Sustainable energy planning for the aspiration to transition from fossil energy to renewable energy in Northern Cyprus

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A R T I C L E   I N F O

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A B S T R A C T

The study aims to reveal the prominent strategic energy alternatives for Northern Cyprus (NC) in its aspiration to transition from fossil fuels to solar energy/clean energy/renewable energy with sustainable energy planning. First, SWOT analysis was used to identify strengths and weaknesses, opportunities and threats; then, Analytical Hierarchy Process (AHP) method was used to determine the weight ratios of all those factors and finally, these results were used together with the TOWS analysis to derive energy alternatives. There results in brief were as follows; “solar energy potential” (S1) and “geostategic position in energy transmission” (S2), both being sub-factors representing strengths, took the first two places respectively in the derived order of importance. The most important sub-criteria of the weaknesses was “insufficient energy management” (W5), while “interconnected connection in energy transmission” (O3) and “energy supply security” (T1) were determined as important for opportunities and threats”. Experts identified eight energy strategies; in particular, the “establishing the interconnected connection” (W02) and “natural gas pipeline laying” (S01) strategies are expected to affect all regional energy stakeholders. This study has the potential to become a foremost source in providing energy strategies to energy planners and academics during the energy transition period, specifically for NC.

1. Introduction

Sustainable energy planning brings the use of renewable energy and the energy transition to the agenda. Although governments and different interest groups mention renewable energy and the sustainable energy sector, it is not possible to discuss energy planning implemented in NC. As there is no sustainable energy planning, it is important to do planning by considering the improvements in the world regarding energy transition and the realities of NC.

Currently, energy transition strategies are gaining strength globally to meet ambitious targets to reduce greenhouse gas emissions. Unlike fossil-based energy consumption, which generates large amounts of carbon emissions, renewable energy applications have minimal impact on the environment. For example, the fact that renewable energy sources are useable by integrating them into smart cities’ energy production systems contributes to the future production of sustainable and clean energy [1]. On the other hand, sustainable energy planning requires careful monitoring of the global transition trend in clean energy. The COVID-19 epidemic, which has seriously affected the lives of millions of people worldwide and caused a global emergency, has led to a decrease in energy production and demand in many countries. This situation encourages countries to produce policies for the production and use of renewable energy, with the thought that new policy decisions regarding renewable resources may effectively increase the speed of energy conversion or reduce carbon emissions [2].

The energy transition requires movement towards alternative energy strategies that are carbon neutral. This movement is connected with the decentralized and deregulated energy sector. Despite discussions on deregulation in the energy sector, no progress has been made yet in NC. In recent years, the development of alternative energy strategies related to decentralization has made deregulation necessary. Renewable solar power generation in NC, albeit in insufficient amounts, reduces the efficiency and sustainability of renewable energy produced due to the lack of storage and interconnected systems. For energy transition, it is necessary to increase the efficiency of solar energy, which NC is advantageous, by considering storage and the interconnected system as a part of decentralization. For energy planning, it is essential to have energy strategies obtained by experts in the sector with the awareness of energy transition. As it is done for energy stakeholders. This study has the potential to become a foremost source in providing energy strategies to energy planners and academics during the energy transition period, specifically for NC.
Like many other small island economies [3], almost all the available energy is obtained from primary fuel with high carbon emissions in NC. The rest comes only from the sun as a renewable energy source, and it is far from the clean energy generation target of countries. The old technology used in the production at fuel-oil and diesel power plants causes an increase in emissions and increases the supply security threat. The dependency on the import of fuel oil results in a high vulnerability to oil shocks. Not only for NC but many other developing small island economies, a vulnerability in energy resources is a barrier in front of the development. High prices increase the cost of production and limit access to energy. According to the United Nations report, energy accessibility affects the development of a country by improving healthcare provision, education, and reducing poverty [4]. Being a small island economy makes it difficult to find solutions for lower energy prices because of their scale. As proposed by Chatzivasileiadis et al. [5], being part of a regional cooperation system would be one solution for affordable energy prices.

The presence of hydrocarbon reserves in the Eastern Mediterranean makes the island of Cyprus important not only for the existence of energy resources, but also for its transmission. The existence of these internal and external factors requires decisions to be made for energy planning and the creation of strategic alternatives. This study aimed to examine the current energy sector in NC and identify strategic energy alternatives based on sustainable energy planning in the transition from fossil energy to renewable energy. For this, SWOT-AHP hybrid approach AWOT and TOWS decision making methods were used. As a result of the analysis made by the expert group through questionnaires, 19 sub-factors related to strengths, weaknesses, opportunities and threats were determined. Group studies have shown that strengths are most important, followed by weaknesses and opportunities, and threats least. “Solar energy potential (S1)” and “Geospatial location in energy transmission (S2)” took the first two places according to the order of importance of the sub-criteria. Eight strategic alternatives have been identified in sustainable energy planning for NC. The potential for implementation of some energy strategies is expected to affect all regional stakeholders.

