Universitat Politècnica de Catalunya

Departament d'Enginyeria Elèctrica

Ph.D. Thesis

Measuring Energy Sustainability by Using Energy Sustainability Indicators

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Kind Regards

Ali (Armin) Razmjoo

Abstract

The main aim of this thesis is to investigate energy sustainability in developing countries using effective indicators. As it is known, serious issues such as global warming and inefficient consumption of energy will lead to serious problems in the future in the world and in particular in developing countries. Those countries which have a proper policy and effective actions by policymakers and energy experts can prevent these problems confidently. For these reasons, the present thesis has focused on developing indicators that can measure the grade of energy sustainability in order to achieve energy sustainability the countries analyzed. In this sense, the thesis starts to investigate the Sustainable Energy Development Index (SEDI) method and improves this method by finding and evaluating the effective indicators to improve and complete the SEDI methodology. In this regard, a numerical analysis of 12 countries has been realized. Following the methodology, new indicators associated with energy are proposed in line with the Habitat III and the SDGs from the UN. Additionally, appropriate strategies to combine the different UN goals are analyzed and indicators are chosen to provide the best performance of the index. For this research, it is needed to analyze many related data and find novel indicators based on these data that can be obtained and applied by policymakers and energy experts for application in developing countries due to a high percentage of energy consumption sector in these communities. Therefore, the main findings of this thesis are proposed indicators for improving the quality of life of the inhabitants of different areas in the world with respect to the different aspects of the energy such as access energy, affordable energy, and saving energy. For achieving these goals, is the need to a correct policy, the evaluation of energy sustainability based on energy systems of a country, the close collaboration of policymakers with energy

experts, using effective indicators, the balance of the energy supply, equity in access to energy and environmental sustainability of the urban and remote areas. These actions will lead to achieving energy sustainability confidently.

Resumen

El objetivo principal de esta tesis es investigar la sostenibilidad energética en los países en desarrollo utilizando indicadores efectivos. Como es sabido, problemas como el calentamiento global y el consumo ineficiente de energía conducirán a serios problemas en el futuro del mundo y en particular en los países en desarrollo. Aquellos países que cuentan con políticas adecuadas y acciones efectivas por parte de los legisladores y expertos en energía pueden prevenir estos problemas con confianza. Por estas razones, la presente tesis se ha centrado en desarrollar indicadores que puedan medir el grado de sostenibilidad energética para lograr la sostenibilidad energética que los países analizaron. En este sentido, la tesis comienza a investigar el método del Índice de Desarrollo de Energía Sostenible (SEDI) y mejora este método al encontrar y evaluar los indicadores efectivos para mejorar y completar la metodología SEDI. En este sentido, se realizó un análisis numérico de 12 países. Siguiendo la metodología, se proponen nuevos indicadores asociados con la energía en línea con el Hábitat III y los ODS de la ONU. Además, se analizan las estrategias apropiadas para combinar los diferentes objetivos de las Naciones Unidas y se eligen los indicadores para proporcionar el mejor rendimiento del índice. Para esta investigación, es necesario analizar muchos datos relacionados y encontrar nuevos indicadores basados en estos datos que puedan ser obtenidos y aplicados por los formuladores de políticas y expertos en energía para su aplicación en los países en desarrollo debido al alto porcentaje del sector de consumo de energía en estas comunidades. Por lo tanto, los principales hallazgos de esta tesis son indicadores propuestos para mejorar la calidad de vida de los habitantes de diferentes áreas del mundo con respecto a los diferentes aspectos de la energía, como el acceso a

la energía, la energía asequible y el ahorro de energía. Para alcanzar estos objetivos, se necesita corregir las políticas, la evaluación de la sostenibilidad energética basada en los sistemas energéticos de un país, la estrecha colaboración de los encargados de formular políticas con los expertos en energía, utilizando indicadores efectivos, el equilibrio del suministro de energía, la equidad en el acceso a sostenibilidad energética y ambiental de las zonas urbanas y remotas. Estas acciones conducirán a lograr la sostenibilidad energética con confianza.

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Chapter 1. State of art

1. Introduction and literature review

Nowadays, humanity is facing different challenges such as climate changes, poverty, health, lack of equality, energy supply etc. The UN mentioned that these issues must be reduced as soon as possible and in this regard, the sustainable development approach for all members' countries as the main instrument is considered by this organization. In fact and according to United Nations General Assembly, (1987, p. 43), the main mean of sustainable development is meeting the needs of the present without compromising the capability of future generations to meet their own needs [1]. Moving toward sustainable development as a future panorama can have effective impacts on all mentioned issues especially energy and conserve the planet for future generations [2]. Fortunately now, many countries in the world are in the process of transforming especially in their energy system's structure. Actually, energy supply for most of the countries in the world is one of the most important issues to be solved. Thus, for addressing all of these existing problems, especially for energy, sustainable development can be an effective solution [3]. With regard to the above explanations and during different years many researchers have been worked on energy subjects with a sustainable development approach and developed it. Some of them will be mentioned in the following text. A conceptual review related to sustainable development has been done by Mebratu D. In this study, sustainable development with respect to importance in national and international, Environmental, and policies have been investigated [4]. A review of sustainable development about thermal energy storage (TES) technologies by Hasnain S.M. et al, has been done. They investigated the development of accessible and their individual pros and cons for space and water heating applications [5]. Rosen M and Dincer I, investigated exergy as a connector for energy, environment, and sustainable development. They discussed important relations between exergy and environmental impact, resource degradation, and waste-exergy emissions and examined important exergy applications in each one. They also in this study emphasized the key role of energy policies play to solve sustainability issues and global environmental concerns [6]. Markandya A et al, investigated climate change and the importance of sustainable development to reduce it. They examined sustainable development situations for developing countries different prospects and problems comprehensively [7]. Alanne K et al discussed the definitions of a distributed energy system in the line of sustainable development. They with regard to different dimensions of sustainable development such as political, economic, social, and technological related to regional energy systems showed that a distributed energy system is a suitable option [8]. A comprehensive review for achieving energy sustainability via renewable energy in the future and by energetic analysis and resources has been done by Hepbasli A et al. In this research energy modeling, exergy, energy technology, energy transferring methods and etc considered by them [9]. Omer AM investigated sustainable development based on energy and environment in Sudan. Economic, environmental, political, social parameters with their details in the line of sustainable development and for Sudan in this study investigated by them. They also emphasized on renewable energy as a suitable way to achieve sustainable development [10]. K Kaygusuz, with regard to increasing Turkey's demand for energy and electricity, investigated sustainable development based on energy and environmental issues. Since CO_2 emissions with increasing energy consumption raised in Turkey, thus in this article with respect to global environmental issues, carbon assessment in order to reduce carbon dioxide (CO_2) investigated in the line of sustainable development [11]. Wang JJ et al, by multi-criteria decision analysis manner, investigated sustainable energy. They for doing it examined different parameters such as criteria selection, criteria weighting, evaluation, and final aggregation based on three important aspects of sustainable development [12]. Neves AR et al, presented different effective energy sustainability indicators to help local energy planning. They showed that since local authorities are using indicators mostly for diagnosis targets and paying less attention to monitoring thus the suggested indicators are able to accurate decision criteria in order to determine the most effective measurements for local energy planning [13]. Mori K et al examined the conceptual requirements for city sustainability with regard to different indexes and indicators. Variety indexes and indicators such as environmental sustainability index, city development index, emergy/exergy, environmental vulnerability index, environmental policy index, and etc investigated in this study. Also, they showed that it needs to make a new CSI for cities that can help to better assess and compare cities' sustainability performance from the environmental point of view [14]. The importance of sustainable development with emphases on access to energy has been reviewed by Bhattacharyya SC et al. They investigated the role of electrical energy through clean energies in order to meet the demand for cooking for different areas. Also, they reviewed energy sustainability with regard to five indicators technical, social, environmental, economic, and institutional [15]. Liu G investigated the sustainability of renewable energy systems as an appropriate way to reduce the negative impact of environmental issues with related and effective indicators. Moreover, the investigation of each method and assessment in this study, advantages, and disadvantages of it also examined. This study showed the correct selection of indicators can be influential to achieve sustainable development [16]. Mardani A et al examined MCDM techniques and approaches in sustainable and renewable energy systems problems using 54 papers published from 2003–2015 years. In this regard, they show that the methods of AHP/fuzzy AHP and integrated methods have been used more than others that show the remarkable effect and the importance of these methods in energy systems [17]. A study of multi-criteria decision-making method for sustainable renewable energy development has been done by Kumar A et al. Since, MCDA is an effective manner to use in energy planning processes also is a suitable manner to solve issues associated with energy, thus, they investigated three different types of MCDM to achieve considered goal [18]. Cîrstea SD et al, with regard to the importance of renewable energy in sustainable development, designed a composite index with the name the Renewable Energy Sustainability Index which is able to show the points out the strengths and weaknesses of a state. The suggested index was capable to supply solutions to enhance the sustainability of a country by improving positive impact indicators and reducing negative impact indicators and used for 15 European countries [19]. Razmjoo et al examined developing various hybrid energy systems as a suitable and reliable method to reach energy sustainability. They investigated a city for a developing country that had good potential for energy production by renewable energy. In this study also they suggested four renewable energy systems for this area [20]. Villa-Arrieta M, et al, investigated different aspects of energy sustainability for smart cities. In this regard, different important aspects of smart cities have been surveyed to achieve this goal [21]. The sustainable development goals are important and effective to achieve a suitable and sustainable future for all. The UN members set by the 2030 year 17 goals for sustainable development that are a shared blueprint for peace and prosperity for people and the planet [22]. Actually regarding the global challenges in the world, such as poverty, inequality, climate, environmental degradation, prosperity, peace, justice, and energy these assigned 17 goals in order to remove or revise these challenges.

Fig 1.1 shows of the three main pillars which show the main sections of sustainable development.

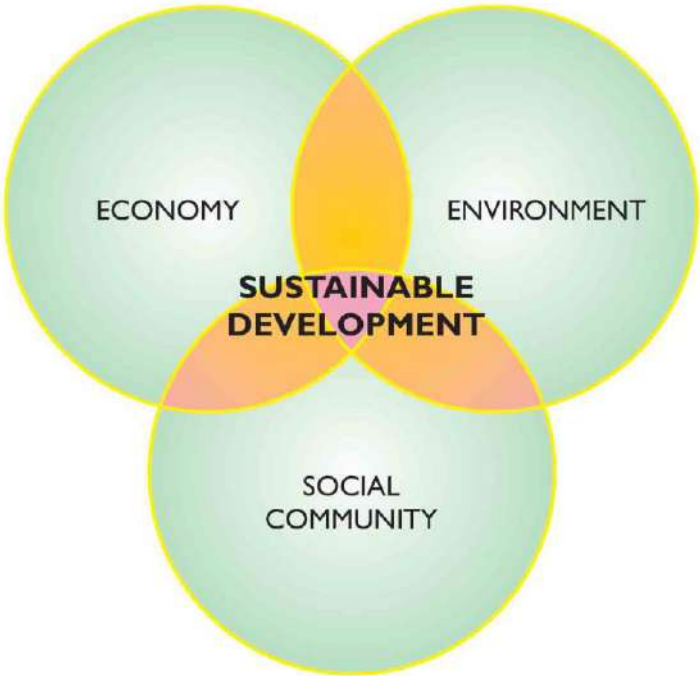


Fig 1.1. Three main pillars of Sustainable development

Fig 1.2 shows assigned 17 goals of sustainable development by the 2030 year with related figures.

These goals are assigned by 2030 in order to reduce the main problems of mankind.

Fig 1.2. Assigned 17 goals of sustainable development by 2030 year with related figures

Table 1.1. shows a summary of 17 SDGs (17 UN goals) by 2030, related to human and sustainable development.

Table 1.1. 17 SDGs by 2030, related to human and sustainable development [22]

Number	Name	Description
1	No poverty	Poverty is one of the most important factors that cause the deaths of a large number of people every year, especially in southern Asia and sub-Saharan Africa. Also, according to statistics, less than 10% of the world's workers in 2016 lived with their families while they had less than $ 1.90 income per person per day, which is a very unfortunate hit. In this regard, the UN has decided to take measures such as eliminating extreme poverty and reducing at least half the poor population of men, women, and children by 2030.
2	Zero Hunger	The major UN plans by 2030 are the end of the hunger of all people, especially the poor and vulnerable people such as babies. In this regard, all types of malnutrition should be eliminated so that all existing populations have access to healthy and nutritious nourishment.
3	Good health and well-being	According to UN plans, the maternal and child mortality by 2030 should be prevented in all countries. It should also reduce the incidence of dangerous diseases such as hepatitis and infectious diseases.
4	Quality education	Education is one of the most important UN programs until 2030. In fact, education for all girls and boys should be effective and targeted until 2030 years and the quality of education should be improved. Equal access for women and men to high-quality education such as universities should be easy and affordable. Also in this year, the population of people with technical and vocational skills will be significantly increased.
5	Gender equality	Discrimination is one of the key negative factors in the community that the United Nations strives to eliminate all forms of discrimination and violence against women and girls. Also, this organization is trying to provide equal public services in the community, to promote family responsibilities, and make a strong role for women in decision-making in the political, economic for the public of people.
6	Clean water and sanitation	From the major UN plans until 2030, is that all people have been fair access to healthy and safe drinking water. In this regard, the organization intends to significantly increase the reuse of drinking water as a recycling cycle and increase water use efficiency in all sectors. Ending the disposal of chemicals, increasing the quality of water with less pollution, prevention of destroying the environment is another program of this organization.
7	Affordable and clean energy	The UN plans to reduce emissions of fossil fuels and increase the use of renewable energies by 2030. In this regard, the organization intends that increase international collaborations in clean energy technologies an increase in the amount of investment in the sustainable energy infrastructure sector, especially for all developing countries.
8	Decent work and economic growth	Developing economic in developing countries in accordance with national conditions, encouraging the growth of small and medium-sized enterprises, increasing their GDP per year, increasing their economic efficiency, promoting technology and innovation, developing entrepreneurship, and increasing their job opportunities and support From creativity and innovation, including is the United Nations programs for economic growth in different countries by 2030.
9	Industry, Innovation and Infrastructure	The United Nations is trying to achieve sustainable development using make high quality, flexible and sustainable infrastructure, such as regional and border infrastructure, fair industrial, and economic growth in all countries by the 2030 year. Also, this organization will seek to upgrade the industry and double its GDP growth rate in developing countries by 2030. Increasing scientific research and spending more cost on the Cleaner and Eco-friendly technologies, are the other plans of this organization, especially for African countries, developing countries, and small developing countries.
10	Reduced Inequality	Eliminating injustice along with economic development and expansion, regardless of political issues such as gender, disability, race, ethnicity, and religion, is one of the major programs of the organization until 2030. In this regard, the elimination of discriminatory practices is considered an appropriate measure for the development of human rights and the supervision of financial markets, especially in developing countries.
11	Sustainable	Ensuring universal access to secure and affordable housing by 2030 and access to

	Cities and Communities	secure and accessible transportation systems is one of the most important programs of the United Nations. By 2030, the organization aims to achieve these goals by improving road safety and expanding public transportation to meet the needs of vulnerable groups such as women, children, people with disabilities, and the elderly. Urban sustainability and integrated participatory human resources management for global access to healthy, comprehensive, and accessible, green, and public spaces are one of the other programs of this organization by 2030.
12	Responsible Consumption and Production	The United Nations intends to act appropriately for sustainable management and utilization of natural resources by 2030, identify and implement appropriate consumption patterns based on 10 years of planning in different countries. These measures could reduce losses of food around the world by half and also reduce food losses throughout the supply chain and reduce the adverse effects of unhealthy food on human health and the environment. The waste generation will also be significantly reduced through prevention and recycling through this program.
13	Climate action	Strengthening flexibility and adaptability to combat climate change against the dangers of air and natural disasters in all countries, is a part of UN policies and strategies. In this regard, it is necessary with improving the quality of education, the promotion Knowledge level in managing various crises and institutional capacity, appropriate preventive measures should be taken especially in developing countries and small developed countries.
14	Life Below Water	In the coming years, the United Nations will have special programs to protect natural ecosystems such as the oceans, seas, and marine resources. These measures are including reducing marine pollution in particular from ground activities, reducing nutrient pollution, managing continuously and protecting marine and coastal ecosystems, aquaculture, tackling the effects of acidification of the ocean, ending over-fishing, and fighting illegal fishing practices in developing countries and low-income countries.
15	Life on Land	Protecting natural ecosystems such as groundwater ecosystems, forests, wetlands, mountains, and land, including biodiversity, combating desertification, restoring land and degraded soils, such as land affected by desertification, drought, and the flood will be the concern of the United Nations in the coming years. In addition, sustainable management of all types of forests and their increase, deforestation, and the restoration of weak forests are some of the immediate and urgent measures that the organization has put in place. These measures significantly affect the prevention of the reduction of natural habitats and the prevention of destroying the endangered species.
16	Peace and Justice Strong Institutions	Creating community security that reduces crime and violence is one of the UN policies and strategies. In this regard, the organization seeks to increase global justice, with full support for the rule of law at the national level of each country to reduce the main problems in all countries such as all types of violence, theft, corruption, weapons smuggling and the organization of bribery everywhere.
17	Partnerships to achieve the Goal	The United Nations intends more support of developing countries uses international assistance from developed countries. In fact, this support will help developing countries for reducing their debts until better internal reconstruction and growth. Also, these actions, will make strengthen their domestic capacities and improve their economic conditions.

1.2. UN-Habitat III

According to the world conference related to the U.N. Habitat III, in 2016 in Quito, all present countries, have pledged to adhere to the following three principles in order to achieve global targets in sustainable urban development [23]. The three commitments are:

1. Delivering the New Urban Agenda through the Urban Agenda for the EU.
2. Developing a global, harmonized definition of cities.
3. Fostering cooperation between cities in the field of sustainable urban development

The outcome of this conference has been the 14 UN-Habitat III goals as described in Table 1.2. Table 1.2 shows a summary of and UN-Habitat III (14 goals).

Table 1.2. UN-Habitat III (14 goals) and description about them [23]

Number	Name	Description
1	Legislation	The importance of legislation, especially the urban law, is very important because it is a set of policies, methods, and rules that play a prominent role in the management and development of the urban environment. These rules and practices are for improvement And reforming and overcoming the major challenges of cities and urban systems.
2	Mobility	Mobility is an indication of the vitality of a city. In fact, urban form is characterized by dynamism and mobility. Therefore, in order to make a decent urban environment suitable infrastructure, such as roads, transportation systems, recreation areas, and safe residential buildings, should be provided. Today, the expansion of cities is still not in accordance with the correct principles, as sufficient access to places and health services in many cities are still difficult. In some cities, the physical separation of residential areas from employment, markets, schools, and health services has caused a lot of problems.
3	Housing & slum upgrading	In urbanization, housing and having it is one of the strong points for citizens because it reduces social inequalities. On the other hand, housing provision will be beneficial, especially in poorer neighborhoods or in areas where there is more urban social and economic deprivation. This will also improve social and urban infrastructure.
4	Safety	In recent years, urban development, especially in developing countries, has been accompanied by an increase in the level of crime, violence, and lawlessness, which has caused many insecurity and problems for the residents of the cities. Crime and violence in the daily life of the city residents have a negative impact. Among the services that planners and policymakers can do to reduce these problems is the development of social culture and the creation of equal opportunities for the people.
5	Climate Change	Considering that the most energy uses in urban logic, thus can say that cities play an important role in climate change and are responsible for a significant percentage of total carbon dioxide emission and it is due to the energy consumption of its vehicles, and its industry. Carbon dioxide emissions also affect the health of human lives in urban areas around the world and the global ecosystem and negative consequences such as rising sea levels, frequent internal floods, severe storms, also more severe heat and severe cold will follow.
6	Gender	Gender inequality is one of the major problems that many societies are involved with it. In fact, the lack of equality and gender equality in urban planning and legislation in this area is one of the most important UN programs that pledged itself to promote gender equality. Unfortunately, gender inequality continues and women and girls in cities face a wide range of gender-based barriers and specific vulnerabilities such as gender inequalities in economic affairs, social and educational decisions.
7	Planning & Design	Increasing rapid settlements, especially in cities of developing countries, causes many problems, especially in the division of urban spaces in residential, commercial, and industrial areas. These problems without proper planning will not only be solved but will also make further social and infrastructural problems. Therefore, urban politics should be in a way that is both effective in terms of designing urban space and reducing social problems.
8	Economy	Economics is considered as one of the main pillars of development, and since the role of wealth creation in cities is more than the rest of the world, cities can be called the main makers of the world's economic wealth. In spite of the presence of more industries in urban areas, dynamic economies, and more job opportunities, these areas have become virtually the focus of rural development, but it should be considered that with the reduction of urban economic opportunities due to the influx of rural population into the city, unpleasant consequences such as the mental health and welfare problems will threaten a large section of the population and the state. In fact, the government should control the growth of urban populations in order to create economic prosperity and create the proper and enough infrastructures with wide and comprehensive services in this regard provided so

		that it can prevent economic irregularities ahead.
9	Reconstruction	Yearly unexpected events, due to many reasons, including poor urban and residential infrastructure, cause many problems in urban and rural areas, causing deaths to millions around the world. According to the statistics by the end of 2011, more than 42 million people worldwide were displaced due to numerous social issues such as conflict and persecution that needed refuge. Also, 336 natural disasters in 2011 caused damage to 209 million people, which they had needed for short-term and long-term asylum. Therefore, the role of crisis management in predicting these problems is crucial.
10	Resilience	Climate change has caused many problems and damages in recent years, including global warming and sudden accidents such as storms and tsunamis. Given the fact that many cities in the world are vulnerable to unexpected accidents, they need to be flexible in this regard. In fact, the role of flexibility in the design and construction of appropriate urban infrastructure is very important and will help improve the ability of these areas to cope with various crises, in particular the dangers of human settlements and natural disasters, and accelerate their recovery. Became the United Nations seeks to strengthen the resilience of cities in facing natural, unexpected crises and all disastrous events in the future.
11	Human rights	Human rights refer to justice in various areas of economic, social, and cultural rights, including cheap housing, safe water, and sanitation. These Human Rights Laws in the housing sector (UDHR) have the 25 articles and in the Economic, Social and Cultural Rights Section (ICESCR) has 11 articles that have been approved by the United Nations.
12	Water & Sanitation	In recent years, many efforts have been made to provide drinking and healthy water to the public, which has enabled more than 6 billion people in the world since 2010 to have access to improved drinking water resources. Despite these efforts, unfortunately, there is still a population of 1.1 billion people are deprived of clean and safe water supply, as well as more than 2.6 billion people do not have access to proper toilet and other sanitation facilities, which will be the main cause of different illnesses and transmitted disease from the body. Therefore, for prevention due to these problems, which will be further increased in the future, appropriate distribution and sanitation systems should be used.
13	Youth	Youth, with high potential and sufficient mobility, play an important role in society, especially for governments. Given that 85% of the youth in the world live in developing countries, and especially in cities, it is estimated that by the year 2030 about 60% of all urban citizens will be young people under the age of 18, and it is evident that finding a job will also be difficult for them. Today, the youth population accounts for 25% of the global working population and 43.7% of the unemployed, of course, which does not mean that almost every unemployed person is between the ages of 15 and 24. Naturally, young people in every country create problems, so it is necessary that they make greater prosperity and job opportunities to prevent any social malformations of this stratum, partly from unemployment in any country.
14	Energy	Energy is one of the major factors in the development of transport, industrial and commercial activities, buildings and infrastructure, water distribution, and food production. Today, energy supplies from fossil fuels are caused by contributing to pollution and environmental problems that current dependence on fossil fuels is one of the main causes of these problems. According to global energy supplies in recent years, 81.3% of the world's energy was supplied from fossil fuels, 9.7% of nuclear power, and only 9% of renewable energy. Therefore, given the importance of the future ecosystem of the world, an approach should be made by policymakers and governments to further enhance the use of clean energy.

1.3. Background of Energy sustainability

The sustainable development concept has been introduced in 1987 and by a report of the World Commission on Environment and Development called Brundtland Commission. The principal of this commission was based on developing three main influential factors in the life of mankind such as social, economic, and environmental factors in the entire world [24]. Due to this reality that huge population of people especially in developing countries still relies on traditional methods for cooking and heating because of the lack of electricity, thus energy sustainability can be used as a reliable way to give more energy services such as available energy and affordable energy for inhabitants of these areas [25]. In fact, access to modern affordable energy services in developing countries is a principal requirement for the achievement of SDGs goals, which these goals emphases on minimizing poverty and improving the conditions and standard of living for the majority of the world's population. On the other hand, energy sustainability is one of the newest world's subjects validated by the UN that attempts to substitute the use of conventional energy resources through renewable energy in order to conserve the environment of the future. Actually, when we hear the word "energy sustainability" we naturally tend to think of renewable fuel sources for reducing carbon emissions as proven ways of keeping the delicate ecosystems of our planet in balance [26]. Energy sustainability is the way that is able to meet the present needs especially energy without treating the ability of future generations to meet their own needs in this field. Sustainable energy sources such as solar energy wind energy and etc., are used to generate the required electricity for using in the heating, cooling, and to power transportation systems in different places or industrials sections, but, to develop these sources is need to effective government policies in all of the world [27].

1.4. Relationship of Energy sustainability with SDGs and UN-Habitat III

Energy sustainability is one of the important parts of sustainable development for having a high direct or indirect impact on these goals. The following list as Table 1.3 shows the SDGs and Urban Habitat III goals related to energy sustainability.

Table 1.3. Related indicators of energy sustainability with SDGs and Urban Habitat III

SDGs direct indicators	**Urban Habitat III direct indicators**
Clean water and sanitation, Affordable and clean energy, Decent work and economic growth, Industry, Innovation and Infrastructure, Sustainable Cities and Communities, Climate change	Mobility, Economy, Climate change, esiliency, Energy

One of the most important issues that have a remarkable effect on SDGs targets and can help to develop these targets is energy sustainability [28]. Actually, relation target of energy, energy sustainability moreover having positive effects on the environment, has a significant key role in developing energy for inhabitants in remote areas [29]. This subject is extremely in the line of SDGs and UN-Habitat III [29]. Energy sustainability with an emphasis on the proper use of existing resources trying to make an effective system in the line of environment conservation and energy supply for the future of mankind [28]. In this regard, energy sustainability is known as an important target of SDGs that to achieve this goal the governments and policymakers have a vital role [30].

1.5. Objective and Scope of the Thesis

The main objective of this thesis is investigation and development energy sustainability indicators for different countries especially developing countries. Based on, the scope of the thesis is as below:

- Investigating SDGs targets and UN-Habitat III

- A review of global warming importance including Tokyo protocol and Paris agreement

- Investigating the key role of policy to develop energy sustainability

- Considering energy sustainability gaps in different countries especially developing countries

- Investigating energy importance and energy supply issues

- Investigating Energy challenges, Energy Security and gaps in developed and developing countries

- Comprehensive consideration of sustainable energy development index method (SEDI)

- Presenting new effective and applicable indicators associated with energy using the improvement of SEDI method

1.6. Outline of the Thesis

This is a thesis by six chapters, including the introduction of each chapter, related publications, and a summary of each chapter. In this regard, this chapter 1 explains energy sustainability based on SDGs and UN-Habitat III also, the relationship of energy sustainability with SDGs.

Chapter 2 explains the key role of policy in energy sustainability with an emphasis on Energy sustainability gaps and energy challenges in different countries especially developing countries.

Chapter 3 investigates energy sustainability indicators for developing countries based on the SEDI method.

Chapter 4 presents improving and completing the SEDI method with new indicators.

Chapter 5 presents new indicators based on energy sustainability for urban areas and chapter 6 is the overall conclusion of the study. Fig 1.3 describes the sequence of the chapters organized according to the context of the field of study.

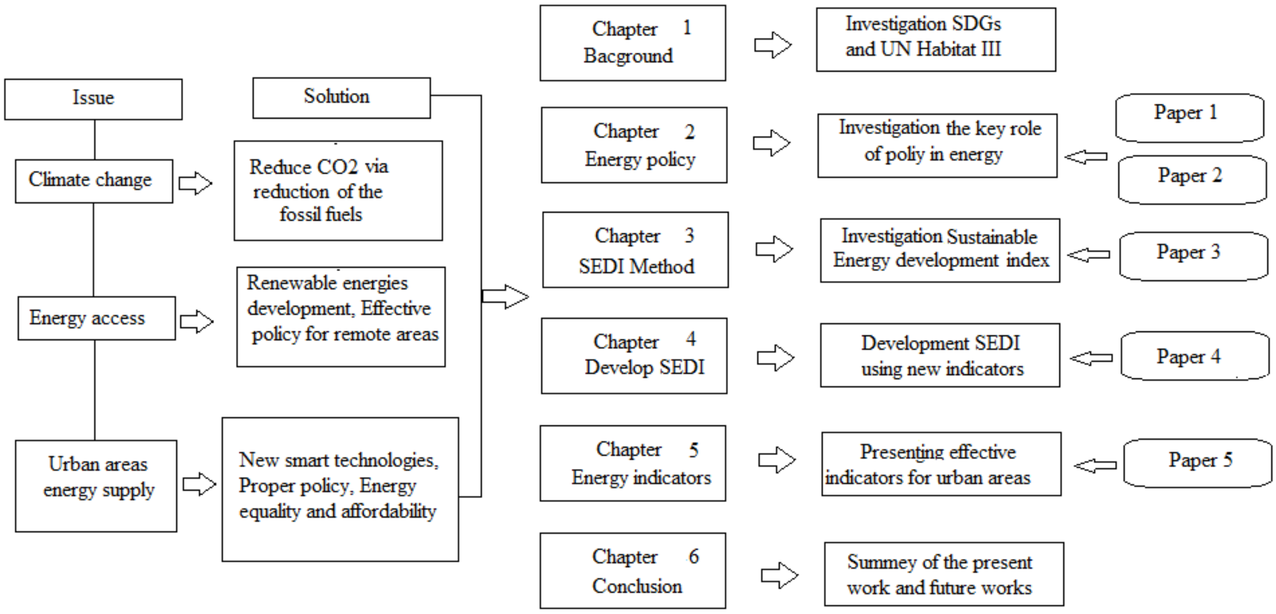


Fig 1.3. Thesis overview: Issues and Solutions, chapters of the Thesis and papers published

Based on Fig 1.3, five articles have published in different journals such as Elsevier, Springer, Taylor & Francis, John Wiley and International Journal of Sustainable Energy Planning and Management belong to Aalborg University as below with the detail of publication:

Paper 1: Energy sustainability analysis based on SDGs for developing countries, A Armin Razmjoo, A Sumper - Energy Sources, Part A, 2019 - Taylor & Francis. https://doi.org/10.1080/15567036.2019.1602215.

