energies

MDPI

Article

A Decision-Making Model Proposal for the Use of Renewable Energy Technologies in Buildings in Turkey

Fatma Cesur [1,2,*], Nilüfer Taş [2] and Murat Taş [2]

[1] Department of Architecture, Bursa Technical University, Bursa 16310, Turkey
[2] Department of Architecture, Bursa Uludag University, Bursa 16059, Turkey; nilufertas@uludag.edu.tr (N.T.); murattas@uludag.edu.tr (M.T.)
* Correspondence: fatma.cesur@btu.edu.tr

Abstract: With the increasing need for energy, issues related to using energy efficiently in buildings and employing renewable energy technologies are gaining significance. The building production process is intricate, involving numerous stakeholders, multiple decisions, and a combination of qualitative and quantitative data. This process necessitates decision making based on specific requirements. The objective of this study is to identify effective criteria in decision making concerning the use of renewable energy technologies (RETs) in buildings in Turkey. It aims to highlight the importance of these criteria and compare them, and it also aims to define a recommendation decision-making model for the widespread adoption of renewable energy technologies. This study employed qualitative and quantitative research methods. Based on information gathered from the literature, the main criteria and sub-criteria for RET utilization were determined through in-depth interviews with an expert group, including individuals influencing the building design process (architects, engineers, consultants, employers, and users). A recommendation model was developed using the analytic hierarchy process method to highlight the significance of the identified criteria, compare the criteria and technologies, and facilitate the selection of the most-appropriate technology. This study demonstrates that the decision-making model can be utilized in determining RET-related criteria in the building production process, establishing their weights, and make informed decisions regarding the appropriate technology.

Keywords: analytic hierarchy process; building production; criteria; decision making; dissemination; renewable energy technologies

Citation: Cesur, F.; Taş, N.; Taş, M. A Decision-Making Model Proposal for the Use of Renewable Energy Technologies in Buildings in Turkey. *Energies* **2024**, *17*, 2354. https://doi.org/10.3390/en17102354

Academic Editor: Gerardo Maria Mauro

Received: 6 March 2024
Revised: 3 May 2024
Accepted: 8 May 2024
Published: 13 May 2024

1. Introduction

Considering the imminent depletion of limited resources due to the increasing need for energy, potential energy crisis, and environmental disasters, it is necessary to choose clean and alternative energy solutions such as renewable energy. Natural resources must be preserved and ecological balance maintained to ensure the sustainability and habitability of our living spaces, while also ensuring that development does not hinder meeting the needs of future generations [1]. Buildings are among the largest consumers of energy and are a major contributor to greenhouse gas emissions [2]. The Global Status Report for Buildings and Construction 2021 [3] reported that the operations of buildings accounted for 30% of world energy demand in 2019, and this rose to 35%, or 151 exajoules, when construction was included. Emissions related to construction (including manufacturing of materials such as cement and steel) came to 13.5 GtCO2 in total and increased the emissions share of buildings to 38% [2,3]. It is expected that the building floor area worldwide will be doubled to over 415 billion m2 by 2050, thereby potentially increasing energy demand by 50% [2]. All new buildings to be constructed from 2030 onwards must be zero-energy buildings, and the renovation rate of existing buildings needs to increase from around 1% to 3% per year [4]. Minimum performance standards and legislation on building energy are increasing in both scope and stringency; the use of more efficient and renewable energy technology in buildings is accelerating as the energy sector continues to decarbonize. However, it is necessary for the construction sector to adopt a more rapid change to get back on track with the net zero emissions by 2050. The next decade is particularly critical for implementing the necessary measures to ensure that all new buildings and 20% of the existing building stock are zero-carbon-ready by 2030 [5].

New laws, regulations, and environmental policies are being developed in many countries around the world—with Turkey being one of them. With the ratification of the Paris Climate Agreement by the Grand National Assembly of Turkey, the Ministry has initiated the "Green Development" approach, which refers to the protection of nature on the one hand and nature-friendly growth on the other hand [6]. The Ministry is making plans for the protection of nature and the development of cities with the vision of a "Sustainable Environment, Civilization Living, Environmentally Respectful, and Climate-Friendly Cities" [6]. The Ministry's strategic plans for 2022–2023 include a significant increase in the share of renewable energy in global energy resources by 2030. It aims to develop international cooperation to facilitate renewable energy, energy efficiency, clean energy research, and access to these technologies. It also encourages investment in energy infrastructure and clean energy technology areas. Within the scope of energy-efficient and environmentally sensitive construction efforts, an Energy Identity Certificate is given to buildings, where minimum energy performance requirements are determined and the applicability of renewable energy sources is increased with the "Regulation on Energy Performance in Buildings" [6,7]. When considering the application scale, the utilization of RETs in buildings brings along certain challenges. In Turkey, as of 1 January 2023, it is mandatory to use RETs only in buildings exceeding a certain square meterage. For buildings not falling within this scope, the decision to use RETs is left to the discretion of actors involved in the building production process. Moreover, determining which technologies to include and how to select the technology in buildings where RETs are mandated poses a challenge. The fundamental issue in the building production process is how to decide on the use of renewable energy technologies. The use of renewable energy technologies in buildings is significant in terms of meeting sustainable development/environmental policies and providing societal, economic, and environmental benefits. Additionally, the reduction in carbon emissions through the use of renewable energy sources instead of primary energy sources contributes to achieving sustainability goals. Therefore, there is a necessity to develop scientific foundations, methods, and tools for RET utilization in buildings. This set of affairs has formed the motivation for this study, which aims to develop a methodological approach based on a model for deciding on the use of renewable energy technologies in buildings in Turkey.

According to Tas, Cosgun, and Tas [8], the building production process is an area shaped by the knowledge, technology, values system, laws and regulations, policies, and strategies of the society, which is influenced by many actors. According to Shove [9] and Cooke et al. [10], it is a complex, multi-actor process that involves systematic and intuitive thinking, and it contains many decisions and criteria. The necessity to solve many complex problems and meet user needs has turned the building production process into a problem-solving and decision-making action. In these decision-making stages, the roles of actors involved in the building production process are important. The aim of this study is to assess, within the context of the challenges posed by climate change and the global emphasis on renewable energy, the criteria by which renewable energy technologies (RETs) in buildings are addressed by various actors (architects, engineers, investors, etc.) in Turkey. This involves identifying the obstacles and driving forces preventing or promoting their use by conducting a comparative analysis to determine the degree of parallelism/divergence among these criteria, thereby proposing criteria to generate data for design and creating an interaction plan based on principles/criteria. This will help to provide recommendations on how and at which stages renewable energy technologies can be integrated into projects by various actors, as well as in developing a decision-making model to facilitate their implementation.

The criteria that are effective in deciding on the use of RETs, along with the opportunities and barriers affecting their use, show parallelism. Buildings have a significant impact on the environment, and all actors in the building production process (designers, architects/engineers, building owners, etc.) play an important role in shaping these environmental impacts. In the building production process, the criteria that are effective in deciding on the use of RETs need to be addressed from the perspective of all actors in the building production process. Effective criteria and their importance levels vary among actors [10]. However, the identification of barriers/opportunities, the establishment of criteria promoting their use, the creation of an importance hierarchy, and the identification of the most-effective criteria in increasing implementation rates regarding the use of RETs in buildings in Turkey have not yet been fully researched.

There are existing legislative efforts in Turkey aimed at sustainable energy development, and the topic of renewable energy technologies (RETs) has also been addressed within the framework of action plans. Government agencies in Turkey aim to increase demand for renewable energy sources, reduce electricity consumption in buildings, and decrease carbon dioxide emissions [6,7]. However, there have been few empirical studies conducted to analyze the selection of RETs in buildings and identify key selection criteria in the Turkish context. This study is designed to fill these research gaps with the goal of solving the decision-making problem related to the use of RETs in buildings and promoting their widespread adoption. To achieve this goal, the following tasks/questions have been identified and investigated:

- The level of use of renewable energy technologies in Turkey.
- The level of use of renewable energy technologies in buildings in Turkey.
- The barriers/opportunities for the use of renewable energy technologies in buildings in Turkey.
- Evaluation of the criteria by which renewable energy technologies in buildings are assessed by different actors in Turkey.
- Development of a model to make decisions regarding the use of RETs in buildings based on the implementation of renewable energy technologies.

This study has been formulated within the framework of the hypotheses outlined below:

- Transitioning to buildings where RETs are used can reduce the consumption of fuel and energy resources, energy costs, and greenhouse gas and carbon dioxide emissions.
- The decision to use RETs in buildings can be rationalized by examining actors and criteria and employing a multi-criteria decision-making method. Within the model, the process can be managed. This could lead to easier decision making and prompt access to the correct decision, thereby directing actors in the building production process toward adoption. The identified and prioritized criteria can provide data to technology producers.

This model will be a step toward addressing the local research gap and will allow for a comprehensive evaluation of the use of RETs in buildings in terms of actors, criteria, and technologies. Furthermore, there are very few studies in Turkey that have developed criteria and proposed decision-making methods for the use of RETs in buildings. Therefore, there is a need to enrich studies that address the use of RETs in buildings through the use of criteria and decision-making methods. With this thesis, the identified criteria and developed decision-making model will provide a theoretical framework for architects, engineers, investors, and users who will decide on RETs in the private sector, as well as for local government officials and public employees, and it will also help to provide a basis for methods that can be applied in the decision-making process. The developed model can be used to facilitate and improve the decision-making process for the use of RETs in buildings by professionals in the sector. It is also aimed at inspiring further research on this urgent topic in the midst of the current global energy crisis. The developed model can be used in different countries by updating the criteria and alternatives according to the country's conditions.

2. Literature Review

This section provides theoretical information relevant to the research topics. A literature review of the renewable energy technologies in Turkey and worldwide was conducted, and information about studies related to RETs being used in buildings is detailed. Research was conducted on actors influencing the building production process (i.e., the stakeholders affecting the decisions) and the obstacles/opportunities related to the use of RETs in buildings, as well as criteria for technology selection.

2.1. Renewable Energy Technologies in Buildings

The Turkish Ministry of Energy and Natural Resources (ETKB) monitors, evaluates, and analyzes studies and developments by following international projects related to renewable energy resources around the world. The strategic objectives of Turkey are to reduce the energy demands and carbon emissions of buildings, as well as to promote sustainable, environmentally friendly buildings using renewable energy sources [7]. As a result of the traditional energy sources used to obtain energy mostly being non-local, external dependency has increased, which negatively impacts the national economy [11]. Of Turkey's electricity generation in 2022, 34.6% was obtained from coal, 22.2% from natural gas, 20.6% from hydraulic energy, 10.8% from wind, 4.7% from solar, 3.3% from geothermal energy, and 3.7% from other sources [12]. Turkey, one of the countries most affected by the consequences of climate change in the Mediterranean Basin, is a party to global agreements such as the UNFCCC, Kyoto Protocol, and Paris Agreement. The Paris Agreement was ratified on 11/10/2021, and, on the same date, the President declared a net zero emissions target for 2053. The agreements that Turkey is party to, and the regulations they entail, affect the resource-intensive and high-emission sectors, such as energy and construction, given their significant resource consumption and emissions. The construction sector in Turkey has been identified as one of the key sectors in achieving the sustainable development goals of the European Union (EU) and the United Nations (UN). Many of the sustainable development goals outlined under the UN's "Agenda 2030" are relevant to the construction sector, and efforts to implement these goals are ongoing. To promote the widespread adoption of renewable energy practices, the government has analyzed the challenges faced by investors in renewable energy projects, and it collaborates with relevant institutions to improve the investment environment. Geographical information system (GIS) techniques have been employed to determine the potential of renewable energy sources, thus leading to the creation of renewable energy potential atlases such as the Turkey Solar Energy Potential Atlas (GEPA). Appendix A (Energy Efficiency Policies in Buildings in Turkey) illustrates the efforts in Turkey regarding energy efficiency policies in buildings, thereby aligning with both global and EU initiatives.

The Increasing utilization of renewable energy systems to offset a portion of building loads is becoming more widespread. The pressure on the world's non-renewable resources can be alleviated through the use of renewable resources worldwide. Employing renewable energy technologies (RETs) to meet a building's electricity demand helps reduce traditional energy consumption. The EU aims to gradually halt fossil fuel imports between 2023 and 2027, and it has targeted the installation of photovoltaic (PV) roofs on all public buildings by 2025. China is promoting on-site renewable energy applications in urban buildings, thereby targeting the installation of 50 GW solar PV capacity for all new public buildings and factories (Chinese Development Plan, 2022). RETs can be utilized in buildings for electricity generation, heating, cooling, and ventilation purposes. Various applications exist for the use of RETs in buildings. According to the Regulation on Energy Performance of Buildings, the concept of renewable energy refers to the energy obtained from non-fossil energy sources such as from hydraulic, wind, solar, geothermal, biomass, biogas, wave, tide, and current energy technologies.

