SUSTAINABLE ENERGY DEVELOPMENT: HISTORY OF THE CONCEPT AND EMERGING THEMES

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Abstract

Sustainable energy development is a complex multi-dimensional concept that can vary in meaning based on the context it is applied in and the perspective of the user. The role of energy in achieving sustainable development was recognized when the concept was first put forward in 1987. However, what that role consisted of was not made clear. Since then, the concept of sustainable energy development has developed to become a prominent policy objective on the international agenda, as evidenced by the introduction of the UN's Sustainable Development Goal 7 on energy. This paper presents an overview of the history of the concept as well as its emerging themes. Through a citation analysis, the most cited open-access publications relevant to the concept were identified. A thematic analysis of these most cited publications led to the identification of four interrelated themes of sustainable energy development; access to affordable modern energy services, sustainable energy supply, sustainable energy consumption, and energy security. The overarching goal of sustainable energy development was defined as furthering sustainability. Equitable access to affordable and reliable modern energy services is integral to sustainable development. A transformation of the current energy system is necessary to reduce its harmful impacts, both on the supply and demand side. This transformation is not possible unless it is economically viable through, for instance, cost-competitive technologies and changes in energy pricing to reflect the external costs of energy.

Highlights

- Sustainable energy development is a young multi-dimensional concept
- Common themes of sustainable energy development are identified
- Access to modern energy services for all is essential to further sustainable development

Keywords

Sustainable energy development; Energy policy; Sustainable development; Literature review; Thematic analysis; Citation analysis

Word Count

10,060

List of abbreviations

CSD – Commission on Sustainable Development
EEA – European Environment Agency
EISD – Energy Indicators for Sustainable Development
ETP – Energy Technology Perspectives
IAEA – International Atomic Energy Agency
IEA – International Energy Agency
IRENA – International Renewable Energy Agency
ISD – Indicators for Sustainable Development
ISED – Indicators for Sustainable Energy Development
MDGs – Millennium Development Goals
RoMEO – Rights Metadata for Open-Archiving
SDG – Sustainable Development Goals
SE4ALL – Sustainable Energy for All
SED – Sustainable Energy Development
UN – United Nations
UN DESA – United Nations Department of Economic and Social Affairs
UNDP – United Nations Development Programme
UNIDO – United Nations Industrial Development Organization
WEA – World Energy Assessment
WEO – World Energy Outlook
WSSD – World Summit on Sustainable Development

1. Introduction

When the concept of sustainable development was first formally put forward in 1987 in the *Our Common Future* report by the UN, the role of energy in achieving sustainable development was recognized [1]. However, what that role consisted of was not made clear. In 2000, the United Nations Development Programme presented a new development paradigm in its *World Energy Assessment* report. There the concept of sustainable energy development was introduced where the impacts of energy development on the economy, society, and environment were considered [2]. In 2001, the IAEA, along with other international organizations and countries presented an initial attempt at developing indicators for sustainable energy development, at the Ninth session of the Commission for Sustainable Development, which further shaped the concept [3]. Sustainable energy development (SED) is a complex and multi-dimensional concept that can vary in meaning based on the context it is applied in and the perspective of the user [4]. The role of energy in achieving sustainable development was further recognized and defined in 2015 with the introduction of goal seven of the United Nation's Sustainable Development Goals, "*Ensure access to affordable, reliable, sustainable and modern energy for all"* [5]. Since the *Our Common Future* report in 1987, the role of energy in sustainable development and what sustainable energy development entails has been further defined. It is now firmly on the political agenda, in particular, due to raised environmental concerns and depleting fossil fuel sources.

Multiple different themes or issues of sustainable energy development exist. These have evolved and changed through time, similar to other issues of sustainable development. Initially, energy was discussed in the context of reducing greenhouse gas emissions and improving air quality [6]. Currently, sustainable energy development is viewed more holistically, where all three pillars of sustainable development are accounted for: economy, society, and environment. Thus, the role energy plays in promoting economic growth and social development is recognized [2]. Considering increasing energy demand and depleting fossil fuel sources, energy efficiency and a transition towards renewable energy sources are emphasized [7]. Environmental degradation with the associated health and social impacts has even further pushed this energy transition [2]. While the topic of energy security has been prominent for some time, it is now viewed as a part of sustainable energy development, which can involve actions such as diversifying energy sources with an emphasis on domestic and renewable resources [8]. None of this is achievable without the necessary political will and policy changes to push a transformation of current energy practices [2].

The objectives of this study are twofold;

1) examine how the concept of sustainable energy development materialized
2) identify emerging themes of the concept

These objectives are met through a review of the relevant literature. The history of the concept of sustainable energy development is examined to analyze how it has become a key policy objective integral to sustainable development. The most influential publications on sustainable energy development are identified through a citation analysis where the most-cited open-access publications are identified. Subsequently, a thematic review is carried out of these publications to identify emerging themes of the concept. To the best of our knowledge, this is the first comprehensive review of the concept of sustainable energy development, its history, and emerging themes based on citation analysis.

2. Method

2.1. Systematic literature review

The study aims to analyze the concept of sustainable energy development, how it has become a prominent policy objective, and what this multi-dimensional concept encompasses. A systematic literature review was carried out to address these objectives. A systematic approach to a literature review increases the comprehensiveness of the search and minimizes potential bias while ensuring rigorous and transparent methods [9,10]. The review consisted of three main steps; literature search, citation analysis, and thematic analysis described in detail in the following paragraphs. An initial pool of publications was identified through the literature search. This search was restricted to openly available publications through either open access publications or self-archiving. Authors often choose to self-archive, i.e., make a free copy of their publication available online, to make their publications more accessible. Despite restricting the literature search to openly available publications, only about 20% of publications were excluded at this step. The citations of these publications were analyzed to identify the most cited publications in the field. Thereafter, a thematic analysis was carried out of these most cited publications to identify emerging themes of SED. It is important to note that while the literature search was limited to openly available publications, the results of the citation analysis were not.

2.2. Literature search

The literature search consisted of three main steps:

1. *Search databases for the search string "sustainable energy development"*

A combination of different databases is recommended for systematic literature reviews to identify all relevant literature [11]. The selection of databases greatly depends on the field of science. As the topic of interest for this analysis was an interdisciplinary topic that rests within numerous disciplines, field-specific databases, such as medical ones, were excluded. When selecting which databases to use, three commonly used non-subscription-based databases were scoped for the search string "sustainable energy development": 1,515 results from ScienceDirect, 521 from Scopus, and 323 from Web of Science. For

this study, only publications in English were considered. No time limitation was put on documents to allow for an analysis of the history of SED.

2. Limit search to open access publications

Invariably, citation analyses are preceded with a restricted literature search or selection of relevant publications to determine an initial pool of publications for further study [12,13]. Quental and Lourenço defined "narrow and precise criteria" for their literature search to ensure the retrieval of relevant papers [14]. Generally, these search criteria significantly reduce the number of results found in the literature search. For this study, restricting search results based on relevance was thought to introduce the authors' bias of what are important issues of SED. Therefore, a relevance criterion could taint later results, namely, the identification of emerging themes of SED. Instead, the literature search was limited to publications that were readily available to the researchers, such as through open access journals or self-archiving (See Table 1). One of the reasons for this criterion was that some of the search results could not be accessed, such as books that were not available to the researchers. Furthermore, the benefit of this criterion is that it allows for the replication of this analysis by others.

Table 1: RoMEO colors.

The table shows the meaning of different archiving colors [15].

Gold	Open access
Green	Archiving allowed for pre-print and post-print
Blue	Archiving allowed for post-print
Yellow	Archiving allowed for pre-print
White	Archiving not supported

Due to the open-access criterion, some search results, including books, book chapters, conference proceedings, and journal articles, were excluded at this stage. Only journal articles that are made available in either open access journals or repositories were kept. The SHERPA RoMEO archiving colors were used to guide this step [16]. The purpose of the RoMEO (Rights Metadata for Open archiving) project was to analyze the rights of authors to self-archive their research [17]. In this project, a publishing color chart was developed that indicates the archiving policies of peer-reviewed journals [15]. For this study, the web-based SHERPA RoMEO database was used to identify the categorization of journals [16]. Articles published in journals categorized as gold, green, blue, or yellow, see Table 1, proceeded to the next step of the literature review. For these journals, the authors can self-archive some version of their paper. In the end, over 80% of search results were kept despite the open-access search criterion. The majority of journals allow for self-archiving in some form and, therefore, only a small number of journals are classified as white.

3. Integrate results from the different databases and eliminate duplications

In the end, a total of 1,253 publications were identified that met the search criteria laid out. The citations of these publications were analyzed further in the next step of the literature review process. It is important to note that the citation analysis itself was not limited to openly available publications, and, therefore, publications identified as influential could be published in, for instance, a closed or white journal.

2.3. Citation analysis

Citation analysis is the assessment of bibliographic references, which can indicate scientific interaction between researchers within a field [13,18,19]. In 1972, Garfield first proposed that citations could be used as a metric for scientific activity and influence, which eventually led to the creation of the journal Impact Factor [14,20]. According to Garfield, frequently cited publications at least have a high level of utility and are of interest to researchers in the field [21]. The premise of citation analyses is that high-quality work is cited more often than low quality work [22]. Thus, the frequency of citations can be an indicator of the „importance and qualitative value“ of a document [23] or its “research impact” [22]. Furthermore, highly cited publications can represent a central contribution to the field [23] or could be considered influential in shaping it [24].

Citation analyses have been found useful to study the history of a concept or a scientific discovery, which fits well with the goals of this analysis [25,26]. Generally, this approach involves analyzing the citations of a pool of publications found through a literature search to identify the most cited documents [13,24]. Citation analysis can be a lengthy process that involves numerous labor-intensive steps. For this study, five mains steps were taken that are described further in the following paragraphs.

1. *Extract citations from publications identified in the literature search*

An initial pool of publications for the citation analysis was identified through the above literature search. The first step of the citation analyses involved extracting the references of those publications to create a list of relevant references. Therefore, 1,253 publications were downloaded, and their 55,152 references were manually extracted and transcribed into an Excel sheet. Through this step, an electronic database was created that could be analyzed further [23]. On average, 44 citations were made per publications; however, in some studies, hundreds of references were made. This step was one of the most time-consuming of the citation analysis.