Paper 2: Deployment of a stand-alone hybrid renewable energy system in coastal areas as a sustainable energy resource, A Kasaeian, A Razmjoo, R Shirmohammadi, A Aslani, A Sumper. Environmental Progress & Sustainable Energy 2019. https://doi.org/10.1002/ep.13354.

Paper 3: Investigating energy sustainability indicators for developing countries: Armin Razmjoo and Andreas Sumper. International Journal of Sustainable Energy Planning and Management. https://doi.org/10.5278/ijsepm.2019.21.5.

Paper 4: Development of sustainable energy indexes by the utilization of new indicators: A comparative study, A Razmjoo, A Sumper, A Davarpanah - Energy Reports, 2019 – Elsevier. https://doi.org/10.1016/j.egyr.2019.03.006.

Paper 5: Energy sustainability analyses using feasible indicators for urban areas, A Razmjoo, A Sumper, M Marzband, International Journal of, 2019 – Springer. https://doi.org/10.1007/s42108-019-00022.

Table 1.4 presents the metric characteristics of the published journal.

Table 1.4. Journal Metrics of published articles

Journal name	**Publisher**	**IF**	**SJR**	**Quartile**
Energy Report	Elsevier	3.595	0.98	Q2
International Journal of Sustainable Energy Planning	Aalborg University	-	1.34	Q1
Environmental Progress & Sustainable Energy	Wiley	1.989	0.47	Q3
Energy Sources, Part A	Taylor & Francis	1.184	0.32	Q3
International Journal of Energy and Water Resource	Springer	-	0.82	Q1

1.7. Methodology

Since energy sustainability is one of the most important factors for progressing each country and also is extremely associated with UN goals and Urban Themes habitat targets (UN-Habitat III), a new methodology based on energy sustainability indicators is proposed in order to achieve energy sustainability in different countries. This thesis considers, first of all, a comprehensive discussion associated with UN goals, Urban Themes habitat targets, and the SEDI method (Sustainable energy development index). Secondly, an explanation of seven selected indicators in framework a group that has the most impact on energy and SEDI indicators analysis and a comparison of different countries together based on this method. Finally, the SEDI method's weaknesses are analyzed and completed by using new indicators based on these seven selected indicators in the line of UN goals and Urban Themes habitat targets (UN-Habitat III) especially the energy.

Chapter 2. Energy sustainability analysis based on SDGs for developing countries

2.1. Introduction

In this chapter energy sustainability analysis based on UN goals and Urban Themes targets in the residential areas and for developing countries is investigated. The goal of this chapter is to show the importance of renewable energy impact to reduce CO_2 emission and presenting effective indicators for energy sustainability. Human activities in recent years with the excessive emission of greenhouse gases have had a negative impact on the increase in global temperatures [31]. In this regard, one of the best ways to control it, move toward sustainability with more use of renewable energy [20]. Today, the use of renewable energy which is a good alternative to fossil fuels has been accepted in many countries of the world [32]. Also use of more renewable energy instead of fossil fuels will be of great help to the environment [33]. Among renewable energies, wind and solar are the most used to energy supply [34]. Now, the utilization of renewable energy rose, and in many countries, a remarkable part of the required energy is supplied by renewable energy [35]. Importance of renewable energy caused many researchers in different zones of the world to have much research on renewable energy that can be mentioned some of them [36]. The potential and prospects of Solar energy as a reliable source has been carried out by E Kabir et al. in this study discussed the advantages and disadvantages of solar energy technologies. Despite different problems such as low solar cell efficiencies and economic problems, they are believed that still, the development of novel solar power technologies is one of the best ways considered to supply worldwide demand for energy [37]. A scientific study regarding energy and sustainable development carried out by Kaygusuz, K et al. In this study has been considered an energy situation for developing countries. They mentioned that access to electrical energy equally and implementing effective indicators are important factors to achieve progress and sustainable development [38]. Sen S et al., in an article, discussed different opportunities, barriers, and issues with renewable energy development in the country. In this article, they showed that Renewable energy in addition to mitigating climate change would lead to a sustainable social and economic development [39]. Laith M. Halabi et al., present a comprehensive investigation study of hybrid renewable energy system design for a tropical climate zone with a deeply techno-economic evaluation and with an environmental aspects attitude [40]. Ellabban O et al. investigated the current status of renewable energy resources and prospects about enabling technology. On the other hand, they in this study investigated the importance of power electronics converter for application in renewable energy and the integration of renewable energy resources into the smart grid system [41]. A study regarding renewable energy development for sustainable development goals in Tanzania country has been done by Bishoge O et al. They in this study showed that one of the appropriate ways to achieve affordable and accessible energy in Tanzania, is the use of renewable energy. Also, in this study renewable energy is emphasized as a way for sustainable development [42]. Marquez MJ et al., investigated and measured for Barcelona and Malaga cities the energy sustainability. They based on different important factors such as the features of the energy end-use, energy systems, and flows, etc., s.uggested a methodology in order to evaluate the energy sustainability of a city [43]. Boran FE et al. evaluated the different technologies of renewable energy to electricity generation. They used of Intuitionistic Fuzzy TOPSIS method for doing it in Turkey. Indeed in this study, they for a long-term application evaluated the effective and well-known technologies regarding renewable energies [44]. Halabi LM et al., based on previous surveys and information, investigated two decentralized power stations in the area of Malaysia that were combined with PV, diesel generators, system converters, and reserve batteries. In this study also, using HOMER software the operational behaviors of a variety of PV influence levels were investigated in order to an exact measure of the effect of PV integration [45]. Analysis of an off-grid electricity system in a Scotish island carried out by Chmiel Z et al. It was a real example of a successful off-grid electrification system. They in this study showed that to supply the electricity needs of a community, it is possible to use electricity 24/7 from a hybrid off-grid system because off-grid energy systems are an independent source of energy to satisfy the electricity needs [46]. An economic assessment for a combined energy wind energy storage system was carried out based on a theory by X Han et al. They investigated, the benefits of the installation of the energy storage system in order to improve the electric quality and obtain more economic advantages [47]. Guichi, A et al., presented a new management algorithm to optimize the produced energy in order to allow the system for having proper action as a distributed source inside the tool network [48]. Monowar H et al., with a deeply operational efficiency analysis presented a combination of several optimal independent renewable energy combinative systems for a large recreational center. They obtained that the best-optimized system in this study is including PV, wind, diesel, converter, battery system [49]. Hosseini SE et al. are presented with a review of green energy potentials in Iran an evaluation of renewable energy potentials. They in this study, investigated alternative fuel and renewable resources to reduce fossil fuel consumption in the future for Iran [50]. Jahangiri M et al. investigated the potential of a hybrid solar cell, wind turbine, and biomass system in order to the electrical supply for the residential building. They showed that, from the economic point of view, solar cells are proper for most climate kind and humid climates, and biomass is appropriate to moderate and humid climates [51]. Shezan, S.A., et al., analyzed the performance of a hybrid energy system. This hybrid system consisted of wind-PV and diesel. They using HOMER software, simulated, and designed this system for a small community with an average load demand of 33 kWh/day. Also, the amount of NPC and CO_2 emission for this system were respectively about 29.65% and 16 tons per year compared to the other power plants [52]. In this study, based on UN goals and Urban Themes targets which emphases on the move toward energy sustainability by renewable energy, has been investigated the energy potential of the Chabahar city. This study has two main parts. First of all, this study presents a comprehensive discussion about energy sustainability including related indicators, and second of all, is to investigate a PV-DG system for a residential area. We discuss the key role of policy to develop energy sustainability and investigate a PV-diesel system for Chabahar city.

2.1.1. The key role of policy to develop energy sustainability

To achieve energy sustainability goals, having a strong and accounted policy program is required. It can lead to more attraction of public support to effectively implement plans and to achieve high efficiency in energy. A key issue to achieve sustainable development especially in the energy field has an appropriate policy and in this regard policy methods and policymakers are most influential [53].

Implementing energy policy need for public support. Implementing participatory processes is not easy and in this regard diversity of stakeholders' rationales must be considered, and use appropriate methods and instruments for participation [54]. It shows high participation is important to reaching success [55]. Policy makers to succeed in implementing policies in particular in sustainability must be integrated into the stakeholder perceptions in decision-making. It can improve the policy design and implementation determined policies and prevent public opposition [56]. On the other hand, providing energy for the present and future generations is an important subject that needs an appropriate policy. indeed, energy security is a serious challenge in the present century and is extremely involved with policy. Policymakers consist of the body of government. Thus they are an important factor in the decision making and for monitoring the progress [57]. To overcome related problems with energy, governments should focus on implementing proper measurements in line with the assigned target to mitigate existing problems and in order to enhance the effectiveness of policies. They can use different indicators which are as an effective tool for development and sustainability. Indeed, indicators play a key role in implement energy sustainability and have the key role of policy-making to implement appropriate indicators [58]. Since the welfare of humans with considering the environment are the most important issue in the world, thus all human activities should be performed in the line to satisfy this reality. Table 2.1 shows the 17 UN goals by the 2030 year that are arranged based on four important indexes in this study.

Table 2.1. The 17 UN goals by the 2030 year based on four important indexes in this study.

Indicators	Policy	Economy	Environment	Social
No poverty	√	√	x	√
Zero Hunger	√	√	x	√
Good health and well-being	√	x	√	√
Quality education	√	x	x	√
Gender Equality	√	x	x	√
Clean water and sanitation	√	x	√	√
Affordable and clean energy	√	√	√	√
Decent work and economic growth	√	√	x	√
Industry, Innovation, and Infrastructure	√	√	x	√
Reduced Inequality	√	x	√	√
Sustainable Cities and Communities	√	√	√	√
Responsible Consumption and Production	√	x	√	√
Climate action	√	x	√	√
Life Below Water	√	x	√	x
Life on Land	√	x	√	√
Peace and Justice Strong Institutions	√	x	x	√
Partnerships to achieve the Goal	√	x	x	√

Also, Table 2.2 shows the 14 Urban themes based on four important indexes and related to the methodology of this study. Policy and social indexes as it is clear are most important than other indexes although none of them should be ignored.

Table 2.2. The 14 Urban themes based on four important indexes in this study

Indicators	Policy	Economy	Environment	Social
Legislation	√	x	x	√
Mobility	√	x	x	√
Housing & slum upgrading	x	x	x	√
Safety	√	x	x	√
Climate change	√	x	√	x
Gender	√	√	x	√
Planning & Design	√	x	x	√
Economy	x	√	x	√
Reconstruction	√	x	x	√
Resiliency	√	x	x	√
Human rights	√	x	x	√
Water & sanitation	x	x	√	√
Youth	x	x	x	√
Energy	√	√	√	√

2.1.2. Renewable energy, environment issue, and energy sustainability

Fossil fuels are the main cause of air pollution and major sources to produce a large amount of carbon dioxide in the air which led to an increase in global warming [59]. In this regard, achieving energy sustainability using renewable energy is one of the effective ways of reducing fossil fuels improving energy efficiency, and is an important target for our future [60]. Since energy sustainability can meet providing the needs of our present generations without hurt to future generations in particular regarding energy, thus, in this regard, subjects such as access to energy, energy affordable, clean, and abundant are most important for us [61]. Sustainable energy is abundant energy that we are capable of using for a long time. On the other hand, Sustainable energy helps us to reduce greenhouse gas emissions and prevent damage to the environment. Thus, since most times is accessing sources energy like sunlight and wind is possible, therefore, move towards sustainable energy should be continued and the approaches for sustainable energy should be encouraged [62]. Fig 2.1 shows the key role of renewable energy to reduce CO_2 emission and achieve sustainable development, especially in the energy and sustainability field.

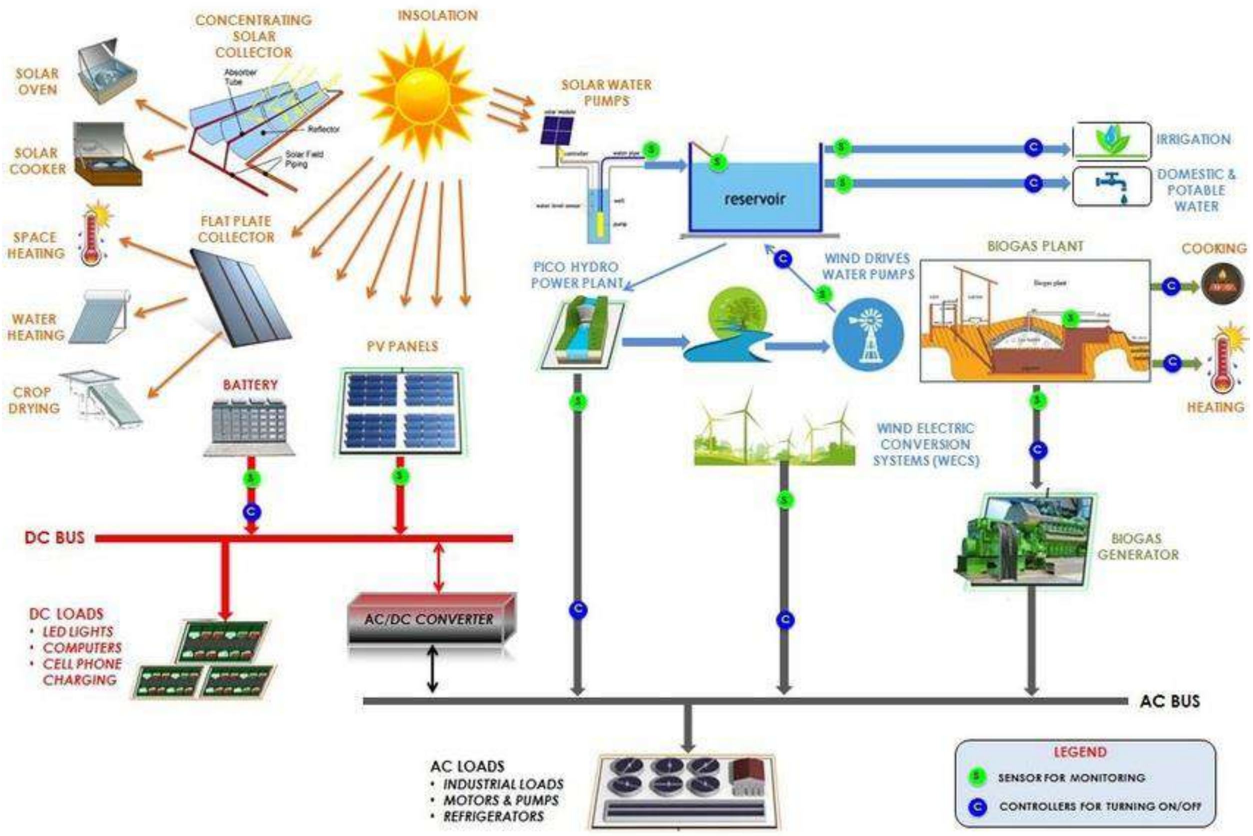


Fig 2.1. The key role of renewable energy to reduce CO_2 emission and achieve sustainable development especially in the energy and sustainability field [63].

2.1.3. Electrical production by renewable energy in the line of energy sustainability

The use of renewable energy today is one of the most appropriate ways of generating electricity [64] and achieve to energy sustainability [13, 31]. Various countries with long-term planning and investment in renewable energy are trying to provide a significant portion of their future energy needs in the future [65]. Among different kind of renewable energies, the role of wind and solar energy is significant for electrical production [66]. Today importance of smart grid system is vital for energy supply and a safe future. Fig 2.2 shows the evolutionary feature of the smart grid that can create bidirectional flows of energy and communication. As can see this system combines a small wind turbine and photovoltaic solar panels. In this system in order to supply energy to an inverter is used of the extracted energy.

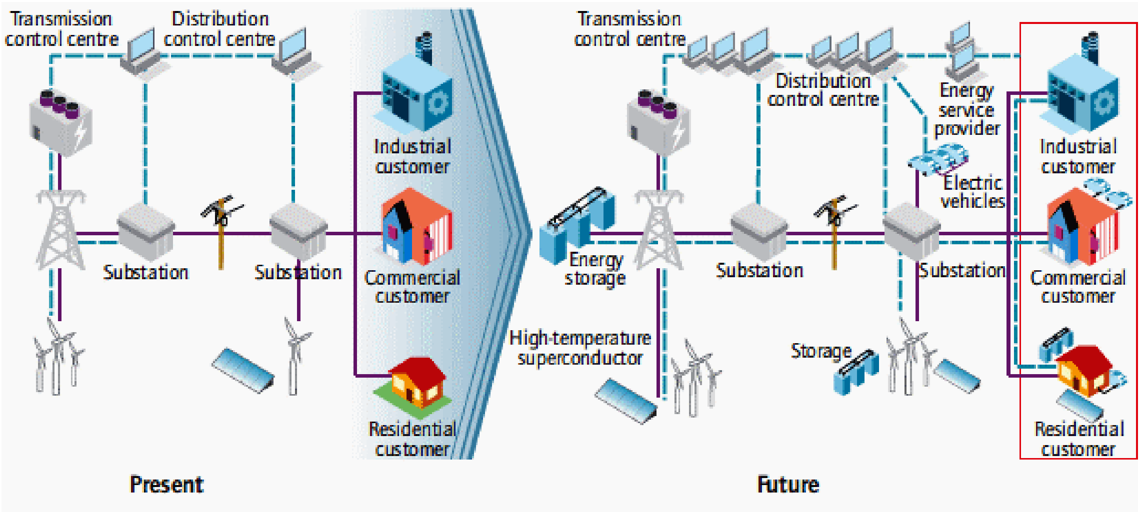


Fig 2.2. Smarter electricity systems [41]

Table 2.3 that obtained based data of international energy agency (IEA) shows the total energy production for Iran country from 2012 to 2016 years. As specified by the blue color in this Table, the share of renewable energies in total energy production is low which shows the most amount of energy production for Iran is by fossil fuels.

Table 2.3. Total energy production for Iran country from 2012 to 2016 years [IEA]

Production/ Year	Coal	Crude oil	Natural gas	Nuclear	Hydro	Geothermal and Solar	Biofuels and waste	Electricity	Heat	Total
2016	739	217616	169066	1725	1412	22	509	0	0	391088
2015	727	163670	155732	759	1212	19	506	0	0	322624
2014	715	165014	147738	1165	1192	31	515	0	0	316369
2013	734	161649	132608	1185	1254	32	508	0	0	297970
2012	695	162368	132285	481	1070	18	509	0	0	297426

2. 2. Discussion about energy sustainability indicators for residential area

Choosing the proper indicators is effective for achieving sustainability in the field of energy. Various types of indicators to improve energy sustainability can be used but which of these indicators are better and more practical in this regard. Hence, an appropriate analysis for selecting indicators to achieve sustainable energy goals is important. We need to know which indicators can be more positive influential to energy sustainability. On the other hand, each analysis should include both quantitative and qualitative indicators that can be better analyzed and selected to achieve energy sustainability. Also, selected indicators should have the sub-indicators that are consistent with the main elements and lead to energy sustainability.

2.2.1. Critical interpretation of urban energy develop

The development of sustainable urbanization plans based on the selection and implementation of urban sustainability indicators should be the priority for each country. These plans if perform and develop inappropriate time and under a proper framework, definitely will have favorable effects for achieving sustainable urbanization. Thus, a set of effective urbanization indicators should be selected and implemented based on energy sustainability goals. Fig 2.3 shows a total schematic of urban energy sustainability and four main divided indexes with relevant indicators. Also, in Fig 2.3, the main indexes as urban energy sustainability pillars are in the above of this Fig and relevant indicators to them are in the bottom of this Fig. In addition, Fig 2.3 demonstrates how energy resource can be divided between the main sectors in the line energy sustainability properly.

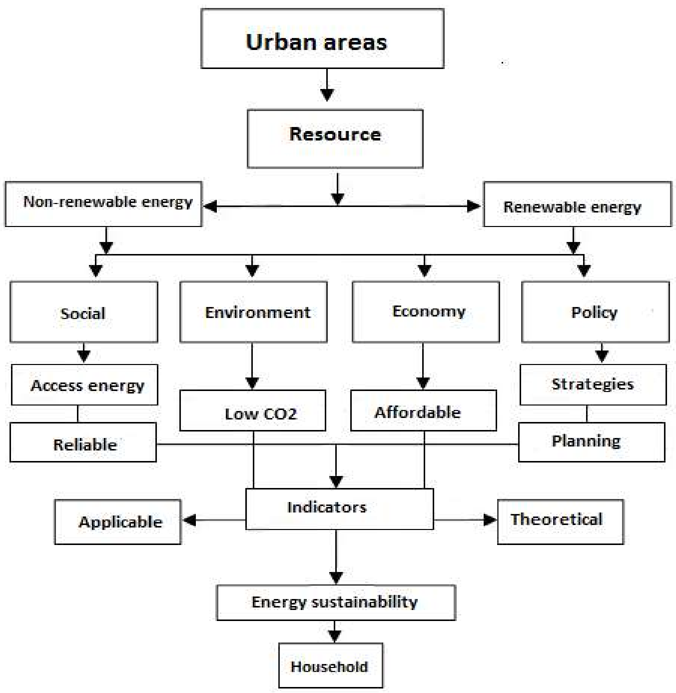


Fig 2.3. A total schematic of urban energy sustainability and divided indexes with relevant indicators

Table 2.4 that is designed based on Fig 2.3 shows the four main indexes with related indicators. In this Table, the most important indicators as separately for each index have been shown that can be effective to achieve energy sustainability.

Table 2.4. Four main indexes with related indicators based on Fig 2.3.

Indicators	Policy	Economy	Environment	Social
Strategies and planning	√	√	√	√
Industrial energy intensity	√	√	x	x
Household energy intensity	√	√	x	√
Total energy primary supply	√	x	x	x
Energy intensity	√	x	x	x
Gross domestic product	x	√	x	x
Energy affordable	x	√	x	√
Energy price	x	√	x	√
Total final consumption	x	√	x	√
Annual freshwater withdrawals	x	x	√	√
Forest area	x	x	√	x
Land area	x	x	√	x
Reduction of CO_2 and GHG	x	x	√	√
Share electricity production by fuel fossil	√	x	√	x
Share electricity production by clean energy	√	x	√	x
Electrical consumption	x	x	x	√
Enough investment on clean energy	√	√	√	√
The efficiency of residential energy use	x	x	x	√
Access energy	√	x	x	√
Total final consumption in transport	x	x	x	√
Share non-renewable in transport	√	x	√	√
Share renewable in transport	√	x	√	√
Energy infrastructure and reliability	√	x	x	√
Resiliency	√	x	√	√

Table 2.5 shows the city energy sustainability and renewable energy indicators. In this table, most important indicators related to two index shows separately.

Table 2.5. City energy sustainability and renewable energy indicators

Indicators	**City energy sustainability**	**Renewable energy**
Electrical consumption	√	√
Enough investment	√	√
Energy Burden	√	√
Access energy	√	x
Loss of energy	√	x
New technology	√	√

Total final consumption in residential	√	√
Total renewable energy production	x	√
Reduction of CO_2 and GHG	√	√
Renewable energy potential	x	√
Energy affordable	√	√

2.2.2. A new approach to renewable energy

Renewable energy development shows that there are a positive approach and strategies to exploit their potential [67]. Also in recent years, using an investment in renewable energy has increased [68]. Low polluting emissions, potential sources of energy, availability are among the important factors that have led to more and more use of renewable energy sources [69].

2.2.3. Renewable energy potential in Iran

Iran has a high potential in renewable energy, especially in solar energy. Because Iran is located on the sun-belt and receives the highest level of solar radiation, thus, it can be used for electricity production [70]. Iran has 300 sunny days per year with an average minimum of about 4.5-5.5 kWh per square meter. It shows the high percentage of solar radiation in this country [50]. Fig 2.4 shows the maps of Iran's annual average global horizontal irradiance (GHI). As can see Iran has a high potential in solar energy.

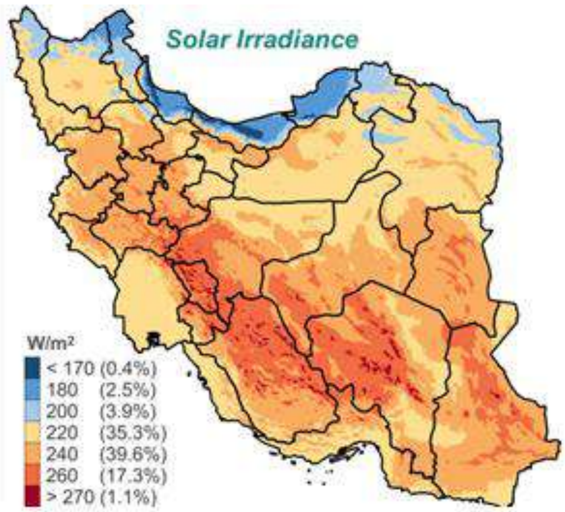


Fig 2.4. Maps of Iran's annual average global horizontal irradiance

2.3. Description studied area

2.3.1. Chabahar city

Chabahar is one of the strategic cities in the Sistan and Baluchistan province and is a well-known port in this zone. It is free trade and industrial zone by Iran's government. It has according to the 2018 census 106,739 populations. It is located at coordinates 25 17 ′N and 60 38′E and the 18 meters above sea level. Fig. 2.5, shows the location zone studied on the map of Iran|. As can see the Chabahar is the end of Sistan and Baluchistan province.

Fig 2.5. Location zone studied on the map of Iran

2.4. Methodology for the objective selection

Regarding importance improvement energy sustainability through renewable energy especially for residential areas, therefore, in this study, a hybrid energy system including PV, DG, batteries, energy converters using HOMER software is modeled with attention to energy sustainability requirements of Chabahar city. This study presents a discussion related to energy sustainability and technical analysis of a hybrid system for a city of Iran. We discuss the importance of renewable energy as a reliable way of achieving energy sustainability. This research divided into two main stages. In the first stage, a conceptual discussion regarding energy and policy in the line of UN goals and Urban Themes targets. In the second stage, a technical analysis of a hybrid system for a city of Iran. Fig 2.6 shows the selected our methodology in this study.

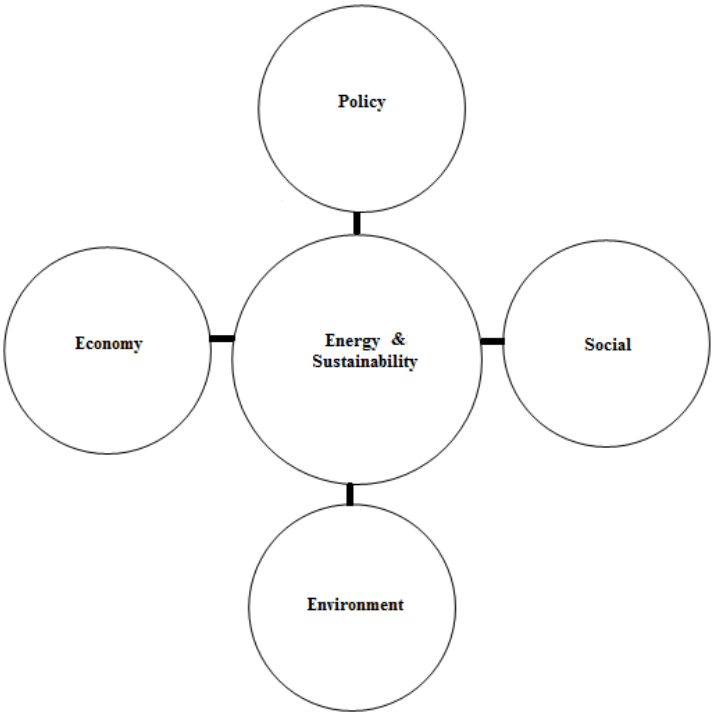


Fig 2.6. The selected methodology in this study

2.4.1. Main cause to select the PV-DG hybrid system for this study

Because of the construction of renewable power plants directly is depended to natural energies potential as solar radiation, wind speed, and wave power. Therefore PV-DG hybrid system regarding Chabahar potential is most proper than another kind, even though wave energy also can be considered. Fig 2.7 shows monthly wind speed and solar radiation for Chabahar city. As can see in

Fig 2.7, regarding low wind speed and high solar radiation, thus, this city only is appropriate to invest in solar energy in order to electrical production.