Turkey is well positioned in terms of solar energy potential. According to the Turkey Solar Energy Potential Atlas (GEPA), which was created by the Ministry of Energy and Natural Resources (ETKB), the average annual total sunshine duration is 2741 h, and the average annual total radiation value is 1527.46 kWh/m^2. According to the Turkish Statistical Institute (TUIK) 2022 data, there are 11.6 million buildings in Turkey, and nearly 87% of these buildings are residential. According to the solar energy data from the Ministry of Energy and Natural Resources (ETKB), more than 100,000 new buildings are processed in Turkey's building statistics every year. The roofs and facades of buildings are seen as potential areas for solar energy investments. Additionally, the buildings mentioned in the Building Energy Performance Regulation (2022), such as hotels, hospitals, dormitories, and sports centers, with a floor area exceeding 2000 m^2, are also considered potential areas for solar energy utilization.

Access to provincial and geographical region-based information on wind energy potential in Turkey is available through the Turkey Wind Energy Potential Atlas (REPA). Wind energy can be utilized in buildings for active and passive systems to generate ventilation, cooling, and electricity [13]. Since 2001, countries such as the UK, Sweden, the Netherlands, and other developed nations have been promoting research and applications related to wind energy production in cities and high-rise buildings. These incentives help reduce the costs associated with long-distance electricity transmission and decrease investment expenses [14]. The rapid urbanization in China has led to the emergence of numerous buildings suitable for integrating small-scale wind turbines, thus prompting discussions on evaluating wind potential [15]. Despite the requirement of wind energy to be situated in open areas and away from urban environments, the proliferation of tall buildings in densely populated urban settings has created new opportunities [16]. Tall buildings spaced at regular intervals can harness and transmit wind energy over short distances. Wind energy has the potential to meet approximately 10% to 20% of the energy demand in high-rise buildings in cities, with urban wind energy systems mainly consisting of wind turbines typically ranging from 1 to 20 kW, and these are installed on buildings and adjacent lands [17].

Due to its geological and geographical location on an active tectonic belt, Turkey is among the rich countries in terms of geothermal resources globally. Throughout Turkey, there are approximately 1000 natural outlets of geothermal resources at various temperatures. According to ETKB, geothermal energy is primarily used for electricity generation, thermal facilities, and the heating of residential and greenhouse buildings. Geothermal energy can be employed in buildings for heating, cooling, and electricity generation. Geothermal heat pumps are used for heating and cooling in buildings [13]. Geothermal energy can be utilized in buildings through heat pump technology, which provides energy savings of 30–70% compared to traditional heating and cooling equipment [18]. The Chinese government particularly promotes the development of heat pump technology, especially in hospitals and schools.

According to the Biomass Energy Potential Atlas (BEPA) prepared by the Ministry of Energy and Natural Resources (ETKB) to determine biomass energy potential, the total economic energy equivalent of our collectible wastes is approximately 3.9 MTEP/year (BEPA, 2023; ETKB Biomass, 2023). With BEPA, the theoretical biomass potential and economic energy calculation module based on waste can be accessed through the website by city and district. In Turkey, biomass is defined under the scope of the "Law on the Use of Renewable Energy Sources for Electricity Generation Purposes" as follows: "Without being imported; municipal waste (including landfill gas), vegetable oil residues, agricultural residues without food and feed value, by-products derived from processing non-industrial wood forest products, waste tires, industrial waste sludges, and treatment plant sludges are defined as sources obtained as a result of processing other than industrial wood". Biomass energy is produced from organic materials such as vegetable residues or biomass types, and it can be used in buildings to generate heat or electricity [19]. Biomass boilers are utilized for heating and providing hot water in buildings [13]. Biomass energy, constituting approximately 10% of the global primary energy demand, represents a crucial renewable energy source [20]. Biomass-fired heaters can provide an economically viable solution for heating needs in buildings when combined with heat pumps. These heaters can effectively reduce dependency on the grid and heat pumps by meeting up to 65% of space heating demand [21].

In 2021, according to the ETKB, hydroelectric sources generated 55.5 billion kWh of electricity in Turkey. As of the end of May 2022, hydro-based electricity production reached approximately 35.2 billion kWh. Hydroelectric energy, which is collected from water sources, can be utilized to generate electricity in buildings [19]. There are other types of renewable energy tested in buildings, such as micro-hydro and hydrogen fuel cells. Micro-hydroelectric systems harness the energy of flowing water to power turbines and generate electricity, and they are often preferred by homeowners in remote areas. While the use of hydrogen energy in buildings is not yet widespread, it is being researched as a potential tool for decarbonizing heating and cooling in buildings. A common approach involves fuel cells that are capable of generating both electricity and heat for buildings [16].

2.2. Decision Making about Renewable Energy Technologies for Buildings

The building production is a process consisting of various stages where numerous decisions need to be made. The decision to use renewable energy technologies in buildings is one of the many decisions in the building production process; thus, it represents a technology selection. This decision is influenced by the decisions of the actors involved in the process. It is important for these actors to determine the technology to be used in the building based on certain criteria, and to examine technology alternatives according to these criteria in order to make selection decisions.

2.2.1. Actors Influencing the Building Production Process

The actors involved in the building production process have different perspectives and priorities during the decision-making stages of building production. Winch [22] describes project stakeholders as "those affected by the outcomes of the project, depicted as internal and external actors. Internal actors include property owners (employers), units dependent on property owners, users, financiers, design team (architect, engineer, consultant, specialist), project management, contractors, and subcontractors, material suppliers. External actors include local government, regulatory bodies, national government, boards and top supervisory organizations, civil society organizations, archaeologists, financiers, local residents, environmentalists". Kılıç [23] groups actors in the building production process as designers, managers, decision makers, founders and sellers, and users. Cooke et al. [10] determined the actors influencing the building design process as architects, building services engineers, customers, expert consultants, planners, project managers, technology suppliers, and contractors. The actors involved in the building production process, such as architects, employers, and users, influence the criteria for deciding on the use of RETs. The selection of renewable energy technology relates to the energy system decision for a building during the design phase. The use of RETs depends on the decisions of actors involved in building production when it is not mandatory at a national or global scale due to policies, laws, etc. Actors may have different motivations and can be influenced by various reasons to make this decision. For example, owners may seek financial profitability while architects may focus on environmental sustainability. In Turkey, the "Regulation Amending the Regulation on Energy Performance of Buildings", which was prepared by the Ministry of Environment, Urbanization and Climate Change and announced in the Official Gazette in 2022, mandates that a certain portion of energy consumption in buildings above a certain square meterage must be obtained from renewable energy sources [24]. However, clarity on how to select the appropriate technology has not been provided. While traditional energy systems and whether RETs should be used instead of the existing system are options, if RETs are to be used, they must also be diversified as alternatives. Actors evaluate both quantitative and qualitative factors in the technology selection decision-making stage and make decisions accordingly. Therefore, the problem-solving process requires a multi-criteria decision-making approach.

2.2.2. Criteria for Technology Selection

It is important to define the criteria affecting the decision process of the use of RETs in buildings. The favorable and unfavorable characteristics of RETs have become both obstacles and opportunities for the use of RETs, and they are instrumental criteria for decision making. The criteria that have an impact on the decision to use RETs vary all over the world, and they are specific to the site and situation [9]. National and global studies identify the categories of opportunities and barriers, as well as the criteria that influence the decision to use RETs in different contexts.

Every energy generation and transmission method affects the environment. Conventional energy generation options can damage the air, climate, water, soil, wildlife, and landscape, and they can also increase harmful radiation levels. RETs are significantly safer technologies that offer solutions to many environmental and social problems associated with fossil and nuclear fuels [25–27]. RETs have environmental benefits such as low carbon emissions, the absence of waste products, reduction in greenhouse gas emissions, the prevention of toxic gas emissions, land reclamation, reduction in necessary transmission lines of electricity networks, and the improvement of the quality of water resources; in addition, they include benefits from a socio-economic perspective, such as increased regional and national energy independence, significant job opportunities, diversification and security of energy supply, support for the deregulation of energy markets, and the acceleration of rural electrification in developing countries [27]. Cooke et al. [10] discussed the opportunities related to RETs under the headings of long-term economic benefits, availability of government support, image benefits, reducing environmental impacts, and corporate social responsibility. The main reasons for the use of RETs in buildings are financial criteria, personal factors (customer values, etc.), and supportive policy plans [10]. Maldonado and Marquez [28] stated renewable energy sources contribute to sustainable development but that some barriers cause their potential to be unrealized. Additionally, they identified four main categories of barriers to the use of renewable energy in Latin America: market, technological or R&D, institutional, and socio-economic. In a study, Weber [29] summarized the barriers as market, institutional, organizational, and behavioral barriers (i.e., professional conservatism, uncertainty, and risk). Painuly [30] proposed 40 sub-criteria within seven criteria (market deficiency, market problems, economic, institutional, technical, socio-cultural, behavioral, etc.). Within the framework of identifying and addressing the barriers to renewable energy use in developing countries, Kılıç [23] conducted a study on smart buildings and classified the barriers as technological, economic, legal, and behavioral (designers, managers, decision makers, builders/sellers, and users). Most of the studies on barriers discuss them as a technical and economic problems [31]. Gann [32] emphasized the lack of dissemination of new knowledge and poor adaptation of new approaches in the construction sector. Reddy and Painuly [31] addressed non-technological barriers to the utilization of RETs through wind and solar energy by interviewing various actors such as consumers, equipment manufacturers, energy developers, and policymakers. They identified the barriers as lack of awareness and knowledge, economic and financial constraints, technical risks, institutional and political barriers, market barriers/market failures, and behavioral barriers.

In their study on the factors affecting the use of renewable energy in the United Kingdom, Foxon et al. [33] discussed the subcategories of R&D, demand for products, information exchange between actors, and economic conditions. According to Tsoutsos, Frantzeskaki, and Gekas [27], it is important to analyze the environmental impacts of these technologies, which are environmentally friendly, to make them common. In addition, measures such as rationing water use for cleaning solar panels, waste disposal practices, and the use of biodegradable chemicals should be taken into account to eliminate possible negative impacts. Wall et al. [34] saw system cost as an overall problem. A general lack of awareness and knowledge about RETs, a general reluctance among construction professionals to use "new" technologies, and the limitations due to architectural and aesthetic concerns are seen as barriers to the use of these systems. It is known that the use of RETs has an impact on the architecture and aesthetics of a building. Systems such as photovoltaic panels occupy large areas and affect building aesthetics. Margolis and Zuboy [35] reported that barriers included the lack of government policy, lack of information dissemination and consumer awareness, high cost, inadequate financing, inadequate labor skills and training, lack of standards and guidelines, poor public perception of renewable energy system aesthetics, and the lack of actor and community participation in energy choices and RET projects. Cooke et al. [10] considered the barriers social and economic criteria, such as high initial investment cost, duration of investment return, lack of information, perception of risk, unsuitable area, perception that RETs have not proven themselves, and inconsistent policies and planning. Wall et al. [34] defined the architectural criteria for solar energy technologies as product diversity, manufacturer knowledge of architecture, architect knowledge of the possibilities offered by existing technologies and innovative products, and whether architects have the tools to make quantitative measurements when making overall design decisions in the early design phase. Wall et al. [34] said the criteria for architectural integration of solar technologies were personal interest, employer's interest, economic viability, government incentives, knowledge about incentives, confidence in technologies, knowledge of the architect/employer/consultant, availability of architectural integration literature, useful guidelines for architects, suitability of products, simple components, the appearance of products, tools to support design, acceptance of technology, time and resources, and climatic conditions. Appendix B contains the criteria that are effective in the use of renewable energy technologies, as derived from the studies reviewed in the literature [9,10,14,27–38].

3. Materials and Methods

Within the scope of this study, which examined the increase in use of RETs in buildings in Turkey, a decision-making model was developed to determine the appropriate option for the need and purpose in cases with many participants and options. This paper utilized a literature review, expert group interviews, and the analytic hierarchy process (AHP) method in the study, and the detailed description of the study process can be found in Table 1.

Table 1. Research methodology.

Step 1 **Literature review**	**Step 2** **Expert Group Interview**
• Research question How can the utilization of renewable energy technologies (RETs) in buildings be increased in Turkey? • Research objectives: This research aims to investigate how the decision-making process regarding the use of renewable energy technologies (RETs) in buildings in Turkey can be conducted by examining the RETs in Turkish buildings. This is achieved by analyzing the relevant policies, regulations, and strategic plans, as well as by exploring the perspectives of stakeholders in the sector and identifying usage criteria.	Situation analysis: The current status of renewable energy technologies (RETs) in Turkey. The strengths and weaknesses of RETs in Turkey. The barriers and opportunities for the utilization of RETs in Turkey. Stakeholder perspectives: The perspectives of stakeholders on RETs in Turkey. Usage criteria: The criteria for the utilization of RETs in Turkey.