The remaining part of the study will continue with materials and methods, data collection and analysis, results and discussion, and ends with the conclusion.

2. Materials and methods

2.1. Energy planning situation of Northern Cyprus

The island of Cyprus is in the access geography of the Mediterranean, Aegean, and Black Seas. This strategic location concerning Eastern Mediterranean geopolitics has been closely related to the energy sector in recent years. In Middle East geography, the Eastern Mediterranean contains 47% of the world’s proven oil reserves and 43% of natural gas reserves [6]. The estimated resources include 3.5 trillion m3 (TCM) of natural gas and 1.7 billion barrels of oil in the Levant Basin alone. Research indicates that there may be 70.2 million tons of undiscovered liquid natural gas liquid in the region [7]. These details are essential to NC’s energy sector. NC has a surface area of 3,355 km2, corresponding to approximately 37% of the island. Cyprus has been divided in two by a green line, which has been under the control of the United Nations since 1974. The northern part of the buffer zone is administered by Turkish Cypriots, while Greek Cypriots administer the southern part of the zone.

Almost all of the electrical energy production is derived from fossil fuels. Renewable energy sources do not play an influential role in energy production. The current grid has an installed power of 405 MW. The electrical energy demand in NC is met from four main power plants. In 2019, Kalesik Diesel is responsible for 43.20% of this, whereas Tekneciel Diesel, Tekneciel Steam Unit no. 1 and Tekneciel Steam Unit no. 2 produce 32.77%, 10.08%, 13.66% of it respectively. The production amount obtained from the Serhatköy PV system is 0.09%, illustrated in Figure 1.

The total electricity production in NC in 2019 was 1.66 billion kWh, and between 2004-2019 the increase in electricity consumption was 5% annually [8], as shown in Figure 2. In the extensive research conducted by Fichter [9] for Kib-Tek, it has been estimated that the 5% increase in load will continue, and this increase will reach 2,350 GWh in 2025, while the peak demand will be 477 MW. The research estimated that annual demand growth will continue between 2025 and 2040, but this rate will be 2%. Accordingly in electricity demand and production forecast, electricity demand, which was 1,234 GWh/a in 2015, will increase to 2,705 GWh/a in 2040. The production, which was 1,443 GWh/a in 2015, will increase to 3,163 GWh/a in 2040. The difference in values is due to losses in the electricity grid and the consumption of fossil power plants, which are ancient technology.

The potential to benefit from solar energy in NC is quite high because of its location. It receives solar radiation almost throughout the year, and this amount corresponds to 2,700 to 3,500 h of sunlight per year [10]. However, due to the small size of the existing grid, only solar energy investments with limited capacity are allowed. For this reason, it isn’t easy to reach the target of 20% of consumption being made up of renewable energy resources set by the European Commission [11]. The transition to renewable energy in Northern Cyprus started in 2009 and the first solar power plant was established in 2011 [12]. Although energy production based on renewable power plants is environmentally friendly, today the only renewable power plant in NC’s installed power is the Serhatköy power plant. It provides penetration of 1,125 MW into the power system. Another solar energy contribution to the energy system is provided by residential and commercial facilities. It is estimated that solar energy production can be realized as 25MW in 2040. This will lead to decreased environmental pollution caused by energy production from fossil fuels. The most important expected benefit of the energy transition will thus be realized. The lack of interconnected connections or Installation of energy storage systems restricts the renewable energy investments necessary for sustainable energy. The renewable energy consumption rate was approximately 6% for 2019, shown in Figure 3 which was very low.

In this research process, the authors compiled the main workshops, reports, and seminars related to the energy sector of NC in chronological order, as shown in Table 1 in chronological order. These documents mainly focus on the current state of energy in NC, predictions, and recommendations for the future.

Studies on renewable energy sources in the northern part of Cyprus, show that the solar and wind potential is intensively investigated, Table 2. Climatic conditions make the installation of solar and wind power plants ideal in the country, but the potential and efficiency of solar energy in NC is much more important than wind energy [20, 21, 22]. In NC, there are not yet large platforms where wind turbines are installed that allow the use of wind energy.

2.2. Aspiration to the energy transition

In recent years, energy networks in almost every region of the world have entered a transition process in line with the basic climate and energy policy objectives of the European Union (EU) [34]. The prominent concept in this process is decentralization to change a one-way address to a multi-directional address in energy. The combination of innovations in energy production, transmission, and consumption is causing a significant change. Countries’ formerly centralized power systems continue to become increasingly decentralized as new technologies and storage systems, come into play. A central authority, Cyprus Turkish Electricity Authority (KIB-Tek), handles energy generation, transmission, and distribution as a central energy grid. Local people who are only consumers, are transitioning from being a one-way energy consumer to being a multi-directional energy prosessor with rooftop energy production and storage. However, for many years in NC, the decoupling of generation, transmission, and distribution in electricity generation has not realized despite having been included in economic development reports [35].