2. A*ggregate identical references*

Variants of the same references were aggregated to shorten the initial long list down to 48,382. As citations could be formatted differently and could contain, for instance, spelling errors, a combination of author information, title, and date of publication was necessary to enable this aggregation [14].

Citations did not directly align when the list of references was alphabetized, making the aggregation a lengthy process.

3. Count number of times cited

The number of times publications were cited was counted to identify the most cited ones. As the pie chart in Figure 1 shows, the majority of publications were referenced only once. A similar result was produced in Quental and Lourenço's citation analysis of the sustainable development literature, where 87% of publications were cited only once [14]. The number of publications drops steadily with a higher number of times referenced. The most cited document was referenced 63 times.

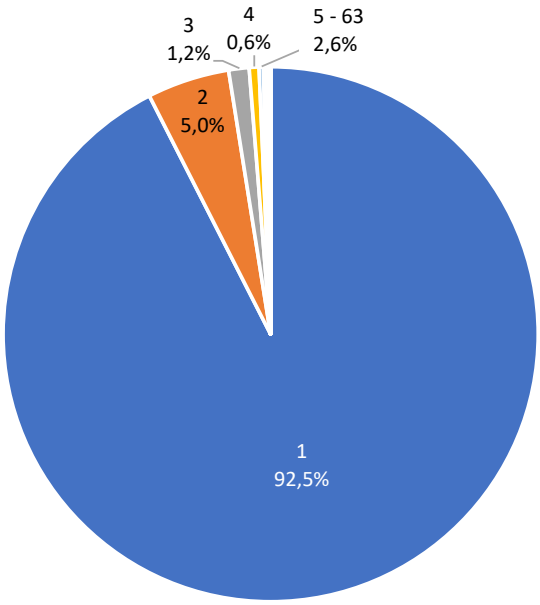

Figure 1: How often were references cited? *Pie chart showing the distribution of how many times references were cited.*

4. Identify the most cited publications

The most common approach to determine the most cited publications is simply to select a specific amount of most cited publications. Citation analyses were found that identified as few as ten most cited publications [27] to as many as to 60 [14], although most studies identified the 20 most cited publications [12,13,19,26]. For this analysis, an approach of identifying the 30 most cited publications was taken, which was deemed an appropriate amount to be influential in the field of sustainable energy development. This approach meant that publications cited at least thirteen times were considered further, which resulted in a total of 34 most cited publications. Appendix A includes a list of these most cited publications.

5. Analyze results

One publication was cited to by far the most often, or 63 times, and that was the UN's *Our Common Future* report, which was also the oldest publications identified as influential [1]. Figure 2 shows the origin of the most cited references, mainly, UN, IEA, and journal articles. The nine most cited references discussed SED at a global level and, thus, applied to many, both UN reports and frequently cited paper in the field. These results are similar to Quental and Lourenço's bibliometric analysis of the sustainable development literature [14]. The topic of 14 of the 34 documents was SED of a single country or region, of which eight analyzed the situation in Turkey and three in Malaysia. An emphasis was placed on examining the concept generally to meet the objectives of this study, and not the specific challenges the country in question was facing.

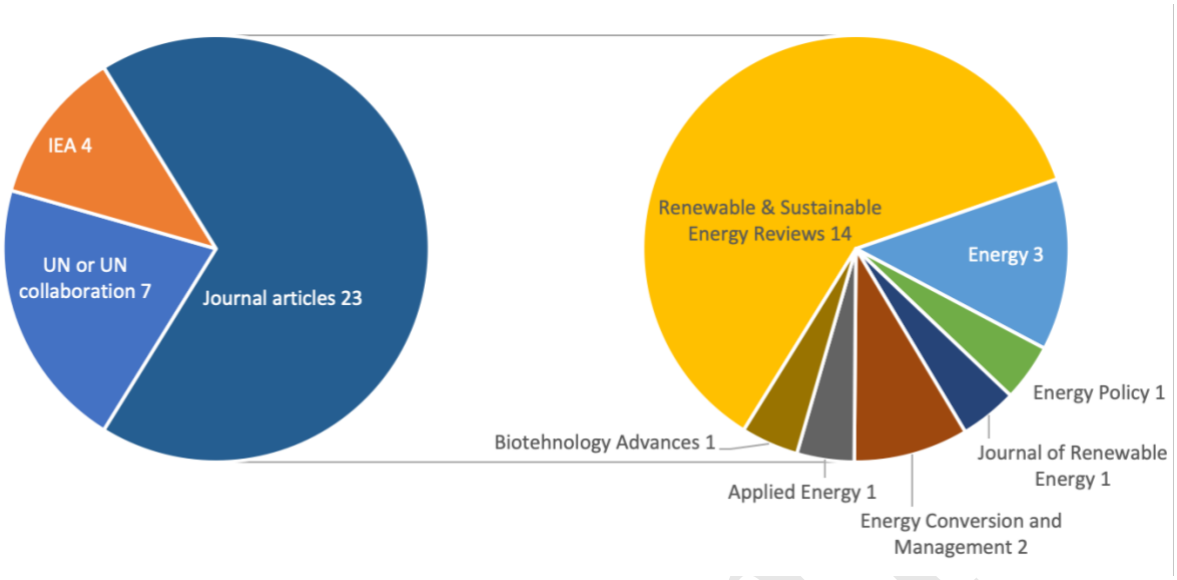

Figure 2: Publishers of most cited publications. *Pie of pie showing where or who published the most cited publications.*

Citation analyses often involve steps of cluster formation and interpretation to identify the main categories of research in the field [13,23,24]. Many of the publications identified as most cited were found too broad to fit within just one cluster, such as the UN's Our Common Future report, and the IEA's World Energy Outlooks [1,28–30]. Therefore, a thematic analysis of the contents of most cited publications was found more fitting to address the objectives of this study. A similar approach was taken by Liñan and Fayolle, where citation and thematic analysis were combined [24].

2.4. Thematic analysis

The purpose of the thematic analysis of the most cited documents was to identify emerging themes of sustainable energy development and assess the current understanding of the concept. The thematic analysis was rooted in Glaser and Strauss's grounded theory, where ideas and themes were not chosen before the analysis but derived from the data collected and developed throughout the process [31]. This approach is sometimes described as a continuous cycle of data collection and data analysis [32]. A six-step iterative method for the thematic analysis was developed based on an established framework for qualitative research by Braun and Clarke [33,34], described further below:

1. *Familiarization with publications*

The 34 most cited publications were read with a focus on sections relevant to sustainable energy development and not country-specific challenges. Initial ideas about the data and potential patterns were recorded [33].

2. *Generation of codes for each publication*

Each publication was manually coded with the research questions of this study in mind: examine how the concept of SED materialized and identify its emerging themes. Therefore, text in the publications that described, for instance, defining elements of SED, underlying challenges, and necessary actions was coded. According to Boyatzis, codes refer to 'the most basic segment, or element, of the raw data or information that can be assessed in a meaningful way regarding the phenomenon' which in this case is SED [35]

3. *Identifying initial themes for each publication*

The constant comparison method was used to identify and refine patterns in the codes [31]. Through this process, similar codes were grouped to form initial categories or themes for SED [32]. As some publications were lengthy, up to 800 pages, it was deemed better and more manageable to code and, subsequently, group codes into potential themes for each publication at a time. No software was used except Excel for the organization of codes.

4. *Integration of themes and codes*

The various themes and codes from each publication were integrated to produce overarching themes of SED. The constant comparison method was also useful during this process [31].

5. *Review themes*

The overarching themes were checked against initial codes. Furthermore, several thematic maps were created to refine themes further and identify connections and overlaps, as suggested by Braun and Clarke [33].

6. *Define and name themes*

A clear definition of each theme was generated [33]. A total of four themes of sustainable energy development were identified along with one overarching goal, further detailed in Chapter 3.2. *Key themes of sustainable energy development.*

3. Results and discussions

3.1. History of sustainable energy development

In this chapter, the first objective of this study is addressed, an examination of how the concept of sustainable energy development materialized. The 34 most cited publications were analyzed with this in mind. Some of these publications did not include information relevant to the history of SED or how the concept emerged. Therefore, these publications were not referenced in this chapter. Similar to Quental and Lourenço's analysis of the sustainable development literature, references with "a global dimension and large diffusion," such as the most cited publications from the UN and IEA, were found to influence the evolvement of the concept [14]. The results of the thematic analysis of all 34 most cited publications are presented in chapter 3.2 on the key themes of SED.

The concept of sustainable development and its most commonly used definition was first proposed in 1987 in the UN's *Our Common Future* report, generally referred to as the Brundtland report [1]. This report was the most cited and the oldest publication reviewed in the citation analysis. The role of energy in achieving sustainable development is recognized in the report, although, how is unclear as is evidenced by the following quote: "A safe and sustainable energy pathway is crucial to sustainable development; we have not yet found it" [1]. Since the adoption of *Agenda 21* at the 1992 UN's Conference on Environment and Development (the Earth Summit), sustainable development has been an important policy objective at the global, national, and local levels [36]. Similarly, in Agenda 21, energy development was mentioned in conjunction with sustainable development, mostly in chapter nine on the protection of the atmosphere [36]. The connection between the atmosphere, greenhouse gas emissions, and energy is further highlighted in the UN's Framework Convention on Climate Change in 1992 and the Kyoto Protocol in 1997. Both international treaties called for a new approach to energy development with an emphasis on reducing emissions from energy generation and consumption [6,37]. The concept of sustainable energy development was yet to emerge during this time. Energy was seen as a necessity for sustainable development, although it was mainly associated with climate-related issues as well as energy security and scarcity of fossil fuel resources [1]. Topics such as renewables, energy efficiency, environmental impacts of energy generation (other than atmospheric emissions), and the role of energy in promoting human progress were discussed. However, the concept of an all-encompassing sustainable energy development was yet to be proposed [36]. For instance, renewable energy resources have been utilized for millions of years; nonetheless, the notion of sustainable utilization and management of those resources is relatively new [38].

