numerical calculations in sustainability research [61].

Yu et al. (2016) claimed that using a grey model to forecast sustainability performance through quantitative data could bring about better forecasting results than an artificial, neural network. They explained that grey forecasting was a good tool for predicting the values of mutual relations in the future among factors based on quantitative data [53]. It must be emphasized that sustainability issues
are complex, multidimensional, and relatively systematic. Because sustainability issues are a combination of economic, social and environmental concerns, they could be approached as complex systems. This complexity affects all sub-systems associated with this field. Clearly, increasing complexity could lead to uncertainty and ambiguity. To handle a considerable degree of ambiguity, uncertainty-based theories and methods must be acknowledged.

Furthermore, analyzing complex and multifaceted issues demands the collection of related data. Complexity, uncertainty, and inaccessibility of large sets of data have led researchers concerned with sustainability to view it as a complex and indeterminate economic, social, and environmental system; they have dealt with its problems through uncertainty-based methods as suggested by GST. Such methods could handle problems with limited information. Additionally, many researchers confirm that GST-based methods, as far as efficiency is concerned, are operationally simpler (but more advanced) mechanisms [12]. The results of this systematic review revealed that GST-based approaches were rapidly and successfully growing in sustainability analysis; however, considering the expansive breadth of all sustainability issues, it must be noted that GST-based approaches, despite their applications and advantages, have been widely utilized in the literature.

As a result, scholars and researchers must specifically consider GST in their sustainability analysis models. Due to incomplete information in sustainability problems and their complexity, such systems appear grey to humans, and this is the very reason why uncertainty must be taken into account in estimates, calculations, solutions, and decision-making processes. Addressing these issues, while ignoring the all-encompassing problem of uncertainty, would be a tactical mistake in finding appropriate solutions. Indeterminate systems and topics must be analyzed through methods that involve uncertainty and imperfect human understanding. Moreover, many important GST-based methods (e.g., grey control methods) and hybrid methods in this area (e.g., system dynamics) have been ignored—while using grey control to process dynamic governing sustainability could serve as a novel field for further exploration.

6. Concluding Remarks

The international movement toward more sustainable societies over the past years has come to the fore as one of the overriding issues among researchers, policy-makers, social/economic activists, and all social strata. Sustainability is an interdisciplinary concept composed of various economic, social, and environmental dimensions, and due to this level of diversity, studies in this area are specifically complex. Sustainability, then, is a notion that works as a system and consists of complex structures with social, economic and environmental elements. Doubtlessly, with numerous elements and complex relationships among them in the wide range of sustainability topics, they must be regarded as uncertain and complex systems. On this account, GST as a method for understanding, modeling and integrating uncertainty in complex and uncertain systems, especially when captured data are inconsiderable.

However, no particular or organized investigation ever tried to report the outcomes of GST-based methods as mechanisms for probing into uncertain systems in sustainability studies. As a result, this study sought to fill this gap and to provide an updated literature review concerned with the role and impact of GST-based methods in sustainability research, as one of the most important areas of economic, social and environmental investigation. Through a systematic scoping review, this study explored the diverse range of studies dealing with sustainability and its sub-topics following a GST-based approach. The findings showed that using GST-based methods in this field underwent a rising trend over the past ten years, while more researchers drew on such methods to survey sustainability. As a general conclusion from the studies conducted in this research, three main points can be acknowledged. First of all, in the recent decade, the internationalization of GST is rapidly developed. It could be viewed from International journal publications and different areas of applications of GST. Secondly, regarding sustainability, many papers focused on applying GST methods in different branches of sustainability studies, as mentioned in Section 4. Third, according to the reviewed articles, it is confirmed that GST can be applied in the development of sustainability studies very well.
An in-depth investigation of the papers selected revealed 10 sub-fields in which GST-based methods were used in the publications: sustainability assessment, industrial sustainability, urban sustainability, energy sustainability, sustainability development, businesses sustainability, agricultural sustainability, sustainable products, tourism sustainability, and social sustainability. The results showed that sustainability assessment and industrial sustainability more frequently used GST-based approaches. Furthermore, among these approaches, a grey relational analysis and other grey decision-making methods were most commonly employed in the publications selected. The papers addressing the practical areas of GST in sustainability studies shared linguistic variables, long-term projects, technical demands, conflicting objectives, and uncertainty.

Plausibly, GST could serve as an approach to sustainability analysis and modelling, in which information is usually limited and incomplete. GST could also detect random uncertainty in sustainability systems because they are basically characterized by a shortage of information, insensitivity to raw data, and a lack of normally distributed statistics. GST-based methods in sustainability studies, which normally involve insufficient and weak information, could make neutral estimates by determining sequences of data. Moreover, a grey relational analysis could effectively process both linear and non-linear relationships. In various sustainability sub-fields, GST could be used to overcome ambiguities and linguistic preferences while enhancing judgment quality. Additionally, in practical sustainability situations, the unpredictable surrounding environment could lead to incorrect judgments made by human agents, although using GST would make it possible to predict and understand the structure of causal relationships among factors affecting sustainability, categorize them into cause-effect groups, and determine the intensity of the associations between the elements involved. GST-based methods not only control indeterminate judgments, but also, they can flexibility handle ambiguity in assessing cause-effect evaluations. They are also capable of striking a balance between data-driven and knowledge-based approaches. Most of the publications under investigation claimed that, compared to other methods such as neural networks, statistical procedures, fuzzy sets, and rough sets, GST did not require forming databanks of classified rules and it could be even more efficient and practical in dealing with sustainability issues as complex systems, while needing fewer numerical computations.

Finally, a serious weakness in most of the sustainability studies, in terms of GST, was the lack of consistent, organized and systematic views about the topics. Apart from systems thinking, most of the studies exclusively investigated the relationships between the variables or decisions, while focusing (in part) of social, economic, or environmental outcomes. Meanwhile, cause-effect and dynamic relationships were not addressed in many of the publications. Systematic approaches, holistic thinking, causal relations, cause-effect loops, feedback loops, and regular/dynamic cycles among elements, and missing loops were explored in GST-based applications to sustainability studies perceived as economic, social and environmental systems. As it seems, using comprehensive approaches and systems thinking methods regulated by GST could help to reach better results in sustainability analysis. Grey control and the methods associated with it could help to create very interesting, practical and effective methods for solving social, economic, and environmental issues, which are usually ignored. Grey control seems to need more consideration, while integrating it with the system dynamics method and using it in sustainability studies could prove to be highly original lines of research for future exploration.

As a result, suggestions for researchers and as potential directions for future research could be social sustainability, agricultural sustainability, and tourism sustainability. Although extensive research has been done in the areas of sustainability assessment or industrial and energy sustainability, the fields of social, agriculture and tourism sustainability have been neglected, and researchers need to pay more attention to these areas in future research. The use of GST-based methods in these areas to analyze and solve problems can be a strategy for future research. Moreover, in addition to assessing sustainability, other areas, such as the study of factors affecting the maintenance and development of sustainability, need more attention. Researchers are also advised to pay more attention to holistic and systemic approaches, and combine them with GST to analyze sustainability issues. Combining grey control methods with system dynamics to simultaneously
analyze the economic, social, and environmental aspects of sustainability can be a significant and pristine approach to future research. Researchers in this field, instead of focusing solely on the problem-oriented approach, should focus on the system thinking strategies.

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