Table 1. *Cont.*

Step 3 **The selection of the method to be used for the model**	
AHP Model	
Model Establishment Process 1. Determination of the hierarchical structure; 2. Development of comparison matrices; 3. Consistency assessment; 4. Data evaluation.	
Step 4 **Analysis**	
Findings	Interpretations

In this model, the analytic hierarchy process (AHP) method [36–38], one of the multi-criteria decision-making methods, was used both for the compatibility of the decision-making process, for defining the criteria, finding the weight of the criteria, and creating the hierarchical structure (decision matrix). The criteria were determined by conducting expert group discussions. In other words, two methods were used within the scope of the model. In the first method, expert group interviews with experts were conducted in two stages. In the first stage of these interviews, open-ended questions were asked to the experts in line with the information obtained from the literature review, and the criteria and sub-criteria to be used in the model were revealed. Within the scope of the second method, i.e., AHP, the hierarchical structure was determined in the 1st stage. As a first step, the system elements consisting of the objective, criteria, sub-criteria, and technological options were sorted in a hierarchical order, with the objective at the top and the options at the bottom. In the 2nd stage of the main criteria (the second stage of the expert group interviews), sub-criteria and options were compared pairwise, and their importance levels were found. These comparisons were carried out by interviewing the expert group for the second time. In the 3rd stage, the consistency ratio of the values was calculated using Excel 2016 to understand the reliability of the results, which were obtained from pairwise comparisons. In the 4th stage, the most-effective criteria for technology selection were found, and the most-appropriate technologies were determined.

3.1. Expert Group Interview

The purpose of expert consultations was to delineate the general framework of utilizing renewable energy technologies in buildings in Turkey and to gather general opinions from RET experts and practitioners to determine selection criteria. The method of expert group discussion is important due to the involvement of multiple actors in the building production process and the influence of their perspectives on the process. The first stage of this study, i.e., the literature review, led to the identification of the following areas of inquiry:

1. Are renewable energy technologies currently being utilized in buildings in Turkey? To what extent is the adoption of these technologies prevalent?
2. Which actors are advocating for or against the incorporation of renewable energy technologies in the building production process, and what are the underlying reasons for their preferences or hesitations?
3. What are the existing barriers and opportunities concerning the integration of renewable energy technologies in buildings in Turkey? Additionally, what are the essential decision-making criteria for the implementation of these technologies?
4. How does the decision-making process unfold regarding the utilization of RETs in buildings?

The actors (expert group) in the building production process to be interviewed within the scope of expert group in-depth interviews were grouped as architects, investors (employers), engineers, consultants, RET system manufacturers/companies, and users (Table 2). The term 'users' refers to the building occupants who are the operational staff using the buildings where RET application is implemented. Listed professionals were chosen based on their experiences with renewable energy technologies in the pre-construction, construction, and post-construction phases of the building production process. These professionals have a minimum of 20 years of experience in the industry. They are individuals who have been involved in designing renewable energy technologies during the building design process, as well as those who have implemented technologies during the construction phase, managed building operations during the use phase, and who were directly involved in the production of technologies within their respective companies. As a result, the conclusions drawn from the literature review can be specifically rationalized and elaborated upon regarding the utilization of RETs in Turkey, thereby enabling a detailed exposition of the Turkish context. Semi-structured, in-depth interviews were conducted by convening participants around a table. At the beginning of the interviews, a brief explanation of the research and its objectives was provided to the participants. Following verbal consent, the participants were presented with the open-ended questionnaire listed above.

Table 2. The actors (expert group) in the building production process that were interviewed within the scope of the expert group in-depth interviews.

	Profession	Company	Role in RET System
1	Architect—A1	Private	Design
2	Architect—A2	Public	Design
3	Engineer—Mechanical Engineer	Private	Design–Implementation
4	Engineer—Electrical Electronic Engineer	Private	Design–Implementation
5	Investor—I1	Public (Municipality)	Design–Implementation–Use
6	Investor—I2	Private	Design–Implementation–Use
7	Consultant—C1	Private	Design–Implementation
8	Consultant—C2	Private	Design–Implementation
9	RET Company—RET1	Private	Design–Implementation
10	RET Company—RET2	Private	Design–Implementation
11	User—U1	Private	Use
12	User—U2	Private	Use

Interview Findings

During the interviews, the focus was placed on the status of the RETs in the building in Turkey, and national standards and regulations were outlined through criteria to understand the progress in the utilization of RETs in the buildings. Based on the findings of the interviews, a comprehensive evaluation of RETs, barriers/opportunities, factors influencing usage by actors, and usage criteria based on building functions were investigated. This study revealed the challenges and opportunities regarding the utilization of RETs in Turkey. From the interviews, it was concluded that RETs are being used in buildings in Turkey, but its usage has not yet become widespread. According to the Ministry of Environment and Urbanization's Strategic Plan for 2022–2023, out of the1,329,566 buildings in Turkey that obtained an energy performance certificate, renewable energy was used in only 63,957 buildings [6]. Both the expert opinions and data from the Ministry of Environment and Urbanization support the conclusion that the usage of RETs has not yet become widespread.

The results of the expert consultation regarding the influential criteria for deciding on the implementation of RETs in buildings are presented in Appendix C (The criteria/opportunities influencing the decision to implement RETs in buildings). The criteria/barriers that are effective in the utilization of RETs in buildings, which were obtained from the findings achieved from the interviews with experts, are listed in Appendix D.

According to the experts interviewed within the scope of the expert group, the reasons architects, customers, and users prefer RETs in buildings are due to environmental concerns, economic benefits, and the effect of RETs on ongoing costs, respectively. The most-effective criterion in applications of RETs was found in observing previous results. If architectural offices had experience in RETs, the application rates increased. One of the most-important criteria for preferring RETs is geographical conditions. The experts in the expert group interview stated that, especially for wind energy, some regions in Turkey are suitable in terms of geographical conditions, while some do not affect the use of RETs. In addition, the fact that solar energy is suitable for use throughout Turkey, although its efficiency rate varies, causes this technology to be used more often. Laws and regulations and long application and approval processes negatively affect the use of these technologies, especially wind energy. The procedure for using solar energy in Turkey is simple, which is one of the factors why this technology is preferred. In the expert group interviews, the practitioners stated that, in buildings where RETs are used, the suggestion of using RETs was mostly not suggested by architects. Moreover, the applications related to solar energy were mostly in industrial buildings or detached houses, and this technology cannot be realized in collective housing projects due to procedural restrictions. An important point emerging from the interviews was the changing actors throughout the building production process, including the design, construction, use, and demolition stages, as well as the varying impacts on stakeholders in terms of costs and benefits. For example, while solar panels may represent an unnecessary investment cost for investors, they may signify a cost-saving opportunity for users in terms of ongoing expenses; yet, they are also obsolete electronic waste for society during the demolition stage. Consequently, a system can have different effects during the construction, use, and demolition/recycling stages. This necessitates the comprehensive evaluation of all potential impacts from both process and stakeholder perspectives, as well as the incorporation of such analyses into the design phase. Unforeseen errors in the construction sector can lead to irreversible damage.

One of the most-significant factors influencing the preference for the adoption or non-adoption of systems when they are not mandatory is the construction and operation models. While not preferred in the build–operate–transfer model, they may be favored in structures where the builder and operator are the same. According to the experts, RETs are generally preferred when the investor, constructor, and person covering the costs during the usage phase are the same (e.g., public buildings, factories, etc.). However, in housing projects where the user is not identified during the construction phase, they are generally not preferred. Another reason for the preference for RETs is the amount of the operating costs. This is especially the case for large structures with high energy requirements (such as factories, stadiums, hotels, etc.), as if the operation is determined in advance, RETs are requested during the design phase.

In the scope of the focus group, the reasons for architect preferences in buildings where RETs are implemented were found to be environmental concerns, while customer preferences were found to be driven by economic benefits, and user preferences were influenced by ongoing costs. Architects generally prefer solar energy due to the variety of products, ease of application, simplicity of procedures, and its established use. The most-effective criterion in applications is the previous observation of results. The rates of implementation increase if architecture firms have previous experience with RET applications. One of the most-important criteria in choosing RETs is also geographical conditions.

According to the interview results, the decision-making process does not progress systematically; rather, it arises when there is a demand from an actor, particularly in the absence of a mandate. Due to the high operational costs in factory buildings, employers may request solar and wind energy. Engineers and consultants implementing biomass energy in agricultural, livestock, and food production facilities have indicated that biomass energy is used due to the disposal issues of waste, as well as due to the fact that these wastes can serve as valuable raw materials. This enables both waste disposal and electricity generation. This demonstrates that the building function influences the choice of technology. As the use of RETs has been increasing as of 2023, applications can result in negative outcomes. Infrastructure constraints such as technical inadequacies in networks are also present with increasing demand. Additionally, an issue that was highlighted by experts was the odor problem in some biomass systems.

3.2. Decision on the Methodology for the Model

To propose a model for the use of renewable energy technologies in buildings, the key questions of who the decision makers are and how the process is related to RET decisions operations was clearly defined through a literature review and expert consultations. The construction sector is characterized by complex, large-budget, and project-based endeavors involving various professional groups and functions. Each project is unique, with a complex process and numerous actors (decision makers) being involved. An important question is what is required for a certain technology or system to be used in buildings. For RETs to be used in buildings, there must be a demand for them. At this point, a crucial aspect of building production is who made the demand and whether it is mandatory. If it is not mandatory, the question of what is needed for it to be preferred by any actor was asked of the decision makers involved in the building production process via in-depth interviews, and this led to the establishment of certain criteria. In the decision-making process, it is necessary to assess the benefits provided by any system or to select one from among the options. Generally, the primary task of evaluation is to select the options that serve the defined purpose and to objectively compare these options with each other. In architecture, the task of evaluation is defined as consciously determining the mutual interactions of the value systems of groups such as property owners and users that contribute to the formation of an architectural product, and this is performed in order to achieve the optimal solution. Various methods and techniques are used for architectural evaluations based on scientific principles. These methods are generally classified into three groups: benefit-based methods, cost-based methods, and multi-criteria decision-making methods [39].

Decision making is a key factor in achieving success in areas such as the construction sector, which involves handling large amounts of information and experience. Since most construction processes involve numerous factors that need to be considered, decision making in such environments often becomes a challenging problem to overcome. At this point, there is a need for a system that can help solve such complex scenarios. Multi-criteria decision-making methods (MCDMs) have emerged as a system to facilitate the resolution of these problems; in subsequent periods, different MCDM methods were developed under different conditions and application areas.

Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP), developed by Thomas L. Saaty in 1977, is one of the most widely used multi-criteria decision-making methods due to its ease of implementation [36–38]. It is commonly preferred by decision-making groups in solving complex problems. The method is used in multi-criteria decision-making situations, i.e., when there are many options and decision makers. In situations requiring decision making, it is important to incorporate the opinions of influential actors into the decision-making process. With AHP, both the subjective and objective thoughts of actors can be included in the process. AHP is based on the principle of combining decision-maker knowledge, experience, and intuitions in a logical framework. Instead of forcing individuals to use a method to make decisions, AHP allows them to recognize their own decision-making mechanisms, thereby facilitating better decision making [36].

In decision-making processes involving multiple criteria, such as the selection of what RETs to use, weightings, importance, or superiority calculations should be made for the many criteria to choose one of the possible technologies. AHP is based on structuring decision problems at different hierarchical levels such as objectives, main criteria, sub-criteria, and alternatives. The application of the method relies on establishing a managerial decision mechanism by assigning relative importance values to decision alternatives and criteria. The decision process is organized by decomposing a complex multi-criteria decision problem into a hierarchical structure. The AHP method, which involves pairwise comparisons at each level, is used to evaluate independent factors within different hierarchical structures. To determine the priorities of actors using the AHP method, pairwise comparisons are made using a comparison scale. The main criteria are compared to each other, the sub-criteria are compared to the main criteria, and, finally, the alternatives are compared to each sub-criteria. The next step involves calculating the eigenvalues and eigenvectors of pairwise comparison matrices to determine and rank the weights of the criteria and alternatives. In this system, numerical performance measurements performed systematically are combined with subjective perceptions to reach a conclusion.

3.3. Establishing the AHP Model

A decision-making process seeks to achieve the most-suitable solution to a problem under the most-appropriate conditions through the use of a model. Otherwise, implementing the real system can be disadvantageous both in terms of cost and time. The modeling approach focuses on identifying the important components and their relationships rather than addressing all the details of the real situation.

In the establishment of the analytic hierarchy process (AHP) model, advanced mathematical knowledge is not required, and both concrete and abstract criteria can be considered together. This eliminates the need for assumptions. During the decision-making process, decision makers reflect their own ideas and evaluations onto the model, and the results are generated based on mutual decisions, which are accepted by the actors involved in the decision process. Consequently, the likelihood of implementing the results increases [40].

The establishment of the AHP model consists of four steps, as explained in Figure 1. Initially, the related elements of the problem (criteria and alternatives) are organized hierarchically. Then, pairwise comparisons are made among the decision elements, and these verbal expressions are quantified using a ratio scale. Subsequently, a consistency ratio (CR) is calculated for each matrix to assess the consistency of the experts' judgments. Finally, the relative weights of the defined decision elements are calculated, and these weights are totaled up to carry out the decision-making process.