At the UN's General Assembly in 1997, the necessity of more sustainable energy use patterns was acknowledged for the first time, and the initial steps towards a sustainable energy development agenda were taken [39]. Even though energy development was a recurring theme on the international policy agenda in the 1990s, it was not until 2000 that the concept of sustainable energy development was introduced. It was presented as a new development paradigm and compared to the traditional, fossil-fuel driven, one in the UNDP's *World Energy Assessment* (WEA) report, the third most cited publication [2]. One of the main differences was that energy development and use were viewed more holistically, where all possible impacts were considered, whether they be economic, environmental, or social [39]. An emphasis was placed on a cleaner and more diversified mix of energy resources, increasing equitable energy access and energy efficiency, and, perhaps most importantly, recognizing that energy systems need to meet current and future needs [2]. In the same year, 2000, the UN's *Millennium Declaration* was adopted, and the associated *Millennium Development Goals* (MDGs) introduced [40]. No energy-related targets or no mention of energy and its role in achieving the MDGs were found in the declaration, which

shows that SED was still not an established policy topic or recognized as a tool for promoting social development [40]. At the time, energy issues were viewed more in isolation, separated from other development issues. Eventually, the failure of leaving energy out of the MDGs forced a more thorough analysis of what enabled social and economic development and recognition of energy's contribution [41].

Energy for sustainable development was a prominent theme for the first time at a UN meeting at the 9th session of the Commission on Sustainable Development (CSD9) in 2001 [42]. This meeting laid the groundwork for the World Summit on Sustainable Development (WSSD) the following year and highlighted the need for international co-operation to form actions towards a more desirable and sustainable energy future [38,43,44]. At the WSSD, the importance of energy access for poverty reduction and meeting the MDGs was discussed as well as the necessity of changing production and consumption patterns of energy [38,39,44]. Thus, the focus was on two main targets regarding SED: improving energy access and promoting a cleaner energy system [38]. However, no agreement on goals or actions for SED and associated issues was reached at the summit [38]. Spalding-Fecher et al. argued that this was because no international collaboration or central authority existed on energy issues that pushed them forward on the agenda [43]. Therefore, the main result of the WSSD, regarding SED, was further solidifying it on the agenda and bringing attention to the need for an institutional home or interagency mechanism, especially considering the issue's cross-cutting nature [43].

The consequence of this realization was seen over the following years with the establishment of various agencies related to SED within the UN structure and the emergence of energy initiatives within established UN organizations [43]. In 2004, UN-Energy was created as an inter-agency mechanism to aid countries in transitioning to sustainable energy and coordinate efforts on energy within the different UN organizations [45]. The UN's Industrial Development Organization (UNIDO) established an *Energy and Climate Change* initiative, the United Nations Development Programme (UNDP) started thematic evaluations on *Energy and Environment* actions, and the UN Division for Sustainable Development pushed for the sustainable development of energy systems [46,47]. Most recently, in 2009, the International Renewable Energy Agency (IRENA) was founded by 75 different states as an intergovernmental agency to promote the adoption and sustainable use of renewable energy [48]. The establishment of these various agencies and initiatives are evidence of the fact that SED was becoming more recognized as a crucial topic on the international agenda. Furthermore, their establishment recognized the growing role of energy in meeting various sustainable development issues and the importance of changing current consumption and production patterns.

Another critical initiative shaping the concept was the development of indicators for sustainable energy development. Indicators can provide more clarity and a deeper understanding of a concept and its underlying themes and interlinkages [39]. The need for indicators to track progress towards sustainable

development was laid out in Agenda 21 [36]. In response to this, the United Nations Department of Economic and Social Affairs (UNDESA) introduced a set of 134 indicators for sustainable development (ISD) in 1996 [49]. Over the following decade, this initial set was revised and reduced to 96 indicators, of which six were energy-related measuring energy access, energy use, and transportation [50]. In 1999, the International Atomic Energy Agency (IAEA), in co-operation with numerous other international agencies, began developing indicators for sustainable energy development (ISED) to complement the ISD set [39,51]. In 2005, the IAEA, UNDESA, IEA, Eurostat, and the European Environment Agency collaborated to produce the interagency report *Energy Indicators for Sustainable Development: Guidelines and Methodologies*, which was the second most cited publication of the citation analysis [52]. The interagency effort aimed to create a core set of indicators for energy development to aid in decision-making and the development of effective energy policies at the national level. In the report, a set of 30 energy indicators for sustainable development (EISD) was presented and arranged into the three dimensions of sustainable development; social, economic, and environmental. The dimensions were categorized into themes and sub-themes, such as equity, health, security, atmosphere, and more [52]. The EISD set represented the most pressing energy issues globally at the time [39]. These themes, sub-themes, and the indicators themselves indicated a broader understanding of SED than earlier where, for instance, social issues were directly linked to energy development.

Ten years after the introduction of the, previously mentioned, Millennium Development Goals (MDGs), in 2010, a follow-up resolution was adopted where energy was presented as necessary in achieving the goals. The access, efficiency, and sustainability of energy, all elements of SED, were emphasized in particular [53]. Ban Ki-moon, former Secretary-General of the UN, pushed the topic further on the agenda with his vision statement introducing the Sustainable Energy for All (SE4ALL) initiative in 2011 [7]. He also highlighted the importance of addressing energy issues to achieve the MDGs, eliminate poverty, and save the planet. As the name indicates, the overarching goal of the SE4ALL initiative is to provide sustainable energy for all by 2030 with an emphasis on energy access, energy efficiency, and sustainable energy sources [7]. In 2015, the 2030 Agenda for Sustainable Development and the associated Sustainable Development Goals (SDG) was ratified [5]. The goals of the SE4ALL initiatives were adapted into the seventh SDG: "*Ensure access to affordable, reliable, sustainable and modern energy for all"* [5]. With the introduction of SDG7, energy was recognized as necessary in achieving sustainable development, and the concept of sustainable energy development was rooted firmly within that discussion.

In 1977, the International Energy Agency (IEA) published the first World Energy Outlook (WEO) report [54]. The WEOs aim is to provide long-term global energy projections and analysis by assessing energy markets, technology development, policies, and emerging issues [55]. Three different

WEO reports, 2008-2010, were identified as most cited in the citation analysis, which sheds light on the importance of these publications [28–30]. The sustainability of the current energy system, especially regarding energy security, was questioned in the WEO-2004 [56]. In the report, a steep trajectory of increasing energy demand was shown, and fossil fuels were presented as the dominant energy source despite concerns of rising emissions and scarcity. The importance of expanding modern energy services was emphasized as well as the need for policies to transform the current energy system and promote sustainable energy development [56]. In 2006, the IEA released the first Energy Technology Perspectives (ETP), which, to an extent, are focused on the role that energy technology can play to address the issues mentioned above [54,57]. Several vital steps and different development pathways towards a sustainable energy future are laid out in the annual ETPs [57]. Since 2006, WEOs and ETPs have highlighted the importance of a cleaner, more technologically advanced, and sustainable energy future with affordable energy prices and effective energy policies [57,58]. Responding to increased climate concerns, WEOs have started to include different climate scenarios, such as the *450 Scenario*, where greenhouse-gas concentration is kept at 450 parts per millions of CO2 equivalent, and climate change is limited to below 2 degrees Celsius [28]. In the WEO-2017, a *Sustainable Development Scenario* was first presented where the necessary energy-related actions to meet the *2030 Agenda for Sustainable Development* were analyzed [59]. In the same year, the necessity of an energy technology transformation towards clean energy technologies was highlighted in the ETP-2017 [60]. The progress of topics analyzed in the IEA's WEOs and ETPs corresponds to the evolvement of the concept of sustainable energy development through time.

As can be seen from the above discussion, the concept of sustainable energy development has evolved considerably over the last few decades. In the late 1980s and early 1990s, a narrow view was taken of energy development where the focus was mainly on reduced emissions and energy security. Furthermore, energy issues were viewed in isolation and not connected to other development issues. Over time, a broader perspective of energy development has been taken where the potential social and economic impacts are considered and not just the environmental ones. Currently, the necessity of energy in advancing social and economic development is recognized. Furthermore, the need to change current production and consumption patterns is emphasized increasingly more with raised awareness of the severity of climate change and its potential impacts globally. Issues such as accessibility, affordability, energy transition towards renewables, and energy efficiency are topics discussed by most, if not all, governments worldwide. Hence, the concept of SED has gradually both grown to have a more comprehensive definition and increased importance. A more detailed analysis of the current understanding of sustainable energy development can be read in the following section. The themes and underlying issues of SED will continue to evolve, corresponding to development and energy issues

worldwide. For instance, access to modern energy services is planned to become a reality for all one day. Once that happens, perhaps issues relating to, e.g., the selection of energy sources and their sustainable utilization, will become even more prominent.

This analysis shows that the role of energy has evolved from being embedded within the concept of sustainable development to becoming an independent concept in itself. This evolvement stresses the importance of energy for sustainable development. On the one hand, a strength of this broader understanding of SED is that the cross-cutting influence of energy is recognized. Nerini et al. analyzed linkages between energy and all 17 SDGs to assess the role of energy for sustainable development. Their study showed that "energy systems are a foundation of social and economic development, and affect delivery of outcomes across all SDGs" [61]. Furthermore, their analysis highlighted the complex dynamics between energy systems and sustainable development issues. On the other hand, a potential weakness of the broader approach is that energy will be given too much credit and connected with too many issues. For instance, improving access to modern energy services does not guarantee social development and economic growth. Although energy services have been described as fundamental to both [62]. Therefore, it will be important to critically analyze how and why energy contributes or not towards different sustainable development issues. A timeline for the concept of sustainable energy development and how it has embedded itself within the international policy discourse can be seen in Figure 3 below.