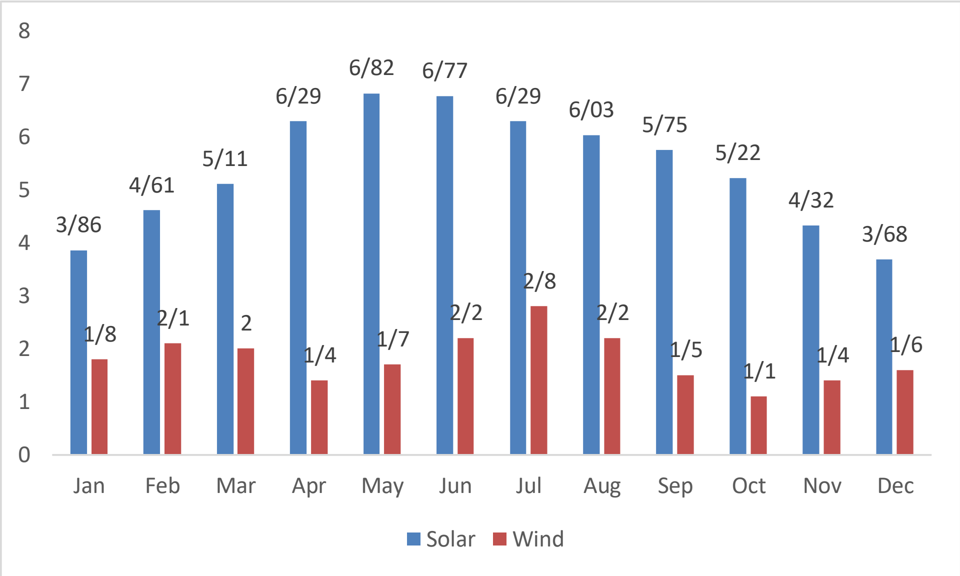


Fig 2.7. Monthly wind speed and solar radiation for Chabahar city

2.4.2. Energy sustainability methodology description (conceptual discuss)

Without the doubt, four important factors which showed in Fig 2.6, has a significant impact on energy sustainability and none of them especially policy factor should not be ignored. Regular and appropriate planning by policymakers makes a positive impact on the economy, social, and environmental factors. Indeed, energy sustainability helps us to better utilizing sustainable energy carriers, improving performance, decreasing negative environmental effects, and improving socioeconomic status. Regarding these explanations, all renewable energy sources like solar, wind, geothermal, hydropower and ocean energy are sustainable because they are abundant and available also proper for our utilization.

2.5. Electrical producing by the proposed system

A schematic of the present system is shown in Fig 2.8 which has different parts includes PV array, converter, battery and diesel generator. As can see the load demand of PV-Diesel system is 22.8

kWh/d and the peak load is estimated at 2.1 kW for this study. This system is capable of electrical production with 10,575 kWh/yr value which 8,447 kWh/yr of it belongs PV and 2,128 kWh/yr is provided by Diesel system. Fig 2.8 shows a schematic of the analyzed system that consists of PV, generator, converter, and battery.

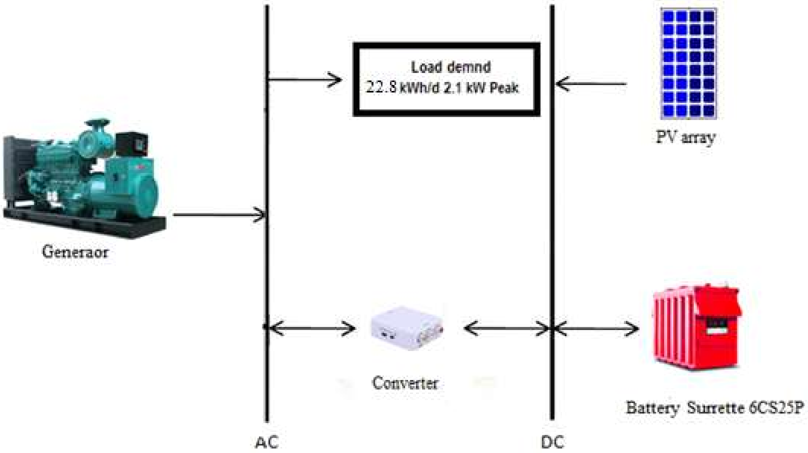


Fig 2.8. Schematic of the analyzer system

2.6. Result and discussion

Today most countries are trying to assess their energy systems in order to achieve proper strategies and implementing them based on UN goals and Urban Themes. That in this regard renewable energy can be a suitable way. Indeed, one of the requirements factors to reach energy sustainability status is the increasing application of renewable energy. Developing renewable energy lead to reducing CO_2 emission, creating more job opportunity, safety energy, etc. With these explanations, assessment of renewable energy potential, especially in the developing countries, is a necessity for policymakers and energy expert them. In this regard one of the practical software to calculate this work is HOMER. In this study using Homer an economic and technical analysis was performed for implementing a small hybrid system based on renewable energy for an area in Iran. This software presents us with a variety of values consisting of fixed expenses and a marginal expense of energy. Actually this software (Homer) based on existing information on geography seeks a proper solution to achieve electrical\thermal loads as well as the operating storage with the lowest expense. HOMER based on data calculates and presents NPC, RF, COE, NPC values. The suggested system is designed in order to serve the entire period project of 5 years over numerous changes, such as components' prices and load demand.

2.6.1. Technical analysis of a case study

One of the best causes to prove that renewable energy can be used for electrical production in the line of energy sustainability is technical analysis by software. Energy software like homer can show how many energies can be extracted from renewable energy systems and could use to energy supply. The technical-economic analysis in this study has been done using homer software. The highest level of solar radiation is equal to 6.820 kWh/m^2/d per square meter, which has been received in May and the lowest level is 3.680 kWh/m^2/d per square meter in December month has been received. Table 2.6 shows the breakdown of the technical specifications for each component of the system.

Table 2.6. The technical specifications for each component of system breakdown.

PV	Rated capacity (kW)	Mean output (kW)	Capacity Factor (%)	Electrical production (kWh/yr)
	5	0.964	19.3	8,447
Generator	Hours of operation (hrs/yr)	Electrical production (kWh/yr)	Fuel consumption (L/yr)	Fuel energy input (kWh/yr)
	2,290	2,128	715	7,039
Battery	Nominal capacity (kWh)	Losses (kWh/yr)	Annual throughput (kWh/yr)	String size
	69,4	900	4,321	1
Converter	Capacity (kWh)	Mean output (kWh)	Hours of operation (hrs/yr)	Losses (kWh/yr)
	Inverter	Inverter	Inverter	Inverter
	5	0.75	7,648	734
	Rectifier	Rectifier	Rectifier	Rectifier
	5.00	0.03	1,110	41

In this research, the load profile was estimated based on related former studies that this assigned the hourly load profile for a residential area. The average electrical energy consumption PV-diesel system is equal to 22.8 kWh/d as Fig 2.8, and the peak load is equal to 2.1 kW. Also, 80% of the fraction in this system belonged to PV and 20% to generator. In this study, PV array 5 kW, generator 1 kW, 10 battery the kind of surrette 6CS25P, inverter and rectifier 5 kW used for this system. For more explanation of Fig. 2.9, it can be mentioned that the lowest electricity production with 1.18 kW was observed in January, February and May months and the highest electricity production was observed in March and September months with 1.25 kW.

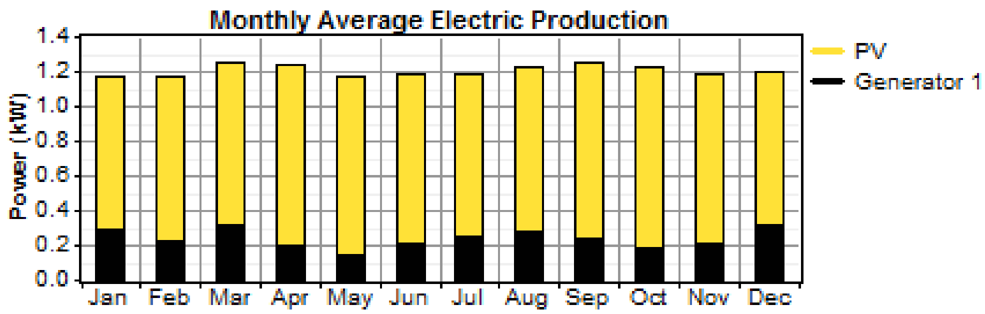


Fig 2.9. Monthly Average Electric Production of PV-generator hybrid for Chabahar

2.6.2. Comparison between this work with some other near studies from the electrical production point of view

Since Iran country is a high potential country for constructing wind power station, solar power station, etc. In this regard, many works close to our works carried out. Table 2.7 shows a comparison between this study with six near work with regard a ratio of electrical production than initial cost. As it is clear in this Table, the amount of electricity production by PV-DG system is remarkable for these areas.

Table 2.7. A comparison between this work and other close work based on electrical production

City	System	Total electrical production (kWh/yr)	Initial cost ($)	Carbon dioxide (kg/yr)	Reference
Chabahar	PV-DG	10575	21000	1,884	-
Damghan	PV-DG	9876	31000	2402	[20]
Dezful	PV-WDG	35085	27720	26936	[71]
Shushtar	PV-WDG	35050	27720	27008	[71]
Hendijan	PV-WDG	34903	27720	27136	[71]
Damghan	PV-WDG	12794	20300	2633	[20]

2.6.3. Comprehensive discussion by attention energy political sustainability

Since natural energy resources such as oil and gas are limited and have a high percentage of air pollution which hurts the environment extremely, therefore, have needed a suitable substitute. On the other hand, regarding a lack of policy stable in the countries producing oil & gas and lack enough resource to energy supply in most countries, therefore it is a necessity to have an accounted plan to achieve energy sustainability for present and future generation based on UN goals and Urban Themes targets. All 17 goals on the UN and 14 targets of Urban Themes are emphases on sustainable development based on the most important parameters that humanity needs for a proper life in the future. In this regard, all governments around the world have adopted ambitious goals to improve the share of renewable energy for providing a part of the required energy and reduce greenhouse gases to achieving energy sustainability. Also governments by regular planning and using energy experts and policymaker's views, assigned effective indicators to achieve energy sustainability. Achieving energy sustainability is extremely dependent on implementing appropriate indicators in the line of social, environmental, and economic dimensions. Parameters such as energy affordable, clean energy, energy access, enough energy, etc., are the most important issues of inhabitants in residential areas. Assigning proper indicators to develop urban areas is a key role factor and a priority for all inhabitants. Energy indicators as a strong tool in the hand of policymakers can help us to have a better life in the future if these indicators implement properly. Policymakers and energy experts should investigate suitable planning as a serious duty for the support of urban areas. Also, the utilization of renewable energy should be extended with an effective policy and as a reliable way to supply a part of the required energy for the countries that have not sufficient resources for a good future. These indexes with indicators make a chain of energy sustainability for residential areas. This Fig as well as show relation between all indexes and indicators in the line of on UN goals and Urban Themes targets. All benefits using renewable energy based on parameters social, Economic, and environmental of sustainable development are shown in Fig 2.10. Indeed, the main objective of present Fig 2.10, is energy access in the best possible state for residential inhabitants as secure, reliable, abundant, accessible, and affordable.

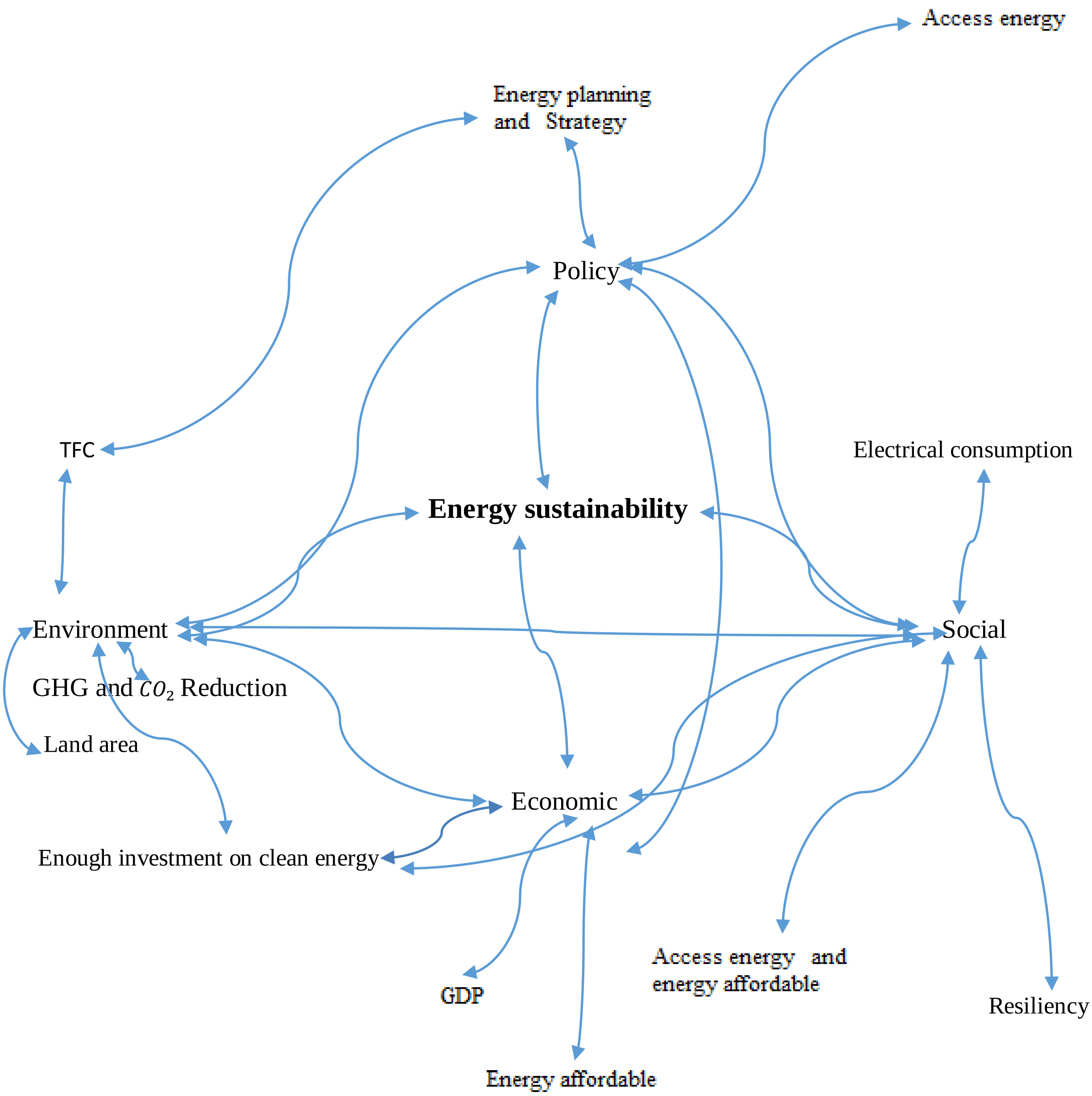


Fig 2.10. Energy sustainability dynamic schematic

2.7. Conclusion

One of the proper ways to achieve energy sustainability is the use of renewable energy which has a very high potential and is a suitable substitute for fossil fuel resources. Since developing countries more needs regular planning with an effective policy to reach this goal, hence, all existing aspects in this regard should be investigated by policymakers and energy experts. Although the achievement of energy sustainability and sustainable development is not easy, some positive actions such as appropriate policy and using clean energy for residential areas can be influential in the path of received to this target in the future. In this study has been presented a comprehensive discussion related to energy sustainability and a technical-economic analysis on combined utilization PV and DG for Chabahar city. Firstly, energy sustainability explained precisely with proper indicators especially for the residential area and with emphases on renewable energy, then a case study investigated from the energy point of view. Chabahar city has a high potential in solar energy; this can be investigated to constructing a solar power station in order to electrical production. The diagram of horizontal radiation for this city showed that the highest level of solar radiation is 6.820 kWh/m2/d and the lowest level is 3.680 kWh/m2/d per square meter which has been recorded in May and December months respectively. The average of solar radiation per year was obtained for this city 5.4 kWh/m2/d. This analysis shows that this site has a desirable solar potential. Also, the technical analysis of this system shows this city has a high capacity for electrical generation by the PV-diesel system. Total electrical production was estimated at 10,575 kWh/yr that 8,447 kWh/yr belongs to PV and 2,128 kWh/yr belongs to diesel generator system. Therefore, energy experts and policymakers can with regard to this potential of energy in Chabahar, make appropriate acts such as attracting energy investors to achieve energy sustainability for this city.

Part 2

Nomenclature

ARDL	Applying the autoregressive distributed lag
COE	Levelized cost of energy
CRF	Capital recovery factor
Ctann	Total annualized cost
GDP	Gross Domestic Product
Eis	Electrical energy of the micro-grid system
Egrid	Amount of electricity sold to the grid by micro-grid
I	Real annual interest rate
HESS	Hybrid energy storage system
HRES	Hybrid renewable energy system
n	Number of years
NPC	Net present cost
PHS	Pumped hydro storage
PV	Photovoltaic
SEMA	Smart energy management algorithm
Tp	Period of the project

2.8. Introduction (Part 2)

Adequate provision of energy has always been a crucial issue and is deemed as one of the best measures for estimating the economic growth and development of a country. In recent decades, increasing CO_2 emission into the atmosphere is considered as one of the main reasons for global warming with adverse environmental effects such as sea-level rise, floods, droughts, etc. Reduction of fossil fuel consumption by energy efficiency, carbon capture, and storage, conversion of CO_2 to different products, application of renewable energies, and reforestation are effective mitigation options [72-74]. On the other hand, regarding the increasing population of the world, the rate of energy consumption increased and it causes further use of fossil fuels [75]. Concerning these realities, employing more sustainable energy sources such as renewable energy can be considered as an appropriate solution for overcoming these problems and achieving sustainable development [20, 27, 76-79]. Renewable energy sources are clean, free, and have many environmental and economic advantages than other conventional energy sources [80-86].Without doubt among clean energies, solar and wind energy are the best and well-known sources of energy and according to the released statistics has a growing influential impact on energy services [87]. Moreover, solar and wind energy has the appropriate potential for supplying a remarkable part of the required energy in the world. Also, the recent breakthroughs in solar and wind energy technology and its related fields has increased the efficiency of different equipment used in this industry [88,89]. The development of hybrid renewable energy systems has become a challenging task because of designing aspects and the intermittencies of renewables and of such hybrid systems [90]. In recent years, many works in this regard have been carried out in different countries for the development of such systems [91]. Jahangiri et al. [92] investigated renewable energy power plants in Afghanistan. In this research, the potential of solar and wind energy was investigated for this country. A study regarding a photovoltaic thermal system for electricity production and low-grade heat was carried out in Iran [93]. Sen and Bhattacharyya proposed a hybrid technology using homer software for electricity production in India. They investigated wind turbines, small-scale hydropower systems, solar photovoltaic, and bio-diesel generators for supplying electrical energy for remote villages [94]. Ma et al. [95] proposed a solution for energy saving in a remote Island in Hong Kong for supporting the microgrid hybrid solar-wind system. A mathematical pattern showed using renewable systems based on PHS technology (pumped hydro storage) could supply energy for remote regions completely. Ntanos et al. [96] investigated the relationship between energy consumption deriving from renewable energy sources with countries' growth (belong to 25 European countries) and their labor forces. Amrollahi et al [97] analyzed a stand-alone microgrid system for remote areas. In this study, wind and solar energy were considered as the main resources for supplying energy. Gangwar et al [98] evaluated the cost and reliability of a hybrid renewable energy system for a lecture building using the HOMER software. In this study, clean energies have a high capacity for electrical production. Tao Ma et al [99] examined the expansion of energy storage of hybrid batteries for remote regions by renewable energy systems. They investigated theoretical analysis and numerical simulation using related software for these systems and in order to enhance the performance of the HESS systems, were presented an electric inductor. Aktas et al. [100] investigated smart energy management using renewable energy and based on an algorithm. In this study, moreover real various operation experiential and tests for HESS systems, effective strategies according to SEMA (Smart energy management algorithm), and in order to support the HESS (Hybrid energy storage system) systems have been suggested. Bölük et al. [101] considered the renewable energies with an ARDL (Applying the autoregressive distributed lag) approach in Turkey. In this research, the growth of renewable energy in this country and the effect on the environment were investigated. Kumar et al [102] analyzed a hybrid system (pumped hydro storage) using different algorithms such as genetic algorithm and gray wolf optimization. They showed that the use of a small battery bank with PHS greatly could reduce the upper reservoir capacity. Razmjoo et al [78] examined energy sustainability indicators for urban areas. In this study, the most important indicators related to energy were considered for improving the urban energy situation. Goel et al [103] examined renewable energy systems such as PV, PEV (plug-in electric vehicle), and HRES (hybrid renewable energy system). Different hybrid energy systems including in off-grid and in grid linked PV systems that have two or more energy resources in order to energy production for rural electrification has been investigated in this article. Jung et al [104] presented optimal planning and design of hybrid renewable energy for microgrids systems. They showed that the use of these technical and economic analyses could be beneficial for microgrid applications. Razmjoo et al performed wind and solar energy potential assessment for Zanjan city in Iran [105]. The main goal of this research was to implement a renewable energy power station in this area for supplying energy. In this part, wind speed and solar radiation potentials are considered in order to investigate the feasibility of implementing a renewable energy power station for Bandar Dayyer of Iran. Using Homer software, economic analysis, and electrical energy production for Bandar Dayyer by renewable energy is investigated for the first time. Although, due to the humid subtropical climate in the coastal areas in comparison with dry zones, some amount of generated energy will be lost. However, using these hybrid energy systems can produce a remarkable amount of energy for this area that this measure has positive environmental effects and enhancing the possibility of more access to energy for inhabitants in the future.

2.8.1. Energy sustainability importance

Energy supply is not a usual challenge and is extremely involved with security and political issues. On the other hand, access to energy for all is essential [106]. In addition, energy is an important sustainable development issue and can have an effect on social, economic and environment development of any country [107]. Thus, ensuring access to affordable, reliable, sustainable, and modern energy should be considered by governments for people. With regard to this reality that fossil fuels are not sustainable energy sources and hurt the environment, having a sustainable energy plan for supplying energy needs, without risk, is necessary for the future [3]. A balanced energy plan is less vulnerable. Furthermore, achieving sustainable development without sustainable energy development is meaningless. In this regard, a sustainable energy plan, for the protection of the environment and prevention of probable issues for the future, should be applied in the practical plan of any nation. Actually, the highest target of energy sustainability, is energy security and energy balance for different countries. Energy sustainability has many advantages such as creating energy opportunities, energy security, energy affordability, and energy reliability [108]. Fig. 2.11 presents energy sustainability based on the demand and supply by 2050. As it is seen, year-by-year, the role of renewable energy will be increased as a reliable source of energy.

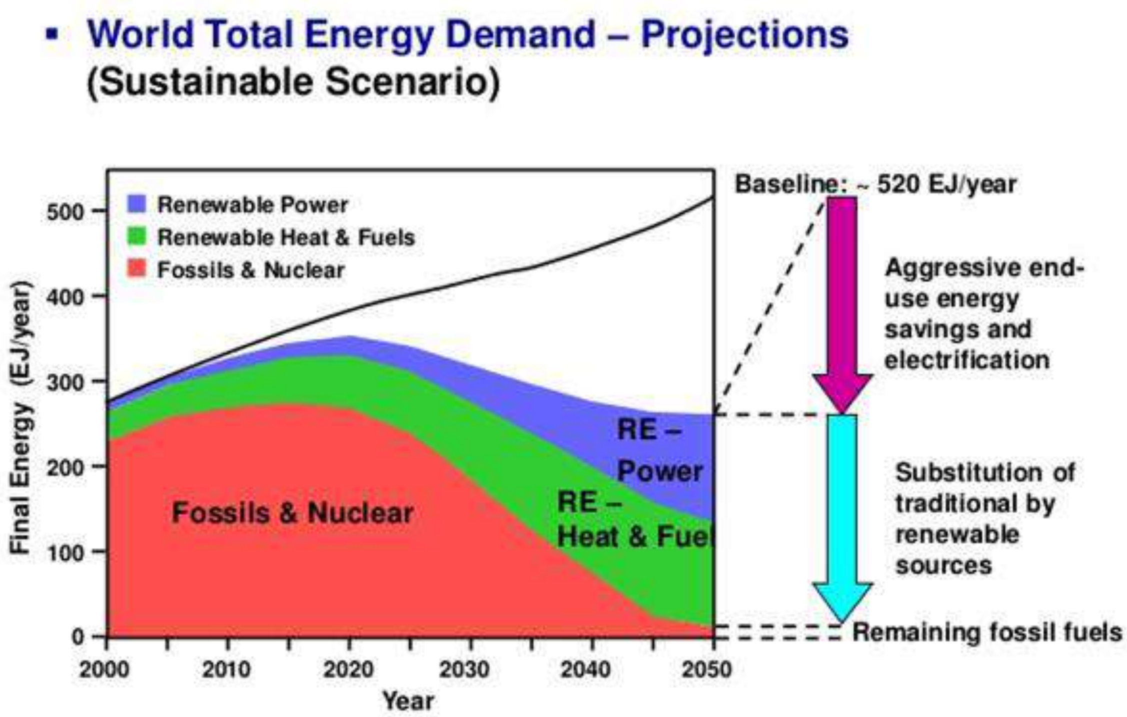


Fig. 2.11. Energy sustainability based on the demand and supply by 2050 [109]

Fig. 2.12 shows Iran's Wind Atlas. In this atlas, the regions which are marked with brown-red, including the northern cities and several cities in the Sistan-Baluchestan province in the south, have the most desirable wind data. There are also other points with very good wind potentials, which are scattered in the central regions of the country.

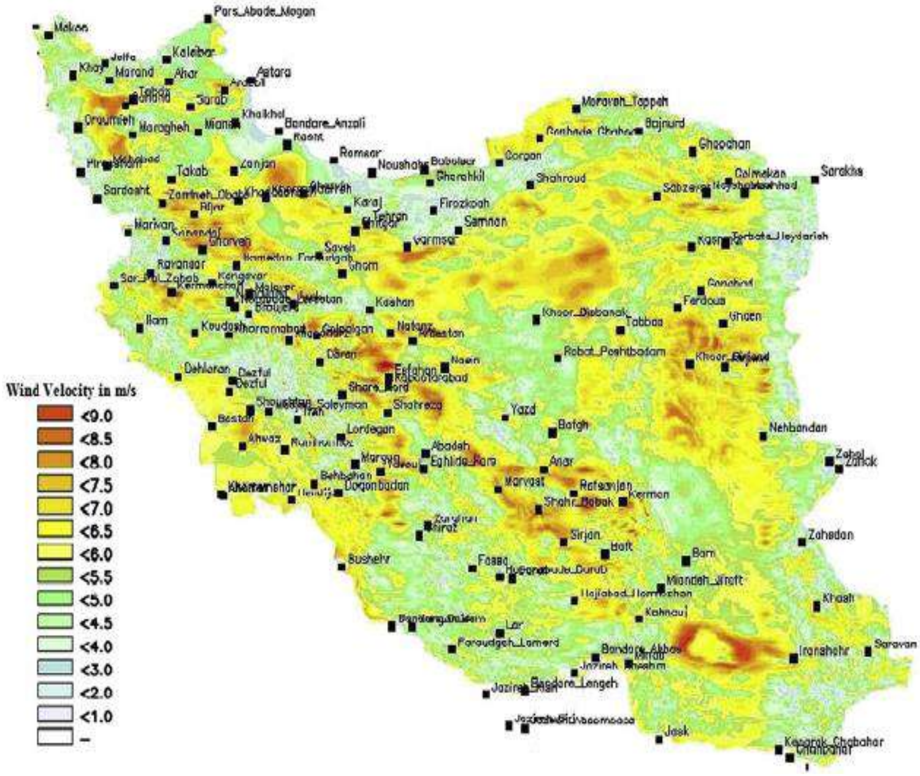


Fig 2.12. The Iran's Wind Atlas

Iran's solar radiation atlas is shown in Fig. 2.13. In this Atlas, Iran is classified into a number of regions based on their solar radiation potential. In this figure, the provinces which receive the highest amount of radiation (Fars, Yazd, and Kerman), are within the middle black frame.

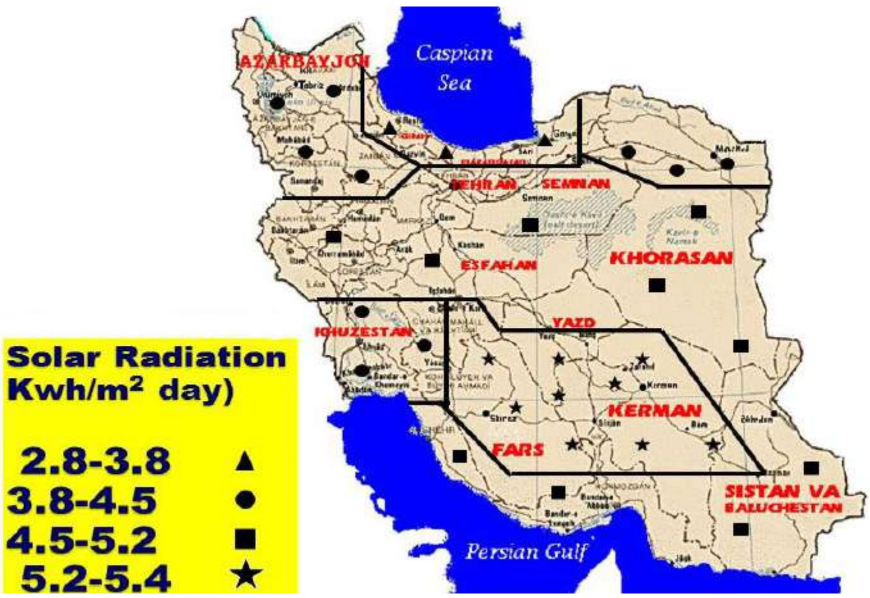


Fig 2.13. Iran's areas receiving high levels of solar radiation

2.9. Site Location

Bandar Dayyer is a known port in the south of Iran, located in Bushehr province. This city is located at the coordinates of 27°50′24″N and 51°56′16″E and an altitude of 12 meters above sea level. At the 2011 census, its population was 24,083. In the south, winters are mild and the summers are very hot, having average daily temperatures in July exceeding 100.4°F. Summer heat in areas abutting the Persian Gulf is accompanied by high humidity. There are three cities near Bandar Dayyer as Kangan, Asaluyeh, and Jam. The distance from Dayyer to the center of Bushehr province is almost 180 kilometers. Fig. 2.14 shows the studied area on the Iran map in this research.

Fig 2.14. The studied area on the Iran map

Table 2.8 shows the average wind speed (m/s) and daily radiation (kWh/m2.d) for Bandar Dayyer. As it is presented, the highest wind speed occurred in March with 3.902 m/s, and the lowest wind speed occurred in August with 2.343 m/s. In addition, the lowest daily radiation is allocated to December with 3.42 kWh/m2.d, while the highest daily radiation corresponds to June with 7.95 kWh/m2.d.