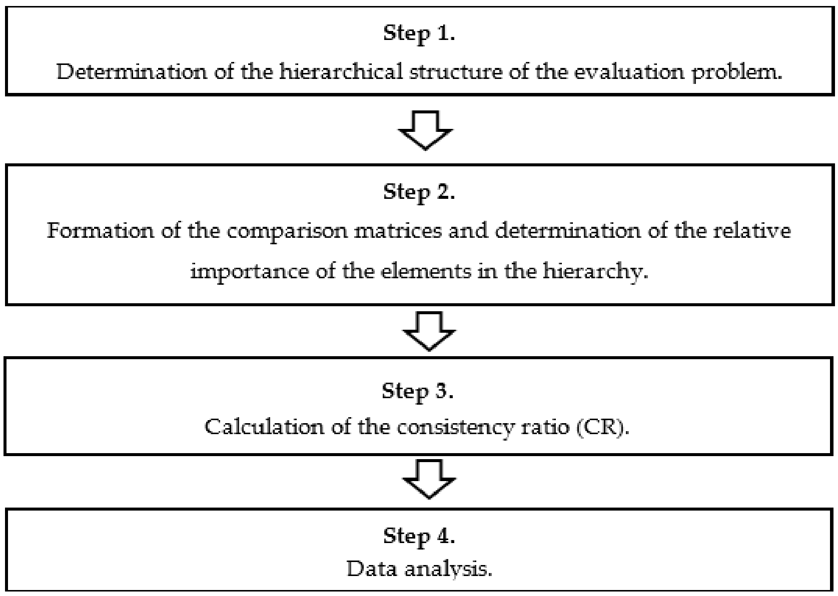

Figure 1. The establishment of the AHP model.

3.3.1. Determination of the Hierarchical Structure of the Evaluation Problem (Step 1)

The first step in using the AHP method is to arrange the system elements, which consist of the goals, criteria, sub-criteria, and alternatives in a hierarchical order, with the goal at the top and alternatives at the bottom, as shown in Figure 2 [38]. General characteristics are placed at the top level of the hierarchy, while specific elements are positioned at lower levels. A consistent and well-structured hierarchical system is flexible in response to minor interventions, as small changes do not significantly impact overall performance.

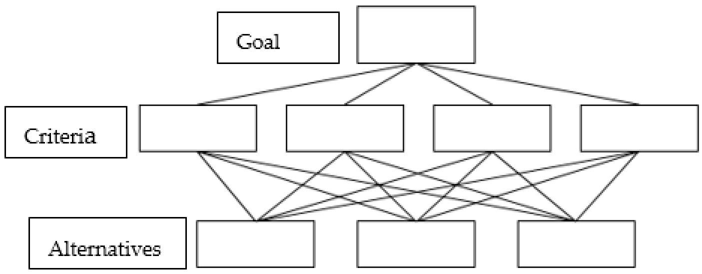

Figure 2. Hierarchical structure.

In the scope of the AHP method, the data obtained from literature reviews and expert group interviews were used to define the criteria and sub-criteria that are effective in making decisions about technologies in the first stage of establishing the hierarchical structure. As shown in Table 3, the criteria effective in decision making regarding technologies have been identified as technic–technological R&D, economic, socio-cultural, environmental, institutional/political, time, and aesthetic criteria (along with their respective sub-criteria).

Table 3. The main criteria and sub-criteria for the use of renewable energy technologies.

Main Criteria	Sub-Criteria
Technical/ technological R&D	1. Ease of implementation 2. Knowledge and experience 3. Fault detection and intervention/probability and frequency of faults/ease of maintenance 4. System lifespan and warranty 5. Production volume/time, product diversity, and logistics
Economic	1. Initial investment cost 2. Return-on-investment period 3. Impact on ongoing costs during usage 4. Maintenance and repair costs during usage 5. Incentives and credits
Socio-cultural	1. Stakeholder interest/knowledge/experience 2. Social values/stakeholder perception of values 3. Image benefits 4. Social responsibility 5. Acceptance of innovations
Environmental	1. Climate conditions/geographical advantages/energy potential in the region 2. Management of energy demand 3. Environmentally friendly energy production/nature-friendly technologies 4. Recyclability of the system 5. Combatting climate change/ecological values
Institutional/ political	1. Bank loans 2. Energy pricing 3. Changes in energy demand/increasing energy demand 4. Government policies/supports and incentives 5. Global agreements 6. Indigenousness and not causing current account deficit 7. Local regulations

Table 3. *Cont.*

Main Criteria	Sub-Criteria
Aesthetic	1. Positioning (roof–facade) 2. Visual impact/aesthetic 3. Integration into the building 4. Ability to integrate with design/standard/special production
Time	

The hierarchical structure comprising the main criteria, sub-criteria, and the renewable energy technology alternatives used/usable in buildings in Turkey was established, as illustrated in Figure 3.

3.3.2. Formation of the Comparison Matrices and Determination of the Relative Importance of Elements in the Hierarchy (Step 2)

The hierarchical structure consists of elements at different levels. At the top level, there is the goal, which is followed by the main criteria at a lower level, and then the sub-criteria under the main criteria. At the lowest level, there are alternatives. Binary comparison matrices are created for each level of elements with respect to the goal. The main criteria are compared based on the main goal, the sub-criteria are compared based on the main criteria, and the alternatives are compared based on the sub/main criteria. Binary comparisons involve first comparing the main criteria, then each sub-criteria within each main criterion, and finally considering all the criteria to compare the alternatives. As a result, 38 binary comparison matrices were obtained by comparing each main dimension with the others, the same process was then repeated for the sub-criteria compared to their main criteria, and the different alternatives were finally compared for each sub-criterion. All binary comparison matrices related to the model are provided in the Supplementary Materials. For the implementation of the comparison matrices, a second meeting was held with the research team, consisting of architects, engineers, and renewable energy technology experts who were all consulted within the scope of this study. The focus group data collection technique was used as the data collection method. The authors served as the moderators and report writers during the focus group discussions. It was important for team members to share their past experiences, opinions, and knowledge. The binary comparison matrices were compared by experts using the nine-point Saaty scale (in relative importance scale), which was developed by Saaty [41] (Table 4).

The scale used in decision making should be statistically and intuitively meaningful. The relative importance scale is the fundamental scale of the AHP as it allows for binary comparisons to be made qualitatively or quantitatively. The relative importance scale describes the definitions of values from 1 to 9 [41]. While comparisons for quantitatively measurable criteria can be easily made, the definitions of values should be shared with the decision makers for the qualitative criteria [42]. If the decision maker cannot determine the degree of importance between two elements being compared, the two elements are considered equally important and the importance degree is marked as 1. If one of the two elements is significantly more important than the other, the marked importance degree is 9. When arranging binary comparison matrices for all elements, the matrix to be created is of size nxn for an "n" criteria goal. The value of comparing an element with itself is placed as 1 on the diagonal corners of the matrix. When two elements are compared, the importance of the criteria is first determined; then, the degree of importance is examined.

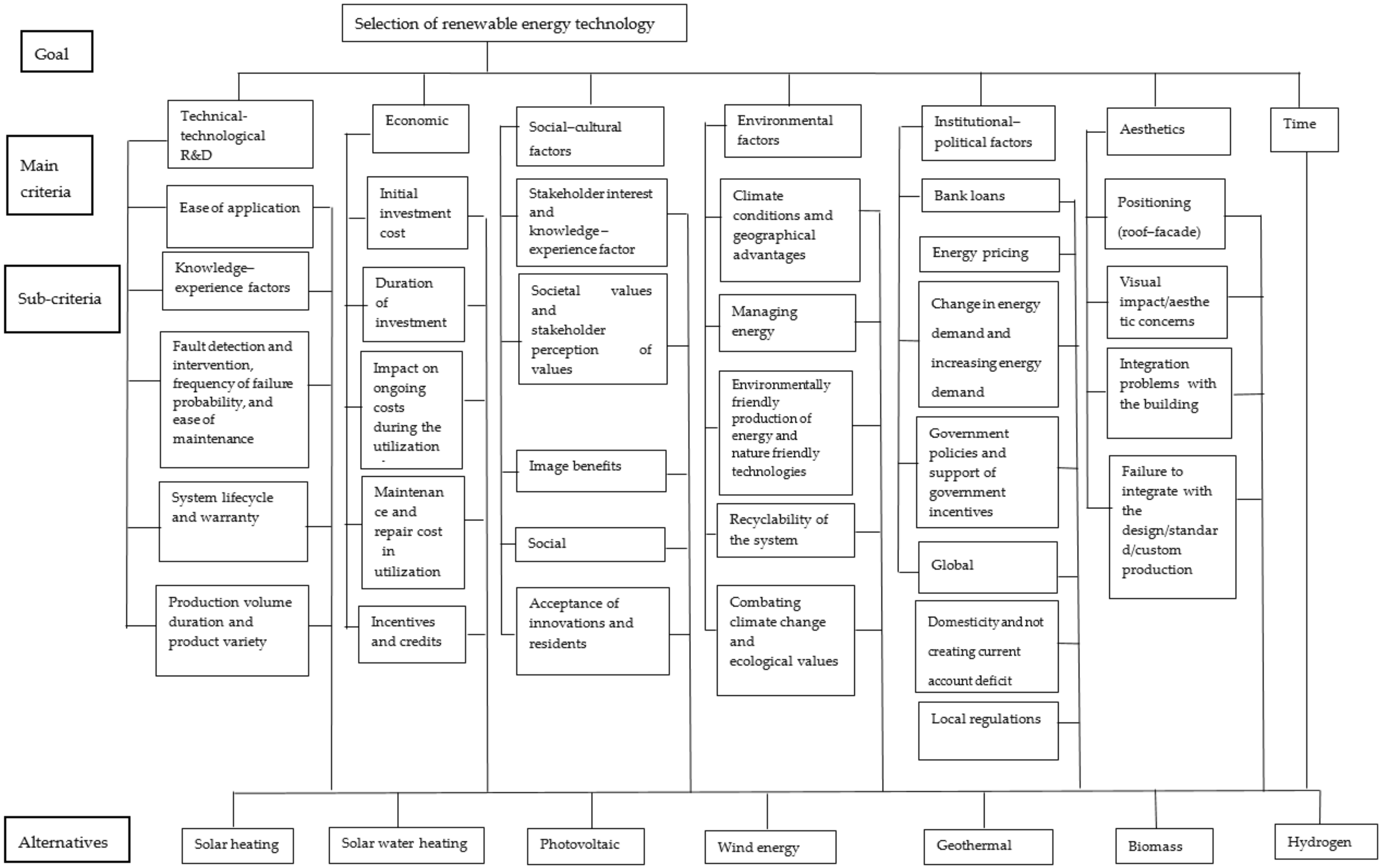

Figure 3. The hierarchical structure.

Table 4. The Saaty scale.

Degree of Importance	Definition
1	Equally important
3-1/3	Moderately more/less important
5-1/5	Considerably more/less important
7-1/7	Absolutely more/less important
9-1/9	Extremely more/less important
2-1/2, 4-1/4, 6-1/6, 8-1/8	Intermediate values

Initially, binary comparisons of the main criteria were made, which was followed by sub-criteria, and, then, comparisons of the alternatives were made for all the criteria. The general representation of the binary comparison matrix is shown in Figure 4 [42].

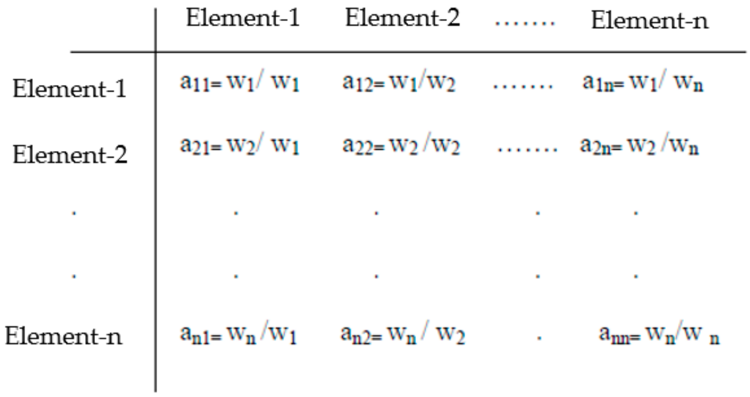

Figure 4. Binary comparison matrix.

In the AHP method, the number of elements in the comparisons should be small. For consistency, the number of elements in the comparisons was taken as seven (±2).

An example of the binary comparison matrix of the main criteria, which is one of the pairwise comparison matrices made within the scope of this study, is illustrated in Table 5 below. The number 7 assigned to the economy criterion in the second row and the aesthetic criterion in the last column of the main criteria's binary comparison matrix indicates that, according to Saaty's relative importance scale, the economy criterion is significantly (7 times) more important than the aesthetic criterion. Similarly, the number 1 assigned to the aesthetic criterion in the last column and the time criterion in the fifth row indicates that the aesthetic criterion and the time criterion were equally important.

In the AHP method, the next step after creating pairwise comparison matrices is to calculate the eigenvalues and eigenvectors of the matrices to determine and rank the weights of the different sub-criteria and alternatives. According to Saaty, the steps for computing the exact priorities involve raising the matrix to a large power, summing the matrix across rows, and finally dividing each entry by the sum of all entries in each row to normalize the weights. The best method, which provides the most-accurate results, is used to determine the priority vectors. In this method, the elements (n in total) in each row of the pairwise comparison matrix are multiplied with each other, and then the nth root is taken. The resulting values are normalized. This process is essentially finding the geometric mean [42].

Upon examining the eigenvector values shown in Table 6, which belong to the comparison of the main criteria, it is evident that the economy criterion has the highest value. This indicates that it is the most-influential criterion in decision making. The ranking of relative importance values in the figure somewhat represents the ranking of criteria importance. The technical–technological R&D criterion follows in second place, while the other criteria have values that can be mathematically neglected.