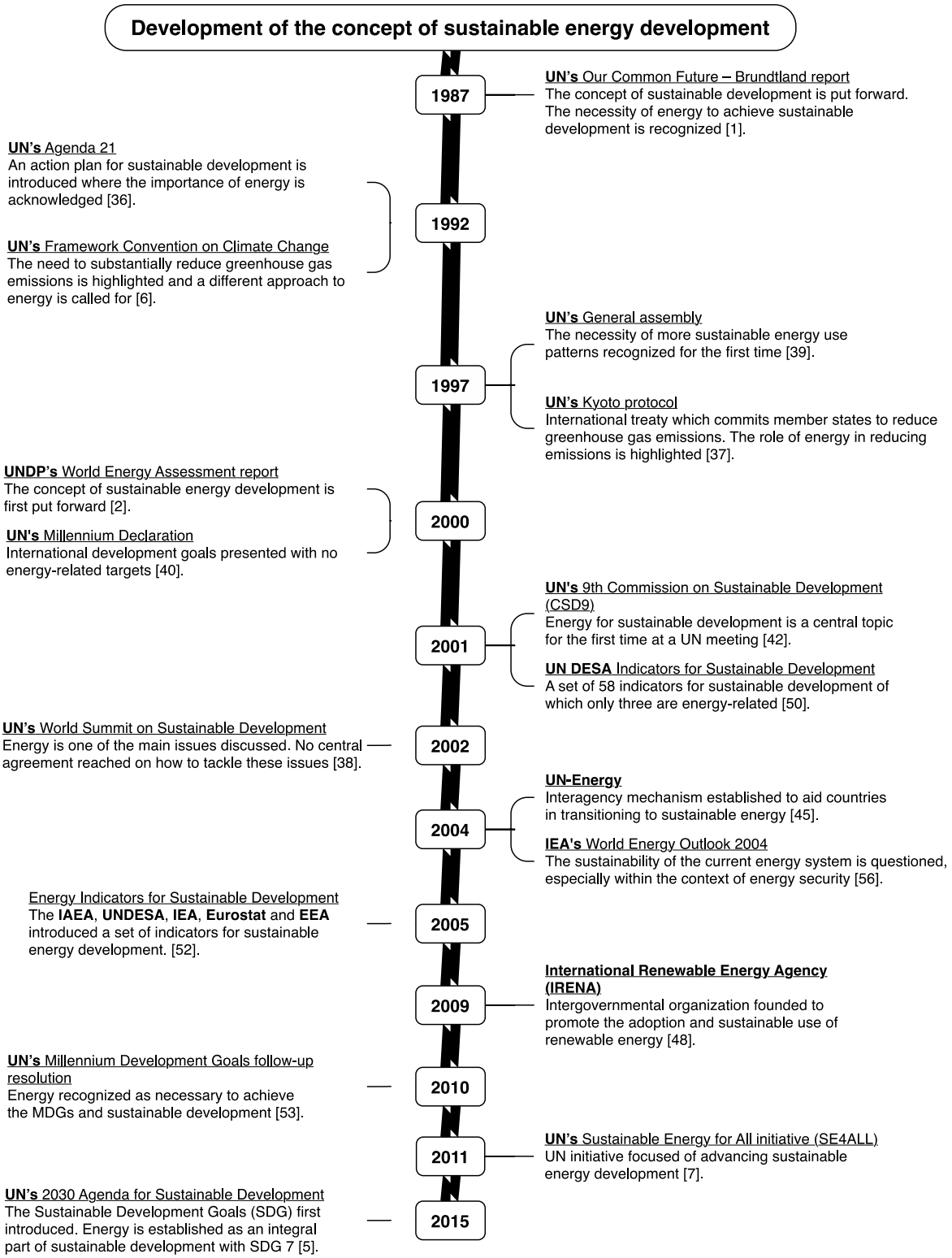

Figure 3: Timeline of sustainable energy development*. Timeline showing the main events and publications that contributed to shaping the concept of sustainable energy development and how it become recognized as integral to sustainable development. Key actors are bolded in the text.*

3.2. Key themes of sustainable energy development

It is apparent from the above analysis that sustainable energy development has evolved to become an essential international policy objective and that energy is integral to sustainable development. One of the aims of this study is to identify the emerging themes of the concept. For this purpose, a thematic analysis was carried out of the most cited publications relevant to the concept. Four themes of sustainable energy development were established, along with one overarching goal. Sustainable development was defined as the overarching goal for the evolvement of energy systems. The four identified themes are essentially sub-goals of SED: access to affordable modern energy services, sustainable energy supply, sustainable energy consumption, and energy security. This categorization can be seen in Figure 4 and is detailed further in the following sections. The order of the themes does not reflect their importance as they are all necessary to SED.

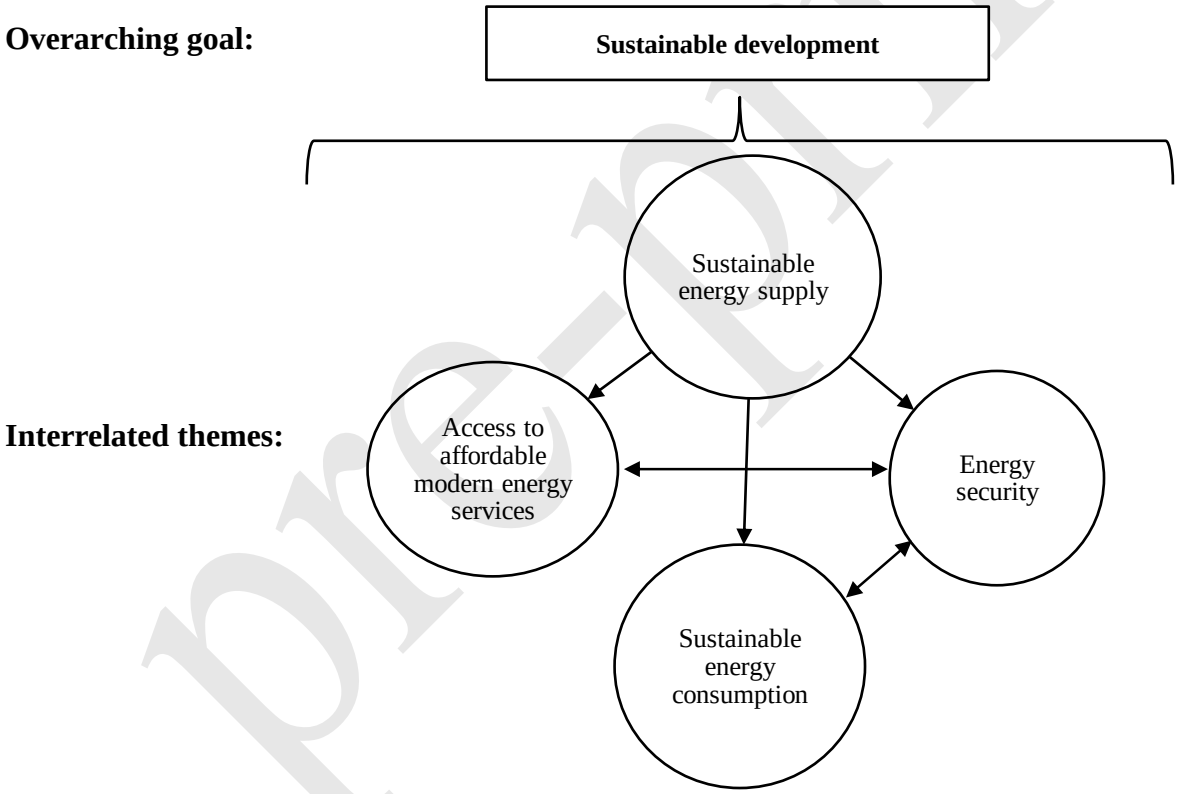

Figure 4: Key themes of sustainable energy development*. Thematic map showing the overarching goal and interrelated themes of sustainable energy development. The arrows illustrate connections between the different themes. The direction of the arrows indicates whether a theme enables another theme.*

Some overlap and linkages between the different themes of SED, indicated by arrows in Figure 4, are inevitable. This claim is evidenced by, for instance, the UN's efforts to develop indicators for both sustainable development and SED [50,52]. For the last two decades, the UN has organized its sustainability indicators into the main themes and sub-themes. A thematic approach was thought better to

capture the relevant policy issues than prior approaches and assist policy and indicator development at the national level [50]. In this approach, an emphasis has been placed on accounting for thematic linkages to consider "the multi-dimensional and integrated nature of sustainable development," and the same applies to SED [50]. For instance, some of the Energy Indicators for Sustainable Development are placed within more than one category to reflect interlinkages between the themes and show that some issues are cross-cutting [52]. In the end, themes are simply tools to make complex concepts, such as SED, more easily understandable.

3.2.1 Overarching goal

Sustainable energy development can differ considerably between countries and energy systems [4]. The energy-related problems facing developing countries as compared to developed ones can vary drastically if only because of different energy needs. Furthermore, the availability of energy resources in a country can be a determining factor for energy development. Nonetheless, the purpose of energy systems is to improve human well-being by providing services that promote economic growth and social development while minimizing environmental and health costs [2]. Moreover, energy is essential in achieving the desirable social, environmental, and economic goals of sustainable development, as confirmed by the introduction of SDG7 [2,5,39,44,50,62–65]. Therefore, despite the different circumstances and energy-related challenges, the ultimate goal of sustainable energy development remains the same, to promote sustainability at all levels [65,66].

3.2.2. Themes

Theme 1: Access to affordable modern energy services

Long before the concept of sustainable energy development emerged, access to energy services has been a topic on the energy policy agenda. Access to energy services is seen as vital to economic growth and promoting social well-being, which makes it essential to sustainable development [2,39,44,50,52,63–65]. Access to energy services refers to the physical availability of energy through the necessary infrastructure and geographic positioning, as well as being affordable to all. A lack of access to energy services has been connected with some of the main challenges of sustainable development, such as poverty, lack of opportunities for women, and environmental degradation [2,39,44]. Therefore, energy poverty needs to be reduced to address some of the main challenges of sustainable development [39,44,52,56]. Moreover, providing everyone access to modern energy services addresses some of the current inequalities of the world [2,5,36,39,44].

Over time, the topic has become more complex and developed into access to modern energy services, which is energy in the form of mechanical power or electricity that is used to fulfill the needs of society [50]. Therefore, having access to modern energy services includes having access to, for instance,

electricity for cooking, lighting, or income generation [2]. In developing countries, many households still lack access to modern energy services and, as a result, use charcoal or traditional biomass for cooking and heating. Utilizing these non-commercial fuels can lead to worsened air quality and adverse effects on health [28,39,44]. This addition of the word modern addresses some of the environmental and health impacts associated with the utilization of non-commercial fuels [50,52]. Although some energy sources utilized to provide modern energy services can also have negative environmental and health impacts, such as fossil fuels.

Modern energy services need to be both accessible and affordable to all, as indicated in SDG 7 [5]. Energy services need to be equitably accessible and affordable to everyone while contributing to human well-being and raising living standards [39,44,52,65–67]. For instance, when improving access to modern energy services in developing countries and rural communities, the affordability of energy needs to be ensured [2,5,39,44,52]. Increased access to affordable modern energy services supports economic growth and social development [2,65,68].