Table 2.8. The average wind speed and daily radiation

Month	Wind speed (m/s)	Daily radiation (kWh/m^2.d)
Jan	3.778	3.72
Feb	3.711	4.73
Mar	3.902	5.44
Apr	2.987	6.77
May	3.700	7.61
Jun	3.413	7.95
July	2.718	7.85
Aug	2.343	7.34
Sep	2.493	6.7
Oct	2.542	5.77
Nov	3.098	4.31
Dec	3.403	3.42

According to Table 2.8, Fig. 2.15 shows the average wind speed and daily radiation for Bandar Dayyer.

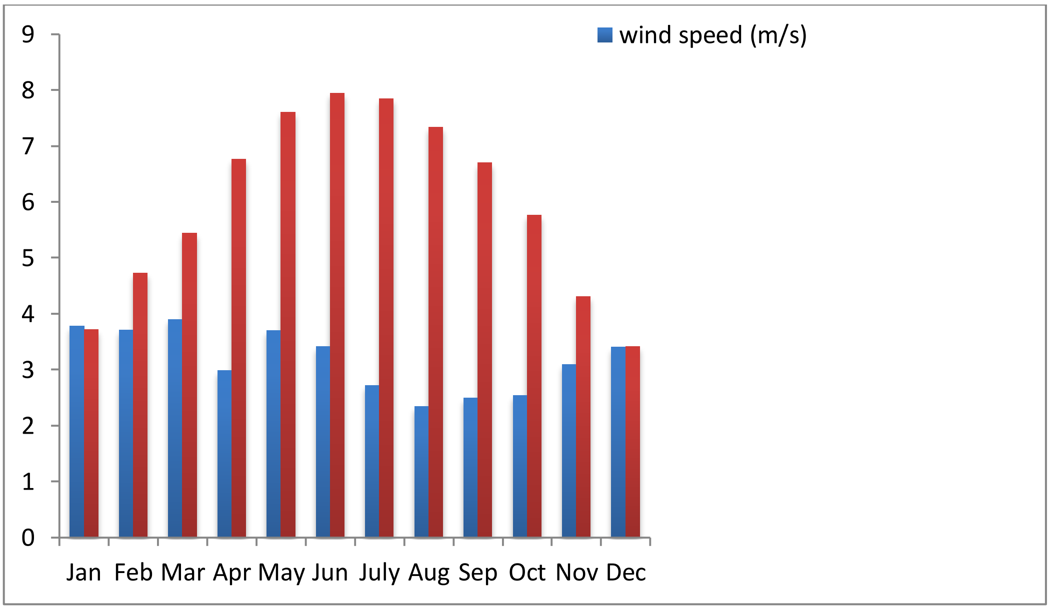


Fig 2.15. The average wind speed and daily radiation for Bandar Dayyer.

Table 2.9 shows the specification of the wind turbine. This wind turbine has 10 kW rated power with 15 kW maximum power. The detail of the turbine is specified in Table 2.9.

Table 2.9 Specifications of the wind turbine with 10 kW rated power

Parameter	Value
Rated Rotated speed	200 r/min
Blade diameter	8.0 m
Weight of the tower top	600 kg
Rated speed	10 m/s
Rated power	10 kW
Max power	15 kW
Startup wind speed	3 m/s
Work speed	3-30 m/s
Security wind speed	50 m/s
High of tower	12 m
Weight of the tower top	60 kg
Capacity and quantity of battery	12V200AH18 pcs
Design lifetime	20 years

Table 2.10 shows the specification of the diesel generator with 100 kW. This diesel generator has 100 kW capacity with a rated voltage of 400/230V. The detail of the diesel generator is specified in Table 2.10.

Table 2.10. Specification of the diesel generator with 100 kW capacity

Parameter	Value
Rated Power	5kW~3500kW
Rated Voltage	400/230V
Speed	1500 r/min
Option	Automatic Transfer Switch
Generator Type	Open, Silent, Trailer, ATS
Alternator	AC 3 phase
Transport Package	Wooden, Pallet or Customized
Rated current	20A-7000A
Prime power	125 kW
Standby power	137.5 kW
Frequency	50 /60 Hz

Voltage	400V/230V
Fuel consumption at 100 % load	238g/kWh
Design lifetime	20 years

Table 2.11 shows the specification of the generic flat-plate PV. The capacity of this generic flat plate is 10 kW with the work time of 24 h/day. The detail of this solar panel is specified in Table 2.11.

Table 2.11. Specification of the flat plate PV with 10 kW capacity

Parameter	**Value**
Rated Capacity	10 kW
Work Time (h)	24 h/day
Battery Type	Lithium
Output Frequency	50/60Hz
Specification	Normal
System type	On-Off-Grid Solar System
Est. Time (Days)	10
Controller Type	PWM or MPPT
USING	Home, Factory, Commercial
Battery	free maintenance Gel battery
Output Voltage (V)	380V, 220V, 110V

Also, Fig. 2.16 shows the real meteorological station of Bandar Dayyer. As can be seen in this figure, the meteorological equipment belongs to the studied area.

Fig 2.16. The meteorological station of Bandar Dayyer

2.10. Methodology

Different software programs are used to calculate the wind speed and solar radiation, one of those is the Homer software, which is used by many researchers in the world [110]. In this study, by using Homer software, the wind speed and solar radiation data for Bandar Dayyer are gathered and measured for implementing a hybrid power station in this area. After this step, the simulated results and the amount of electricity production for these systems are investigated. In the end, a comparison investigation between these systems and others is presented in the table 2.19.

2.10.1. The Homer software benefits

Homer is an optimization and simulation software for renewable energy. This software is able to present a model for renewable electricity and micro-power optimization for evaluating the designs of both off-grid and grid-connected power systems. In addition, this software can analyze the economy of hybrid renewable energy systems. Indeed, the Homer software models a power system's physical behavior and its life-cycle cost, so that it is able to estimate the total cost of installing and operating of the considered systems. Homer software has three main tasks: simulation, optimization, and sensitivity analysis. For the simulation step, this software model the performance of a specific micro-power system for determining its technical feasibility and life-cycle cost. For the optimization step, Homer is able to analyze and select the feasible system for implementation in the studied areas. For the sensitivity analyses, this software simulates each configuration and discovers the effects which change the factors.

2.11. Results and discussion

By using the Homer software, technical analysis for this study is performed. Homer software is applied for the techno-economic feasibility of the wind-solar-generator hybrid system. Initially, the related data of wind speed and solar radiation for the studied area were extracted via Iran's weather forecasting website; then, the data were entered into the software and analyzed.

2.11. 1. Load demand

Fig. 2.17 shows a schematic of the PV-Wind-Diesel-Converter-Battery system. The load demand for this unit is 11.25 kWh/d and the peak load is estimated at 0.89 kW, which is obvious in Fig. 2.17.

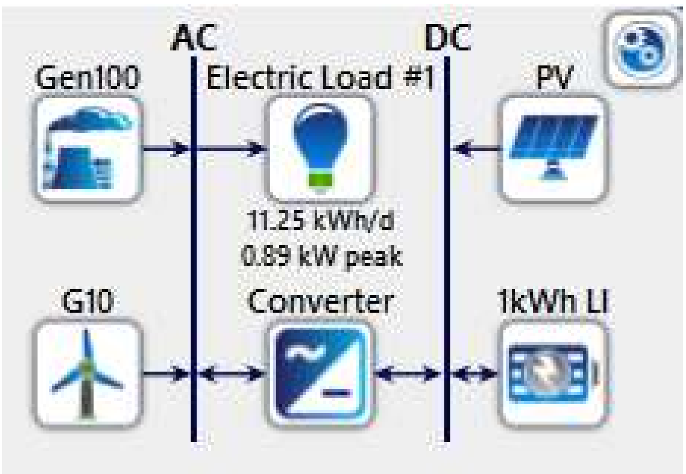


Fig 2.17. A schematic of the PV-Wind-Diesel-Converter-Battery unit

2.12. Technical analysis

In this study, two separate units were considered and analyzed for producing electrical energy. In this regard, firstly, the input data were entered into Homer software; then, with regard to the output data, the analyses were carried out.

2.12.1. Electrical production analysis

Since producing electrical energy by fossil fuels could lead to environmental issues, the importance of electricity production for residential areas by renewable energy is extremely essential for each country. In this regard, Table 2.12 shows the electrical production by each main component for the PV-Generic system.

Table 2.12. Electrical production by each main component for PV-Generic system

Generic flat plate PV	Generic 100	Generic 10	Total Production	Fuel consumption (L)	Excess electricity
18862 kWh	0	3545 kWh	22409 kWh	0	17983 kWh

To complete this table, Fig. 2.18 shows the monthly average electric production for the PV-Generic. As it is shown in this figure, among different months, May has the highest amount of electrical production, while December has the lowest amount of electrical production.

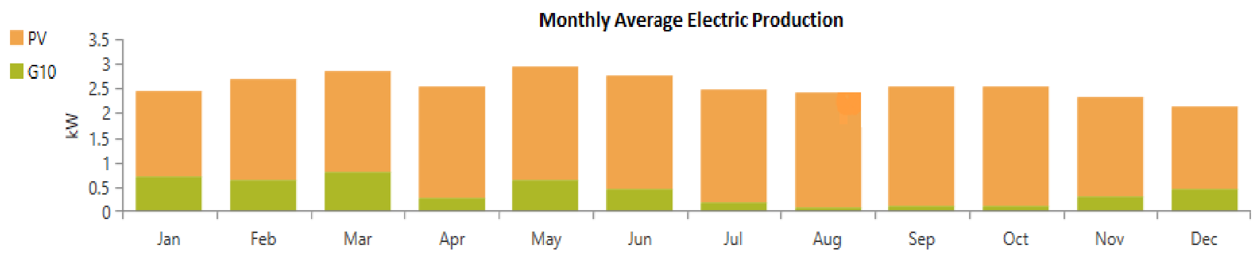


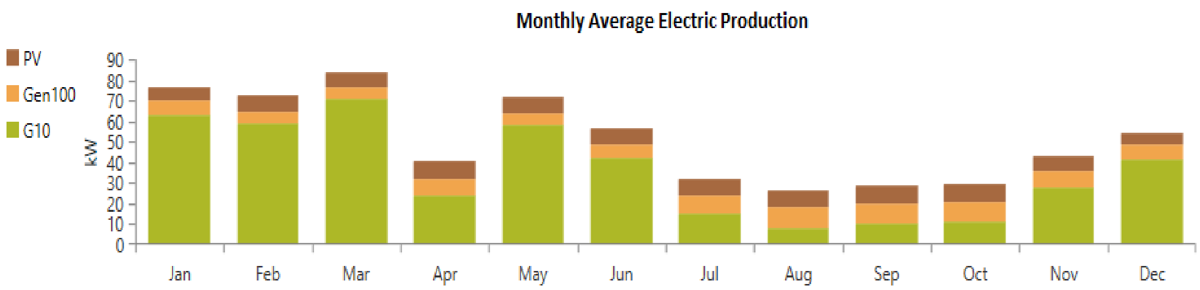
Fig 2.18. Monthly average electricity production for the PV- Generic system.

In addition, Table 2.13 shows the electrical production for the PV-diesel-Generic system by each main component. With this regard, the total amount of electrical production is 447,767 kWh that most amount electrical production of it is producing by generic 10 kWh and with an amount value of 315,481 kWh. In addition, this system is able to produce 443,629 kWh excess electricity.

Table 2.13. The electrical production for PV-diesel-Generic system by each main component.

Generic flat plate PV	Generic 100	Generic 10	Total Production	Fuel consumption	Excess electricity
67536 kWh	64750 kWh	315481kWh	447767 kWh	236341	443629 kWh

Moreover, Fig. 2.19 shows the monthly average electrical production by the PV-diesel-Generic. According to the figure, March and August have the highest and lowest amount of electrical production, respectively.



Figs 2.19. Monthly average electric production by PV-Generator 100 kW-Generator 10 kW.

2.12.2. Battery analyses for PV-Wind-Diesel-Converter-Battery system

The importance of battery for energy storage has been caused that selection of this section was done with high accurate by designers of hybrid systems. Table 2.14 shows the specifications of the utilized battery for the hybrid unit. As it could be seen, the battery receives 1,744 kWh/yr and energy out is 1,571 kWh/yr, actually the battery only losses 175 kWh/yr that it shows the battery has high percent to save energy.

Table 2.14. Specifications of the utilized battery for the hybrid unit

Energy In (kWh/yr)	1744
Energy Out (kWh/yr)	1571
Storage Wear Cost ($kWh)	0.0126
Nominal Capacity (kWh)	25
Lifetime Throughput (kWh)	24857
Storage Depletion (kWh)	2
Losses (kWh)	175
String Size	1
Bus Voltage (V)	6
Expected Life (year)	15

Fig. 2.20 shows the state of charge for the battery. The oscillating's in this figure demonstrates that this battery does not have 100% performance, which means in some times the wind turbine and PV are not able to produce and receive energy completely and this system will be forced to use the generator.

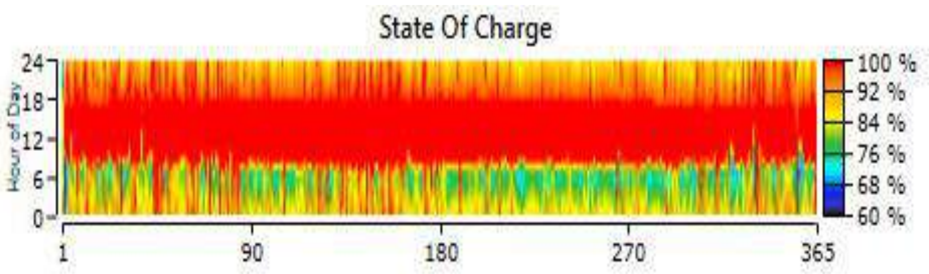


Fig 2.20. State of charge for the utilized battery

2.12.3. Converter analyses for the hybrid system

The converter is an essential part of each hybrid component. Table 2.15 demonstrates the total specification of the used converter for the PV-Wind-Converter-Battery System. As it could be seen, this converter has 2,847 amount of energy in and 2,705 amount of energy out with 142 kWh/yr losses.

Table 2.15. Specification of the utilized converter

Specification	Inverter	Rectifier
Hours of Operation (hrs/yr)	7044	327
Energy In (kWh/yr)	2847	126
Energy Out (kWh/yr)	2705	120
Losses (kWh/yr)	142	6.32
Capacity (kW)	1.17	1.17
Mean Output (kW)	0.309	0.0137

2.12.4. Economic evaluation

Careful and accurate technical-economic evaluation of solar and wind potentials is considered as the most important step in the construction of wind or solar power systems because these evaluations are the pre-requirements of a successful source utilization plan. Parameters required for such evaluations can be obtained by the following formulas.

Net present cost can be calculated by the following equation [111]:

$$NPC = \frac{Ctann}{CRF(i,Tp)} \tag{2.1}$$

NPC in the above formula is the net present cost (in dollars), $Ctann$ is the total annualized cost, *CRF* is the capital recovery factor, i is the real annual interest rate (in percentage) and T_p is the period of the project.

Capital recovery factor can be calculated by the following formula:

$$CRF(i,n)=\frac{i(1+i)^n}{(1+i)^n-1} \quad (2.2)$$

In the above formula, *CRF* is the capital recovery factor, *i* the nominal interest rate, and *n* is the number of years. In the Homer software, the energy cost balance can be obtained from the following equation [111]:

$$COE=\frac{Ctann}{\text{Eis+Egrid}} \quad (2.3)$$

In the above formula, COE is the levelized cost of energy, Ctann is the total annualized cost; Eis is the electrical energy that the micro grid system actually serves, and Egrid is the amount of electricity sold to the grid by the microgrid.

Table 2.16 shows the output economic analyses for two considered systems. As it is shown in the table, the total NPC for the PV-Diesel-Wind-Converter system is approximately more eight times of PV-Wind-Converter-Battery system, and so on the costs of PV-Diesel-Wind-Converter system is more.

Table 2.16. The output economic analyses for two considered systems

System	Total NPC	Levelized COE	Operating Cost	Present Worth	Annual Worth
PV-Wind-Converter-Battery	$23148.84	$0.44	$260.59	$17316	1339 ($/yr)
PV-Diesel-Wind-Converter	$186969.00	$3.52	$12623.38	$181136	14012 ($/yr)

Table 2.17 demonstrates the cost summary for the PV-Wind- Battery-Converter. The highest cost value in this system belongs to the generic 10 kW at $15,000, and the lowest cost value is for the converter with a value of $280. In addition, the total cost value for this system is $23,148.84.

Table 2.17. Cost summery for PV-Wind- Battery-Converter System

Component	Capital $	Replacement $	Q&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 10 kW	15000	3825.69	646.38	0	2156.02	17316.04

Generic 1kW Li –Lon	1000	381.85	129.28	0	71.87	1439.25
Generic flat plate PV	3500	0	387.83	0	0	3887.83
Converter	280	118.8	129.28	0	22.36	505.71
System	19780	4326.33	1292.75	0	2250.25	23148.84

Also, Table 2.18 indicates the cost summary analysis for the PV-Wind-Diesel-Converter. The lowest cost value was estimated for the converter at $280, while the highest cost value was for the generic 10 kW with a value of $15,000. In addition, the total cost value for this system was $186,968.99.

Table 2.18. Cost summary for the PV-Wind-Diesel-Converter system

Component	Capital($)	Replacement($)	Q&M($)	Fuel($)	Salvage($)	Total($)
Generic 10 kW	15000	3825.69	646.38	0	2156.02	17316.04
Generic 100 kW	5000	7481.70	669.65	152762.85	654.79	165259.40
Generic PV	3500	0	387.83	0	0	3887.83
Converter	280	118.8	129.28	0	22.36	505.71
System	23780	11426.19	1833.12	152762.85	2833.17	186968.99

2.13. Validation

A comparison of the results of the present simulation with the published literature with similar electrical power demand is presented here. Since the main goal of the hybrid systems is energy production, thus different types of hybrid units could be used and coupled for this target. Table 2.19 shows a comparison of the results of the study with other similar cases. As it is shown, various types of hybrid systems with different amounts of energy production are presented in Table 2.19.

Table 2.19. A comparison of results of the study with other similar electric power demand situation

System	**Total electrical production**	**High producer section and amount of electric production**	**Authors**
PV-Wind-Generator	49835 kWh	Wind turbine 25230 kWh	[112]
PV-Wind	2575 kWh	PV 2079 kWh	[113]
PV-Wind-	447767 kWh	Wind turbine generic 10	Present study (case 1)

Generator		315481 kWh	
PV-Generator	37948 kWh	Diesel generator 5kWh 25379 kWh	[114]
Wind-Generator	2641666 kWh	Wind turbine 1807624 kWh	[115]
PV-Wind	22409 kWh	Wind turbine generic 10 3545 kWh	Present study (case 2)
PV-Generator	31722 kWh	PV 26567 kWh	[116]
PV-Wind-Fuel cell	2 126 048 kWh	Wind turbine 1461955 kWh	[117]
PV-Wind-Generator	229617054 kWh	Generator 156680000 kWh	[118]

2.14. Conclusion

Achieving energy sustainability using renewable energy has many advantages such as reducing fossil fuels and reliable energy supply for deprived areas, especially in developing countries. The main goal of this study is a techno-economic analysis using Homer software for two different hybrid systems. With regard to this reality that the average wind speed in Bandar Dayyer is 3.174 m/s, and the average solar radiation is 5.96 h/d, PV array, wind turbine, generator, converter, and battery are chosen as the main sections for energy production. The electrical production analysis for two considered systems shows that the total amount of electricity production for the PV-Generic system is 22409 kWh, and for the PV-Generator 100 kW-Generator, 10 kW systems are 447,767 kWh with the total amount of 470176 kWh electricity production for two systems. In addition, the economic analysis shows that the net present cost for the PV-Generic system is $23148.84, and for the PV-Generator 100 kW-Generator 10 kW systems are $186969.00. In addition, the capital cost for two systems was obtained as $ 15000 with the replacement cost of $ 3825.69. In general, it should be mentioned that Bandar Dayyer has suitable potential for energy production, and investment in this area would have economic justification in the near future.

Chapter 3. Investigating energy sustainability indicators for developing countries

Nomenclature

AER	Access to electricity urban and rural	Pc	Production coal
AFW	Annual freshwater withdrawals	Pe	Production energy
CCh	Climate change	Pg	Production gas
CCP	Changing consumption patterns	PISEG	Promote inclusive and sustainable economic growth
Cr	Coal reserve	Po	Production oil
EA	Energy accessibility and equity,	REC	Renewable energy consumption
EAFF	Energy affordability	RS	Resilient and sustainable.
EC	Electricity consumption	SS	Social Sustainability
ECS	Economic Sustainability	TCEC	Total final consumption in commercial
EEI	Enhance economy infrastructure	TCO_2	Total CO_2
EI	Energy intensity	TCNR	Total consumption natural resource
EIM	Energy intensity management	TFC	Total final consumption
ENS	Environment Sustainability	TFCT	Total final consumption in transport
EP	Energy productivity	TFA	Total Forest area
ES	Energy sustainability	TLA	Total land area
ESe	Energy security	TS	Technical Sustainability
Et	Energy technology	TNR	Total natural resources
GNI	Gross national income	TPES	Total primary energy supply
GDP	Gross domestic product	ULCT	Use of low carbon technologies
Gr	Gas reserve	UP	Urban planning
IRS	Increase share of renewable energy in different sectors	USG	Use of smart grids and electric grid
IS	Institutional Sustainability	WS	Water & Sanitation and access to health water
ITI	Improvement transport infrastructures	Vact	Actual number of indicators
INV	Investment	X	Actual number
Or	Oil reserve	Xmax	Maximum number of indicators
Pb	Production Biomass	Xmin	Minimum number of indicators

3.1. Introduction

This chapter has studied the SEDI method as one of the most important methods for achieving energy sustainability, especially in developing countries. SEDI method (sustainable energy development index) consists of five indicators, Technical sustainability, Economic sustainability, Social sustainability, Environmental sustainability, and Institutional sustainability. To calculate, SEDI is required to obtain technical sustainability, economic sustainability, Social sustainability, Environmental sustainability, and institutional environmental sustainability. When all indicators were obtained, should be normalized and obtain the average of them. The main purpose of these indicators is a conceptual investigation of sustainability for each country. Actually, each country needs to have an appropriate infrastructure in various sustainability sectors. Sustainability depends on a variety of factors, which, by their general integration, will make the development of a country. Sustainability can make a good situation in different sections of each country that it will have a good impact on the quality of life for inhabitants. In this chapter investigating energy sustainability indicators for developing countries is investigated. The goal of this chapter is to show the importance of the indicators to achieve energy sustainability in these countries. One of the most important current issues in the world is the energy supply that has a remarkable effect on communities [119,120]. In addition, energy supply is one of the most important factors for development [20, 121]. Today, more than half of the world's people are living in cities, which will be much more populated by 2050, reaching about two-thirds of the world's population [122]. On the other hand, increasing the world's population will lead to more fossil fuels and global warming [107, 123]. In this regard, the UN intends by 2030 to implement many practical goals to prevent more problems relating to human rights, especially in the energy field. One of the most important factors of SDGs is energy sustainability [124]. Energy sustainability provides a better situation to energy consumers from various aspects such as access, affordable, technology and etc. Also, energy sustainability has a significant effect on the environment [125-127]. Energy sustainability is a range spread of different subjects like policy, environment end efficiency [128].

3.1.1. Theoretical background

Indicators are conceptual tools for sustainability assessments that can be influential in many sectors. Energy policymakers and energy experts using indicators are able to make better decisions for activity areas [129]. With regard to these descriptions, some of them done studies can be presented for better understanding [73]. Neves et al, investigated with a review of existing practices investigated energy sustainability indicators in order to local energy planning. They in this review showed that how indicators can be effective for energy planning and assessment of different current problems. In addition, they showed, with the use of the indicators can monitor the targets and do proper actions [13]. With regard to energy accessibility importance especially electrical energy, razmoo et al presented, a technical study in order to investigate energy sustainability using renewable energies. They used homer software and with regard to wind-solar energy potential, analyzed energy sustainability hybrid systems for two cities in the south-east of Iran. In this study, total electrical energy production by PV array for Zabol and Zahak were 1700 (kWh/yr) and 1669 (kWh/yr), and the amount of wind turbine capacity was calculated at 9036 (kWh/yr) and 7263 (kWh/yr) for Zabol and Zahak respectively [3]. Bhattacharyya et al presented a critical review and analysis of energy access programmers for sustainable development. These indicators are conceptual tools for sustainability assessments that can be influential in many sectors. Energy policymakers and energy experts using indicators are able to make better decisions for activity areas [129]. With regard to these descriptions, some of them done studies can be presented for better understanding [73]. Neves et al, investigated with a review of existing practices investigated energy sustainability indicators in order to local energy planning. They in this review showed that how indicators can be effective for energy planning and assessment of different current problems. In addition, they showed, with the use of the indicators can monitor the targets and do proper actions [13]. With regard to energy accessibility importance especially electrical energy, razmoo et al presented, a technical study in order to investigate energy sustainability using renewable energies. They used homer software and with regard to wind-solar energy potential, analyzed energy sustainability hybrid systems for two cities in the south-east of Iran. In this study, total electrical energy production by PV array for Zabol and Zahak were 1700 (kWh/yr) and 1669 (kWh/yr), and the amount of wind turbine capacity was calculated at 9036 (kWh/yr) and

7263 (kWh/yr) for Zabol and Zahak respectively [3]. Bhattacharyya et al presented a critical review and analysis of energy access programmers for sustainable development. In this article, they emphasized an overall revision related to access energy methods and more use of renewable energy as one of the proper ways to access energy. Also, an important energy indicator is investigated in this study [15]. they emphasized an overall revision related to access energy methods and more use of renewable energy as one of the proper ways to access energy. Also, an important energy indicator is investigated in this study [15]. Mardani et al, by using multiple criteria decision-making methods investigated energy sustainability, especially by renewable energy. They reviewed many related articles in this regard into two main application areas such as sustainable energy and renewable energy and based on them presented their results [17]. Assess energy technologies for rural electrification using a sustainability index that has been done by Mainali et al. They presented the energy technology sustainability index (ETSI) to this evaluation. Also, they proved that mature technology have better sustainability performance than among the other options [130]. Moreira et al investigated the effective indicators associated with energy sustainability. They used academic and institutional sources, analyzed influential indicators in the line of energy sustainability. In fact, they showed that indicators have an effect on all aspects of energy sustainability dimensions, thus, should be considered by policymakers and energy experts accurately. Also, in this study, they emphasized that achieving energy sustainability, in addition to a mutual review, needs to have appropriate infrastructures in this regard [131]. Correct Energy policymaking in Denmark, investigated by Sovacool et al. They showed that how Denmark by the appropriate policy in the energy field, obtained a good situation in energy sustainability [132]. Energy services situation for rural development, investigated by Kaygusuz et al. They investigated practical programs to access energy in this regard. They also in this study, to improve access energy for inhabitants, emphasized more attention to women [133]. There are four important reasons to write this research. First of all, this study presents a comprehensive discussion related to energy sustainability. Second of all, effective sets of indicators are presented that have a remarkable effect on energy sustainability. These selected indicators are in the framework of a group that is related to SDGs (17 UN goals), Urban Habitat, and SEDI method. Also, these seven indicators, are a valuable benchmark to policy-making and can be used to determine practical priorities and to monitor the progress of 10 developing countries. Third of all, this work presents a conceptual discussion in regard to energy sustainability and gives an answer to many questions related to it. Actually, our focus in this research is based on identifying and presenting suitable indicators to measure energy sustainability in line SDGs (17 UN goal), UN-Habitat III (14 goals), and SEDI for developing countries. Fourth of all, we try to find a common gap between 10 studied countries. This work, in addition, is analyzing energy sustainability using essential indicators and based on the sustainable energy development index method (SEDI). In this regard, correct policies and measures developed to achieve improvements in energy sustainability. Also discussed appropriate indicators for energy sustainability and choosing strategies based on them.

3.2. Comprehensive description related to group of selected indicators

Achieving energy sustainability needs different factors such as the use of appropriate indicators, and have energy planning. In this regard, indicators and sub-indicators could be influential as tools for measuring it [2, 27,134]. Indicators are a strong tool to help the policymakers and energy experts to measure energy sustainability which is useful to policymakers, energy analysts, and statisticians. Also, indicators give us a deeper understanding of the existing problems [13]. Indeed, energy sustainability indicators are selected by policymakers or energy experts [135]. They can demonstrate to us, what needs to be done to improve the weak points in regard to the current energy system of a country. Thus, if we can identify and use them correctly, the political targets will be easily achieved [136]. In this research, we present effective indicators related to energy sustainability that are appropriate to implement in developing countries. These presented indicators are to identify the weak points in the line of achieving to energy sustainability. The use of the seven selected indicators can help us to identify the main gaps in energy sustainability policy. The group of selected indicators in this study are strongly dependent on the energy field. According to the layout of Table 2, seven selected indicators are the minimum number of an influential group relevant to energy sustainability. Also, they are extremely related to SDGs (17 UN goal), UN-Habitat III (14 goals) and SEDI indicators. Each indicator alone has sub-indicators that more complete it. All indicators have a close relationship together because they together make an effective set to improve infrastructure a country, especially in energy.

3.2.1. Environmental impacts

The use of fossil fuels in the industry has led to significant industrial development [137]. Today, a significant part of human energy needs is satisfied by fossil fuels [138]. But apart from these benefits, fossil fuels are the main source of carbon dioxide emissions, which is one of the greenhouse gases which results in environmental pollution and global warming [74]. Todays global warming and air pollution have become a major challenge in many countries around the world [81]. In fact, global warming and air pollution have widespread effects that cause environmental, climatic and health problems, and if they continue, severe consequences will be created around the world [139]. Among fossil fuels, coal is considered the most polluting fuel source and natural gas as the cleanest fuel source [140]. Thus, with these descriptions, pollution prevention should be recognized as a key component of sustainable development and long-term planning.