Table 5. Binary comparison matrix of the main criteria.

	Technical/Technological/ R&D	Economic	Socio-Cultural	Environmental	Institutional/ Political	Time	Aesthetic
Technical/technological/ R&D		1/9	6	2	6	6	5
Economic			7	7	5	9	7
Socio-cultural				1	2	4	3
Environmental					2	9	3
Institutional/ political						9	3
Time							1
Aesthetic							

Table 6. Computing the exact priorities.

		Technical/Technological/ R&D	Economic	Socio-Cultural	Environmental	Institutional/ Political	Time	Aesthetic	Row sum	Eigenvector
Technical/technological/ R&D		1	0.1111111	6	2	6	6	5		
Economic		9	1	7	7	5	9	7		
Socio-cultural		0.16667	0.1428571	1	1	2	4	3		
Environmental		0.5	0.1428571	1	1	2	9	3		
Institutional/ political		0.16667	0.2	0.5	0.5	1	9	3		
Time		0.16667	0.1111111	0.25	0.11111	0.1111111	1	1		
Aesthetic		0.2	0.14285714	0.333333	0.33333	0.3333333	1	1		
Square matrix		7	3.946032	20.944	16.111	30.88889	114	58.7778	192.89	0.211403
		26.4	7	82.083	44.833	95.33333	215	125	470.65	0.51582
		3.719	1.720106	7	5.7778	9.15873	40.2857	20.8333	67.661	0.074155
		4.8857	2.312698	10.25	7	11.71429	47.2857	27.5	83.448	0.091457
		4.5667	1.989947	7.15	5.2333	7	30.3	20.2333	56.24	0.061638
		1.6491	0.457407	2.7778	1.9722	2.833333	7	5.02778	16.69	0.018292
		2.1302	0.580952	3.6167	2.6778	4.025397	11.819	7	24.85	0.027235
									912.43	

3.3.3. Calculation of Consistency Ratio (CR) (Step 3)

To evaluate the consistency of the experts' judgments and to understand the reliability of the results obtained from pairwise comparisons, a consistency ratio (CR) needs to be calculated for each pairwise comparison matrix. For an acceptable level of consistency, the CR value should be less than 0.10. If the ratio is greater than 0.10, it indicates that the decision makers have provided inconsistent judgments. The inconsistency ratio is obtained by multiplying the comparison matrix with the relative importance vector from the right. The first element of the resulting vector is divided by the first element of the relative importance vector, the second element by the second element, etc., until a new vector is obtained. The sum of the elements of this new vector is divided by the number of elements to obtain an approximate value for the largest eigenvalue (max λ), which is crucial for assessing the consistency of the judgments. For the pairwise comparison matrix to be consistent, the largest eigenvalue (max λ) of the matrix should be equal to the number of elements (n) involved in creating the matrix. In other words, in a consistent scenario, n = max λ, and the deviation from consistency is called the consistency index (CI). The consistency index (CI) is compared to the random index (RI) to calculate the inconsistency ratio (IR). In a sense, IR = RI/CI. Here, the random index (RI) represents the average values of the pairwise comparison matrices that are randomly derived based on the number (n). The random index values prepared for matrices of size 1–15 are shown in Table 7 [43]. CR is given by CI/RI, where λmax is the maximum eigenvalue and n is the size of the matrix. RI represents a random index depending on n [44].

Table 7. Random index (RI) values.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45

The overall weights of the alternatives are obtained by multiplying their priorities with the priorities of sub-criteria and dimensions, as well as by, finally, summing up the values obtained for each alternative.

3.3.4. Data Analysis (Step 4)

The most-effective criteria determined for the decision to use RETs were as follows: initial investment cost, ease of implementation, production volume duration, product variety and logistics, incentives and credits, return-on-investment period, system lifespan and warranty, fault detection and intervention, fault probability, maintenance ease, knowledge and experience, maintenance and repair costs during use, and ongoing costs during usage.

The technologies were compared based on criteria, and photovoltaic was selected as the best technology. Meanwhile, other effective technologies included solar water heating + solar heating, wind, geothermal, biomass, and hydrogen.

To evaluate the data obtained from the experts' opinions, the following steps were followed:

- The total value and average value were calculated for each criterion;
- The elements in the pairwise comparison matrix were divided by the sum of the column to obtain a normalized matrix;
- Then, the arithmetic mean of the values in the column after the normalization of the matrix was calculated. The obtained value provided the relative importance coefficient for the respective criterion;
- The consistency ratio was calculated to understand the reliability of the calculated relative importance coefficients (Table 6 and Figures 5 and 6).

	Ease of implementation	Knowledge-experience	Fault detection and intervention, Frequency of failure probability, Ease of maintenance	System lifecycle and warranty	Production volume duration, Product variety	Initial investment cost	Duration of investment return	Impact on ongoing costs during the utilization phase	Maintenance and repair cost in utilization	Incentives and credits		Total
	0.599296239	0.04029519	0.086772719	0.098648681	0.174987172	0.690763971	0.112375642	0.023582258	0.025278396	0.147999733	2	
Global weight	0.126693023	0.00851852	0.018344013	0.020854627	0.036992813	0.356310148	0.057965649	0.01216421	0.013039112	0.076341282	0.727223	
Solar heating	0.215664081	0.02563229	0.189893201	0.142857143	0.073321472	0.247443308	0.142857143	0.142857143	0.142857143	0.142857143		0.147670228
Solar water heating	0.215664081	0.04256632	0.189893201	0.142857143	0.073321472	0.247443308	0.142857143	0.142857143	0.142857143	0.142857143		0.147814481
Photovoltaic	0.215664081	0.02201640	0.189893201	0.142857143	0.248618785	0.247443308	0.142857143	0.142857143	0.142857143	0.142857143		0.154124166
Wind-powered	0.215664081	0.07833983	0.189893201	0.142857143	0.248618785	0.095375722	0.142857143	0.142857143	0.142857143	0.142857143		0.100420735
Geothermal	0.086409188	0.14714662	0.189893201	0.142857143	0.248618785	0,095375722	0.142857143	0.142857143	0.142857143	0.142857143		0.084631174
Biomass	0.030809154	0.26030608	0.032352175	0.142857143	0.059837063	0.044686527	0.142857143	0.142857143	0.142857143	0.142857143		0.050616413
Hydrogen	0.020125335	0.42399246	0.018181818	0.142857143	0.047663638	0.022232103	0.142857143	0.142857143	0.142857143	0.142857143		0.041946204
												0.727223400

Figure 5. The global weights of the technologies based on the criteria.

	Ease of implementation	Knowledge-experience	Fault detection and intervention, Frequency of failure probability, Ease of maintenance	System lifecycle and warranty	Production volume duration, Product variety	Initial investment cost	Duration of investment return	Impact on ongoing costs during the utilization phase	Maintenance and repair cost in utilization	Incentives and credits		Total
	0.599296239	0.04029519	0.086772719	0.098648681	0.174987172	0.690763971	0.112375642	0.023582258	0.025278396	0.147999733	2	
Normalized weight	0.29964812	0.02014759	0.043386360	0.049324341	0.087493586	0.345381986	0.056187821	0.011791129	0.012639198	0.073999867	1	
Solar heating	0.215664081	0,02563229	0.189893201	0.142857143	0.073321472	0.247443308	0.142857143	0.142857143	0.142857143	0.142857143		0.194390782
Solar water heating	0.215664081	0.04256632	0.189893201	0.142857143	0.073321472	0.247443308	0.142857143	0.142857143	0.142857143	0.142857143		0.194731962
Photovoltaic	0.215664081	0.0220164	0.189893201	0.142857143	0.248618785	0.247443308	0.142857143	0.142857143	0.142857143	0.142857143		0.209655321
Wind-powered	0.215664081	0.07833983	0.189893201	0.142857143	0.248618785	0,095375722	0.142857143	0.142857143	0.142857143	0.142857143		0.158268698
Geothermal	0.086409188	0.14714662	0.189893201	0.142857143	0.248618785	0.095375722	0.142857143	0.142857143	0.142857143	0.142857143		0.120924003
Biomass	0.030809154	0.26030608	0.032352175	0.142857143	0.059837063	0.044686527	0.142857143	0.142857143	0.142857143	0.142857143		0.065683992
Hydrogen	0.020125335	0.42399246	0.018181818	0.142857143	0.047663638	0.022232103	0.142857143	0.142857143	0.142857143	0.142857143		0.056345242
												1

Figure 6. The normalized weights of the technologies based on the criteria.

Synthesis of the Data Using Global Weighting Method

The importance coefficients of the criteria were calculated through pairwise comparisons using the analytic hierarchy process (AHP) method based on the data obtained from the survey. Additionally, the weights of each sub-criterion were determined through sample analysis. The data were integrated in Excel to create the model, as illustrated in Figure 5.

In the context of the model solution, in terms of the percentage ranking of the main criteria, the economy criterion emerged as the most-important main criterion with 51.58%, which was followed by the technical–technological R&D criterion with 21.14% as the second-most important criterion. The rankings of the other main criteria were as follows: environmental impact 9.14%, socio-cultural 7.41%, institutional–political 6.16%, aesthetic 2.72%, and time 1.82%.

When examining the sub-criteria of the main criteria, the most-important sub-criteria were as follows: first investment cost with a value of 0.345381986, ease of implementation (0.29964812), production volume duration product diversity (0.087493586), incentives and credits (0.073999867), duration of investment return (0.056187821), system lifespan and warranty (0.049324341), fault detection intervention fault probability maintenance ease (0.043386360), knowledge experience (0.02014759), maintenance repair cost in utilization (0.012639198), and impact on ongoing costs during uutilization phase (0.011791129).

In the model solution, among the alternative renewable energy technologies, photovoltaic technology was ranked first with a value of 0.209655321, thus indicating it was the best technology. The ranking of the alternative renewable energy technologies was as follows: solar water heating (0.194731962), solar heating (0.194390782), wind (0.158268698), geothermal (0.120924003), biomass (0.065683992), and hydrogen (0.056345242).

When the sub-criteria of the economic criterion were compared in pairs

The initial investment cost was seen as the most-important criterion, and this was followed by incentives and credits and then the duration of investment return. The impact on the ongoing costs during the usage and maintenance repair costs when being used were found to be the least effective in decision making.

When the sub-criteria of the technical–technological R&D criterion were compared in pairs

Ease of application is seen as the most-important criterion, followed by production volume duration and product variety/logistics. Fault detection/intervention/probability, system life and warranty, knowledge and experience criteria may be considered ineffective in decision making.

Comparison of the RETs with the sub-criteria of the economic criterion

Comparison of the RETs according to the initial investment cost sub-criterion

Solar heating, solar water heating, and photovoltaic were the most-preferred technologies, which was followed by wind + geothermal, biomass, and hydrogen.

Comparison of the RETs according to the duration of investment return sub-criterion

The return-on-investment period sub-criterion did not affect the technology decisions.

Comparison of the RETs according to the impact on ongoing costs during the utilization phase sub-criterion

The impact on the ongoing costs during usage sub-criterion did not affect the technology decisions.

Comparison of the RETs according to the incentives and credits sub-criterion

The incentives and credits sub-criterion did not affect the technology decisions.

Comparison of the RETs according to the maintenance repair costs during usage sub-criterion

The maintenance repair costs during usage sub-criterion did not affect the technology decisions.

Comparison of the RETs with the sub-criteria of the technical–technological R&D criterion

Comparison of the RETs according to the sub-criterion of ease of application

When the RETs were compared to the sub-criterion of ease of application, the solar heating, solar water heating, photovoltaic, and wind applications emerged as the easiest technologies, while hydrogen, biomass, and geothermal applications emerged as the most-difficult technologies, respectively.

Comparison of the RETs according to the knowledge and experience sub-criterion

The knowledge–experience sub-criterion was the most-important for hydrogen, biomass, and geothermal energy, respectively. Decision makers were generally knowledgeable about the other technologies.

Comparison of the RETs according to the fault detection sub-criterion

Although fault detection is difficult for biomass and hydrogen energy, it is considered easy for other technologies.

Comparison of the RETs according to the system life and warranty sub-criterion

The system life and warranty sub-criterion was not found to be effective for decision making. Alternative technologies were found to be of equal importance.

Comparison of the RETs according to the production volume duration and product variety sub-criterion

Photovoltaic, wind, and geothermal were the most-advantageous technologies, and these were followed by solar heating, solar water heating, biomass, and hydrogen.