One of the main challenges within this theme is providing energy services in remote rural areas [2,44]. By expanding and improving infrastructure, it is possible to provide access to more people. However, often, it is infeasible or too expensive to connect these areas to the grid. Therefore, local solutions through decentralized generation can fit better and enable rural electrification [44]. To ensure the success of these actions, the involvement of stakeholders in decision-making and innovative financial schemes is necessary [44]. The utilization of renewables on a small-scale is often appropriate, which promotes an energy transition from conventional fuels [44,62]. By transitioning to modern renewables, access to environmentally-sound energy services is provided, and the harmful environmental and health impacts of energy utilization in these areas are reduced or avoided [28,39,44]. Additionally, distributed generation can make energy more affordable in remote areas as it reduces transmission costs and the infrastructure investments that would have been necessary for a grid connection [44].

For any of this to be possible, political will is necessary to push this on the agenda and develop national energy policies that promote access to modern energy services. These actions include removing market barriers, providing the necessary financing, and supporting research and technological advancements for innovative supply-side technologies [44,64,66,67,69].

The main reasons why access to affordable modern energy services is necessary for sustainable energy development and how this theme should be addressed were identified and presented in a thematic map seen in Figure 5. The prominence of the theme and underlying topics within the most cited publications can be seen in Table 2.

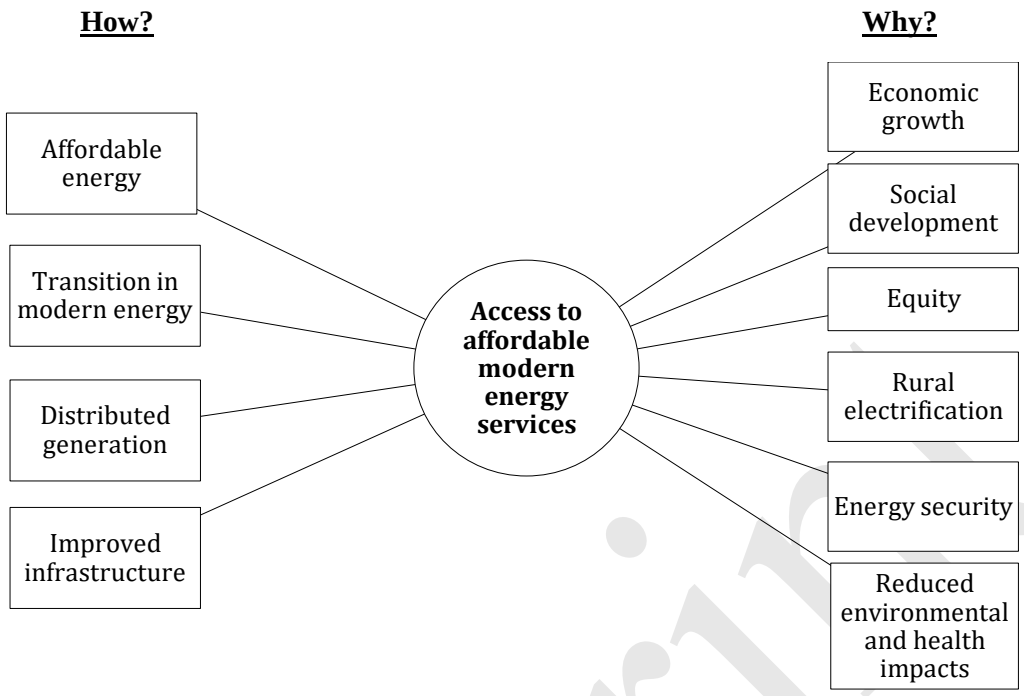

Figure 5: Access to affordable modern energy services. *Thematic map showing how and why access to affordable modern energy services is part of sustainable energy development.*

Table 2: Theme 1 within the most cited publications

Analysis of references made to theme 1, access to affordable modern energy services, and its underlying issues in the 34 most cited publications.

Topic	References	Count
Access to affordable modern energy services	[1,2,50,52,62–64,66,70–73,8,74–77,28–30,36,37,39,44]	24
How?		
Affordable energy	[1,2,62,64,66,67,70,71,74,75,77,28–30,36,39,44,50,52]	19
Transition in energy generation	[1,2,50,52,62,63,70–75,8,76,77,28–30,36,37,39,44]	22
Distributed generation	[1,2,70,71,73,76,77,8,28–30,36,44,62,63]	15
Improved infrastructure	[2,28,72–75,29,30,36,44,52,63,64,71]	14
Why?		
Economic growth	[1,2,62–67,70–73,28,74–79,29,30,36,39,44,50,52]	26
Social development	[1,2,52,62–67,70–72,8,73–81,28–30,36,39,44,50]	29
Equity	[1,2,66,70,73–76,28–30,36,39,44,50,52]	16
Rural electrification	[1,2,62,64,70–73,76,77,8,28–30,36,39,44,52]	18
Energy security	[2,8,67,70,72–75,82,28–30,39,44,52,62,66]	18
Reduced environmental and health impacts	[1,2,50,52,62–64,66,67,69–71,8,72–77,80,28–30,36,37,39,44]	27

Theme 2: Sustainable energy supply

The environmental impacts of current energy systems, from production to consumption, are felt in the air, water, land, biodiversity, human health, and more [2,39,52,62,65,83,84]. The importance of

staying within ecosystem boundaries or carrying capacity regarding energy development was emphasized when the concept of sustainable energy development was first introduced in 2000 [2]. With increased awareness of climate change and the harmful environmental impacts of energy systems, the necessity of decreasing the environmental footprint of the energy system is becoming apparent to most [36,52]. If energy development has harmful environmental or health impacts, it is not adequately serving its ultimate purpose of improving human well-being [2]. Current energy practices are not sustainable and need to be changed, especially considering depleting conventional fossil fuel sources [28,44,66,69,73]. Therefore, a transition in energy generation towards low-carbon and more environmentally-friendly sources, such as renewable sources, is necessary [28,37,71,78,79,85–87,44,50,52,62–64,67,69]. The fact that initiatives to promote renewables are taking place all over the world shows that the necessity of sustainable energy supply is becoming apparent to most [69].

The choice of energy sources and their mix largely depends on what is available in the country in question [86]. Less desirable energy sources include low-quality biomass and nuclear energy with the associated health, safety, and waste issues [68,88]. Renewable energy sources include solar, biomass, geothermal, wind, tide, and hydropower [2,29,75]. Some of these renewables show more promise than others [80], although the purpose of this study is not to assess the different energy sources. Electricity generation from hydropower has played and still plays a significant role in furthering SED worldwide. However, the environmental costs of large scale hydroelectric dams can be high [2,77]. Intermittency is a considerable problem with energy generation from solar or wind power [63,81,87]. Utilizing those renewables involves "designing integrated energy system solutions," where other flexible energy technologies are added to ensure a constant supply of energy [87]. In response to the intermittency problem, efforts are being made to improve energy storage technologies that can complement these renewables [63,81]. The sustainable utilization of renewable energy sources is necessary, such as efficient management of geothermal energy and biomass sources to hinder overexploitation [38,62,82,89].

Sustainable energy supply involves having an economically viable supply of energy [1]. A transition to sustainable energy supply is not possible if energy options are not cost-competitive and economically viable [69,81]. Several actions can be taken to make environmentally sound technologies more cost-competitive, such as correct energy pricing, provide innovative financing schemes, and support research [1,28,68,69,81,90,29,30,39,44,62,64,66,67]. Current energy pricing does not adequately reflect the real costs of energy; for instance, the harmful environmental and health impacts of fossil fuels [1,44,62,66,81]. As a result, conventional fossil fuels are favored over new options. Although fluctuating and rising fossil fuel prices and falling prices of renewables make them a more attractive option [78]. Governments need to incentivize desirable behavior by internalizing the negative costs of energy systems and removing market distortions, such as fossil fuel subsidies [39,44,64]. Such actions would promote

energy efficiency and increase the competitiveness of renewables [44,69]. Often, research and technological advancements are aimed at improving the cost-effectiveness of technologies and, thus, make new options more desirable [91]. Based on the theories of Schumpeter, one can say that invention and innovation are not enough for technological advancements. The diffusion of innovations through investment has to take place as well [92]. Therefore, investments in the deployment of new technologies are also needed [28,56,73,84,93].

This transition towards sustainable energy supply is sometimes referred to as the "energy transition challenge" [94], which highlights some of the associated difficulties, including the necessary systemic changes and infrastructure development to address challenges such as the intermittency of some renewable energy sources [63,87,94]. According to the WEO-2004: "a truly sustainable energy system will call for technological breakthroughs that radically alter how we produce and use energy" [56]. Therefore, research to accelerate the development and deployment of better energy technologies should be supported [2]. In some cases, this will involve facing the costs of the early retirement of existing capital stock [28,56]. Significant efforts have been made to increase renewables in the energy mix with a SE4ALL goal of doubling its share by 2030 [5,7]. Despite improved technologies and reduced prices of energy generation for most renewables, the share of renewables still needs to be increased considerably [95]. Therefore, the theme is expected to stay firmly within the energy policy discourse as highlighted by SDG 7.2: "By 2030, increase substantially the share of renewable energy in the global energy mix" [5].

A thematic map illustrating why a transition towards a sustainable energy supply is necessary for sustainable energy development and how this should be enabled can be seen in Figure 6 below. The prominence of the theme and underlying topics within the most cited publications can be seen in Table 3.