3.2.2. Renewable energy

Renewable energies or alternative energy, are those kinds of the energies that are used to generate energy without net carbon emission [34]. Renewable resources are affordable, available and clean also these energies are sustainable because they have the least environmental impact [141]. Sustainable energy should be widely encouraged because it does not harm the environment and is widely used to reduce energy costs [142]. Today, the use of renewable energy has reduced a part of global power generation costs that was produced by fuel fossils [78, 107, 143]. According to the analysis by Lazard’s 2017, that was about the levelized cost of energy among four kinds of conventional energy resources for electrical production in recent years, the cost of energy for both solar- wind technology, then other resources has dropped by almost 6% compared to the year before last year. Actually, wind energy with $45 and solar with $50 in comparison with nuclear energy $148, coal $102, and gas $60 are most affordable and cleaner [144].

3.2.3. Transport

Urbanization is a social and physical process that requires a public and regular transportation sector [145]. Transportation is primarily a special means of social activity that should be accessible to all people and affordable [146]. Since transport is an important sector for energy and use of fossil fuels thus use of new vehicles and reducing dependence on fossil fuels in the transport sector is a priority that can be done by proper policy actions. At present variety of transportation systems and vehicle used in the world that the most important them including airplane, train, bus, motorcycle, bicycle and electrical vehicles. Also, hybrid systems such as electrical cars are expanded and become using day to day which has a significant impact to reduce CO_2 emission and annual world sales of electric vehicles (EVs) increased during recent years [147,148]. The transportation system, if accompanied by proper planning, will increase job opportunities, market access, contribute to climate change (reducing air pollution), improve road safety. Significant measures have been taken and ongoing in various cities for developing countries, particularly in the field of transport, such as the development of transport infrastructure, the creation of modern transportation systems like highways, public transportation, airport improvement in order to increase travel opportunities and more choices. These measures also have positive effects on the safety of roads and environmental issues [149,150].

3.2.4. Use of Energy & Energy efficiency

Energy use is essential for all humans especially in buildings, industries, and other sections [151-153]. According to recent estimates and should be more considered forecasts regarding the storage of oil, gas, and coal, energy consumption and in this regard should be more used of proper methods [154] Today, people are well aware of the different and hard ways to energy production and the environmental issues associated with it, and they themselves are also eager to save energy [155,156]. Also today, energy saving in the industrial and building sectors of, which are the most consumer sectors, is of great importance. There are several ways to save and manage energy consumption such as energy audits, training expansion save energy field, and using the low consumption types of equipment and controller of energy. In fact, the role of the use of equipment and facilities for energy saving has highly significant. All consumers and users, with the use of energy-saving technologies such as high-performance machines (HEMs), variable speed drives (VSDs), and intelligent control systems for buildings (lighting and HVAC systems), can have more control on the amount of energy consumption in industrial and building sectors. On the other hand, it saves a significant amount of electrical energy and energy costs, which will be economically significant [157,158].

3.2.5. Resource access of energy in developing countries

Today, developing countries are faced with a variety of energy challenges, which are increasing day by day. In fact, developing countries have more need to access energy to expand different industrials and remove basic problems such as health and education than developed countries because in developing countries still, an important part of the population does not have access to basic energy services [159]. Energy availability and energy affordability are important and very necessary. Despite all the global advances, millions of households in developing countries have insufficient access to energy or cheap energy. This situation causes poverty, health damage, local service delivery constraints, increasing vulnerability to climate change, limiting the expansion of opportunities, reducing environmental sustainability at the local, national and global levels, and has a negative impact on education and health. On the other hand, it can be said that today access to energy should be a political goal. Because most of the countries that have enjoyed better access to electricity have made significant progress since, indeed, their government has addressed this issue as a national political goal [160].

3.2.6. Resiliency

Now, the stability and security of energy supplies in parts of the world and especially in cities is threatened through unpredictable hazards such as natural disasters, Internet problems, and various fluctuations. Therefore, in this regard, it is necessary to prevent such problems by appropriately planning and creating the necessary infrastructure. The frequency of recent incidents including natural disasters such as earthquakes, tsunamis, and hurricanes, and also difficulties caused by the economic downturn has highlighted the vulnerability of human settlements and makes the appropriate consideration of resiliency in the planning for future of urban areas of vital significance. The concept of flexibility is an approach to managing socio-ecological systems that address the development of preventive measures and disaster risk management. Flexibility given the identification of future risks, a conceptual framework for assessing urban energy flexibility identifies planning and design criteria that can have to be a positive effect on some aspects of human life [161].

3.2.7. Policy

Population growth in various cities and increasing use of energy especially in developing countries, has caused many problems including in the field of the environment. The long-term nature of sustainable development leads countries to design a sustainable global planning system [162]. In fact, appropriate policies must be adopted to prevent future problems, and long-term and appropriate measures. For instance measures such as the implementation of sustainable development policies that have a significant impact on the conservation and proper utilization of energy resources and will take place in order to eliminate barriers and limitations of economic, organizational, and general development prospects [163]. The adoption of correct and growth-oriented policies within the framework of modernization theory, will bring sustainable development in all sectors and at different global, regional, and local levels [164]. Policies such as sufficient energy supply, proper urban transport planning, environmental measures, educational and cultural programs are including applied policies for sustainable development [165].

3.3. Importance of indicators

There are several important goals to measure energy sustainability which can be interpreted in a few questions and answers. What aspects of energy sustainability to measure are important? Which ones are for conserving or developing? And how they can improve energy sustainability? [139]. To answer these questions, we should know that energy sustainability will not be obtained easily and it needs a long-time plan and a correct and practical policy. Hence, to measure energy sustainability, identification of the weaknesses is very important, because it can help us to improve energy sustainability and achievement it [19,166]. Indeed, all aspects of energy sustainability are important and should be considered. But always all of them are not in priority. So one should be paid attention to the most important aspects and these are as a necessity for help to policymakers [141]. Therefore, to find the most important aspects of energy sustainability, we should define different indicators and criterion based on the need [130]. These indicators and criteria, allow us to locate ourselves present condition relative to conditions that have prevailed in the past, then we can with regular planning move in the line of our self-targets. Indicators can be divided into different groups such as descriptive indicators, performance indicators, and efficiency indicators. Overall, energy sustainability indicators should be simple, easy, useful, feasible, appropriate, benchmark, understandable, and reasonable [167]. The main target of the indicators is collecting the required information by multiple data and simplification them. Actually, indicators are able to simplify complex information. They are as influential tools in the hand of policymakers and can be used to measure the main issues and to find appropriate ways [168]. Also, indicators are used to supply correct and useful information to help policymakers in order to identify the main issues of a country. Indicators increase public awareness in order to strengthen the public support of policy measures and monitoring on assigned targets [135]. Fig 3.1 shows a relation between energy sustainability and group of indicators for developing countries

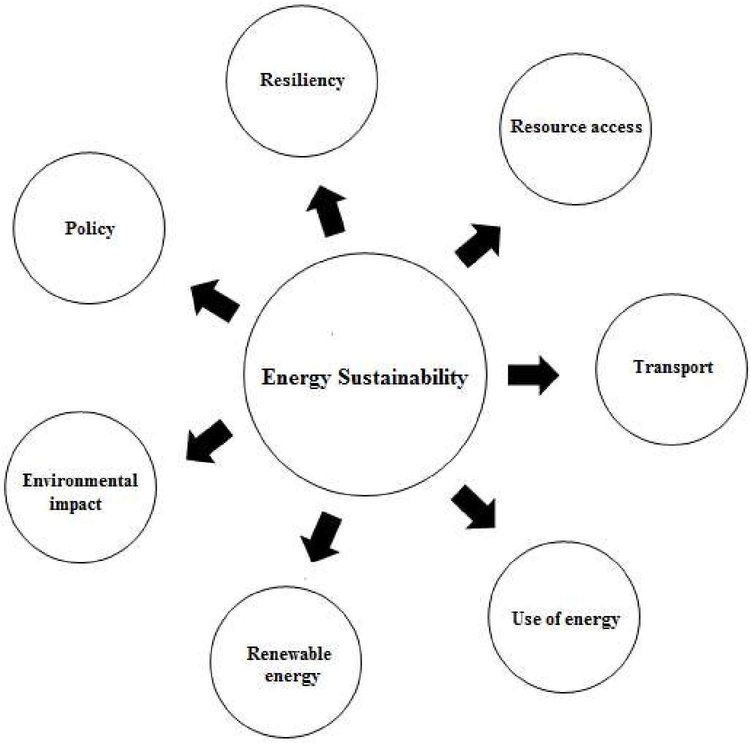


Fig 3.1. Relation between Energy sustainability and group of indicators for developing countries

Table 3.1 shows the relation between Items and related indicators to SDGs (17 UN goal), UN-Habitat III (14 goals) and SEDI. As can see in this table a group of indicators related to UN17 goals and Urban Habitat themes presented that can have a good effect on sustainability.

Table 3.1. Relationship between Items and related indicators to UN17 goals and SEDI

Group of indicators	SDGs Indicators	UN-Habitat III indicators	SEDI indicators
Environmental impacts	CCh, AFW, WS, Et, CO_2 , ENS	CCh, WS, AFW, Et, CO_2	ENV, INS, TEC
Renewable energy	EAFF, ES, INV, Et, IRS, REC	INV, ES, EAFF,	ENV, SOC , TEC, ECO, INS
Transport	AER, EA, EAFF, Et, EC, ITI, UP, TFC,TFCT, RS, USG	UP, ITI, EAFF, ES, RS, TFCT, USG	SOC, TEC, ECO, ENV
Use of Energy	AER, CCP, EA, EAFF, EC, EI, EIM, EPI, ESe, Et, Pb, Pg, Po, Pc, TPES, REC, RS, TCEC, TFC, TFCT, USG	EA, EAFF, ESe, AER, Et, USG EC, USG	ENV, TEC, SOC , INS
Resource of energy	AFW, Cr, Gr, Or, LA, FA, TNR, TCNR	LA, Cr, Gr, Or, AFW	ENV, TEC, SOC
Resiliency	AER, AFW, LA, EIM , INV, ITI, PISEG, UP, WS, EEI	UP, WS, AER, EIM, INV	SOC, TEC, ECO
Policy	GNI,GDP, PISEG, CCP, ES, EA, UP, ULCT,TNR, EIM, ESe, INV, REC, Ese	UP, GNI, GDP, REC, ESe	SO, ECO, TEC

Table 3.2 shows the most important sub-indicators which has a positive impact on the group of selected indicators in this study. This Table is most important because this table will be assigned the relationship between groups of indicators with SEDI. This Table has three main parts. First part is the group of indicators that have described them above and have the remarkable effect on sustainability. The second part shows the sub-indicators related to the group that can be as a help for them. And the third part, it shows the related these sub-indicators with SEDI indicators. As can see in this Table, INV (Investment) and REC (Renewable energy consumption) sub-indicators have most repetition

time than other sub-indicators in this table, because two mentioned sub-indicators can create mostpositive changes in the line of energy sustainability. Table 3.2. demonstrates the group of indicators with sub-indicators.

Table 3.2. Group of indicators with sub-indicators

Environmental impact	ULCT, IRS, CCP,ET, INV	ENV1-2, TEC1-3, SOC1
Renewable energy	EIM, IRS, EAFF, ET, INV, TS	ENV1-2, TEC1-3, SOC1,INS1
Transport	AER, EA, IRS, ET, INV, UP, USG	TEC1-3, ECO1-3,ENV1-2, SOC1
Use of energy	AER, REC,ET,IRS, TNR,INV,ES, EIM,EA	TEC1-3, INS1,ECO1-3,ENV1-2, SOC1
Resource of energy	TNR, TLA	SOC1-2, TEC 1-3
Resiliency	UP,WS,AER,ET,IS,INV	SOC1,TEC3,ECO1-3,INS1
Policy	INV,ESe,EAFF,EIM,ES,TLA,TPES	SOC1-2, ECO1-3,TEC1-3

3.4. Methodology for the objective selection

In this study, energy sustainability for 12 developing countries is considered based on SDGs (17 UN goals), UN-Habitat III (14 goals), and SEDI method. Firstly, seven influential indicators associated with energy sustainability and in the line of SDGs is selected and described. Then with having four years of data from IEA and World Bank, the sustainable energy development index (SEDI) is investigated. For both the group of indicators and the SEDI method, related sub-indicators are obtained and analyzed. To do these stages, firstly, we described in detail SDGs (17 UN goals) and UN-Habitat III (14 goals) and then we determined which goals are most related to SEDI. After that, we described the group of indicators and found the proper sub-indicators for them and determined which of them is related to SEDI indicators directly and indirectly. Finally, we collected related data with indicators and analyzed them. After these stages, obtained the SEDI rank for each developing country. It is believed that the discussions and results drawn in the present study will be effective for energy experts and energy policymakers.

3.5. Results and discussion

As previously mentioned and emphasized, appropriate determination of indicators and sub-indicators can be influential for achieving energy sustainability by policymakers and energy experts. Also, since the SEDI consists of five main indicators and several sub-indicators, thus for obtaining proper results in this regard should be investigated from different aspects and dimensions. Actually, if we can investigate all main indicators of SEDI accurately and for each of them to determine the proper sub-indicators, achieving desirable targets will be carried out easily. To calculate SEDI is necessary to obtain technical sustainability, economic sustainability, Social sustainability, Environmental sustainability, and institutional environmental sustainability. When all indicators were obtained, should be normalized and obtained an average of them [169]. The main purpose of these indicators is a conceptual investigation in regards to Sustainability for each country. Each country needs to have an appropriate infrastructure in various sustainability sectors. Sustainability depends on a variety of factors, which by their general integration, will make the development of a country. The close relationship between social development, economic development, environmental conservation, and enhancement of life quality is essential in sustainability. The main concept of sustainability is to achieve the lasting satisfaction of human needs and improvement in the quality of life. Thus, it needs to select the proper method and investigating the most important sectors from all different aspects. Based on this review, we conclude that it is necessary to create a new method to improve the SEDI in order to assess sustainability performance. In this study, proper analyses with requirements on the concept of sustainability are made in order to set-up the general framework and the specific cases of country sustainability are discussed.

3.5.1. Technical sustainability

Technical sustainability that can calculate with different data such as share of depletable (non-renewable) energies, depletion coefficient of local energy resource and overall system conversion efficiency is for improving the ability of the energy supply system to providing the now and future needs of society effective, reliable, and from clean sources. In this part resources such as crude oil, coal, natural gas, hydro-power, nuclear or renewable energies are used as inputs include the primary energy resources. This part is including TEC1-3 that for normalization it can be used of Eq. 3.1.

3.5.2. Economic sustainability

Economic always an important part of our living and has a vital role in the future and progress. GDP for all countries has important for growth and welfare inhabitants; actually, it is the main factor in development. The normalization of this dimension is better that has been the higher value, thus for normalization can be obtained by Eq. 3.1. Also, to obtain this dimension calculate per capita consumption of commercial energy, final energy intensity, and share of productive use of energy data are needed.

3.5.3. Social sustainability

To assess the distributional effect of energy for society, can obtain the accessibility to energy supply by calculating this dimension. Per capita consumption of clean energies in the residential sector and Income inequality (GNI coefficient) is necessary to obtain this dimension. In this indicator, normalization can be calculated by Eq. 3.1

3.5.4. Environmental sustainability

This dimension has is related to environmental problems and the CO_2 issue. Actually, global warming and Climate change have been caused as a world problem and all a special obligation to reducing greenhouse gases. Environmental sustainability can be calculated by obtaining a share of dirty fuels in residential energy consumption and carbon intensity. Also for normalization of this dimension the smaller value is better, thus Eq. 3.2 will be used.

3.5.5. Institutional sustainability

Institutional sustainability is one of the most important sectors in sustainability. It can show the level of local participation in the management and control of the energy system. The sector depends on several factors such as public participation, local skill base, local regulation, and protection of investors and consumers is needed. Calculate overall self-efficiency is important for this dimension. Also, since has a higher value is better for this part, thus normalization can use for Eq. 3.1. With regard to that these indicators have various dimensions and expressed with different measurement units, hence is used the normalization technique [169]. In this study after collect data and elementary calculation, each indicator should be normalized between 0 and 1 using the two following methods:

$$V = \frac{V_{ACT} - V_{Min}}{V_{Max} - V_{Min}} \tag{3.1}$$

$$V = \frac{V_{Max} - V_{ACT}}{V_{Max} - V_{Min}} \tag{3.2}$$

In this study, the UNDP method was used for normalization, actually when a definition indicator should have high-value eq. 3.1 is better than used and when that the indicator should have low value is better than the use of eq. 3.2 for evaluation. In two formula V is the indicator value, V_{act} is the actual indicator such as a country, V_{max} is the maximum value of indicator and the V_{min} is the minimum value of the indicator. Table 3.3 shows the used method for SEDI calculation. Actually, in this table five essential indicators related to SEDI with solvation methods have been presented.

Table 3.3. Selected indicators for analysing SEDI of for studied developing countries

Dimension	Indicators (Units)	Used method
TEC 1	Share of depletable (non- renewable) energies in TPES	$\frac{TCNR}{TPES}$
TEC 2	Depletion coefficient of local energy resource	$\left(\frac{Po}{Ro}\right) + \left(\frac{Pg}{Rg}\right) + \left(\frac{Pc}{Rc}\right) + \left(\frac{\frac{Pb}{\frac{Pe}{Tfl}}}{Tla}\right)$
TEC 3	Overall system Conversion Efficiency	$\frac{TFC}{TPES}$
ECO1	Per capita consumption of commercial energies	$\frac{TCEC}{Population}$
ECO 2	Final energy intensity	$\frac{TFC}{GDP\ PPP}$
ECO 3	Share of productive use of energy	$\frac{TFC-REC}{TFC}$

SOC 1	Per capita consumption of clean energies in the residential sector	$\frac{\text{TCE}}{\text{Population}}$
SOC 2	Income inequality	GNI Coefficient
ENV 1	Share of "dirty fuels" in residential energy consumption	$\frac{\text{TNR}}{\text{REC}}$
ENV 2	Carbon intensity	$\frac{\text{TCO}_2}{\text{TPES}}$
INS 1	Overall Self Sufficiency	$\frac{\text{EP}}{\text{TPES}}$

3.6. Indices calculation

This work investigates the strengths and weaknesses of a country with attention to their existing resources, economic, environment situation; hence the ranking is based on these mentioned factors. It is obvious that each country after considering these factors will obtain a specific ranking, although this study emphasizes that results are not absolute, using collected data of each country between 2012-2015 years and via IEA information will lead to these results. Therefore, if a country intends that to gain a better rank in the future,, it needs to strengthen the sectors that are weak in them, and that should minimize their problems. That means each country should determine its energy policy according to the results obtained, and act in this regard to follow the correct practices, which they can learn from developed countries. For calculating SEDI we need to obtain technical, economic, social, environmental and institutional indicators as following [169]:

Technical sustainability can be obtained as following formula

$$\text{TS} = (1 - \text{TEC1} \times \text{TEC2}) \times \text{TEC3} \quad (3.3)$$

For calculate economic benefit per capita there is a formula as following

$$\text{Eb} = \text{ECO1} \times \text{ECO2} \quad (3.4)$$

Social sustainability can be calculated as following formula

$$\text{Ss} = \text{SOC1} \times (1 - \text{SOC2}) \quad (3.5)$$

Also can be calculated environmental sustainability by below formula

$$\text{ENs} = \text{ENV1} - \text{ENV2} \quad (3.6)$$

Economic sustainability can be obtained as following formula

$$\mathrm{ECs} = (\mathrm{ECO1} \times \mathrm{ECO3}) / \mathrm{ECO2} \tag{3.7}$$

Table 3.4 shows obtained results by 2015-year data for SEDI calculation. As it is clear, Albania has first rank and India has end rank between these countries in this table.

Table 3.4. Obtained results by 2015-year data for SEDI calculation

Rank	Country	TEC	ECO	SOC	ENV	INS	SEDI
1	Albania	1	0.479	0.132	0.921	0.682	0.642
2	Croatia	0.309	1	0.144	0.918	0.366	0.547
3	Jordan	0.366	0.332	1	1	0	0.539
4	Iran	0.646	0.498	0	0.443	1	0.517
5	Bulgaria	0.195	0.987	0.077	0.849	0.461	0.513
6	Peru	0.589	0.343	0.024	0.842	0.75	0.509
7	Tunisia	0.067	0.403	0.23	0.942	0.412	0.41
8	China	0.346	0.251	0.829	0	0.603	0.405
9	Georgia	0.17	0.404	0.073	0.914	0.189	0.35
10	India	0	0	0.022	0.556	0.462	0.208

Table 3.5 shows obtained results by 2014-year data for SEDI calculation. As can see in this table studied country in different indicators has a better score than together.

Table 3.5. Obtained results by 2014-year data for SEDI calculation

Rank	Country	TEC	ECO	SOC	ENV	INS	SEDI
1	Albania	1	0.42	0.119	0.995	0.635	0.633
2	Croatia	0.499	1	0.138	0.977	0.393	0.601
3	Peru	0.61	0.387	0.002	0.9	0.858	0.551
4	Iran	0.736	0.464	0	0.496	1	0.539
5	Jordan	0.311	0.367	1	0.989	0	0.533
6	Bulgaria	0.221	0.935	0.074	0.92	0.463	0.522
7	Tunisia	0.116	0.451	0.238	1	0.464	0.453
8	China	0.379	0.235	0.843	0	0.624	0.416
9	Georgia	0.089	0.448	0.076	0.963	0.215	0.358
10	India	0	0	0.007	0.598	0.48	0.217

Table 3.6 shows obtained results by 2013-year data for SEDI calculation. Albania and Croatia have obtained first and second rank in this table in sustainability energy development index (SEDI).

Table 3.6. Obtained results by 2013-year data for SEDI calculation

Rank	Country	TEC	ECO	SOC	ENV	INS	SEDI
1	Albania	1	0.464	0.114	0.978	0.64	0.639
2	Croatia	0.433	0.977	0.115	0.943	0.374	0.56
3	Peru	0.795	0.371	0.002	0.88	0.864	0.568
4	Jordan	0.425	0.388	1	1	0	0.562
5	Iran	0.795	0.477	0	0.492	1	0.552
6	Bulgaria	0.253	1	0.074	0.882	0.452	0.532
7	Tunisia	0.098	0.466	0.204	0.964	0.507	0.447
8	China	0.393	0.223	0.762	0	0.618	0.399
9	Georgia	0.183	0.357	0.084	0.912	0.252	0.357
10	India	0	0	0.016	0.603	0.487	0.221

Table 3.7 shows obtained results by 2012-year data for SEDI calculation. As above mentioned in SEDI analyses all studied countries can have different scores and rankings. For instance, Jordan country in this table that has investigated by 2012 data, has been acquired second-ranking between other countries.

Table 3.7. Obtained results by 2012-year data for SEDI calculation

Rank	Country	TEC	ECO	SOC	ENV	INS	SEDI
1	Albania	1	0.427	0.116	0.951	0.599	0.618
2	Jordan	0.414	0.386	1	1	0	0.56
3	Iran	0.702	0.512	0	0.541	1	0.551
4	Croatia	0.32	1	0.106	0.947	0.34	0.542
5	Peru	0.628	0.31	0.002	0.882	0.818	0.528
6	Bulgaria	0.188	0.988	0.068	0.889	0.454	0.517
7	Tunisia	0.052	0.451	0.194	0.96	0.526	0.436
8	Georgia	0.317	0.179	0.074	0.981	0.195	0.349
9	China	0.331	0.201	0.566	0	0.611	0.341
10	India	0	0	0.017	0.656	0.486	0.231

Table 3.8 shows a comparison results of SEDI calculation for selected countries belongs 2012-2015 years. This table shows a total average ranking for a studied country that has investigated by four years' data. Totally, Albania, Croatia, and Jordan have obtained the high score in SEDI.

Table 3.8. Comparison obtained results of indicators calculation for obtaining SEDI belongs 2012-2015 years

Rank	Country	TEC	ECO	SOC	ENV	INS	SEDI
1	Albania	1	0.447	0.12	0.961	0.639	0.634
2	Croatia	0.413	0.994	0.125	0.946	0.368	0.568
3	Jordan	0.379	0.368	1	0.997	0	0.548
4	Iran	0.719	0.487	0	0.493	1	0.539
5	Peru	0.638	0.352	0.007	0.876	0.822	0.538
6	Bulgaria	0.214	0.977	0.073	0.885	0.457	0.521
7	Tunisia	0.083	0.442	0.216	0.966	0.477	0.438
8	China	0.362	0.227	0.75	0	0.614	0.39
9	Georgia	0.189	0.347	0.076	0.942	0.212	0.353
10	India	0	0	0.015	0.603	0.478	0.219

In addition, Fig 3.2 shows the total average illustrative diagram of sustainable energy development based on indicators. In addition can be added that, Fig 3.2 has been created by a mathematical model also obtained results are relative for each dimension.

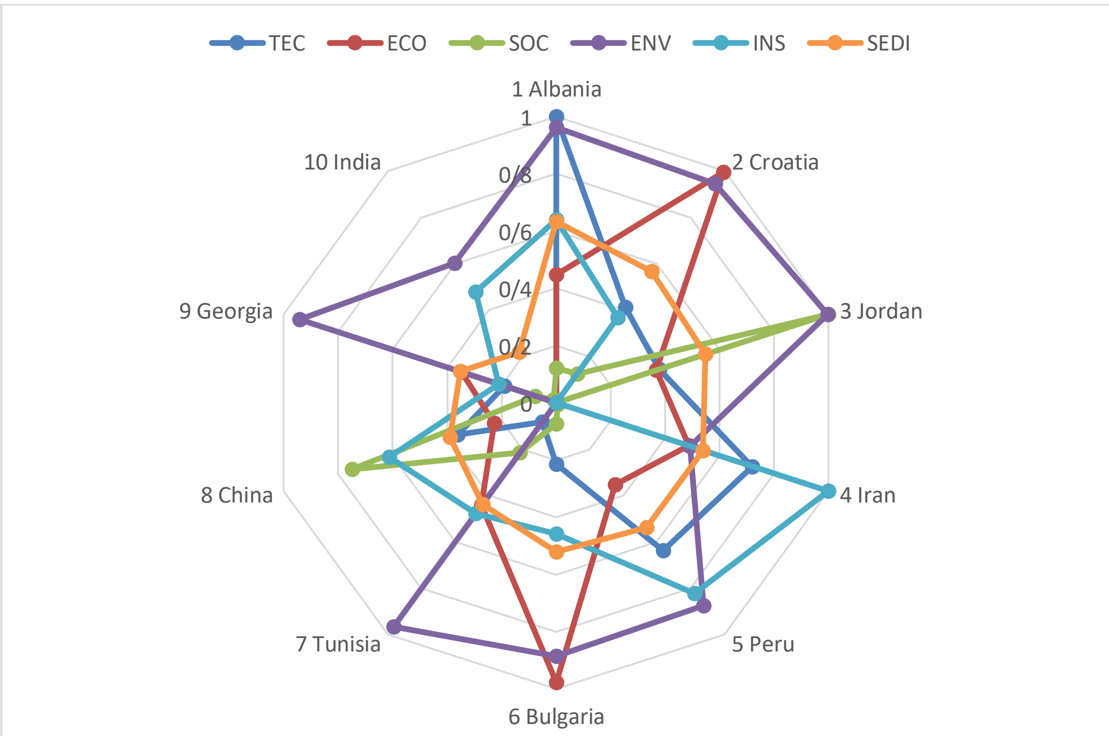


Fig. 3.2. Total average illustrative diagram of sustainable energy development

Table 3.9 shows a chart of considered countries based on SEDI averagely. This table shows the amount of growth for these countries during four years in SEDI. As can see Croatia in all considered years, has a stable rank and is first.

Table 3.9. SEDI ranking of considered countries

Country / Year	Albania	Croatia	Jordan	Iran	Peru	Bulgaria	Tunisia	China	Georgia	India
2012	0.618	0.542	0.56	0.551	0.528	0.517	0.436	0.341	0.349	0.23
2013	0.639	0.569	0.562	0.552	0.568	0.532	0.447	0.399	0.357	0.22
2014	0.633	0. 601	0.533	0.539	0.551	0.513	0.453	0.416	0.358	0.22
2015	0.642	0.547	0.539	0.517	0.509	0.513	0.41	0.405	0.35	0.21
2012-15	0.633	0.552	0.548	0.54	0.539	0.521	0.436	0.39	0.353	0.22

SEDI ranking with a number for developing countries is obvious in fig 3.3. In this table moreover, the score rank for each country in four years' investigation, the obtained number of them is obvious in the side of each country.