4. Results and Discussion

In terms of the use of RETs in the buildings in Turkey, the economy was acknowledged as the most-important primary criterion as it received the highest weight of 0.5158204 in the selection and prioritization of renewable energy technologies in buildings in Turkey. The technical–technological R&D primary criterion was found to be the second-most-significant criterion by receiving a weight of 0.211403 points. Although other primary criteria were of mathematically negligible value, their weight ranking was still recorded and went as follows: environmental impact (0.0914573), socio-cultural (0.0741551), institutional–political (0.0616375), aesthetic (0.027235), and time (0.0182916). The emphasis on the importance of the economy as a primary criterion has also been highlighted in the literature [9,10,14,27–35,44–47]. Although environmental criteria remained in the background of this study, environmental impact-related criteria were found to increasingly be gaining importance due to climate change and the increasing awareness of environmental protection in many countries [44]. The aesthetic criterion was found to be one of the least-effective criteria; however, according to the transfer of architects participating in the expert group meetings, it is an important criterion for architects. The aesthetic criterion is not considered important by engineers, consultants, and investors. This has been perceived as an issue where architects and other actors fail to find common ground. The institutional–political criteria, such as the importance of government incentives (which is one of the most-critical results of many studies), were left behind in the importance ranking that was determined as a result of this study. During the interviews conducted with the expert group, the experts stated that the reason for this was that there are no current initiatives, such as grants, etc., in Turkey that would provide motivation to make decisions on government policies and support. In the future, this impact will increase when there are policies and state support to motivate decision makers. It is very important to create policies and incentives that will influence decision making by the state. For example, there may be win–win approaches such as the Dutch government's practices [48].

The most-important sub-criteria are, in order, as follows: initial investment cost, ease of implementation, production volume period, product variety, incentives and credits, investment payback period, system life and warranty, fault detection and intervention fault probability maintenance ease, knowledge–experience, maintenance repair cost during use, and ongoing cost impact during use. These criteria are associated with the economic and technical–technological–R&D criteria. Among the prominent primary criteria in this study, the economy and ease of implementation were among the sub-criteria, and the observability of the technologies highlighted in the interview were found to be compatible with the economic benefits it offers economically, as was stated in the innovation adoption model put forth by Rogers [49].

According to the model, the preferred order of alternative renewable energy technologies went as follows: photovoltaic, solar water heating, solar heating, wind, geothermal, biomass, and hydrogen. Photovoltaic technology ranked first, thus indicating it as the best technology. Renewable energy efficiency analysis for buildings in Kuwait confirms that solar energy systems are the most widespread and suitable technologies for utilization [50]. It is expected that PV systems, which are widely used in reducing power source pollution, will account for more than half of the total electricity production from renewable energy by 2050 [51]. According to the Statista 2023 data, the share of grid-connected PV production has been continuously increasing for China, Australia, Germany, Japan, and the USA [52]. Although wind energy requires vast open spaces and distances from urban areas, the proliferation of tall buildings spaced at regular intervals in densely populated urban environments has created new opportunities [17,53]. Geothermal energy, which can provide energy savings of 30–70% through heat pump technology in buildings, is also considered an efficient alternative technology according to studies in the literature [13,15,18,49,53–55]. Due to its geological and geographical location on an active tectonic belt, Turkey is among the rich countries in terms of geothermal resources globally. Although biomass usage lags behind in Turkey, it constitutes approximately 10% of the global primary energy demand, is significant for rural areas, offers an economically viable solution, and can provide substantial income for farmers according to the literature [15,19–21,56]. While the use of hydrogen energy in buildings is not yet widespread, it is being investigated as a potential tool for decarbonizing heating and cooling in buildings. The common approach includes fuel cells that are capable of generating both electricity and heat for buildings [16]. Hydrogen energy is still in its early stages along with the projects that are ongoing to explore its potential [57]. Embracing hydrogen energy in buildings faces challenges such as high production costs, limited infrastructure, and safety concerns regarding hydrogen transportation, thus limiting its widespread integration in buildings [58]. Studies have been conducted in recent years on the development and evaluation of new solar-geothermal-based integrated energy systems with sonic hydrogen production for buildings, thereby suggesting that hydrogen energy can be used in hybrid systems [59].

4.1. Findings Related to the Main Criterion of Economy

Turkey is a developing country with limited financial resources, and renewable energy technologies are capital-intensive. Therefore, the initial investment cost was ranked as the most-crucial sub-criterion. Despite the presence of projects with a considerably short investment return period, limited financing has prevented the investment return period criterion from surpassing the initial investment cost criterion.

4.1.1. Initial Investment Cost

Within the scope of this study, the economy emerged as the most-important criterion. According to the results of this study, solar heating, solar water heating, and photovoltaic were the most-preferred technologies in terms of initial investment cost. This result reveals that wind, biomass, and hydrogen production should be increased, and producer companies should be supported. Recent studies indicate that obstacles such as high initial investment costs and long investment return periods, especially for solar energy, have been overcome [60,61]. According to expert group discussions, the increase in companies producing RETs in recent years and local production have been effective in reducing costs. In Turkey, many domestic RET facilities have also been produced, which facilitates access to technologies and creates a positive impact for their widespread adoption. Within the context of overcoming the problems such as high initial investment cost and long duration of investment return, the increase in the number of companies engaged in production related to RETs facilitates access to technologies and creates a positive effect for making it common [12,62,63].

4.1.2. Duration of Investment Return

The return-on-investment duration is crucial for the widespread use of RETs. The return period of the investment varies according to the technologies and building type, as well as according to the organizations implementing the same technology and the amount of energy consumed or increasing energy costs. According to SHURA [60] data, the payback periods for investments in photovoltaic panels are calculated as 9.77 years for single-family homes; 8.50 years for multi-family homes; 3.84 years for education, hotel, health, and shopping mall building types; and 2.91 years for commercial, public, and industrial buildings. According to the expert group discussions, the increase in the local production of solar energy technologies in Turkey has recently created opportunities where investments can be recovered within 1–2 years, thereby significantly contributing to their widespread adoption. The increase in the electricity costs used in the industry has considerably reduced the duration of investment return in RETs, especially in industrial buildings. For example, the period determined in the feasibility phase of the investment may be shortened due to increasing energy costs. Additionally, the location of the project is also important regarding the investment payback period. For instance, for solar energy technologies, the payback period shortens in regions with high solar potential.

4.1.3. Impact on Ongoing Costs during the Utilization Phase

According to the expert group discussions, when the monthly electricity consumption and consequently the cost during the operational phase of buildings are high, RETs may be preferred more. For example, monthly bills in residential buildings are not motivating enough for users due to relatively low costs. However, in industrial buildings where monthly bills are considerably high, it triggers the search for new solutions and directs attention toward the use of RETs.

While it is important to use RETs in large buildings with high energy consumption, residential buildings contribute the most to energy consumption [60]. In Turkey, the energy consumption in residential buildings is 190–477 TWh/year, while the energy consumption of commercial, public, and industrial buildings is 13–78 TWh/year [60]. Although it is important to use RETs in large buildings with high energy consumption (industry, stadiums, etc.), different incentives for residential buildings with high energy consumption, legal regulations in zoning plans, etc., should be encouraged in the use of RETs.

Different types of buildings have different energy costs during the operational phase. For example, in buildings like hotels and dormitories where water heating costs are high, solar water heating is preferred, while in buildings where heating costs are prominent, such as greenhouses, geothermal heat pumps are preferred as renewable energy technologies.

4.1.4. Incentives and Credits

Incentives and credits play a crucial role in the utilization of RETs. During expert group discussions, it was emphasized that the beneficiaries of incentives and credits, and the entities that realize the economic benefits, may not always align. The divergence between users and producers, and the issue of different parties benefiting from economic gains, remains a significant economic challenge that needs to be addressed. Approaches proposed to overcome these challenges should aim for mutual benefits among all stakeholders. Models should be developed to ensure simultaneous benefits for both users and producers. Particularly in mass housing projects where RET implementation is carried out by contractors without a designated end user, resolving this issue is essential for widespread adoption. Another example pertains to homeowners and tenants in the housing market. A homeowner may be reluctant to install a system to reduce electricity usage as any resulting savings would be realized by the tenant. Conversely, a tenant may be hesitant to invest in installation without enjoying the cost savings firsthand. Careful consideration of these factors is necessary regarding incentives and credits.

4.2. Findings Related to the Main Criterion of Technical–Technological R&D

The main criterion of technical–technological R&D displays the results of its subcriteria. Technical–technological R&D criteria are crucial factors in selecting efficient renewable energy technologies for buildings.

4.2.1. Ease of Implementation

When we look at the technical and technological barriers related to these technologies, the most-important criterion is the ease of application. For example, in cities where gales are effective, the panels should be well fixed in order to not fly away. Many different mounting methods have been developed to solve this problem. The ease of application is very effective in the decision to use these technologies. For this reason, it is very important to carry out R&D in terms of the ease of application for each technology. In terms of ease of application, studies on hydrogen and biomass technologies should be carried out.

4.2.2. Knowledge–Experience

According to the studies in the literature [9,10,14,27–30], knowledge and experience, which are seen as effective criteria, are being overcome as technology advances and access to information becomes easier. The knowledge–experience factor, which is considered an important criterion in many studies in the literature on solar energy and wind energy, has lost its importance today. These technologies have been produced locally and introduced to employers, architects, and users by many consultancy firms. However, the knowledge–experience factor is still an important criterion for hydrogen, biomass, and geothermal energy. Decision makers are not as knowledgeable about these technologies as other technologies.

4.2.3. Fault Detection and Intervention/Probability and Frequency of Failure/Ease of Maintenance

During the expert group discussions, experts have stated that there is fault detection and maintenance for solar, wind, and geothermal energies. The possibility of failure is rare. This is especially the case for solar energy, where each panel is connected to the system and gives an instant warning when there is a problem with one of them. Carrying out fault detection is difficult in hydrogen and biomass.

4.2.4. System Life and Warranty

When considering the selection of RETs, the system life and warranty do not have a significant impact because these conditions are similar for all technologies. Each technology typically has an average lifespan of 25–30 years, with expert opinions suggesting that they can continue to be used with minimal efficiency loss afterward. For example, according to the information provided by companies involved in the implementation within the scope of this study, solar energy systems that were installed 25 years ago still achieve close to 80% efficiency.

4.2.5. Production Volume Time/Product Variety

The most-advantageous technologies in terms of production volume/product diversity are photovoltaic, wind, and geothermal technologies. According to the expert group discussions, the diversity of photovoltaic panel products (such as transparent panels serving as windows, panels produced as roof tiles, panels manufactured as parapets, etc.) plays a significant role in the widespread adoption of their usage.

5. Conclusions

The common problem of energy crisis, environmental pollution, and climate change we are facing today underscores the importance of using environmentally friendly and sustainable technologies in buildings to leave a livable world for future generations. In this study, which addresses this issue, literature reviews on the use of renewable energy technologies in buildings, expert group discussions, and the situation in Turkey, as well as the barriers, opportunities, effective actors in RETs, criteria and alternative technologies, and processes were all examined. A decision-making model for RETs in buildings in Turkey was developed based on the AHP method.

The importance of this study is in presenting a comprehensive situational analysis and in developing a decision-making model for the widespread adoption of RETs in buildings in Turkey. Comprehensive results were obtained regarding identifying barriers/opportunities, thereby establishing the criteria that lead to their use and creating an importance hierarchy. The most-effective criteria for increasing adoption rates, which have not yet been fully researched, was identified. The delineation of criteria and the roles of actors in the use of RETs in buildings, the evaluation of renewable energy technologies in the pre-construction phase of the building production process, and the determination of criteria related to the use of technologies in a study conducted within the scope of examining the criteria, actors, and technologies of RET use in buildings in Turkey are important.

The building production process consists of pre-construction, construction, and post-construction stages. Decisions regarding the inclusion of renewable energy technologies in the process, such as technology and product selection, system integration and aesthetic integrity, and decisions related to innovative approaches and R&D proposals, are all decisions taken in the pre-construction stage. Planning applications related to renewable energy technologies in the pre-construction stage, which approach applied systems as a design element within the project, as well as ensuring system and aesthetic balance through interdisciplinary work, are necessary. It is imperative to determine the criteria related to renewable energy technologies in buildings in the pre-construction stage. Hence, this study was confined to the decision-making process in the pre-construction stage. Conducting studies at the local level is one of the best approaches to examine the use of RETs in buildings.

The literature review and expert group discussions conducted within the scope of this study revealed that, although efforts to increase the use of RETs have been made by the Ministry of Energy and Natural Resources and The Republic of Turkiye Ministry of Environment and Climate Change, the usage level in buildings has not yet become widespread; however, many studies have been conducted on this issue. Since Turkey is a highly resourceful country in terms of potential, there are many options available for the use of technologies in buildings. The identified barriers to the use of all these alternative technologies describe the usage criteria. At the same time, these criteria vary according to the actors. Within the scope of this study, the results regarding technologies, criteria, and decision makers were obtained from RET experts using the AHP method. The results of the main criteria, sub-criteria, technology alternatives, and discussions have been presented. A comparison of the results with the literature review was made, and recommendations have been made for the widespread adoption of RET use in Turkey and the development of decision-making methods. This study will facilitate the selection of appropriate technologies through criteria and sub-criteria regarding the use of RETs in buildings, and it will also enable stakeholders involved in the building design process to determine the appropriate technology for the building with a common decision. With this model study, the criteria affecting the use of RETs and their degrees of importance have been determined. It is important to be able to determine which technologies should be selected through criteria and sub-criteria for the correct technology to be selected within the scope of project objectives and principles, as well as for efficiency. The implementation of the model used in the Excel program is quite simple and suitable for use by all actors in the decision-making process. The biggest problem in the building production process related to the subject is the complexity of the process of including RETs in the project (i.e., having many decision makers, the behavioral barriers related to each of them, each having different awareness levels, the resulting decision possibly being a joint decision, or that it could arise from the dominance of one actor, etc.). For example, in the teams consulted within the expert group, in buildings where RET applications were made, the reasons for architects' preferences were environmental concerns, the customers' preferences were economic benefits, and the users' preferences were the impact on ongoing costs. Therefore, the results and discussions are detailed under actor, criteria, and technology headings.