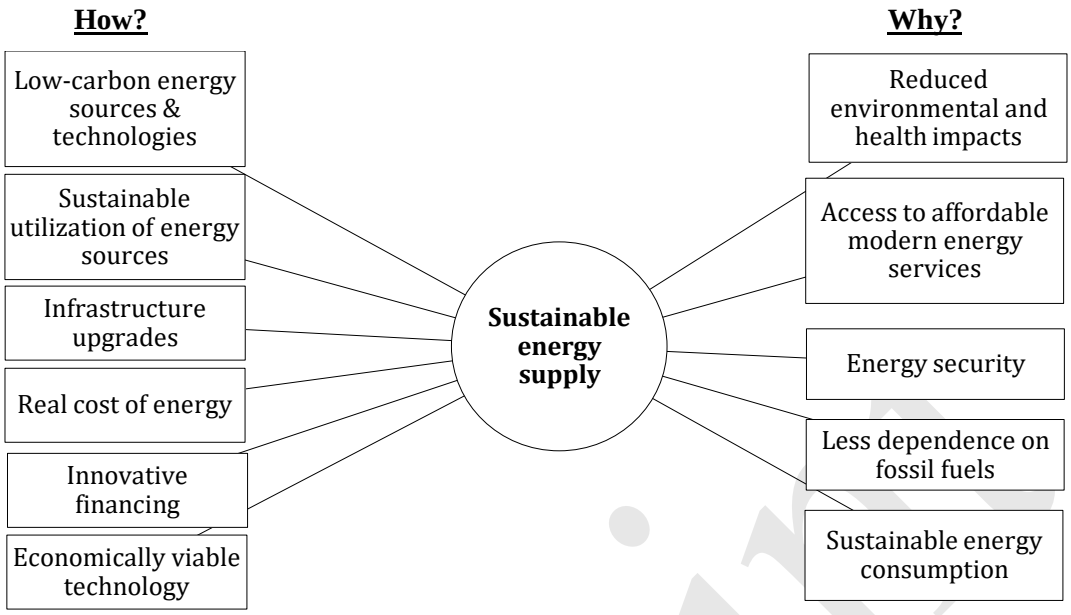

Figure 6: *Sustainable energy supply.* *A thematic map illustrating the main reasons how and why a sustainable energy supply is necessary for sustainable energy development.*

Table 3: Theme 2 within the most cited publications

Analysis of references made to theme 2, sustainable energy supply, and its underlying topics within the most cited publications.

Topic	References	Count
Sustainable energy supply	[1,2,50,52,62–67,69,70,8,71–80,28,81,85–87,29,30,36,37,39,44]	34
How?		
Low-carbon energy sources & technologies	[1,2,50,52,62–67,69,70,8,71–80,28,81,85–87,29,30,36,37,39,44]	34
Sustainable utilization of energy sources	[1,36,39,52,62,67,71,75,79,81]	10
Infrastructure upgrades	[2,28,67,69,71–75,78,87,29,30,36,39,44,52,63,64]	19
Real cost of energy	[1,2,66,69,71,75,76,8,28–30,36,39,44,52]	15
Innovative financing	[1,2,65–67,69,71,73,75,78,79,8,28–30,39,44,62,64]	19
Economically viable technology	[1,2,63–67,69–73,8,74–81,85,28–30,36,39,44,62]	29
Why?		
Reduced environmental and health impacts	[1,2,50,52,62–67,69,70,8,71–80,28,81,85,86,29,30,36,37,39,44]	33
Access to modern energy services	[1,2,50,52,62,64,70–75,8,76,77,28–30,36,37,39,44]	22
Energy security	[2,8,66,67,69–75,78,28,79,81,86,29,30,39,44,50,52,62]	23
Less dependence on fossil fuels	[1,2,52,62–64,66,67,69–72,8,73–79,81,85,86,28,87,29,30,36,39,44,50]	32
Sustainable energy consumption	[1,2,52,62,66,67,69,71–73,78,8,28,30,36,37,39,44,50]	20

Theme 3: Sustainable energy consumption

If access to modern energy services is to be expanded to all, it seems inevitable that demand for energy will grow rapidly around the world, especially in developing countries and those where access is not universal yet [2,30,62,63]. Without a swift transition in energy generation towards environmentally benign energy sources, this will result in increased emissions and harmful environmental impacts as well as greater competition for finite natural resources [1,63,96]. By increasing energy efficiency and conservation, this growing demand can be combated to some extent [2,65,67]. An essential objective of sustainable development is to decouple economic growth from energy use, which means a decoupling of economic activities and increased environmental pressures in most cases [50,52]. Therefore, current energy generation and consumption patterns need to be transformed to be able to provide access to all while sustaining supply and minimizing harmful environmental impacts [2,28].

It is generally acknowledged that increased energy efficiency and conservation is an integral part of sustainable energy development [1,38,44,63,65,66,81,87]. The importance of energy efficiency was highlighted in Agenda 21, where the necessity of improving the efficiency of energy production, distribution, and consumption was mentioned [36]. In the WEO-2009, energy efficiency even is presented as the greatest tool to reduce emissions [29]. Improved energy efficiency is vital, considering increasing energy demand and depleting fossil fuel sources [2,67]. Aside from energy efficiency just making economic sense since energy costs are cut, improved efficiency also leads to a reduction in the harmful environmental impacts of energy production [2,28]. Therefore, the goal of "doubling the rate of improvement in energy efficiency" by 2030 is put forward in the UN's SE4ALL initiative and SDG7 [6,4]. The inclusion of energy efficiency measures in the energy policy directives of many countries highlights its importance [97].

Experience has revealed that sometimes there is a rebound effect in response to efforts to increase energy efficiency [2]. By increasing energy efficiency, the costs and price of energy and its services can drop. Thus, improved energy efficiency can result in increased total energy demand that offsets potential energy savings [2,29,30]. The direct rebound effect refers to increased consumption of energy due to lower energy expenditures. The indirect rebound effect refers to the increased consumption of other energy-intensive goods and services that indirectly leads to an increase in energy consumption [98]. Sorrell et al. found that in the long-run, the direct rebound effect is „likely to be less than 30%" of the expected savings [98]. Furthermore, their analysis argued that the direct rebound effect „is expected to decline in the future as demand saturates and income increases" [98]. Nevertheless, decision-makers need to be aware of the rebound effect when developing energy efficiency policies and, for instance, control energy pricing appropriately [30].

Energy pricing can be a valuable tool to incentivize both sustainable energy consumption and a transition in energy generation [39,44,64]. Changing energy pricing by removing fossil-fuel subsidies and internalizing the real costs of energy promotes a transition towards environmentally-friendly energy and increased energy savings [1,2,8,30,39,44,62,66,81]. The necessity of changing current energy pricing was recognized as early as 1992 in Agenda 21; "Without the stimulus of prices and market signals that make clear to producers and consumers the environmental costs of the consumption of energy, materials and natural resources and the generation of wastes, significant changes in consumption and production patterns seem unlikely to occur in the near future" [36].

A change in current consumption patterns is necessary for sustainable energy development [1,39,44]. Educating consumers and making them aware of the harmful impacts of current energy practices can push for a change in behavior [36,62]. These efforts also should promote the efficient use of energy by teaching energy-saving techniques and advocating for energy-efficient appliances [36,62,96]. Promoting the use of improved stoves in developing countries can reduce emissions that cause health problems and contribute to climate change [2,83,90]. Education and training are vital to the success of an energy transition, especially in remote communities with less access to technical support. Furthermore, informing the local community of actions and having them involved increases the likelihood of social acceptability [64]. An energy transition cannot be sustained unless the local community is on board and given the necessary training and technical know-how to maintain the system [2,36,38,62,68,90,91]. These efforts also result in better energy management and less wasteful consumption [38].

The main reasons how and why sustainable energy consumption is vital to SED are shown in Figure 7. The prominence of the theme and underlying topics within the most cited publications can be seen in Table 4.

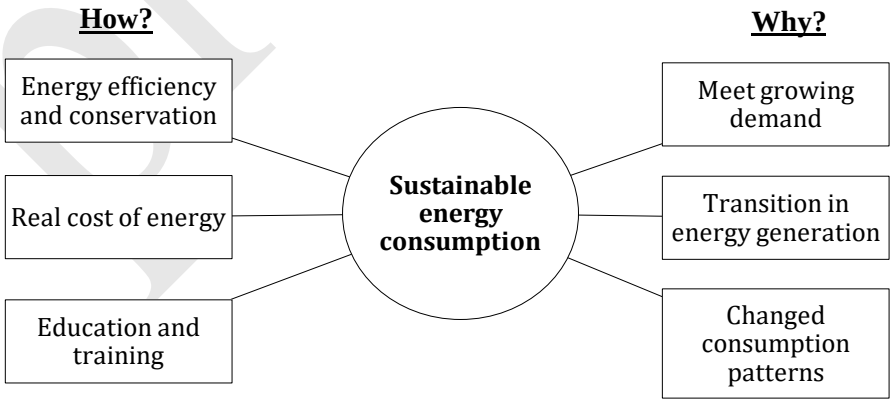

Figure 7: Sustainable energy consumption. *A thematic map highlighting how sustainable energy consumption can be achieved and why it contributes to sustainable energy development.*

Table 4: Theme 3 within the most cited publications

Analysis of references made to theme 3, sustainable energy consumption, and its underlying issues in the most cited publications.

Topic	References	Count
Sustainable energy consumption	[1,2,50,52,62,66,67,69,71–73,76,8,87,28–30,36,37,39,44]	21
How?		
Energy efficiency and conservation	[1,2,50,52,62,63,65–67,69–71,8,72–81,28,87,29,30,36,37,39,44]	31
Real cost of energy	[1,2,66,69,71,75,76,8,28–30,36,39,44,52]	15
Education and training	[1,2,73,28,29,36,37,44,62,67,69]	11
Why?		
Meet growing demand	[1,2,65,67,69–74,76,77,8,78,79,28–30,36,44,62,63]	23
Transition in energy generation	[1,2,50,52,62,66,67,69,71–74,8,75,76,78,79,87,28–30,36,37,39,44]	25
Changed consumption patterns	[1,2,62,66,67,69,71–73,87,8,28,30,36,39,44,50,52]	18

Theme 4: Energy security

Energy security is a well-established theme of sustainable energy development and has been historically in the energy policy discourse [2,39,44,65,66,99]. A reliable supply of energy is the basis for economic activity and social development [39,52,69]. Generally, energy security refers to the low vulnerability of vital energy systems, which can include energy's reliability, availability, and resiliency [4,65]. The four As of energy security are often used as a basis for discussion on the concept, namely; availability, affordability, accessibility, and acceptability [4]. In the UNDP's World Energy Assessment, energy security was described as "the availability of energy at all times in various forms, in sufficient quantities, and at affordable prices" [2]. Therefore, there are clear linkages between this theme and the first two on access to affordable modern energy services and sustainable energy supply.