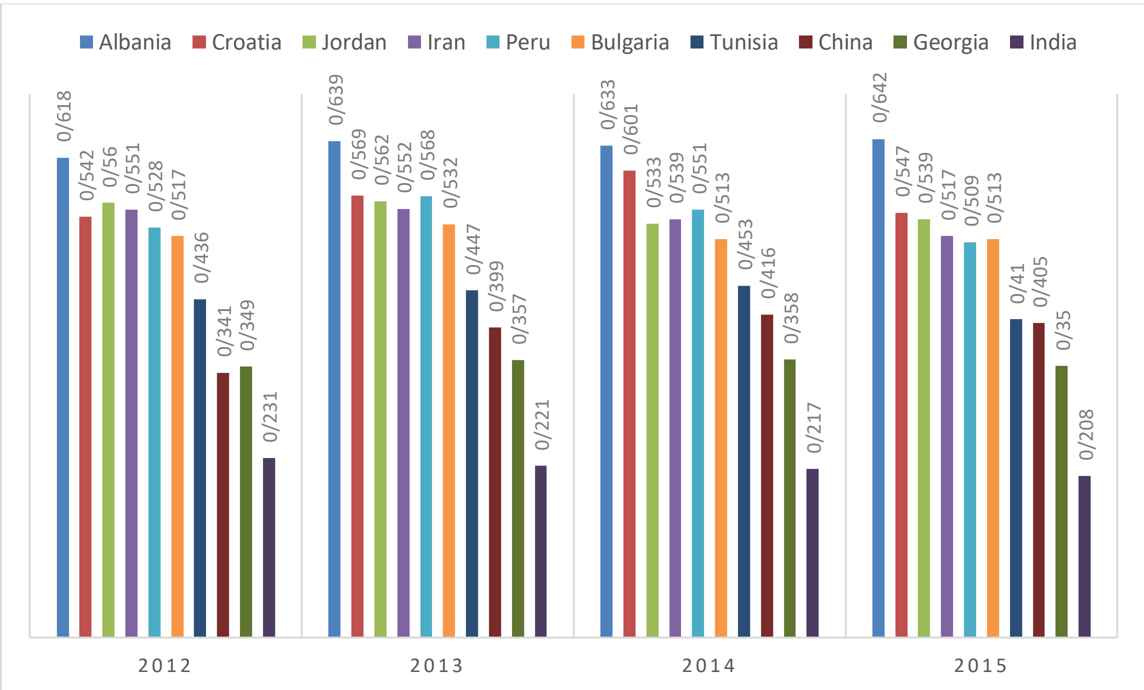


Fig 3.3. SEDI ranking with number

3.7. Conclusion

Since evaluating sustainability performance is a multi-dimensional issue, then it is necessary that from different dimension views analysed and considered. At present, most countries in the world have regular programming and policy to reach sustainable development. Indeed, sustainable development is vital for the future of each country, especially in developing countries. The purpose of this research is to investigate a set of appropriate energy sustainability indicators for the 10 developing countries according to the SDGs and SEDI method. This analysis has been carried out with various and real data from well-known organizations. Firstly, we collected four years of required data that belonged 2012 to 2015 years from IEA and World Bank data organizations from and then analysed them separately. A comparison between considered countries showed that all parts of sustainability have to need to extend and enforce essential indicators to achieve sustainability equally. In addition, the results show that in comparison with past years, all studied countries, have seen remarkable growth in sustainability during these years. Based on this study, there are two common issues between them that are the most important problems. One of them is that these countries are still dependent on fossil fuels as the main energy source. The other is that in these countries there is not a practical policy for monitoring the operational system. In fact, in order to implement effective indicators in regards to energy sustainability, there needs to a strong policy. Among studied countries, Albania and Croatia had the highest ranking in SEDI from 2012-2015 years and India had ranked at the bottom. It should be mentioned that these analyses are not absolute for these countries and these results only were obtained based on their resources. Thus, should be noticed that this study is relative and only can be showed the performance of these countries in energy sustainability based on existing data. For instance, as we can see in table 8, Peru in technical and institutional sustainability indicators has a high relative score and in social indicator has low score among these countries. Indeed, with regards to obtained results, we can say that this study first identifies weak and strong indicators of each country's sustainability especially in the energy sector, and then compares them. Also, it should be implemented useful measures by policymakers, to improve each indicator related to social, economic, and environmental sectors. Each research has many advantages and disadvantages. Although this study, determined the strengths and weaknesses of each country, it is extremely dependent on the resource and policy system of each country. Indeed, without regular planning by policymakers and energy experts and with regards to existing capacities in any country, the achievement of energy sustainability is challenging. Thus, we presented a group of indicators with a comprehensive description, which is important to achieve energy sustainability and have a decisive role in achieving it. If these presented indicators get implemented by policymakers, it can be influential to improve energy sustainability. It could be mentioned that changes in the determined indicator structure, can lead to changes in the different sectors of energy such as supply, intensity, and consumption. In fact, based on principles and scientific perspectives, selected these indicators to measure energy sustainability.

Chapter 4. Development of sustainable energy indexes by the utilization of new indicators

Nomenclature

AE	Access of electricity	TFCET	Total final consumption of electricity in transport
AREE	Amount of renewable energy	TFCI	Total final consumption in industry
CO_2	CO_2 emission	TFCFT	Total final consumption of fossil fuel in transport
EC	Energy conversion	TFCR	Total fuel consumption in residential
EEX	Energy export	TFCRC	Total final consumption renewable energy commercial
EIX	Energy import	TFCRR	Total final consumption of renewable energy residential
ELC	Electricity conversion	TFCT	Total final consumption in transport
GDP	Gross domestic product	TFFP	Total final fossil production
LA	Land area	TPES	Total primary energy supply
LE	Loss of energy	TREP	Total renewable energy production
POP	Population	Vact	Actual number of indicators
RIFR	Renewable internal freshwater resources	X	Actual number
SEDI	Sustainable energy development index	Xmax	Maximum number of indicators
TCO_2	Total CO_2 Emission	X min	Minimum number of indicators
TEP	Total energy production	WAP	Waste and Pollution
TEPR	Total energy production	X	Array1
TFCBT	Total final consumption of Biofuel	Y	Array2
TFCC	Total final consumption in comerical	-	-

4.1. Introduction

Todays, with respect to increasing energy demand and limited resources of fossil fuels and their pollution, energy sustainability is a necessity for each community. In this regard is important to assign and implement effective indicators in the line of sustainable development in different societies. Sustainable energy development index (SEDI), that is based on five important factors such as Technical, Economic, Social, Environmental, and Institutional sustainability, emphases a comprehensive investigation and removes main problems in this regard to achieve energy sustainability. The SEDI method previously has investigated by some of the researchers in different countries, but all SEDI indicators, could not be influential and sufficient to achieve energy sustainability, therefore, this method should be improved by new indicators. Thus, as mentioned before the SEDI method has some weaknesses, and these weaknesses should be minimized and improved accurately by new effective indicators. These new indicators are able to cover all of the weaknesses points in energy sustainability. In this chapter, SEDI method is investigated using new indicators. In fact, because the SEDI method is not completed therefore needs to be found new indicators to complete it. Energy importance is not covered on anyone and is a vital need for human, hence the ways of energy providing is also most important [34]. The affordable and adequate energy supply has a key role in economic development and progress for each country especially in the industrial sector [3]. On the other hand, energy is a significant factor to achieve sustainable development goals because the use of energy is necessary for economic, environmental, and social development [170]. At present, the main way of providing energy is fossil fuels but in this sense, two main problems global warming and air pollution that threaten human life and plant and these are creating by fossil fuels. Indeed, the main cause of these problems is CO_2 the issue that creates fuel fossils [74]. To more prevent of extent this problem, the move toward sustainability is useful and effective [171]. Sustainability is a sophisticated subject and needs for conceptual and analytical discussion and study. The concept of sustainability has means that existing needs can be removed without the need for future generations to meet their needs [172]. To achieve sustainability moreover specific variety indicators, it also requires regular monitoring of the impacts of selected policies and strategies. One of the most important things related to sustainability is measuring a country's state of development and monitoring its progress or lack of progress towards sustainability. For example, policymakers in each country should have full knowledge of their current state of energy and sustainability in order to help alleviate the problems and develop the country. They must also have a conscious and balanced choice in terms of sustainability indicators so that they can provide development and operation conditions for the country [173]. In this regard, it can be mentioned that policy decisions are important to implement effective measurements to achieve sustainable development over time [174]. Thus, energy sustainability indicators can be used as a strong tool in the hand of policymakers to assess the level of sustainability of different areas and energy sectors and activities [175]. Many works in this regard have been conducted. Kemmler A. investigated energy indicators for tracking sustainability. They showed that energy indicators are not only used for environmental and economic issues. Also, it is used and related to social issues [176]. Razmjoo A et al., investigated the role of renewable energy to achieve energy sustainability. They with a study for a city of Iran showed that renewable energy has a remarkable effect on achieving sustainability in energy [20]. Assessing rural energy sustainability has been carried out by Brijesh M et al., in developing countries. According to this analysis, China has the highest rural energy sustainability index among these countries, and South Africa has the sixth rank. This shows that one of the most important causes of the progress of South Africa is more access to electrical and renewable energy especially in a rural area [57]. Terrapon-Pfaff, J et al. with investigate different projects done, shows that one of the ways to reduce poverty in developing countries is more access to sustainable and affordable energy services. They also showed that long-term small sustainable energy projects in developing countries are an effective and important factor to improve the quality of life for inhabitants of these countries [177]. An applied quantitative method to evaluating energy sustainability using the pressure-state-response as a case study in China has been done by S Li et al. They in this study and three main dimensions of energy, economy, and environment developed a sustainable energy index system including of 20 indicators. They showed to improve the energy sustainability in China's country, should be more effort in these three dimensions [178]. Saygin, D et al. investigated a benchmarking the energy use of energy-intensive industries in industrialized. They presented a comprehensive overview of the energy use, based on effective benchmark and indicators data with the importance of energy efficiency indicators [179]. Kaygusuz, K investigated a study relevant to the energy situation in developing countries to achieve sustainable development, considered in this study. Also in this study, access to electrical energy equally, and implementing effective indicators to monitor progress, investigated as important factors to sustainable development [180]. Few S et al. investigated the energy access via electricity storage to achieve energy sustainability. In this study through different interviews from companies and consumers, the best solutions in order to improve technologies and optimal management of energy presented [181]. A critical review and analysis of energy access programmers for sustainable development, presented by Subhes C. Bhattacharyya. In this paper investigated important energy indicators, on the other hand, emphasized an overall revision related to access energy methods. Also, in this study, suggested more use of renewable energy as one of the proper ways to access energy [15]. RFR de Rangel Moreira et al. presented influential indicators relevant to energy sustainability. They in this study, to measure energy sustainability, considered different methods to identify the academic and institutional sources of energy sustainability indicators [131]. Since sustainable energy development index is leading to achieving completed sustainability, so it needs more investigation. The use of these indicators by policymakers and sustainability experts can be effective to remove the most relevant problems in this regard and lead to more progress. Indeed, when sustainability is complete that all problems have been removed or be minimum. Hence, as much as possible can add more effective indicators to the SEDI, which is useful to achieve to complete sustainability. These indicators are effective to progress a country, provided that they become implemented and enhanced properly. Indeed, the indicators of energy sustainability are a set of indicators according to the required dimensions of SEDI including different themes and sub-themes and the same conceptual framework. Thus, the main purpose of this paper is to focus on identity and presenting appropriate indicators to measure energy sustainability for different countries. This study has forth main novelties. First of all, this study investigates all of the weak points of the SEDI method and in order to enhance them, presented a new method by effective indicators that can cover all of the problems. Second of all, this study a new methodology to measure energy sustainability for different countries. Third of all, this study investigates the most influential indicators that have more effect on energy sustainability. Forth of all, this study trying to find the energy sustainability problems related to 12 studied countries in this research and specify the weak and strong points them by analysis data.

4.2. Importance and relationship of proposed indicators

Indicators are a strong tool to help the policymakers and energy experts to measure energy sustainability which is useful for policymakers, energy analysts, and statisticians. Also, indicators give us a deeper understanding of the existing problems [13]. Indeed, energy sustainability indicators, are selected by policymakers or energy experts [135]. They can demonstrate to us, what needs to be done to improve the weak points regarding the current energy system of a country. Thus, if we can identify and use them correctly, the political targets will be easily achieved [136]. In this research, we present effective indicators related to energy sustainability that are appropriate for implementing in different countries. These presented indicators are to identify the weak points of countries in the line of achieving energy sustainability and can help us to identify the main gaps in energy sustainability policy. Seven selected indicators are the minimum number of an influential groups relevant to energy sustainability. The most important cause for selecting this group of indicators is having a key role in most sections of our life. Proper implementation of these indicators can make a high quality of life for all humans in the world. On the other hand, when we improve these indicators, almost the essential problems related to humans will be solved and obtains a high quality of welfare for them. In this section, we describe this group of indicators as below separately.

- The use of fossil fuels is significant for development, but fossil fuels are the main source of carbon dioxide emissions, which is a greenhouse gas and causes environmental pollution and global warming [182].
- Renewable energy can help human beings to develop and supply energy. Besides, these resources are available and have a positive impact on the environment.

- The importance of transportation as a strategic sector for cities and countries is significant. This section can provide prosperity for residents and play an important role in energy consumption.
- Proper use of energy is most important for preventing significant energy loss. In this regard, it is important to use of new energy-saving technologies.
- Access to affordable and easy energy is essential for all city residents. Providing new technology and creating the right policy can be effective to gain affordable and proper energy.
- Unexpected accidents can be the main cause of the problems and damage to a city and its people. Creating an adequate infrastructure and having the right program is one way to prevent this problem. In this regard, creating an appropriate policy, welfare insurance, and development is vital.
- The government plays an important role in the development of cities and countries. They can plan in all areas necessary for the people. Energy supply, the use of new technology, easy access to energy, etc., is part of the government's task.

4.3. Novel index calculation of SEDI

In this study, have investigated the Energy sustainability indicators for 12 countries. Since to achieve energy sustainability the SEDI method is not complete and has some limitations. Thus it should be improved and completed. Hence, at first, we investigated all of the energy indicators related to seven selected indicators in this research and after that, using correlation analysis chosen proper indicators and then we obtained the strong and weak points of each them. In the final step and according to this analysis, we obtained the weak and strong sections of each country based on existing indicators. Fig 1 shows a schematic of the energy supply from primary resources. This Fig was designed based on the existing resource which uses by different sections and about seven selected indexes. As can see, resources will be divided into two main parts as total primary energy supply (TPES) and then these resources used in three important sections such as transport, industrial, and household used. At the end of this figure, these resource with breakdown impacts on waste and economics. This figure shows that achieving energy sustainability based on resources is a need to proper planning and effective policy. Indeed, if we can modify the amount of consumption of energy with considerable resources and use them correctly in a different section, without a doubt will have low problems in the future. As can see in fig 4.1 seven selected indicators were arranged based process.

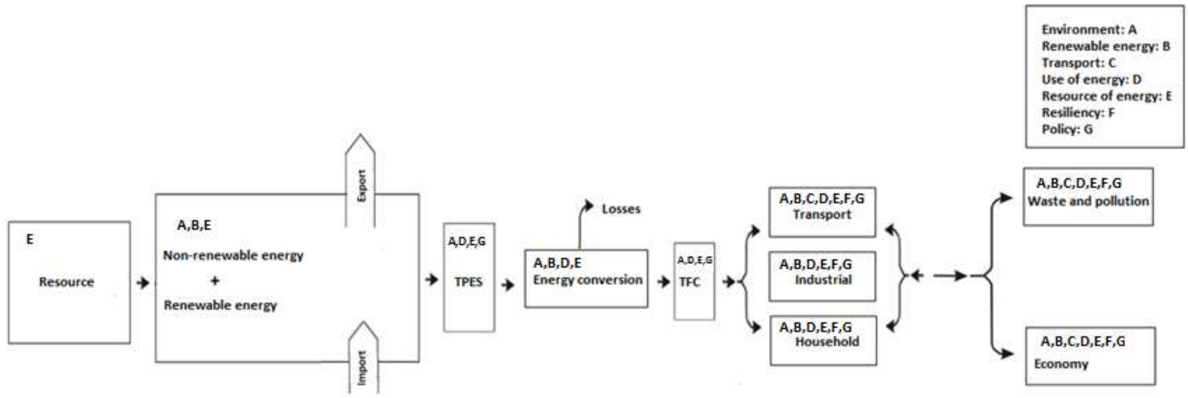


Fig 4.1. A schematic of energy supply from primary resources:Source: Authors

Table 4.1 shows the indicators and sub-indicators related to energy based on the design of Fig 4.1. These indicators have the most impact on energy sustainability.

Table 4.1. Influential indicators and sub-indicators based on the design of Fig 4.1.

Sub-indicators/Indicators	Resource	TPES	EC	TFC	Transport	Industrial	Household	WAP	Economy
Total non-renewable and renewable energy	√	√	x	x	√	√	√	√	√
Total production energy by non-renewable energy	x	√	x	x	√	√	√	√	√
Total production energy by renewable energy	x	√	x	x	√	√	√	√	√
Non-renewable end renewable resource	√	√	√	√	√	√	√	√	√
Total consumption energy by non-renewable energy	x	x	x	√	√	√	√	√	√
Total consumption energy by renewable energy	x	x	x	√	√	√	√	√	√
Amount of CO_2 emission	x	√	√	√	√	√	x	√	√
Amount of investments in energy	x	√	x	√	√	√	√	√	√
Reduction fuel fossils by technology	x	x	√	√	√	√	x	√	√
Amount of energy intensity	x	√	x	√	√	√	√	√	√
Electrical consumption by RE non- RE	x	x	x	√	√	√	√	√	√
Percent of economic growth by energy sector	x	√	√	x	√	√	x	√	√
Amount of investment on industrialization and energy	x	√	x	x	x	√	x	√	√
Amount of energy export and energy import	x	x	x	x	√	√	x	x	√

Table 4.2 shows the selected indicators related group of indicators before correlation. As it is clear in this table, there are the most influential indicators related to a group of indicators.

Table 4.2. Selected indicators related group of indicators before correlation

Group of indicators	Sub-Indicator (Energy)
Environmental impact	Total CO_2 (Mt of CO_2), CO_2/TPES(Mt CO_2), CO_2/population (Mt CO_2), CO_2/GDP (billion 2010 USD -Mt CO_2)
Renewable energy	Total Energy production from renewable energy /Renewable heat consumption, Amount of renewable energy in electricity production / Total Energy production from renewable energy (Ktoe), TFC Renewable energy consumption in Residential / Total Energy production from renewable energy (Ktoe), TFC Renewable energy consumption in Commercial / Total Energy production from renewable energy (Ktoe)
Transport	Total TFC in transport (Ktoe), TFC of Fuel fossils use in transport /Total TFC in transport (Ktoe), TFC of Electricity in transport /Total TFC in transport (Ktoe), TFC of biofuels and waste consumption /Total TFC in transport (Ktoe)
Use of energy:	Loss/TPES, TFC Residential /population (Ktoe), TFC Industry /population (Ktoe), TFC Commercial /population (Ktoe), TPES/GDP (Ktoe), Electricity consumption/population (Ktoe)
Resource access to energy	Total Energy production (Ktoe), Total fossil fuel production/Total Energy production, Renewable energy production/Total Energy production (Ktoe)
Resilient & safety	Access to electricity (Million population), Renewable internal freshwater resources, per capita (cubic meters), Electricity consumption/population (MWh/capita), CO_2 /population(Mt CO_2 /capita, Population/Land area(sq. km)
Policy	Energy exports /Energy imports (Mtoe), GNI Coefficient, GDP (billion 2010 USD)/population

4.3.1. Main causes of indicators selection

After gathered raw data, by correlation method analysis, were selected the proper indicators from between all of the existing sub-indicators before final analysis. These analyses show us which indicators are appropriate to final analysis and can effective for achieving energy sustainability in studied countries. Also selected indicators to show us which sub-indicators, if become controlled, can be effective to achieve energy sustainability. Table 4.3 shows the selected indicators after correlation and normalization step with related used formula.

Table 4.3. The selected indicators after correlation and normalization step

Group of indicators	Sub-Indicator formula
Environmental impact	CO_2/TPES CO_2 /Population CO_2/GDP
Renewable energy	Amount of renewable energy in electricity production / Total Energy production from renewable energy TFC Renewable energy consumption in Residential / Total Energy production from renewable energy TFC Renewable energy consumption in Commercial / Total Energy production from renewable energy
Transport	TFC of Fuel fossils use in transport /Total TFC in transport TFC of Electricity in transport /Total TFC in transport
Use of energy	Loss /TPES TFC /GDP
Resource access to energy	Total fossil fuel production/Total Energy production Renewable energy production/Total Energy production
Resilient & safety	Access to electricity Renewable internal freshwater resources, per capita Electricity consumption/population
Policy	GNI Coefficient

4.4. Result and discussion

To achieve an acceptable result in this study firstly should be collected the required data for all of the related sub-indicators with the main group of indicators. Therefore, in this regard, the necessary data gathered for each country using IEA and Word bank. Moreover, after these data should be investigated and arranged by breakdown formula. These raw data can help us to acquire the proper final sub-indicators that have a remarkable effect on achieving energy sustainability for these countries. Table 4 shows all of the selected indicators data before normalization. As can see a set of indicators were selected to better and comprehensive analysis for this study. The high number of these indicators allows us to take better making the decision also we can be select effective indicators accurately.

4.4.1. Importance of correlation and normalization

The correlation and normalization method of obtained numbers is used to achieve better results. Since the main target of this study is achieving energy sustainability, thus it is required that different measure sub-indicators based on related indicators and then obtain main results. In this regard after select, all of the sub-indicators that are related to every seven indicators should be divided all of them into each other before the main correlation step accurately. After that, with the normalization method of the raw data and according to the situation of each main seven indicators, the appropriate sub-indicators will be obtained. Table 4.4 shows the raw data selected of Indicators before normalization.

Table 4.4. Raw data selected of Indicators before normalization

Indicator / Country	New Zealand	Austria	Iran	Denmark	Poland	Peru	France	Romania	Turkey	Tunisia	Jordan	Slovakia
CO_2/POP	6.392	7.241	6.976	5.761	7.716	1.594	4.382	3.441	4.299	2.252	2.499	5.529
CO_2/GDP	0.17	0.15	1.156	0.094	0.511	0.264	0.104	0.341	0.302	0.51	0.774	0.285
TCO_2	30	63	563	33	293	51	293	68	339	25	24	30
CO_2 /TPES	1.427	1.891	2.273	1.995	2.95	2.114	1.199	2.142	2.479	2.273	2.674	1.181
TEPR	8720	9770	1940	3490	9030	4700	23900	6100	17130	1180	270	1600
AREE/TEPR	0.356	0.471	0.741	0.433	0.221	0.477	0.359	0.387	0.453	0.042	0.296	0.368
TFCFFT/TFCT	0.9981	0.9062	0.9991	0.9346	0.96	0.9578	0.9079	0.9396	0.9922	0.9966	1	0.9215
TFCET /TFCT	0.001	0.0314	0.0008	0.0086	0.0152	0.0005	0.0211	0.0156	0.0037	0.0033	0	0.0212
TFCT	4891	8559	44838	4160	18539	7873	43830	5762	26483	2388	2768	2448
LE/TPES	0.013	0.018	0.012	0.048	0.015	0.019	0.018	0.033	0.022	0.023	0.019	0.02
TFCI/POP	0.00009	0.0009	0.00054	0.00037	0.00038	0.00015	0.0004	0.00003	0.00033	0.00019	0.00011	0.00061
TFCR/POP	0.00003	0.00072	0.00068	0.00077	0.00051	0.00011	0.00059	0.00374	0.00026	0.00018	0.00013	0.00003
TFCC/POP	0.00026	0.0003	0.00014	0.00034	0.00022	0.00003	0.00034	0.000091	0.00015	0.00005	0.00004	0.00024
TPES/GDP	119380.6	79330.9	508546.2	47525.8	173310.6	124984.4	86896.1	159492.4	121852	224469.3	289516.1	157104.7
ELC/POP	8.523	8.275	3.135	5.935	4.187	1.18	7.149	2.682	3.094	1.531	1.874	5.16
TREP/TEP	0.5	0.9	0	0.3	0.1	0.2	0.2	0.2	0.5	0.2	0.8	0.3
TFFP/TEP	0.5	0.1	1	0.7	0.9	0.8	0	0.6	0.5	0.8	0.2	0.1
TEP	16,450.00	12,371.00	391,088.00	15,036.00	66,666.00	25,379.00	131,560.00	24,868.00	36,102.00	6,044.00	355	6,543.00
AE	100	100	100	100	100	94.9	100	100	100	100	100	100
RIFR	72,510.00	6,435.00	1,639.00	1,063.00	1,410.00	52,981.00	3,016.00	2,129.00	2,947.00	376	77	2,325.00
POP/LA	17.8	105.4	49.6	135.5	124	25	122.1	85.9	102.4	71.5	108.2	112.8
EEX /EIM	0.31	0.329	13.323	0.862	0.404	0.985	0.2	0.464	0.064	0.324	0.071	0.348
GNI	0.361	0.305	0.388	0.285	0.321	0.443	0.323	0.275	0.412	0.358	0.337	0.261
GDP /POP	38	48	6	61	15	6	42	10	14	4	3	19

4.4.2. Correlation and normalization formulation

As before mentioned, the correlation coefficient takes a value between -1 and 1 indicating perfect correlation and normalization is a value between 0 and 1. Returns the correlation coefficient of the Array1 and Array 2 cell ranges that are used to determine the relationship between two properties. Thus the correlation can be obtained as follows a formula that extracted of the excel software:

$$Correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}} \tag{4.1}$$

In this formula, n is $\bar{x}$ and $\bar{y}$ are the sample means average (array1) and average (array2). Also, the main below formula can be used to calculate normalization:

$$X_m = \frac{X - X_{min}}{X_{max} - X_{min}} \tag{4.2}$$

Where in this formula, X_m is indicator value, x is the actual number; X_{min} is the minimum number, and X_{max} is the maximum number. On the other hand, about difference indicators with various ranges and dimensions, the normalization technique called UNDP method is used to obtain results [169]:

$$V = \frac{V_{act} - V_{min}}{V_{Max} - V_{Min}} \tag{4.3}$$

$$V = \frac{V_{Max} - V_{act}}{V_{Max} - V_{Min}} \tag{4.4}$$

To arrange the numbers equally, it should be considered that when a definition indicator should have high-value, the Eq.4.3 is better to use for normalization and when an indicator should have low value is better than the use of Eq.4.4 for normalization. In two formula V is the indicator value, V_{act} is the actual indicator such as a country, V_{Max} is the maximum value of indicator and the V_{min} is the minimum value of the indicator. Table 4.5 shows the correlation analysis step for all of the existing indicators before the final assessment. In this table, the correlation method was performed for all arrays and in comparison to each other with regard to main its indicator separately. This analysis helps us to select appropriate sub-indicators in the final step also this analysis shows which sub-indicators are more close to energy sustainability before final selection. Of course, it is possible in this analysis instead of one sub-indicator, two sub-indicators be appropriate for the main indicators, thus each two of them can be used in the final selection step.

Table 4.5. The correlation analysis step for all of the existing indicators before the final assessment

Indicator	A	B	C	D	E	F	
Environmental impact	CO_2/TPES	CO_2/Pop B	CO_2/GDP	Total CO_2			
Column	A-B	A-C	A-D	-			
Correlation number	0.906	0.535	0.239				
	B-C	B-D	-	-			
	0.023	0.393					
	C-D	-					
	0.531						
Renewable energy	TEPR	AREE/TEPR					
	A-B	A-C					
	0.047	0.232					
	B-C	B-D					
	0.191	0.169					
	C-D	-					
	0.968						
Transport	TFCFFT /TFCT	TFCET/TFCT					
	A-B	A-C					
	0.786	0.009					
	B-C	-					
	0.005	-					
	-						
Use of energy	LE/TPES	TFCI/POP	TFCR/POP	TFCC/POP	TPES/ GDP	ELC/POP	TFC/GDP
	A-B	A-C	A-D	A-E	A-F	A-G	-
	0.164	0.427	0.16	0.423	0.055	0.323	
	B-C	B-D	B-E	B-F	B-G	-	
	0.225	0.559	0.017	0.481	0.157		
	C-D	C-E	C-F	C-G	-		
	0.096	0.031	0.108	0.067			
	D-E	D-F	D-G	-			
	0.488	0.903	0.195				
	E-F	E-G	-				
	466	0.0844					
	F-G	-					
	0.221						
Resource of energy	TREP/TEP	TFFP/TEP	TEP				
	A-B	A-C	-				
	0.592	0.513					
	B-C	-					
	0.352						
Resiliency	AE	RIFR	ELC/POP	EC/POP	POP/LA		
	A-B	A-C	A-D	A-E	-		
	0.534	0.371	0.491	0.509			
	B-C	B-D	B-E	-			
	0.243	0.081	0.785				
	C-D	C-E	-				
	0.667	0.161					
	D-E	-					
	0.217						
Policy	EEX /EIM	GNI	GDP/POP				
	A-B	A-C	-				
	0.281	0.242					
	BC	-					

0.425

In this research, the below formula was used to final calculation of each indicator.

$$U = \frac{\sum_{k=i}^{n}(1-V_x)+\sum_{y=n+1}^{m} U_y}{N} \tag{4.5}$$

In this formula, N is the number of indicators and $1 - V_x$ is a ratio for the indicators that should be low value. In fact, when a definition indicator should have high-value is not need to use the $1 - V_x$ for it and it can be calculated without considering -1 for it and when the indicator should have low value is better than the use this equation $1 - V_x$. Table 4.6 demonstrates the obtained numbers of Indicators data after the normalization step. Since the range of obtained data for easy analyses should be identical, thus as can see in this table all numbers are arranged in 0 and 1 ranges by Minitab software.

Table 4.6. Sub-Indicators data after normalization

Indicator / Country	New Zealand	Austria	Iran	Denmark	Poland	Peru	France	Romania	Turkey	Tunisia	Jordan	Slovakia
CO_2/POP	0.783	0.922	0.879	0.681	1	0	0.455	0.301	0.441	0.107	0.147	0.642
CO_2/GDP	0.072	0.053	1	0	0.392	0.16	0.009	0.233	0.196	0.392	0.64	0.179
CO_2/TPES	0.139	0.401	0.617	0.46	1	0.527	0.01	0.543	0.734	0.617	0.844	0
AREE/TEPR	0.356	0.471	0.741	0.433	0.221	0.477	0.359	0.387	0.453	0.042	0.296	0.368
TFCRER/TEPR	0.002	0.014	0.001	0.003	0.007	0.004	0.004	0.001	0.108	0.041	0.47	0.003
TFCREC/TEPR	0.006	0.005	0.001	0.001	0.001	0.003	0.001	0.003	0	0.002	0.13	0.001
TFCFT/TFCT	0.998	0.906	0.999	0.934	0.96	0.957	0.907	0.939	0.992	0.996	1	0.921
TFCET /TFCT	0.001	0.031	0.001	0.008	0.015	0.001	0.021	0.015	0.003	0.003	0	0.021
LE/TPES	0.013	0.018	0.012	0.048	0.015	0.019	0.018	0.033	0.022	0.023	0.019	0.02
TFC/GDP	0.104	0.023	1	0.04	0.133	0.152	0.045	0.143	0.026	0.141	0	0.063
TREP/TEP	0.531	0.855	0.004	0.257	0.146	0.185	0.194	0.248	0.486	0.195	0.757	0.275
TFFP/TEP	0.467	0.143	0.991	0.742	0.853	0.814	0.007	0.633	0.513	0.792	0.242	0.115
AE	1	1	1	1	1	0	1	1	1	1	1	1
RIFR	1	0.088	0.022	0.014	0.018	0.73	0.041	0.028	0.039	0.004	0	0.031
ELC/POP	1	0.965	0.24	0.635	0.388	0	0.806	0.176	0.234	0.014	0.062	0.526
GNI	0.361	0.305	0.388	0.285	0.321	0.443	0.323	0.275	0.412	0.358	0.337	0.261
GDP /POP	0.603	0.776	0.052	1	0.207	0.052	0.672	0.121	0.19	0.017	0	0.276

4.4.3. A comprehensive discussion about obtained results after normalization for sub-indicators

To achieve logical results in this study, all countries should be evaluated based on each indicator separately. These stages have two main goals. First of all, it shows the performance of each country based on these indicators and then obtains weak and strong sections of these countries.