5.1. Actors

The final product in the building production process was constructed based on the joint decisions of all stakeholders. It is important for stakeholders with different priorities to make joint decisions. The proposed model is important for defining the problem in the project process, determining the common criteria by the actors, establishing their priorities, and forming the result with the common opinion of each actor. It can be used to determine which technologies can be used in the project, or which decisions will be made based on the criteria. As indicated by the consultants and engineers in expert group discussions, most projects using RETs in Turkey do not have recommendations from architects. Studies need to be conducted in architecture education programs, both at the undergraduate and professional levels. It has been concluded that aesthetics is an important criterion for architects, and efforts should be made in this regard. One of the most-important results obtained from the expert group discussions in this study was that stakeholders in the building production process are willing to use technologies they perceive to have positive outcomes in their environment. In addition to being economically viable, the widespread use of RETs in buildings has been observed to be effective, particularly through leadership in public structures.

5.2. Criteria

In this study, the criteria were determined to evaluate their weights nationwide, with the economy being considered the most-important criterion. It was seen that it received the highest weight in the selection and prioritization of renewable energy technologies in buildings in Turkey. However, as mentioned in the expert group discussions, different motivations may exist for the technology selection in different project examples depending on their specific conditions. Besides the economy criterion, the expert group discussions and literature review indicated that social responsibility is also crucial in Turkey, particularly in public buildings. The increasing importance of environmental protection awareness, along with the developing environmental laws and regulations related to environmental protection, forms the basis of social responsibility. In addition, the economic, social, and environmental principles of sustainability, along with the multifaceted sustainability goal, have created pressure both at the global and national levels, which were investigated both in terms of governments and sectors. There is a need for more efficient decision-making processes incorporating environmental and social sustainability goals and criteria beyond the traditional economic criteria.

5.3. Technologies

In the expert group discussions and literature review conducted, to analyze the potential of renewable energy technologies used in Turkey in the project area, it was necessary to utilize data from the Ministry of Energy and Natural Resources (ETKB). In the ETKB data system that was examined while analyzing the appropriate technology alternatives by region, it was seen that the Biomass Energy Potential Atlas (BEPA) facilitated the research process in biomass potential studies. The existing systems for technology analysis are BEPA, GEPA, and REPA. However, ETKB data for geothermal and hydroelectric energy should also be developed like other energy data systems. Improving the potential data of technologies nationwide and providing access to data through official institutions are among the necessary actions to promote the widespread use of these technologies. It is essential for these systems to be advanced to quickly select alternative technology options according to the region. Recent research and focus group interviews have emphasized the importance of using RETs in a hybrid way [64,65]. For example, systems such as solar energy for water heating, geothermal energy for heating, and biogas for cookers should be used. With the model developed within the scope of this study, it will be possible to decide which alternative renewable energy technology can be used in the region based on the stakeholders (decision makers) and criteria determined within the project. In future studies, software can be developed based on ETKB data that show the potential of technologies by province and district, thereby enabling faster applications of the model in alternative technology selection according to the project area.

If the use of renewable energy technologies is not mandatory at the national and global levels by policies or regulations, then the usefulness in terms of their application depends on the decisions of actors involved in building production. In Turkey, the transition to the concept of “Nearly Zero Energy Buildings”, which have higher energy efficiency than regular buildings and derive a certain portion of their energy from renewable energy sources, is gradually becoming mandatory to achieve the goal of “2053 net zero-emission buildings”, as outlined in the Regulation on Amendment of the Regulation on Energy Performance in Buildings prepared by the Ministry of Environment, Urbanization, and Climate Change [24]. It is crucial for the implementation of this regulation to cover all buildings and to be developed and closely monitored according to geographical regions, the potential of the area, and the type of building, all the while providing incentives and credits for the development of regions. Aligned with EU Directives such as Directive 2010/31/EU and Directive 2012/27/EU, which focus on energy performance and efficiency, respectively, the significant role of EU funding in co-financing energy renovation projects should be emphasized. These funds not only support the enhancement of energy efficiency, but also facilitate the integration of renewable energy sources into building infrastructure, thereby contributing to sustainable development objectives. For instance, initiatives like the “Competitiveness and Cohesion” operational program prioritize the promotion of energy efficiency and renewable energy sources within the construction sector. Similar to the example of China (who have encouraged biomass promotion in rural areas and have promoted the development of heat pump technology in hospitals and schools, etc.), technology analyses should be conducted and encouraged based on geographical regions, and this should also be performed on the development status and potential of regions in Turkey. Funds should be allocated based on national priorities and potentials, such as the example of the US Department of Energy announcing a goal to reduce solar energy prices by 60% within 10 years and thus allocating funds toward this goal. The importance of government policy, support, and regulatory mechanisms in the widespread adoption of renewable energy technologies cannot be denied.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/en17102354/s1, All binary comparison matrices related to the model.

Author Contributions: Conceptualization, F.C.; Methodology, F.C.; Validation, F.C.; Investigation, F.C.; Resources, F.C.; Data curation, F.C.; Writing—original draft, F.C.; Visualization, F.C.; Supervision, N.T. and M.T. This study was generated from the doctoral dissertation of Fatma Cesur, a student at Bursa Uludağ University, Department of Architecture. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: This study was conducted in accordance with the guidelines detailed in the Declaration of Helsinki, and it was also approved by the Institutional Ethics Committee of Bursa Uludag University (protocol code—E-92662996-044-85744, with a date of approval of 28 November 2022).

Informed Consent Statement: Informed consent was obtained from all the subjects involved in this study.

Data Availability Statement: The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Acknowledgments: The authors would like to thank the interviewees for their help in improving this paper.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. The Process of Energy Efficiency Policies in Buildings in Turkey

Year	Number	Regulation
1999	23725	Thermal Insulation Regulation Studies
2008	27019	Thermal Insulation Regulation
2007	26510	Energy Efficiency Law
2008	27075	Building Energy Performance Regulation
2010	27539	Building Energy Performance Regulation–Amendment
2010	27627	Building Energy Performance Regulation–Amendment
2011	27851	Building Energy Performance Regulation–Amendment
2011	27911	Building Energy Performance Regulation–Amendment
2017	30051	Green Certificate Regulation for Buildings and Settlements–Amendment
2018	30289	National Energy Efficiency Action Plan 2017–2023
2022	31755	Building Energy Performance Regulation—Amendment

Appendix B. The Criteria That Was Effective in the Use of Renewable Energy Technologies

Technical/ technological R&D	Barriers	Lack of architectural integration literature; Lack of useful guides for architects; Lack of suitable products in terms of building aesthetics; Perception of products as high-tech and the lack of other options; Lack of support tools for the integration of systems in the design phase and lack of technical knowledge; Use of existing technologies/techniques produced by different sectors and the failure to adapt them for use in buildings; Resource availability: technology (design, installation, and performance), the skill requirement for design and development, production, installation, operation, and maintenance; Complexity and obtaining variable outputs from technologies; Lack of experienced workforce and training in the field of RETs.
	Opportunities	Increasing environmental concerns among architects and a growing desire for knowledge about RETs; Interdisciplinary collaboration opportunities in RETs; The presence of consulting firms capable of providing technical information.
Socio-Cultural Behavioral	Barriers	Personal lack of interest, knowledge, and experience; Employer's lack of interest, knowledge, and experience; Architect's lack of interest, knowledge, and experience; Consultant's lack of interest, knowledge, and experience; Stakeholders' lack of interest, knowledge, and experience; Lack of information about incentives; Delayed acceptance of technology; Lack of acceptance by users (social acceptance); Failure to involve users and relevant organizations in the planning process to achieve social acceptance; Lack of training for workers (use of special sunglasses during operation and construction, use of heat insulation uniforms, and familiarity with the system); Social structure, norms and value systems, awareness and perception of risk, and behavioral or lifestyle issues; Stakeholders' perceptions of values; Customer motivation; Perceived lack of evidence for energy-efficient technologies; Lack of dissemination of new knowledge and weak adaptations of the construction sector to new approaches; Divided incentives—homeowners and tenants; Fear factor: avoiding dealing with it rather than learning and being resistant to innovations.
	Opportunities	Image benefits; Corporate social responsibility; Involvement of users in the process and its dissemination with social acceptance.
Economic	Barriers	Economically unfeasible; Inadequate economic resources; Market structure, energy pricing, incentives, purchasing power, spending priorities, financial issues, awareness and risk perception, high initial investment costs, and long payback periods.
	Opportunities	Long-term economic benefits; Government incentives.
Environmental	Barriers	Unsuitable climatic conditions/geographical factors; Negative environmental impacts of technologies; Lack of appropriate operational practices (including rational water usage, security measures, waste disposal practices, use of biodegradable chemicals, etc.); Insufficient time given for the reestablishment of local flora and fauna and environmental restoration; Lack of comprehensive environmental impact assessment studies for technologies; Negative effects on resources (soil and water) such as soil and water pollution, water consumption, etc.; Unsuitable site conditions (e.g., being in the migratory path of birds for wind energy).
	Opportunities	Efforts to reduce negative environmental impacts; Presence of renewable resources; Less environmental harm compared to traditional systems.

Institutional-Political	Barriers	Lack of government incentives; Absence of policies and regulations; Infrastructure deficiency; Inconsistent policies and planning restrictions; Resilience of the energy industry; Political barriers.
	Opportunities	Image benefits; Corporate social responsibility.
Time	Barriers	Insufficient time (i.e., the desire to shorten the design process and the research extending the design process).
	Opportunities	
Aesthetics	Barriers	Aesthetic concerns related to positioning (roof, facade, etc.); Concerns regarding visual impact; Challenges in integrating with the building; Perception of weak aesthetics of renewable energy technologies.
	Opportunities	Custom production capabilities for technologies used in buildings to ensure compatibility with the building.

Appendix C. The Criteria/Opportunities Influencing the Decision to Implement RETs in Buildings

Profession	Criteria	RET Implementation
Architect/A1	Ease of implementation Geographical advantage/energy potential in the region Production volume/time and product variety Positioning (roof–facade) Integration with design/standard/special production	Solar, wind, and geothermal
Architect/A2	Knowledge and experience Frequency of fault detection intervention/fault probability Ease of maintenance Production volume/time and product variety Visual impact/aesthetics Building integration	Solar and biomass
Engineer/E1	Initial investment cost Return-on-investment period Climate conditions/geographical advantage System recyclability	Solar, wind, geothermal, biomass, and hydrogen
Engineer/E2	Changes in energy demand/increasing energy demand Management of energy demand Environmentally friendly energy production/nature-friendly technologies	Solar, wind, geothermal, biomass, and hydrogen
Consultant/C1	Stakeholder interest/knowledge/experience Social values/stakeholder value perceptions System recyclability Combatting climate change/ecological values	Solar, wind, geothermal, biomass, and hydrogen
Consultant/C2	Avoiding current account deficits by being domestic Local regulations Global agreements Acceptance of innovations	Solar, wind, geothermal, biomass, and hydrogen
Investor/I1	State policies/supports and incentives Acceptance of innovations Social responsibility Initial investment cost Return-on-investment period Climate conditions/geographical advantage	Solar
Investor/I2	Energy pricing Bank loans Image benefits Geographical advantage/energy potential in the region Frequency of fault detection intervention/fault probability Ease of maintenance Incentives and credits	Solar
User/U1	System lifespan and warranty Production volume/time and product variety Impact on ongoing costs during usage Maintenance and repair costs during usage	Solar
User/U2	Initial investment cost Return-on-investment period	Solar

Appendix D. The Criteria/Barriers That Are Effective in the Utilization of RETs in buildings

Profession	Criteria	RET Implementation
Architect/A1	Incompatibility with design	Solar, wind, and geothermal
Architect/A2	Visual impact/aesthetic concerns Construction models	Solar and biomass
Engineer/E1	Grid connection	Solar, wind, geothermal, biomass, and hydrogen
Engineer/E2	Physical space required for equipment	Solar, wind, geothermal, biomass, and hydrogen
Consultant/C1	Length of application processes Lack of employer motivation regarding documentation process	Solar, wind, geothermal, biomass, and hydrogen
Consultant/C2	Geographical barriers (freezing, severe winds, etc.)	Solar, wind, geothermal, biomass, and hydrogen
Investor/I1	Lack of credit/grant	Solar
Investor/I2	Lack of information and examples of implementation	Solar
User/U1	Lack of information and examples of implementation	Solar
User/U2	Lack of credit/grant	Solar