Numerous efforts can be taken to enhance energy security, as shown in Figure 8. Diversification of energy sources involves not relying on a single form of energy or supplier that can impact energy security [2,38,52,67]. Diversification efforts should aim at increasing the share of domestic energy sources and renewables as well as reducing dependence on a small number of suppliers or sources [39,52,69,93]. Geographical hindrances and geopolitics generally make domestic fuels more secure than imported ones [2,39,44,66,90]. Furthermore, the stability of energy prices is improved when countries are not highly dependent on fuels potentially imported from or through politically volatile areas [1]. Considering the current depletion rate of conventional fuels such as fossil fuels, increasing the share of renewable sources enhances energy security in the long-term [77]. A transformation of the current energy system and reducing dependence on fossil fuels is necessary to increase energy security and combat

climate change [29,44]. However, for renewable energy sources to contribute to energy security in the long-run, they need to be utilized sustainably and not be overexploited [38,62,82,89]. Diversifying a country's energy supply towards domestic and renewable energy sources should not only increase energy security if properly managed but also reduce harmful environmental impacts of the energy system and have positive social impacts such as job creation [2,39,44,52].

For sustainable development to be possible, a sustainable supply of energy is required [39]. Therefore, energy infrastructure upgrades should be aimed at making the system both more efficient and resilient to disruptions, such as natural disasters or terrorist attacks [65,93]. Distributed or decentralized generation, often with renewables, can increase the resilience of a system by emphasizing local solutions and reduce dependence on the grid [38,93]. Furthermore, a greater share of renewables and low-carbon energy sources will secure energy supply for future generations [62,76,95].

Energy prices need to be affordable and stable for energy to promote economic and social development [36,39,67]. Both affordability and accessibility are often mentioned in conjunction with energy security. An example of how affordability can affect energy security can be seen from historical trends of oil prices and the resulting consequences [67,78]. Links between accessibility and energy security are, for instance, geopolitical factors and geographical hindrances that can hinder both [44]. Some of the actions mentioned above, such as increased distributed generation, reduced dependence on imported fossil fuels, and infrastructure upgrades, can increase both energy security and access to modern energy services while promoting a transition towards a sustainable energy supply.

In Figure 8, the main ways how energy security can be increased and why it is vital to sustainable energy development are shown. The prominence of the theme and underlying topics within the most cited publications can be seen in Table 5.

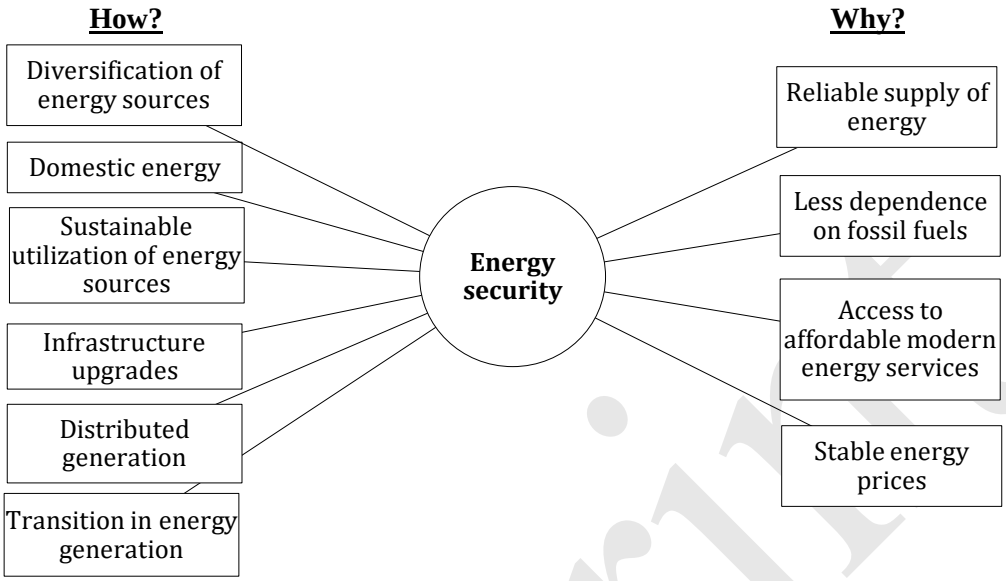

Figure 8: Energy security. *A thematic map showing why energy security is integral to sustainable energy development and how it can be increased.*

Table 5: Theme 4 within the most cited publications

Analysis of references made to theme 4, energy security, and its underlying topics in the most cited publications.

Topic	References	Count
Energy security	[2,8,63–67,69–73,28,74–76,78,79,81,86,29,30,39,44,50,52,62]	27
How?		
Diversification of energy sources	[2,8,63,66,67,69–74,78,28–30,36,39,44,50,52]	20
Domestic energy	[2,8,67,69–76,78,28,86,29,30,39,44,52,64,66]	21
Transition in energy generation	[2,28,64–67,69–74,29,75,78,79,86,30,39,44,50,52,62,63]	27
Distributed generation	[2,8,73,76,28,29,44,62,63,69–71]	12
Infrastructure upgrades		16
Sustainable utilization of energy sources	[39,52,62,67,71,75,79,81]	8
Why?		
Reliable supply of energy	[2,8,63,65–67,69–72,74,75,28,76,78,81,29,30,39,44,50,52,62]	23
Less dependence on fossil fuels	[2,8,63–67,69–73,28,74–76,79,81,86,29,30,39,44,50,52,62]	27
Access to affordable modern energy services	[2,8,63,66,70–75,28–30,39,44,50,52,62]	18
Stable energy prices	[2,28,77–79,29,30,36,63,67,69,73,74]	15

3.2.3 Assessment of themes

The most frequently discussed theme by the highest number of publications was identified by analyzing Tables 2 to 5 above, see Table 6. Arguably, this analysis shows which theme is most prominent within the SED literature. Furthermore, it highlights which themes were mentioned less often, which might indicate a gap in the literature on these topics or highlight potential avenues for further research. The importance of sustainable energy supply was discussed to some extent in all 34 publications. The least discussed theme was sustainable energy consumption indicating that more analysis could be done on how this theme could be addressed, for instance, how training and education can promote a change in consumption patterns. When looking at the sub-topics of each theme in Tables 2-5, the least discussed topic was the sustainable utilization of energy resources, both within the context of sustainable energy supply and energy security. Even though everyone discussed the necessity of sustainable energy supply, only a few directly addressed the vitality of utilizing resources sustainably and the possibility of depleting resources considered renewable, specifically stock-based renewables like geothermal and biomass energy.

Table 6: Most referenced theme within the most cited publications
Analysis of references made to theme 1, access to modern energy services, and underlying issues.

Goal and themes	Reference count
Sustainable development	26
Access to affordable modern energy services	24
Sustainable energy supply	34
Sustainable energy consumption	21
Energy security	27

To further assess the above themes, they were compared to three existing SED themes or classification schemes. The World Energy Council's Energy Trilemma emphasizes energy security, energy equity, and environmental sustainability of energy systems [100]. These align well with the themes of this study, where energy equity broadly covers the same topics as *access to affordable modern energy services* and environmental sustainability corresponds to *sustainable energy supply* and *sustainable energy consumption*. The Energy Indicators for Sustainable Development (EISD) are organized into the three dimensions of sustainable development: social, economic, and environmental [52]. Within those dimensions, both themes and sub-themes of SED are defined, see Table 7. The first theme of this study fits well with topics within the social dimension. The second theme belongs to the environmental dimension. *Sustainable energy supply* and *energy security* correspond to themes within the economic dimension of the EISDs. A recent study by Shortall et al. defined eight main themes of

sustainable energy development: access & electrification, affordability & equity, security, efficiency, renewables, economic or cost-efficiency, environmentally benign & clean, and contributes to well-being [101]. The first two themes correspond to the first theme of this study. Security and this study's *energy security* theme cover the same SED issues. Efficiency is discussed within the theme of *sustainable energy consumption*. The second theme on *sustainable energy supply* includes both renewables and environmentally benign & clean themes of their study. Economic or cost-efficiency is discussed to some extent within the second and third themes of this study. Finally, the overarching goal of promoting sustainable development lines up with their final theme of contributing to well-being. This comparison shows that the results of this study align well with existing SED themes, which verifies the value of the methods chosen in this study. That is, the comparison demonstrates that the analysis of the 34 most cited publications in the SED literature led to comprehensive and complete coverage of the underlying issues of SED.

Table 7: Themes of EISD
Organization of the *Energy indicators for sustainable development* showing SED themes and sub-themes

Dimension	Theme	Sub-theme
Social	Equity	Accessibility
		Affordability
		Disparities
	Health	Safety
Economic	Use and production patterns	Overall use
		Overall productivity
		Supply efficiency
		Production
		End use
		Diversification (fuel mix)
	Security	Prices
		Imports
		Strategic fuel stocks
Environmental	Atmosphere	Climate change
		Air quality
	Water	Water quality
	Land	Soil quality
		Forest
		Solid waste generation and management

3.3 Potential limitations of this analysis

There are a few potential weaknesses to this analysis and the methodology chosen. First, there is a possible bias in the selection of databases utilized for the literature search. A choice was made to focus on general databases and not field-specific ones. This choice could have resulted in the omission of publications that were influential in the development of the concept of sustainable energy development. A limitation of this analysis is, for instance, the fact that no well-functioning database for grey literature was found and included.

Second, the literature review was limited to publications in English. According to Hamel, scientific literature has shifted towards an apparent "dominance of English" [102]. The same cannot be said as definitively about public documents, evidenced by the fact that a few highly cited publications were omitted from further analysis as they were not available in English. Furthermore, the literature search was limited to openly available publications, which could have resulted in the omission of influential publications on SED. Even though this criterion omitted only about 20% of initial search results, it could still influence the results of this analysis. However, the citations of these publications were not filtered based on whether they were open access or not. Therefore, the resulting most cited documents in the field did not have to meet this initial criterion for the literature search.

Third, while a citation analysis can be a useful approach to identify the most cited and influential literature, it is not without faults. The main criticism of citation analysis is the lack of analysis of why or how a source is cited, such as whether a publication might be referenced because it is incorrect or controversial [22,103]. Responding to this criticism, Garfield discussed the "reluctance of scientists to go to the trouble of refuting inferior work" [21]. Some argue that citations are "a function of many variables besides scientific impact," such as time, field, journal, article type, availability of publication, and technical problems [22]. For instance, recent research is cited rather than older, and frequently cited publications are more likely to be referenced even more [22]. This fault was demonstrated by the fact that the newest most cited publications were published in 2011. Technical problems with citations include differences in formatting that can complicate and delay a citation analysis as well as the fact that references, typically, are not available outside of the publication itself. Furthermore, incorrect citations are "unfortunately far from uncommon" [22]. Finally, self-citations can skew a citation analysis, even though self-citations are a standard and reasonable procedure against self-plagiarism [21,103,104]. In response to this criticism, Garfield argued that a "high publication count could be achieved only if the person had a lot to say that was at least marginally significant" [21]. This flaw is illustrated in this study by the fact that two prolific authors wrote a few of the most cited papers on Turkey's energy situation. These papers were found to analyze various SED issues comprehensively and did not merely reflect issues relevant to Turkey.