- **Environmental impacts:** In this factor, the countries should have has low consumption of CO_2 is better. Because of these indicators emphases on low emission of fossil fuels.
- **Renewable energy:** High consumption of renewable energy has two benefits. Firstly, decreasing the dependence on fossil fuels and secondly low pollution. Therefore, as possible as using renewable energy should be the priority for each country in the energy sustainability plan.
- **Transport:** In this indicator, although fossil fuels are the main resources of energy supply but should be used renewable energy instead of fossil fuels and it can be performed during specified times slowly.

  Access to more electricity is recommended for this indicator because it will have caused more use of public transport and it leads to low emission CO_2.
- **Use of Energy:** This indicator is low complicated. It means that if a country can more use of energy, actually it shows that this country is independent of energy import. However, the most important thing in this regard is balance in the kind of energy that uses in a country. Countries should have the correct consumption of energy.
- **Resource access of energy:** More resource for each country is a value, but correct usage them is more valuable. A country with appropriate planning also effective policy can use energy resources properly in the line of energy sustainability.
- **Resilient & safety:** Access to electricity, healthy water is more important in this indicator because providing primary requirements is very important for having the welfare of inhabitants.
- **Policy:** This indicator should be attended than other indicators. Because proper policies are one of the most important things to progress and keep up the existing resources, also appropriate policy can lead to achieving energy sustainability.

Table 4.7 shows the obtained number only for selected indicators after the normalization stage. This numbers table including the amount of total energy consumption, amount of fossil fuel consumption, amount of renewable consumption based on resource and policy. As can see in this table, there are two remarkable colors green and red. It means for these countries the strong and weak indicators. The green color represents the desired indicators for the same country and the red color red an undesirable indicator that needs improvement. Since that for easy arrangement of the raw numbers, the normalization should be in range 0 and 1, therefore, the maximum range for this table 1 and the minimum is 0.

Table 4.7. The obtained number only for selected indicators after normalization stage

Indicator / Country	Environmental impact	Renewable energy	Transport	Use of energy	Resource of energy	Resiliency	Policy
New Zealand	0.636	0.121	0.001	0.697	0.532	1	0.621
Austria	0.509	0.163	0.062	0.657	0.856	0.684	0.735
Iran	0.116	0.247	0.001	0.751	0.007	0.421	0.332
Denmark	0.588	0.146	0.044	0.546	0.258	0.55	0.858
Poland	0.163	0.076	0.027	0.509	0.147	0.469	0.443
Peru	0.736	0.161	0.028	0.377	0.186	0.243	0.304
France	0.81	0.121	0.061	0.613	0.594	0.616	0.675
Romania	0.605	0.13	0.04	0.438	0.308	0.401	0.423
Turkey	0.507	0.187	0.005	0.421	0.487	0.425	0.389
Tunisia	0.588	0.028	0.002	0.388	0.202	0.339	0.33
Jordan	0.411	0.299	0	0.358	0.758	0.354	0.332
Slovakia	0.691	0.124	0.052	0.528	0.58	0.519	0.507

Fig 4.2 shows the status of each country based on obtained numbers of data and indicators. This fig showed the performance of 12 studied countries based on seven selected indicators. For example, in the resiliency indicators, New Zealand country has a better situation than other countries that are a good situation for this country. On the other hand, and as can see in the use of energy indicators, Iran has the most percent of energy consumption than other countries that this cannot be desirable for this country, as a result, this policy should be revised as soon as possible.

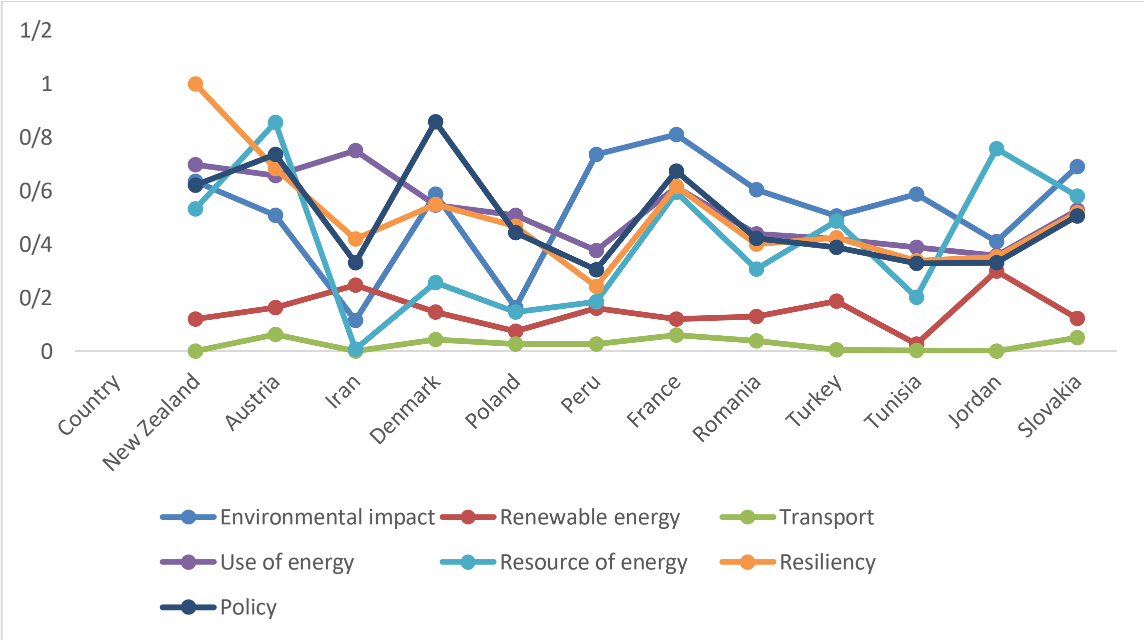


Fig 4.2. Status each country based obtained numbers of data and indicators

Fig 4.3 shows the chart number of each country based obtained numbers of data and indicators. All obtained numbers belong to main indicators are between 0 and 1 for all countries in this chart that shows the status them based on their existing data and analysis. In this fig, as can see for each indicator specified a range between 0 to 1 that shows the situation of each country from the energy sustainability point of view. This divided range of indicators demonstrates that for these countries and in which indicators should make an essential change for achieving energy sustainability. Also, which indicator need to be strengthened or continue the existing situation of the indicator.

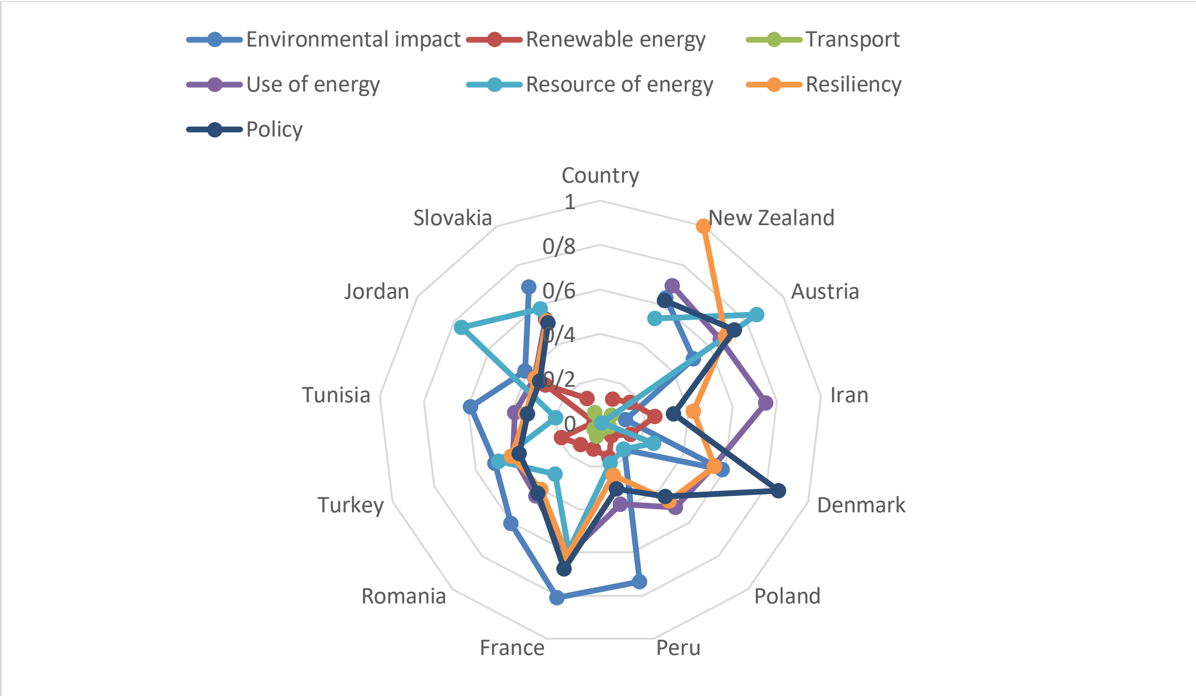


Fig 4.3. Chart number of each country based obtained numbers of data and indicators

4.5. Conclusion

The importance of energy sustainability is not to cover by each person and country. In this regard take correct decisions by energy makers and energy experts are as a necessity to achieve this goal. Also, the correct determination of energy indicators by them is effective and required to improve and enhance the infrastructure of energy sustainability. In this study, is developed the feasible indicators based on a previously presented method called Sustainable Energy Development Index. This study was presented with new indicators and indexes to improve energy sustainability for different countries. At first, during a deep study seven indicators in framework, a group were selected, and the related data for each one from the IEA and World Bank cites gathered and analyzed. The conceptual analysis results showed that to achieve energy sustainability is necessary that policymakers and energy experts with regular planning implement the applied policies. Policies such as lower use of fossil fuels over time and substitute them with renewable energy, more attention to public transport, proper utilization of resources, improving energy infrastructure and resiliency for city inhabitants and rural areas, providing energy access in all area, using new technology to optimize energy consumption and to prevent energy loss. Also, numerical results for 12 studied countries that were presented with two colors green and red have been specified to show which indicators need to enhance and which indicators need to revised and implementing effective actions for it. For instance in the environment section and according to Table 4.7, the policy of Iran due to more use of fossil fuels as the main resource should be changed and move toward a France that has a desirable situation in this index. Also, for other examples and in the transport section, Jordan should be changed and improved the present its situation and use of effective plans of Australia to achieve sustainability.

Chapter 5. Energy sustainability analyses using feasible indicators for urban areas

Nomenclature

AE	Access energy	FA	Forest area
AEUR	Access to electricity urban and rural	GDP	Gross domestic product
AFW	Annual freshwater withdrawals	GNI	Gross national income
CCP	Changing consumption patterns	LA	Land area
CE	CO_2 Emission	NRE	Nonrenewable resource
CESDI	City energy sustainability development index	POL	Policy
EA	Energy accessibility and equity	POP	Population
EAFF	Energy affordability	RE	Renewable resource
EC	Electricity consumption	SDGs	Sustainable development goals by 2030
ECON	Economy	SOC	Social
Eco	Energy conversion	St	Strategies
EI	Energy intensity	TFC	Total final consumption
EIN	Energy investment	TFCC	Total final consumption in Commercial
ENV	Environment	TFCH	Total final consumption in Household
EPR	Energy production from renewable energy	TFCT	Total final consumption in Transport
EPNR	Energy production from non renewable	TPES	The total primary energy source
ESE	Energy security	Habitat	Housing and Sustainable Urban
ET	Energy technology	UP	Urban planning

5.1. Introduction

This chapter investigates energy sustainability analyses using feasible indicators for urban areas. As the urban areas have importance from the energy consumption view and population, therefore attention to these areas is remarkable for energy sustainability. Cities are known as an important and strategic worldwide area because in these areas doing main human social and economic activities [183]. Now, more half of the world's population lives in an urban area, and this population increases in the future that this factor can make different problems for its inhabitants definitely [122]. Also, cities have a role to play in energy consumption, thus improving energy consumption situation in them, can extremely lead to saving energy of each country. Indeed, the increased population of cities increases the required energy of their inhabitants; hence, having a proper plan can be effective to prevent this issue [184]. Energy supply security, economic growth, environmental conservation, and social acceptability are among targets that now investigate by the policymakers and energy experts in the line of energy sustainability achievement [27]. Also with expanding the cities, CO_2 emission increases and it threatens our future and our environment day today [185]. With this description, move toward energy sustainability is a proper way to overcome existing problems. Energy sustainability is one of the most significant challenges facing urban today's society and the future world. Energy supplying needs of the present without compromising the ability of future generations to meet their own needs is the main mean of energy sustainability [186]. Also, now energy sustainability is one of the most important issues for each country that is extremely involved with policy. It means that the reliable energy supply and affordable is important and is the main policy in each country. Since urban density extremely leads to more energy consumption, thus how access to energy and use of energy by cities inhabitants, is important for the future [187]. Hence, it can say that achieving sustainability and especially energy sustainability is one of the most issues of our time. Of course, political and energy experts are well aware of this concept and trying with different proper planning, reduce the cost and energy intensity for inhabitants of cities [188]. Nowadays, all governments are trying to enhance quality life for inhabitants of cities especially in access and consumption of energy [108]. Thus, the reality that city areas have importance as a strategic dimension for governments needs to special planning in the line of energy sustainability

[189]. It means, to achieving energy sustainability in cities, a set of powerful sustainability indicators is indispensable. These indicators could allow and help us to identify the present problems and remove them [13]. Also, to evaluate the energy sustainability in different sectors, it is necessary to determine the driving factors influencing all parts. For example, it can find that in which sector the most energy consumption has and how they can control it. Finding the main cause of problems leads to how we can revise and remove an issue [190]. Many types of research around the world have investigated the energy sustainability of urban areas in different subjects. These research works include: Investigating three important challenges for the compact city with emphases on sustainability [191]. Energy planning for environmental, social, and economic dimensions and in the line of sustainability [192]. Measuring urban energy sustainability for Malaga and Barcelona cities in Spain [43]. Developing new indexes and indicators to achieve sustainable energy [27]. Evaluating energy saving in residential building systems [193]. Also, Kammen D et al. (2016) investigated city-integrated using renewable energy and to achieve sustainability. This research showed that renewable energy has a positive effect on the environment and energy supply in urban areas [194]. Cumo F et al. investigated sustainable management for urban areas with a holistic approach. In this study presented some powerful instruments that can be effective for EU contributions with help to reduce the energy consumption and energy balance [195]. Carreón JR et al. presented a research agenda for urban metabolism to sustainable development and using urban energy systems. They investigated various options to create sustainable energy systems such as energy consumption reduction, energy supply, technology development, etc. [196]. Effects urbanization on energy demand and urban structures investigated by Madlener R et al. [197]. These researchers considered different processes and mechanisms and relevance of these mechanisms between developed and developing countries to answer to the energy demand of inhabitants in urban areas using proper urban planning and urbanization management [198]. This chapter has three novelties: first of all, it comprehensively reviews energy sustainability studies for urban areas; second of all, it considers a group of indicators that has the most effect on energy sustainability for the metropolitan area; and thirdly, it present proper indicators as practical tools for policymakers and energy experts.

5.1.1. Importance of energy sustainability for cities with emphases on clean energy and technology

Energy supply is one of the most critical issues for each country and a stiff challenge [121,151]. In this regard, different resources with their inherent potential have the most effect on energy production. But yet fossil fuels are the primary resource for producing energy that hurts environmental. Thus, the reduction of CO_2 Emission by fossil fuels is in the main plan of each country [74, 81]. Table 5.1 shows Total Primary Energy Supply (TPES) by the source from 1990 to 2016 years based on the IEA report and in-unit ktoe. As can see in this table the primary resource for supplying energy are fossil fuels that lead to more production of CO_2emission, but fortunately, the use of renewable energy from 1990 to the 2016 year has been increased year to year.

Table 5.1. Total Primary Energy Supply (TPES) by the source from 1990 to 2016 years based on IEA report and based on Ktoe.

Year	Coal	Natural gas	Nuclear	Hydro	Geothermal, solar, etc.	Biofuels and waste	Primary and secondary oil
1990	2220183	1663518	525520	184324	36603	909368	3233897
1995	2207026	1807686	608098	213142	42464	972036	3374906
2000	2316125	2072073	675467	225131	60159	1022197	3662923
2005	2993746	2359231	721706	252346	70265	1096114	4000746
2010	3652298	2735488	718829	296247	110420	1221756	4139699
2015	3850534	2943686	670298	335745	204339	1317216	4347259
2016	3730886	3034954	679649	349223	225627	1349289	4390197

On the other hand, energy consumption is a stiff challenge for policymakers and energy experts. Huge waste of energy in the cities due to the high demand of its inhabitants should be considered accurately [97]. Supplying power for residential areas and industrial areas have been caused that policymakers have had an exceptional view on this issue [25]. Fig. 5.1 shows the percentage of total energy consumption by sector in 2015 and 2016 years. As can see in this fig, industrial, transport, and residential sections have more presence of energy consumption respectively. Also, it should be mentioned that these three sections, has the most global CO_2 emissions [199].

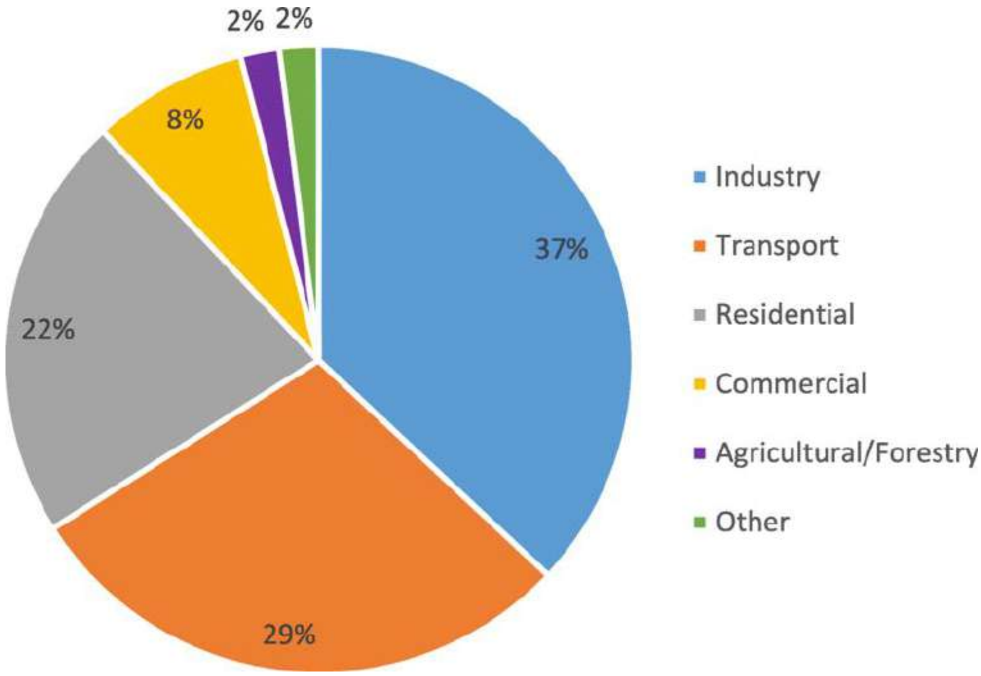


Fig 5.1. Percentage of total energy consumption by sector in 2015 and 2016

With these descriptions, it should be noticed that energy sustainability could be applied in the whole of the energy system of urban areas using new technologies such as EVs to energy storage and to provide energy services to inhabitants in different seasons. Also, using modern techniques such as EVs could have positives effects on the environment and an excellent way to achieve energy sustainability [200, 201]. No only energy supply on time is vital for cities population also can say that forecasting energy needs of the future for them and city active industrials is a crucial issue [202]. Energy sustainability as much as can make energy balance for different cities also can prevent most problems related to energy such as lack of proper accessible energy of inhabitants [191]. Also, regarding energy resources limitation and environmental impacts, energy sustainability is becoming a global necessity. Thus, moving toward energy sustainability has numerous benefits for all countries of the world [200].

5.1.2. Identifying influential indicators to achieve energy sustainability in cities

The majority of the energy sustainability challenges it belongs to the urban environment because these zones have more need for energy. Also, the vital role of energy sustainability is clear for each person [3]. Recently many attention has been given to developing assessment energy sustainability frameworks and the use of proper tools for urban areas. It shows that architects, urban planners, and decision-makers have specific targets related to energy sustainability. To reach energy sustainability, the use of a particular indicator is required for measuring and monitoring energy use in an urban area. Since energy indicators have a crucial valid role for urban areas, hence, having innovative approaches and policies targeted to select and implement them, can be more remarkable to achieving energy sustainability successfully [203]. Having features such as applicable, influential, measurable, and compatible with an urban area, are the most important factors to select and implement indicators related to energy sustainability in society to achieving the considered objectives. Confidently can say that, if signs decide in an appropriate framework, can enhance the quality of life of urban inhabitants. Thus, proper indicators if based on an accounted policy were implemented, sustainable energy, affordable, and safe will bring for all households and society [27, 204]. Providing the reliability of sustainable energy supply is an important goal to gain energy sustainability for inhabitants in urban areas. Presenting applicable patterns for inhabitants in energy field such as low energy consumption patterns, more training people in energy consumption field, improvement the policies and regulations energy, use of new systems with high efficiency, use of envelope in building, more use of public transport and especially EVs to reduce CO_2 is the best energy sustainable indicators to help people and can be influential in enhancing the quality of life for them. Also, attention to indicators compatible with both policy and energy balance program has the most impact on energy sustainability of cities [25, 205].

5.2. Proper policies to consume the energy of inhabitants

Many energy policies are not enough or not well-defined; thus, need that again be investigated and revised. Understand people needs should be the priority for politicians, and they can easily forecast the essentials for urban inhabitants in the future. Attending to people requirements should be necessary for politicians, and always they are making the correct decision about all aspects of society and people's life [204, 206]. There are many differences between selecting and implementing indicators in an ideal world and the real world. It means that many of the selected indicators in the perfect world, are not possible to achieve in the real world. Indeed, even if investigated with the highest precision in an ideal world, is not enough reason to implement them, because it is possible that in the real world, some unexpected incidents intervene and make different problems. By the way, multidimensional analyses from various aspects can be sufficient to reach acceptable results before implementation indicators. Policy acting as a principal framework to find and making decision indicators in a plan. Proper and timely policy more quickly can lead to desirable results in sustainability. Selecting appropriate, logical and executive criteria can contribute to finding measured indicators in direction achievement to energy sustainability for urban areas [207, 208].

5.3. Methodology for the objective selection

Since implementing appropriate energy, indicators can be affected by the quality of life for city inhabitants. Hence, urban energy sustainable indicators are a crucial and important tool for measuring urban energy status and helping society progress to achieve energy sustainability. The emphases of this study are on energy sustainability for urban areas using effective indicators and in the line of SDGs and Habitat lll and CESDI method. This research divided into two stages. In the first stage, four effective indexes in sustainable development investigated especially for urban areas and explained comprehensively. In the second stage, an impressive group including eight indicators investigated that has the most effects on urban areas from the energy sustainability point of view and for them was selected sub-indicators. For selecting final sub-indicators, a lot of sub-indicators in framework a set were selected and then from among of them the best, and most effect sub-indicators were used in this study. These chosen sub-indicators with a high percent of effect on energy sustainability, are main and could minimalize current issues in urban areas.

5.4. A comprehensive description of four important indexes

5.4.1. Policy

Because of high facilities and better progress in cities, people prefer to live in urban areas, so they can have a better quality of life and access to many things that they want [209]. Also since so many of us live in cities. Thus the urban area is important for all of us and in this regard can be more seen importance of indicators [14]. On the other hand, the remarkable key role of policy and policymaker will be increased simultaneously. Actually, in the policy section, attention to a good relationship between urban planners and policymakers are important, because friendly relation can be a good policy to eliminate many problems [175]. Public interests must always be prioritized, and appropriate decisions are taken using expert person views and in a specific framework to achieving desirable results [210]. The use of city inappropriate and incompatible programs not only make many problems and negative impacts in an urban area also lead to adverse effects for policymakers and urban planners [211]. Thus, all actions should be prioritized and implemented concerning common goals and be compatible in the direction of urban developing and achieving satisfying public results for city inhabitants [212]. The policymaker that focuses on energy sustainability in cities has a personal view on the sets of indicators that present by city planners and that it shows the importance of indicators [213]. Since each indicator is used to the effectiveness of the policy change and progress, hence, it is important that from the first to be considered a transparent and targeted approach in this field. Indeed, indicators are a key role in energy sustainability, but they cannot easily and automatically impact policymaking and need some specific laws to implement. Firstly, it should be proved that the sets of presented indicators are practical and useful. Secondly, these are coherent with society, and thirdly governments can implement them easily [174]. As above mentioned, to use of indicators in society, it is important the considering of cycle of policy-making. It means that the indicators are effective in both theoretical and operational views; thus, the role of policy-making is remarkable to implement indicators in cities [214]. Actually, to achieve energy sustainability goals in specific terms, having a strong and accounted policy program in the side of an excellent managing and monitoring on the progress, not only can lead to desirable results but also it will be caused the attract more public support that can be effective to continue other plans in the future. As a result, can say to implement energy sustainability indicators in cities, is a need for proper strategies and practical instruments in this field, accurate evaluation and finally executive them [13].

5.4.2. Economy

Economic is an essential factor to reach energy sustainability. Because affordable energy supply for city inhabitants can be lead to access energy them easily [170]. Since now the quality of our life is extremely dependent on accessing energy [197] hence energy supply for all people especially urban areas that have more consumption of energy than others should be affordable, reliable, and abundant [215]. Energy sustainability in the economic sector should be elaborated and implemented within an appropriate framework for urban areas. Indeed, the main goal of energy sustainability from the economic point of view should be based on a useful and applicable assigned program to correct energy consumption, having low cost and high efficiency for all of the people [216]. It means that only more use of resources should not be considered a goal by planners for consumers, and an equilibrium plan combination simultaneous of high efficiency and economy should be investigated in this sense. Only attention to energy efficiency increases energy use by consumers, and it makes the most cost by them [217]. Also can be mentioned that the inefficiency of energy sustainability programs in the economic sector, moreover increases energy consumption, so increases the cost for inhabitants of urban areas [218]. Thus, from the economic point of view, energy sustainability indicators must be correctly selected and applied in a way that is both appropriate and acceptable to the people of the community and also suitable for governments.

5.4.3. Environment

Daily consumption of energy, has an impact on the environment that we live in it. This kind of energy consumed and the environment is the main issue for all of us [202]. On the other hand, the use of fossil fuels causes global warming and air pollution and threats to our plant [34, 219]. At present, in most countries of the world, a plan related to less carbon-intensive and even carbon-free energy is investigated as a part of the main programs of governments to achieve energy sustainability for the future [25]. A variety type of programs has been presented by policymakers such as more use of natural gas as the cleanest major fossil fuel [220] and renewable energy to more help in energy supply [34]. Low carbon policy should be considered as the most important policy in for environment sector.

Determining appropriate environment indicators and implement it, is a positive step to achieve energy sustainability. Undoubtedly use of practical indicators that are compatible with the environment, is most effective for urban areas in this sense [221]. These programs, first of all, need a comprehensive plan to demonstrate to policymakers to convince them. Then selection proper indicators and finally implementation them respectively. Fortunately, today's in the environment sector is carried out much progress to use of proper indicators for an urban area, but still, it needs to be more measurement and enhancement by governments [208]. Also in this regard, other appropriate solutions can be very effective such as increase new technologies based on economic policies, limitation regulations for production growth in rich countries, and financial support of big producers to reduce greenhouse emissions and more use of renewable energy.

5.4.4. Social

Can confidently say that the most produced energy by industrials, is consumed in urban society. Urban areas are the most consumer [191]. Planning to develop energy sustainability especially for the social sector is one of the most important tasks of energy planners of each area [43]. Energy planners and policymakers need to consider and have appropriate and sustainable targets for urban development in terms of energy [222]. If energy planners and energy experts are not able to measure the ultimate goal of society, it will be impossible to manage it. energy sustainability management, therefore, needs to define sustainability goals that need to be continuously investigated and evaluated, and the end was capable of implementation [197]. Since the performance of each society in the energy sector and especially in the social energy sustainability program is different and it depends on a variety of factors in the community. Therefore, the most important indicators related to energy sustainability from the social aspect should be assessed, determined, and implemented [223]. In this regard determination and assessing social indicators by experts of society have important, and it is considered as a priority to gain energy sustainability [224]. Because, indicators play an important role in energy sustainability for urban areas, hence, achieving to energy sustainability of society, without a strong insight, use of a set of credible sustainability indicators, practical and an intelligent decision is made to implement it is impossible. Indeed, real energy sustainability indicators, are capable of defining the goal, also measure the method and degree of implementation of it [225]. Surely only a general definition of energy sustainability social is not enough to reach energy sustainability in urban areas, and it should be measured in practice [226]. Thus to gain energy sustainability in urban areas, needs to an accounted strong strategies with the cooperation of government policymakers and cities programmers based on both theoretical and applicable program [227]. Fig 5.2 shows the four main indexes in this study in the line of energy sustainability. As it clears in this fig, for achieving energy sustainability, policy, environment, social issues and economy are main indexes.