References

1. United Nations Conference on Human Settlements (Habitat 2). In Proceedings of the United Nations Conference on Human Settlements, Istanbul, Turkey, 3–13 June 1996.
2. United Nations Environment Programme. *2020 Global Status Report for Buildings and Construction: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector*; United Nations Environment Programme: Nairobi, Kenya, 2020; p. 4.
3. IRENA. *Renewable Energy Policies for Cities: Buildings*; International Renewable Energy Agency: Abu Dhabi, United Arab Emirates, 2021; p. 6.
4. IRENA. *Global Renewables Outlook, Edition 2020*; International Renewable Energy Agency: Abu Dhabi, United Arab Emirates, 2020.
5. IEA. *Buildings*; IEA: Paris, France, 2022; Available online: https://www.iea.org/reports/buildings (accessed on 2 February 2023).
6. Republic of Turkiye Ministry of Environment and Climate Change. 2022–2023 Strategic Plan. 2022. Available online: https://webdosya.csb.gov.tr/db/strateji/haberler/cevre-seh-rc-l-k-ve-ikl-m-deg-s-kl-g--bakanligi_sp_2022-2023-20221111154234.pdf (accessed on 2 February 2023).
7. Republic of Turkiye Ministry of Energy and Natural Resources. Renewable Energy. 2023. Available online: https://enerji.gov.tr/enerji-isleri-genel-mudurlugu-yenilenebilir-enerji (accessed on 2 February 2023).
8. Tas, N.; Cosgun, N.; Tas, M. A qualitative evaluation of the after earthquake permanent housings in Turkey in terms of user satisfaction- Kocaeli, Gundogdu Permanent Housing model. *Build. Environ.* **2007**, *42*, 3418–3431. [CrossRef]
9. Shove, E. Gaps, barriers and conceptual chasms: Theories of technology transfer and energy in buildings. *Energy Policy* **1998**, *26*, 1105–1112. [CrossRef]
10. Cooke, R.; Cripps, A.; Irwin, A.; Kolokotroni, M. Alternative energy technologies in buildings: Stakeholder perceptions. *Renew. Energy* **2007**, *32*, 2320–2333. [CrossRef]
11. Uslusoy, S. Examination of Energy Efficient Buildings That Use Renewable Energy Resources from the Viewpoint of Building Components. 2012. Available online: https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp (accessed on 19 September 2023).
12. Republic of Turkiye Ministry of Energy and Natural Resources, Energy. 2023. Available online: https://enerji.gov.tr/bilgi-merkezi-enerji-elektrik (accessed on 2 February 2023).
13. Toprak, M.E.; Küçük, Y. Sustainable energy sources and energy performance of buildings. *J. Energy Technol. Policy* **2018**, *6*, 56–63.
14. Ai, Z.G. Design strategy based on the integration of high-rise building and wind power generation. *Archit. J.* **2009**, *5*, 74–75.
15. Yuan, X.; Wang, X.; Zuo, J. Renewable energy in buildings in China—A review. *Renew. Sustain. Energy Rev.* **2013**, *24*, 1–8. [CrossRef]
16. Ma, Z.; Awan, M.B.; Lu, M.; Li, S.; Aziz, M.S.; Zhou, X.; Du, H.; Sha, X.; Li, Y. An Overview of Emerging and Sustainable Technologies for Increased Energy Efficiency and Carbon Emission Mitigation in Buildings. *Buildings* **2023**, *13*, 2658. [CrossRef]
17. Kwok KC, S.; Hu, G. Wind Energy System for Buildings in an Urban Environment. *J. Wind Eng. Ind. Aerodyn.* **2023**, *234*, 105349. [CrossRef]
18. Li, Q. Ground source heat pump and its advantages. *Shanxi Archit.* **2010**, *36*, 170–171.
19. Han, B. Studies and Recommendations on Sustainable Architecture and Energy Efficiency. *Hars Akad.* **2023**, *6*, 57–72.
20. Zhu, Y.; Li, W.; Li, J.; Li, H.; Wang, Y.; Li, S. Thermodynamic Analysis and Economic Assessment of Biomass-Fired Organic Rankine Cycle Combined Heat and Power System Integrated with CO_2 Capture. *Energy Convers. Manag.* **2020**, *204*, 112310. [CrossRef]

21. Behzadi, A.; Thorin, E.; Duwig, C.; Sadrizadeh, S. Supply-Demand Side Management of a Building Energy System Driven by Solar and Biomass in Stockholm: A Smart Integration with Minimal Cost and Emission. *Energy Convers. Manag.* **2023**, *292*, 117420. [CrossRef]
22. Winch, G. Zephyrs of creative destruction: Understanding the management of innovation in construction. *Build. Res. Inf.* **1998**, *26*, 268–279. [CrossRef]
23. Kılıc, H. Smart Buildings, Applications and Operations. 2007. Available online: https://polen.itu.edu.tr/items/ffd4511d-8dbb-49da-a203-20991361da2e (accessed on 19 September 2023).
24. Republic of Turkiye Ministry of Environment and Climate Change. Regulation Amending the Regulation on Energy Performance in Buildings. 2022. Available online: https://www.resmigazete.gov.tr/eskiler/2022/02/20220219-2.htm (accessed on 2 February 2023).
25. European Commission. *Externalities of Energy' Externe Project*; DGXII, JOULE, Report No EUR 16520 EN; European Commission: Brussels, Belgium, 1995.
26. European Commission. *Energy for the Future: Renewable Sources of Energy*; White Paper, DG XVII; European Commission: Brussels, Belgium, 1997.
27. Tsoutsos, T.; Frantzeskaki, N.; Gekas, V. Environmental impacts from the solar energy technologies. *Energy Policy* **2005**, *33*, 289–296. [CrossRef]
28. Maldonado, P.; Márquez, M. Renewable energies: An energy option for sustainable development. *Renew. Energy* **1996**, *9*, 1072–1075. [CrossRef]
29. Weber, L. Some reflections on barriers to the efficient use of energy. *Energy Policy* **1997**, *25*, 833–835. [CrossRef]
30. Painuly, J.P. Barriers to renewable energy penetration; a framework for analysis. *Renew. Energy* **2001**, *24*, 73–89. [CrossRef]
31. Reddy, S.; Painuly, J.P. Diffusion of renewable energy technologies—Barriers and stakeholders' perspectives. *Renew. Energy* **2004**, *29*, 1431–1447. [CrossRef]
32. Gann, D.M. Trading places—Sharing knowledge about environmental building techniques. In *Building Culture & Environment—Informing Local & Global Practices*; Cole, R.J., Lorch, R., Eds.; Blackwell: Oxford, UK, 2003; pp. 37–56.
33. Foxon, T.J.; Gross, R.; Chase, A.; Howes, J.; Arnall, A.; Anderson, D. UK innovation systems for new and renewable energy technologies: Drivers, barriers and systems failures. *Energy Policy* **2005**, *33*, 2123–2137. [CrossRef]
34. Wall, M.; Probst MC, M.; Roecker, C.; Dubois, M.; Horvat, M.; Jørgensen, O.B.; Kappel, K. Achieving Solar Energy in Architecture-IEA SHC Task 41. *Energy Procedia* **2012**, *30*, 1250–1260. [CrossRef]
35. Margolis, R.; Zuboy, J. National Renewable Energy Laboratory. Nontechnical Barriers to Solar Energy Use: Review of Recent Literature. 2006. Available online: https://www.nrel.gov/docs/fy07osti/40116.pdf (accessed on 19 September 2023).
36. Saaty, L.T.; Vargas, G.L. Uncertainty and rank order in the analytic hierarchy process. *Eur. J. Oper. Res.* **1987**, *32*, 107–117. [CrossRef]
37. Saaty, L.T. *Multicriteria Decision Making: The Analytic Hierarchy Process*, 2nd ed.; RWS Publications: Pittsburgh, PA, USA, 1990.
38. Saaty, L.T. *Decision Making with Dependence and Feedback: The Analytic Network Process*; RWS Publications: Pittsburgh, PA, USA, 2001.
39. Deniz, O.S. A Decision-Making Approach for Selecting Structural Elements to Meet Users' Flexibility Demands in High-Rise Residential Design. Doctoral Dissertation, Istanbul Technical University, Istanbul, Turkey, 1999.
40. Gulenc, I.F.; Bilgin, G.A. A Model Proposal for Investment Decisions: AHP Method. *Oneri J.* **2010**, *9*, 97–107.
41. Saaty, L.T.; Vargas, G.L. *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2001.
42. Arıkan Kargı, V.S. *Analytic Hierarchy Process Model for Manager's Outsourcing Selection Decision*; Ekin Publishing: Ankara, Turkey, 2015.
43. Saaty, L.T. How to make a decision: The analytic hierarchy process. *Eur. J. Oper. Res.* **1990**, *48*, 9–26. [CrossRef]
44. Mastrocinque, E.; Ramírez, F.J.; Honrubia-Escribano, A.; Pham, D.T. An AHP-based multi-criteria model for sustainable supply chain development in the renewable energy sector. *Expert Syst. Appl.* **2020**, *150*, 113321. [CrossRef]
45. Yaqoot, M.; Diwan, P.; Kandpal, T.C. Review of barriers to the dissemination of decentralized renewable energy systems. *Renew. Sustain. Energy Rev.* **2016**, *58*, 477–490. [CrossRef]
46. Cicek, B.N.; Murat, O.; Nuri, O. Renewable energy market conditions and barriers in Turkey. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1428–1436.
47. Seddiki, M.; Bennadji, A. Multi-criteria evaluation of renewable energy alternatives for electricity generation in a residential building. *Renew. Sustain. Energy Rev.* **2019**, *110*, 101–117. [CrossRef]
48. Government of the Netherlands. Renewable Energy. 2023. Available online: https://www.government.nl/topics/renewable-energy (accessed on 2 February 2023).
49. Rogers, E.M. *Diffusion of Innovations*, 4th ed.; Free Press: New York, NY, USA, 1995.
50. Alshuraiaan, B. Energy-efficient buildings with renewable energy technologies: The case of Kuwait. *Energies* **2021**, *14*, 4440. [CrossRef]
51. Kuskaya, S.; Bilgili, F.; Mugaloglu, E.; Khan, K.; Hoque, M.E.; Toguc, N. The role of solar energy usage in environmental sustainability: Fresh evidence through time-frequency analyses. *Renew. Energy* **2023**, *206*, 858–871. [CrossRef]

52. Statista. Grid-Connected Solar PV Capacity by Select Country. 28 September 2023. Available online: https://www.statista.com/statistics/665864/solar-capacity-in-selected-countries-by-grid-connection/ (accessed on 19 September 2023).
53. Ma, L.X.; Tian, S. Current situation and development of geothermal energy utilization in China. *Nat. Resour. Econ. China* **2006**, *19*, 19–21.
54. Zhang, M.J.; Wang, J.G.; Bao, L.L. Development situation of ground-source heat pump in China and the popularizing policy of heat pump in foreign country. *J. Hebei Univ. Eng. (Nat. Sci. Ed.)* **2008**, *25*, 25–28.
55. Lin, W.J.; Lin, L.J.; Wang, G.L. Research on the status quo, problems and countermeasures on shallow geothermal resources utilization in China. In Proceedings of the Symposium of Urban Geological Environment and Sustainable Development Forum, Shanghai, China, 23 August 2010; pp. 356–360.
56. Chen, Y.J.; Meng, H. The present situation and countermeasures for bioenergy development in China. *Chin. High Technol. Lett.* **2007**, *17*, 1312–1316.
57. Lancaster University. Lancaster Hydrogen Hub. 2023. Available online: https://www.lancaster.ac.uk/energy-lancaster/research/hydrogen-hub/ (accessed on 12 December 2023).
58. Wu, Y.; Zhong, L. An Integrated Energy Analysis Framework for Evaluating the Application of Hydrogen-Based Energy Storage Systems in Achieving Net Zero Energy Buildings and Cities in Canada. *Energy Convers. Manag.* **2023**, *286*, 117066. [CrossRef]
59. Sharifishourabi, M.; Dincer, I.; Mohany, A. Development and assessment of a new solar-geothermal based integrated energy system with sonic hydrogen generation for buildings. *J. Build. Eng.* **2023**, *80*, 107944. [CrossRef]
60. International Energy Agency (IEA). Global Energy Crisis. 2023. Available online: www.iea.org/topics/global-energy-crisis (accessed on 8 March 2023).
61. SHURA. *Rooftop Solar Energy Potential in Buildings—Financing Models and Policies for the Deployment of Rooftop Solar Energy Systems in Turkey*; Energy Transition Center: Calgary, AB, Canada, 2020; pp. 16–58. Available online: www.shura.org.tr (accessed on 8 March 2023).
62. Pillai, U. Drivers of cost reduction in solar photovoltaics. *Energy Econ.* **2015**, *50*, 286–293. [CrossRef]
63. Chenic, A.Ș.; Cretu, A.I.; Burlacu, A.; Moroianu, N.; Vîrjan, D.; Huru, D.; Stanef-Puica, M.R.; Enachescu, V. Logical Analysis on the Strategy for a Sustainable Transition of the World to Green Energy—2050. Smart Cities and Villages Coupled to Renewable Energy Sources with Low Carbon Footprint. *Sustainability* **2022**, *14*, 8622. [CrossRef]
64. Malik, P.; Awasthi, M.; Sinha, S. A techno-economic investigation of grid integrated hybrid renewable energy systems. *Sustain. Energy Technol. Assess.* **2022**, *51*, 101976. [CrossRef]
65. Bae, S.; Nam, Y. Feasibility analysis for an integrated system using photovoltaic-thermal and ground source heat pump based on real-scale experiment. *Renew. Energy* **2022**, *185*, 1152–1166. [CrossRef]