Fourth, only the 34 most cited publications were identified, which might seem like a low number. However, identifying a relatively small number of most cited publications in citation analyses is a common practice [12,13,19,26,27]; see discussion in section 2.3. above. Furthermore, the results of the thematic analysis showed that saturation was reached with regards to the topics of SED. Reaching data saturation means that the same themes and patterns present themselves repeatedly, and reading more publications would not reveal new themes or data. Therefore, reaching saturation confirms the validity and comprehensiveness of chosen methods. Evidence of this saturation is that the themes identified in this study align well with the results of other studies, as discussed in Section 3.2.3. Therefore, including 34 publications covered the development and themes of SED adequately to allow for an in-depth analysis of the concept.

Fifth, as with any research, especially of qualitative nature, there is always some potential for the authors‘ bias that might influence the study in some way. During the thematic analysis, the authors' subjective judgment can influence the interpretation of the text, coding, and generation of themes. One way to address this is by being aware of one's own bias when collecting and analyzing the data [32]. Furthermore, comparing the resulting themes to the original text or initial codes to ensure a match is valuable [33].

4. Conclusions

This study has reviewed the concept of sustainable energy development and its transformation through time. The concept of sustainable energy development has evolved to become an important policy objective addressed by governments around the world. Initially, energy was viewed narrowly in conjunction with emissions and air quality. Now, energy is considered to be a necessary enabler for social and economic development and, consequently, sustainable development. As a result, energy issues are no longer viewed in isolation and are instead connected to other development challenges. This broader understanding of SED and the cross-cutting influence of energy highlights both its importance and multi-dimensionality. However, this more comprehensive understanding could also lead to too many issues being associated with SED. Energy and the services it provides are vital to sustainable development, but sustainable development will not be reached solely through SED.

The overarching goal of the development of energy systems is to further sustainable development according to the analysis presented here. Four interrelated themes of SED were identified: access to affordable modern energy services, sustainable energy supply, sustainable energy consumption, and energy security. According to these themes, energy development should increase international equity by providing modern energy services to all. Energy services need to be equitably accessible and affordable to everyone while contributing to human well-being and raising living standards. A transformation of the

current energy system, both in generation and consumption, will be required to address this challenge. This transformation calls for a transition to a sustainable energy supply with efficient low-carbon and environmentally-sound energy generation and increased utilization of renewable energy sources. A transition is only feasible if modern technologies and renewables are economically viable. Sustainable energy consumption will involve increased energy efficiency and awareness of the negative impacts of the current energy system, as well as the positive implications of an energy transition. Changes in consumption patterns can, for instance, result in increased electricity demand for transportation and heating. A secure and reliable supply of energy is necessary for the sustainable development of a society. Linkages between these SED themes are inevitable as, for instance, some actions address multiple themes.

A comparison of these themes with existing SED themes shows that the main issues of SED were identified in this study. These results confirm that the methodological approach chosen was suitable and of value. Over time, these themes of SED will continue to evolve, responding to global development issues. Hopefully, access to modern energy services and wasteful consumption patterns will be less pressing issues, and emphasis will be placed on the sustainable utilization of environmentally sound resources and technologies.

According to this analysis, the most prominent theme of SED is a sustainable energy supply, which was discussed to some extent in all 34 most cited publications. The least discussed theme was sustainable energy consumption, which brings attention to a potential gap in the literature and avenues for further research. The least discussed sub-topic of the themes was the sustainable utilization of energy resources, both concerning energy security and sustainable energy supply. This highlights that more attention could be given to the sustainable management of, for instance, stock-based renewables to prevent their depletion. Further analysis of citing behavior within the SED literature could lead to the identification of more gaps in the literature. Such an analysis could also highlight which types of publications are cited most often and within which fields those publications lie. The majority of the most cited publications were those with a global and broad reach that were published by established international agencies, such as the UN and IEA. The topic of several of the publications identified as influential in shaping the concept was indicators for SED. It is vital that indicators, tracking progress towards SED, capture the concept accurately.

Future research and actions towards SED need to take account of this more comprehensive definition and the role of energy in promoting sustainable development. Multiple different steps and pathways can be taken toward sustainable energy development. The purpose of this analysis was not to present a list of actions towards SED but to analyze what SED entails. When developing an action plan

towards SED, the analysis performed here, and the interrelated themes of the concept should be considered as well as the overarching goal of furthering sustainability.

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Appendix A: Most cited publications on sustainable energy development

	Most cited publications	# of times cited
1	World Commission on Environment and Development. Our Common Future. New York: 1987. [1]	63
2	International Atomic Energy Agency, United Nations Department of Economic and Social Affairs, International Energy Agency, Eurostat, European Environment Agency. Energy indicators for sustainable development: Guidelines and methodologies. Vienna: 2005. [52]	47
3	Lund H. Renewable energy strategies for sustainable development. Energy 2007;32:912–9. [87]	33
4	United Nations Development Programme, United Nations Department of Economic and Social Affairs, World Energy Council. World Energy Assessment: Energy and the Challenge of Sustainability. New York: 2000. [2]	32
5	International Energy Agency, OECD/IEA. World Energy Outlook 2010. Paris, France: 2010. [30]	26
6	United Nations. Kyoto Protocol to the United Nations Framework Convention on Climate Change. United Nation 1998. [37]	21
7	Wang JJ, Jing YY, Zhang CF, Zhao JH. Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renew Sustain Energy Rev 2009;13:2263–78. [65]	21
8	Vera I, Langlois L. Energy indicators for sustainable development. Energy 2007;32:875–82. [39]	21
9	International Energy Agency, OECD/IEA. World Energy Outlook 2009. Paris, France: 2009. [29]	20
10	Yuksek O, Komurcu MI, Yuksel I, Kaygusuz K. The role of hydropower in meeting Turkey's electric energy demand. Energy Policy 2006;34:3093–103. [70]	19
11	Ahmad S, Kadir MZAA, Shafie S. Current perspective of the renewable energy development in Malaysia. Renew Sustain Energy Rev 2011. [69]	18
12	Dincer I. Renewable energy and sustainable development: A crucial review. Renew Sustain Energy Rev 2000. [62]	17
13	Hashim H, Ho WS. Renewable energy policies and initiatives for a sustainable energy future in Malaysia. Renew Sustain Energy Rev 2011. [67]	16

14	International Energy Agency, OECD/IEA. World Energy Outlook 2008. Paris, France: 2008. [28]	16
15	United Nations Development Programme, United Nations Department of Economic and Social Affairs, World Energy Council. World Energy Assessment: Overview 2004 Update. New York: 2004. [44]	16
16	Afgan NH, Carvalho MG. Multi-criteria assessment of new and renewable energy power plants 2002;27:739–55. [80]	15
17	Kaygusuz K, Kaygusuz A. Renewable energy and sustainable development in Turkey. Renew Energy 2002;25:431–53. [71]	15
18	Kaygusuz K, Sarı A. Renewable energy potential and utilization in Turkey. Energy Convers Manag 2003;44:459–78. [72]	15
19	United Nations Sustainable Development. Agenda 21. Rio de Janeiro: United Nations; 1992. [36]	15
20	Bilgen S, Keles S, Kaygusuz A, Sari A, Kaygusuz K. Global warming and renewable energy sources for sustainable development: A case study in Turkey. Renew Sustain Energy Rev 2008;12:372–96. [73]	14
21	Evans A, Strezov V, Evans TJ. Assessment of sustainability indicators for renewable energy technologies. Renew Sustain Energy Rev 2009;13:1082–8.[81]	14
22	International Energy Agency. Energy Policies of IEA Countries: Turkey 2005. Paris, France: 2005. [74]	14
23	Kaygusuz K, Kaygusuz A. Geothermal energy in Turkey: The sustainable future. Renew Sustain Energy Rev 2004;8:545–63. [75]	14
24	Shafie SM, Mahlia TMI, Masjuki HH, Andriyana A. Current energy usage and sustainable energy in Malaysia: A review. Renew Sustain Energy Rev 2011;15:4370–7. [78]	14
25	United Nations Department of Economic and Social Affairs. Indicators of Sustainable Development: Guidelines and Methodologies. 3rd Edition. New York: 2007. [50]	14
26	Demirbas MF, Balat M, Balat H. Potential contribution of biomass to the sustainable energy development. Energy Convers Manag 2009;50:1746–60. [79]	14
27	Akpinar A, Kömürcü MI, Kankal M, Özölçer IH, Kaygusuz K. Energy situation and renewables in Turkey and environmental effects of energy use. Renew Sustain Energy Rev 2008;12:2013–39. [8]	13
28	Balat H. A renewable perspective for sustainable energy development in Turkey: The case of small hydropower plants. Renew Sustain Energy Rev 2007;11:2152–65. [76]	13

29	Chisti Y. Biodiesel from microalgae. Biotechnol Adv 2007;25:294–306. [85]	13
30	Connolly D, Lund H, Mathiesen B V., Leahy M. A review of computer tools for analysing the integration of renewable energy into various energy systems. Appl Energy 2010;87:1059–82. [86]	13
31	Nautiyal H, Singal SK, Varun, Sharma A. Small hydropower for sustainable energy development in India. Renew Sustain Energy Rev 2011;15:2021–7. [77]	13
32	Streimikiene D, Ciegis R, Grundey D. Energy indicators for sustainable development in Baltic States. Renew Sustain Energy Rev 2007;11:877–93. [66]	13
33	Baños R, Manzanp-Agugliaro F, Montoya FG, Gil C, Alcayde A, Gómez J. Optimization methods applied to renewable and sustainable energy: a review. Renew Sustain Energy Rev 2011;15:1753–66. [63]	13
34	Zhang P, Yanli Y, Jin S, Yonghong Z, Lisheng W, Xinrong L. Opportunities and challenges for renewable energy policy in China. Renew Sustain Energy Rev 2009;13:439–49. [64]	13

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