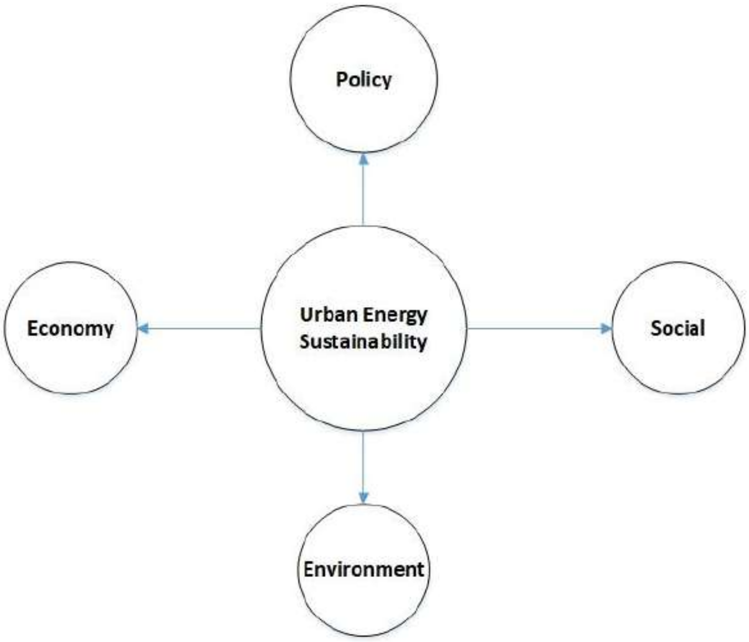


Fig 5.2. Four main indexes in this study in the line of energy sustainability

Table 5.2. Shows four main indexes with important indicators based on Fig 5.2. This table is made based on four main indexes and related indicators in the line of energy sustainability. The most important indicators were selected to identify the best framework for energy sustainability. On the other hand, we are able to use this suggested table for choosing the appropriate strategies to improve the quality of life of urban inhabitants and near to energy.

Table 5.2. Four main indexes with related indicators based on fig 5.2.

Index	**Indicator**
Policy	ESe, EI, EIN, ET, UP, St, TPES,TFC
Economy	EAFF, EIN, GDP, GNI, EC, EA, TFC
Environment	CE, AFW, FA, LA, NRE, RE
Social	AEUR, CCP,EA, EAFF, EC, ESe, ET,TPES, TFC, TFCC, TFCH,TFCT, POP

Moreover, Fig 5.3 shows a total schematic of urban energy sustainability and four main divided indexes with relevant indicators. Also, the main indexes as civic energy sustainability pillars are in the above and appropriate indicators to them are in the bottom of Fig 5.3. In addition, Fig 5.3 demonstrates how energy resources can divide somewhat between main sectors to gain energy sustainability.

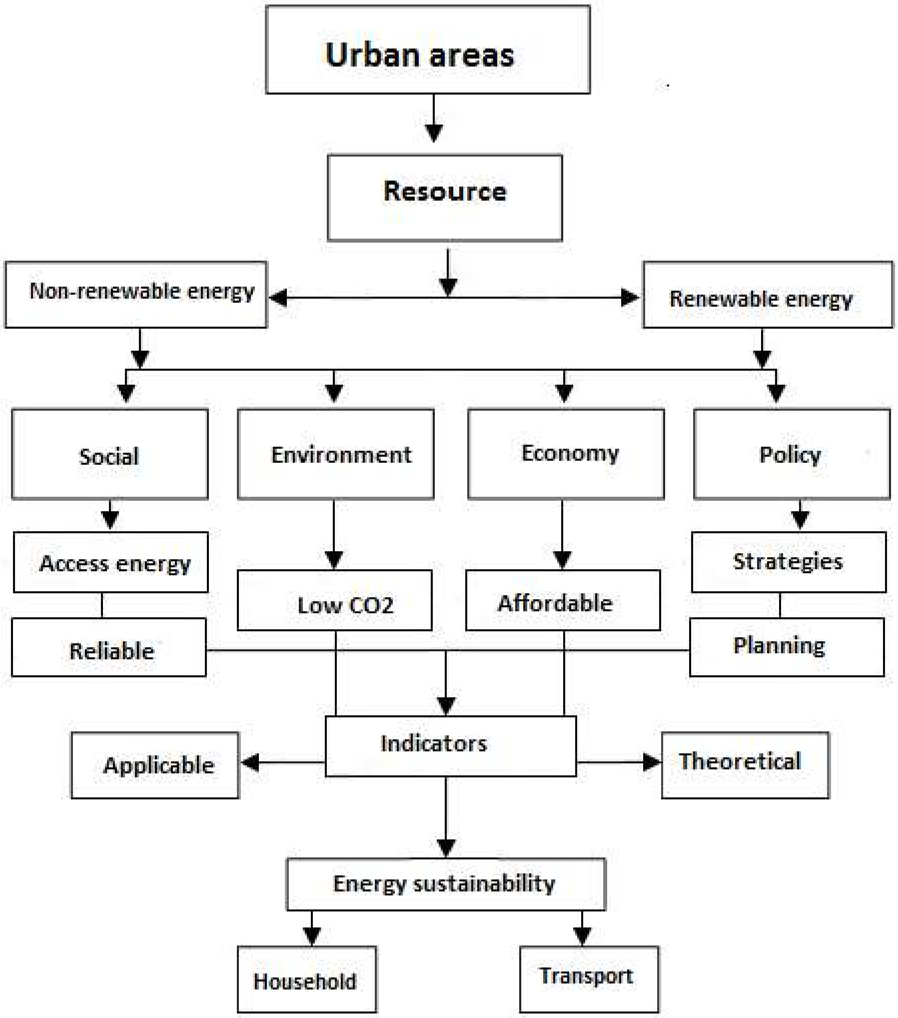


Fig 5.3. A total schematic of urban energy sustainability and divided indexes with the relevant indicator

5.5. Group of useful indicators of energy in an urban area

The selection of appropriate indicators is a practical step to achieve sustainability in the energy field. There are different types of indicators to improve energy sustainability, but which of these indicators are better and more practical in this sense. Hence, properly analyze for selecting indicators is an essential thing to achieving goals of energy sustainability. Indeed, it is necessary to know which indicators can focus better impact on energy sustainability. On the other hand, this investigation should be consisting of both quantitative and qualitative indicators that could better be analyzed and selected to achieve energy sustainability. The chosen indicators have sub-indicators that correspond to the principal elements and lead to energy sustainability. In this regard, eight indicators in framework a group relevant to four main indexes of sustainable development, investigated. These indicators have the most effect on energy sustainability.

- **Energy resource**
- **Environment**
- **Economy**
- **Transport**
- **Use of Energy**
- **Resiliency**
- **Policy**
- **Household**

Table 5.3 shows the group of indicators with sub-indicators that have the most effect on energy sustainability in cities. Also in this fig, the third pillar shows the relation between sub-indicators pillar with four indexes CESDI respectively.

Table 5.3. Group of selected indicators with sub-indicators

Group of indicators	Sub-Indicator	Related to 4 indexes CESDI respectively
Energy resource	NRE, RE, LA, FA	ENV, POL, ECO, SOC
Environment	AFW,CE , FA, LA, NRE	ENV, SOC, POL, ECO
Transport	AE, EC, NRE, RE, TFCT, TPES, TFC	SOC, POL, ENV, ECO
Use of energy	AE, AEUR, EAFF,EC, TPES, TFC, EI, EPR, EPNR, EA	POL, ECO, ENV,SOC
Resiliency	AE, AFW, EC, TPES,TFC, UP	ENV, SOC, POL, ECO
Policy	ESe, EI, EIN, EPR, EPNR, ET, UP, St, TPES	POL, SOC, ECO, ENV

Economy	EAFF, EIN, GDP, GNI, EC, EA, TFC	ECO, SOC, POL, ENV
Household	AE, AFW, AEUR , EA, EAFF, EI, EC, TPES, TFC, UP	SOC, ENV, ECO, POL

5.6. Result and discussion

Importance of a city when it will be specified that most or all of its inhabitants are satisfied with the quality of life. Indeed, live in a town for a person is vital from various aspects such as welfare, education, economics, access energy, etc. Approximately in each city, there are many urban problems that this subject impacts on the degree of quality of life for inhabitants Access energy subject that leads to energy sustainability always considered a remarkable issue for all of cities inhabitants. In this regard, our results suggest that about increasing day to day population of cities and energy supply sensitive for inhabitants, thus needs regular planning. The following sections report our findings on this issue. Fig 5.4. demonstrates a schematic of the energy supply from primary resources made by authors and were designed in different parts and based on existing support and about eight selected indexes. As it is clear, resources are divided into two parts such as RE sources and NRE sources, and then these resources used in transport and household sections about the economic section. The emphases of Fig 5.4, is for achieving energy sustainability based on resources, should be considered effective policy and appropriate planning. If we can modify the amount of consumption of energy with excellent management in a different section correctly, surely will have not a problem in the future for energy supply for inhabitants of cities.

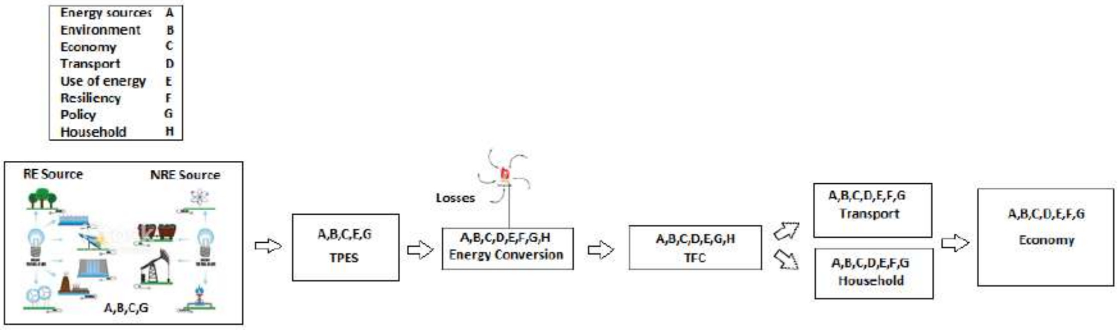


Fig 5.4. A schematic of energy supply from primary resources with relevant indicators

Also, Table 5.4 demonstrates the most critical sub-indicators related to eight selected indicators that are based on the design of Fig 5.4.

Table 5.4. Important indicators and sub-indicators based on the design of Fig 5.4.

Total non-renewable and renewable energy	Resource	TPES	EC	TFC	Transport	Household	Economy
Total production energy by non-renewable energy	√	√	x	x	√	√	√
Total production energy by renewable energy	x	√	x	x	√	√	√
Non-renewable end renewable resource	x	√	x	x	√	√	√
Total consumption energy by non-renewable energy	√	√	√	√	√	√	√
Total consumption energy by renewable energy	x	x	x	√	√	√	√
Amount of CO_2 emission	x	x	x	√	√	√	√
Amount of investments in energy	x	√	x	√	√	√	√
Reduction fuel fossils by technology	x	x	√	√	√	√	√
Amount of energy intensity	x	√	x	√	√	√	√
Electrical consumption by renewable end non-renewable	x	x	x	√	√	√	√
Percent of economic growth by energy sector	x	√	√	x	√	√	√

5.6.1. Energy sustainability

SDGs targets by 2030 extremely emphases on energy sustainability and especially energy access, also, the utilization of renewable energy with an active policy and as a reliable way to supply a part of the required energy for the countries that have not sufficient resource for a good future. In this regard as above mentioned, using feasible indicators for implementation as useful tools are the most factor for achieving energy sustainability [204]. These indicators with sub-indicators make a chain of energy sustainability for urban areas. Fig 5.5 shows energy sustainability by considering the most essential indicators and sub-indicators in the line of SDGs and UN-Habitat III. Indeed, the main objective of

Fig 5.5, is energy access in the best possible state for residential inhabitants as secure, reliable, abundant, accessible, and affordable. It is shown in Fig 5.5.

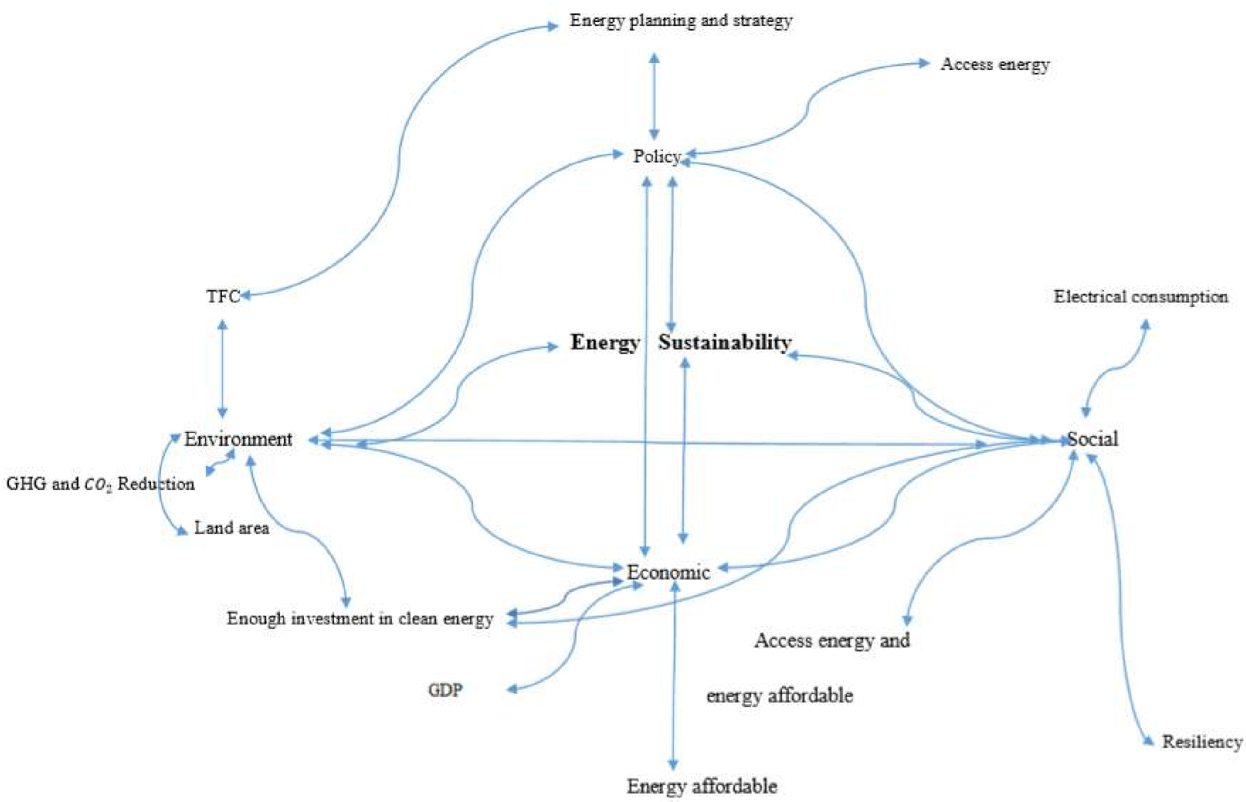


Fig 5.5. Energy sustainability dynamic schematic

5.7. Smart city and energy sustainability

Without a doubt, concerning expanding cities and different demands by its inhabitants, moving toward a lively town that uses of incorporates information and new technologies to improve the quality and performance of municipal services will be increased in the future. Important issues such as energy supply regarding the limitation of fossil fuels, climate change, public transportation, and city costs, are enough causes for making smart cities. Also, it should be emphasized that a smart city needs a smart economy, smart governance, smart mobility, smart environment, smart living, and intelligent people. Thus, having an appropriate approach by policymakers and city programmers to select correct indicators in this regard can catalyze the solution of related issues and achievement to energy sustainability. Fig 5.6 shows the hierarchical structure of application areas related to smart cities. As can see energy sustainability can be influential in some parts of Fig 5.6 [228].

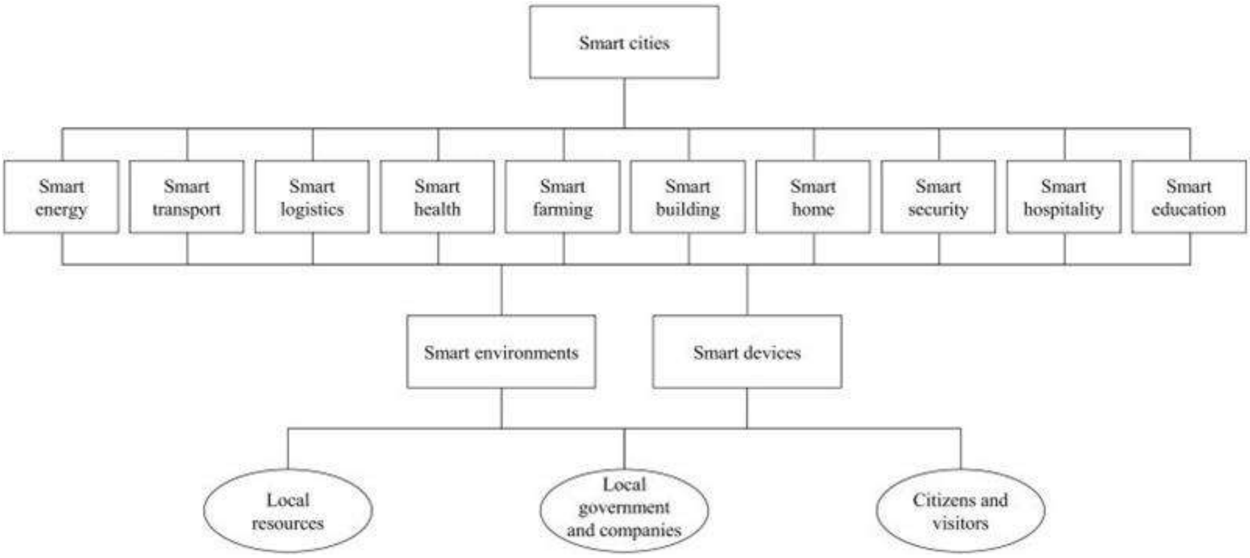


Fig. 5.6. The hierarchical structure of application areas related to smart cities [228]

Since the smart city has a near relation with energy sustainability, this was presented in Table 5.5 that shows carried out studies in this regard.

Table 5.5. Studies on energy sustainability and smart cities.

Main author	Summary description of the work
[229]	Consideration smart energy city both theoretical and practical and presented smart energy
[230]	Presentation a new method and calculated, smart indicators weight for the smart city by fuzzy logic
[231]	Investigation national plan for smart cities for Spain based on Policy, Sustainability
[232]	Presentation practical standards in the field of energy and for building
[233]	Investigation information technology knowledge to reduce energy use in cities
[234]	Suggestion a sustainable energy microsystem for the integration of different subsystems for buildings in cities.
[194]	Consideration city-integrated using renewable energy for urban sustainability
[235]	Investigation carrier networks in urban areas for distributed renewable energy generation
[236]	Investigation smart city practices for 15 UK cities to in achieving sustainable urban outcomes.
[237]	Consideration user-centric smart buildings to achieve energy sustainable for smart city

5.8. Conclusion

Energy supply for urban areas is an important issue for each country. Since that contemporary cities are more dependent on the use of fossil fuels to energy supply, thus, has a high potential to produce CO_2 and move toward global warming. About this reality that cities usually are known for having a compressed population as a high consumer of energy; hence, energy supply for them has been becoming a strategic issue for city planners and policymakers. Therefore, achieving energy sustainability can be useful as an appropriate way in this regard. This chapter investigated the indicators and sub-indicators that effects on energy sustainability in urban areas. The article commenced with a review of energy sustainability concept, essential indicators, and policy, then, four influential indexes in the line of sustainable development described comprehensively. In the next stage, have described eight sub-indicators that had the most effect on energy sustainability and for each of them, were selected proper sub-indicators. And finally, results are over with a description of energy sustainability and connect with the smart city. Indeed, the main objective of this study was to define and determine a set of indicators that can be effected to measure the energy sustainability of the urban area and their influence on the quality of urban life. All of these selected indexes, indicators, and sub-indicators are related to the energy sustainability of the metropolitan regions directly. The results show that achieving energy sustainability in urban areas have an appropriate strategy, planning, and useful indicators that should be considered and applied for different sections.

Chapter 6. Conclusion

6. Conclusion

In this thesis, energy sustainability has been investigated based on SDGs and Urban Habitat III for different countries. In this regard, the sustainable energy development index method (SEDI), firstly has investigated and then this method has been completed and improved by new indicators. Actually, this thesis was focused on finding the new effective indicators related to energy sustainability through consideration of many different indicators, and after analysis, selected the best of them to do this. These selected indicators are able to improve the quality of life of inhabitants in different areas if applied correctly by policymakers and energy experts. Also, in this thesis, other important issues such as energy security, important gaps in developing countries associated with energy, the key role of policy and impact this on energy sustainability, main causes of global warming and the key role of renewable energy as a reducing way for this issue has been investigated in the line of energy.

6.1. Contributions

In this section, the contributions are explained following the chapters. The main contribution of chapter 2 energy sustainability analysis based on SDGs for developing countries, Armin Razmjoo, A Sumper - Energy Sources, Part A, 2019 - Taylor & Francis. https://doi.org/10.1080/15567036.2019.1602215, was for consideration the key role of policy to developing energy sustainability in different countries. In particular, this chapter shows that policy can be considered as a strong and vital factor for developing energy sustainability. Also, due to the importance of access to energy especially electrical energy in remote areas, implementation of the correct policy by policymakers can facilitate this process easily and rapidly. The main contribution of chapter 2 part 2, Deployment of a stand-alone hybrid renewable energy system in coastal areas as a sustainable energy resource, A Kasaeian, A Razmjoo, R Shirmohammadi. Environmental Progress & Sustainable Energy 2019. https://doi.org/10.1002/ep.13354, was for developing renewable energies as a reliable way to reduce global warming and energy access in remote areas. Indeed, this chapter emphasis on that some of the remote areas can be known as high potential areas to produce electrical energy via renewable energy, thus, their potentials has been investigated by analyzing relevant meteorological data though Homer software. This investigation also has shown that clean energy development is vital for combating climate change and limiting its most devastating effects. Therefore, investment in renewable energy should be considered as a correct policy by governments to achieve energy sustainability requirements such as reliable energy and access to energy for inhabitants in remote areas and etc. Also, this chapter has emphasized that lack of access to a reliable energy source and energy services is commonly known as energy poverty in many countries, which affects many people because energy is able to provide all of the basic necessities for human beings such as lighting, heat and appropriate water services. On the other hand, this chapter has shown that proper investment in renewable energy can assist countries to supply adequate energy services to their populations by creates jobs and the positive contributions renewable energy in countries'energy infrastructure. The main contribution of chapter 3, Investigating energy sustainability indicators for developing countries: A. Armin Razmjoo and Andreas Sumper. International Journal of Sustainable

Energy Planning and Management. https://doi.org/10.5278/ijsepm.2019.21.5, was for investigating sustainable the energy development index method (SEDI) for 10 developing countries and presenting seven influential indicators on energy. Actually, this chapter has been investigated a set of energy sustainability indicators for developing countries based on SDGs and using sustainable energy development index (SEDI) method. Also, has been explored a group of indicators that has a greater impact on energy sustainability. Results of this chapter have shown that all studied countries intend to achieve significant growth in energy sustainability in comparison with past years. On the other hand, two main common issues in this study have been shown for these studied countries as the main gaps. Firstly lack of proper policy for monitoring the operating existing system in these countries and secondly dependent on fossil fuels as the main energy source in them. The main contribution of chapter 4, Development of sustainable energy indexes by the utilization of new indicators: A comparative study, AA Razmjoo, A Sumper, A Davarpanah - Energy Reports, 2019 – Elsevier. https://doi.org/10.1016/j.egyr.2019.03.006, was for exploration on completing SEDI by new indicators. In this chapter has investigated and developed a variety of applicable indicators to enhance sustainable energy development index (SEDI). In fact, in this chapter has been presented new effective indicators related to sustainable development goals. To find the best indicators, firstly many related to energy sustainability indicators were investigated and then by correlation and normalization analysis the best and effective of them were selected. The new indicators have been applied to 12 countries to show the effectiveness of them. These indicators if implemented correctly by policymakers and energy experts are able to improve quality of life for inhabitants of different areas, especially in the energy field. The main contribution of chapter 5, Energy sustainability analyses using feasible indicators for urban areas, A Razmjoo, A Sumper, M Marzband - International Journal of, 2019 – Springer. https://doi.org/10.1007/s42108-019-00022, was to find the best and effective indicators and SubIndicators for urban areas in the line of energy sustainability. First of all, eight indicators with high impact on these areas have been investigated and based them near 100 Sub-Indicators were selected. Then, to select the final effective Sub-Indicators to implement in urban areas, all of them again explored based on SDGs, Urban Habitat III, and eight selected indicators. In this regard, the final investigation obtained that all selected Sub-Indicators have a high effect on the energy sector in particular for achieving energy sustainability. The main criterion to choose these sub-indicators was the effectiveness of them on energy and improve the quality of inhabitants' life in different areas. More saving energy, low pollution, affordability and feasibility of them, was the most important factors for selecting these indicators and Sub-Indicators for implementing in urban areas by policymakers and energy experts. Thus, these indicators are proper and harmonious with the situation of these areas from different aspects and will able to cover all sections and measure existing issues in these areas and improve them in all sections confidently.

6.2. Future works

The present research has discovered the possibility of addressing the following four broad research works in the future.

- Finding effective new indicators with emphasis on cities due to their high new consumption of energy and preventing loss energy in different industrials.
- Specifying appropriate policies for policy makers and energy experts to applying new saving energy systems (nearly zero energy) in urban areas.
- Measurement of the expansion of the new effective technologies associated with renewable energies such as electrical vehicles and make green buildings in the line of creating smart cities.
- Investigating effective indicators and strategies to develop renewable energies in remote areas and developing smart cities in the future.
- Presentation of the best ways and methods for achieving energy sustainability in different countries using appropriate indicators.
- Identification of barriers for energy sustainability development of the urban areas and finding the solution for each of them and for smart cities.
- Investigating the impact of aggregation of electricity, gas, heating and transportation networks on energy consumption for small and big projects.
- Definition of new indexes for preventing of uncertainties caused by the production of renewable resources.
- Presenting new designs for creating transportation systems based on combination of electrical vehicles, charging stations and appropriate parking's.

6.3. Publications

1.Development of sustainable energy indexes by the utilization of new indicators: A comparative study, AA Razmjoo, A Sumper, A Davarpanah - Energy Reports, 2019 – Elsevier. https://doi.org/10.1016/j.egyr.2019.03.006.

2.Investigating energy sustainability indicators for developing countries: A. Armin Razmjoo and Andreas Sumper. International Journal of Sustainable Energy Planning and Management. https://doi.org/10.5278/ijsepm.2019.21.5.

3.Energy sustainability analysis based on SDGs for developing countries, A Armin Razmjoo, A Sumper - Energy Sources, Part A: Recovery, Utilization and Environmental Effect 2019. https://doi.org/10.1080/15567036.2019.1602215.

4.Energy sustainability analyses using feasible indicators for urban areas, A Razmjoo, A Sumper. International Journal of, 2019 – Springer. https://doi.org/10.1007/s42108-019-00022.

5.Deployment of a stand-alone hybrid renewable energy system in coastal areas as a sustainable energy resource, A Kasaeian, A Razmjoo, R Shirmohammadi, A Aslani, A Sumper, Environmental Progress & Sustainable Energy 2019. https://doi: 10.1002/ep.13354.

6.4. Other publications and participation

- Publications as first author

6.Developing various hybrid energy systems for residential application as an appropriate and reliable way to achieve energy sustainability, A Razmjoo. Energy Sources, Part A: Recovery, Utilization and Environmental Effect 2019. https://doi.org/10.1080/15567036.2018.1544996.

7.Stand-alone hybrid energy systems for remote area power generation, A Razmjoo, R Shirmohammadi. Energy Reports 5, 231-241. https://doi.org/10.1016/j.egyr.2019.01.010.

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11. A Technical Analysis Investigating Energy Sustainability Utilizing Reliable Renewable Energy Sources to Reduce CO_2 Emissions in a High Potential Area. Armin Razmjoo, L. Gakenia Kaigutha, Mohammad Amin Vaziri Rad, Mousa Marzband, Afshin Davarpanah, Mouloud Denai, Renewable Energy, 9, 2020. https://doi.org/10.1016/j.renene.2020.09.042 0960-1481.

6.5. Collaborations in other publications

12. An overview of management, recycling, and wasting disposal in the drilling operation of oil and gas wells in Iran, A Davarpanah, A Razmjoo, B Mirshekari, Cogent Environmental Science 4 (1), 1537066. https://doi:10.1080/23311843.2018.1537066.

13. A simulation study of water injection and gas injectivity scenarios in a fractured carbonate reservoir: A comparative study, A Davarpanah, B Mirshekari, AA Razmjoo, Petroleum Research. https://doi.org/10.1016/j.ptlrs.2019.02.001.

14. A parametric study to numerically analyze the formation damage effect, Afshin Davarpanah , Behnam Mirshekari and Armin Razmjoo, Energy Exploration & Exploitation2019, https://doi.org/10.1177/0144598719873094.

15. Recent Residential Applications of low-temperature solar collector. Ahmadi, A., Ehyaei, M. A., Doustgani, A., Assad, M. E. H., Hmida, A., Jamali, D. H., ... & Razmjoo, A. (2020). Journal of Cleaner Production, 123549. https://doi.org/10.1016/j.jclepro.2020.123549.

16. Evaluation of an Integrated Cryogenic Natural Gas Process with the Aid of Advanced Exergy and Exergoeconomic Analyses. Ghorbani, B., Roshani, H., Mehrpooya, M., Shirmohammadi, R., & Razmjoo, A. (2020Gas Processing Journal, 8(1), 17-36. http://doi. 10.22108/gpj.2019.117170.1056.

17. A SWOT Analysis for Offshore Wind Energy Assessment using Remote Sensing Potential. Meysam Majidi Nezhad, Riyaaz Uddien Shaik, Azim Heydari, Armin Razmjoo, Niyazi Arslan, Davide Astiaso Garcia. Appl. Sci. 2020, 10(18) 6398; https://doi.org/10.3390/app10186398.

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