Energy transition studies have been studied in depth in the last five years due to increasing global warming [36]. For example, there are
energy transition studies in the literature where the term sustainable [37, 38, 39]. Based on the SWOT analysis method, in Jiao et al. [40], analyzes China's energy development's internal and external factors, examines its strengths and weaknesses in the energy transition, the external opportunities and threats it faces and makes several recommendations for China's energy transition strategy. In another study uses the SWOT-AHP methods to explore rural-based bioenergy system in Zambia for sustainable development [41].

As in many countries, NC aspires to energy transition to reduce its dependence on petroleum products and its carbon emissions for sustainability in energy. Strategies are needed to ensure a sustainable transition from non-renewable to renewable sources. The conclusion frequently reached in the literature is that the main motivation of underdeveloped or developing countries in energy transition research is the need for economic and social development and the desire to reach a sustainable and affordable energy supply [42].

There is a direct relationship between the choice of renewable energy sources and energy planning [43, 44]. However, the International Energy Agency has also stated that the priority should be shaped in line with national targets and constraints while forming the policy strategies of countries in sustainable energy transitions [45]. As a matter of fact, NC has exclusive values in energy due to the presence of hydrocarbon deposits in the Eastern Mediterranean and its geostrategic importance. For this reason, the study primarily focused on the necessity of sustainable energy planning in the transition to renewable energy.
2.3. Methods of the study

In this study, the A’WOT (a hybrid structure formed by using the SWOT and AHP methods together) and TOWS methods, which are frequently used in strategic decision-making and planning problems, were used. The literature review of the methods used in the study is given below.

2.3.1. SWOT analysis

SWOT analysis involves comprehensive management, planning, and systematic thinking diagnosis. In the analysis, S and W describe the strengths and weaknesses of strategic planning, and O and T identify opportunities and threats. The strengths and weaknesses of the analysis deal with the internal factors of the subject under study. Relates to the broader context or setting as opportunities and threats are influenced by external factors [46, 47]. All aspects of the subjects examined after the SWOT analysis are classified as sub-factors.

SWOT analysis plays an active role in representing the early stage of the planning process, determining strategic alternatives, and making decisions [48]. Recently, studies have been conducted to create regional and national energy policies, sustainable energy planning, and energy efficiency [49, 50, 51, 52, 53, 54]. SWOT analysis provides an accurate understanding of the current energy potential to investigate energy sector conditions and develop a strategic plan that includes internal and external environmental impacts. It also supplies a basis for objectives and strategy recommendations [55].

2.3.2. AHP analysis

The analytical hierarchy process (AHP) was first developed by Thomas Saaty [56]. The method can deal with qualitative and quantitative features, so the quantitative results obtained make the decision debatable. This feature makes the AHP method one of the most practical multi-criteria decision analyses [57]. The AHP method has been the subject of scientific studies in many areas requiring decision-making and planning for a long time [58].

AHP is based on constructing the decision hierarchy of a problem that needs to be decided and comparing pairs of elements by the decision-makers according to their priorities. A scale of relative priority is used, with numbers one through nine and their meanings (see Table 3) [59]. In the AHP method, if more than one expert or decision-maker participates in the AHP method, the geometric mean of the evaluations results is taken [60].

In the classical AHP method, n refers to the number of criteria and \( (n-1)/2 \) pairwise comparisons are required [61]. The diagonal elements of the matrix formed as a result of pairwise comparisons take the value of 1. The symmetry of each resulting cell is equal to the inverse of that cell with respect to multiplication. The results are expressed by the positive pairwise comparison matrix A, represented by Eq. (1), following the general steps of the method [62].

\[
A = (a_{ij}) = \begin{bmatrix}
W_1/W_1 & W_1/W_2 & \cdots & W_1/W_n \\
W_2/W_1 & W_2/W_2 & \cdots & W_2/W_n \\
\vdots & \vdots & \ddots & \vdots \\
W_n/W_1 & W_n/W_2 & \cdots & W_n/W_n \\
\end{bmatrix} \tag{1}
\]

The rows in the equation show the relative weight ratios of the individual factors. All numbers in matrix A are \( a_{ij} > 0 \) and when \( i = j \), which means \( a_{ij} = 1 \). Multiplying vector, A by W yields Eq. (2).

\[
AW = nW = \lambda_{\text{max}} W
\]

Here, \( n \) represents the number of rows and columns, \( W = (W_1, W_2, \ldots, W_n)^T \) and \( \lambda_{\text{max}} \) is the largest Eigen factor. Questioning \( \lambda_{\text{max}} = n \) is necessary and must satisfy the conditions required for consistency. The matrix is consistent when \( \lambda_{\text{max}} = n \) Conversely, if \( \lambda_{\text{max}} \neq n \), the matrix is inconsistent.

Therefore, matrix A should be examined using the formulation in Eq. (3).

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]

Finally, the results were subjected to the consistency test shown in Eq. (4) to calculate the consistency ratio (CR).

\[
CR = \frac{CI}{RI}
\]

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Table 2. Studies on renewable energy sources in Northern Cyprus.

| Study Title | Year |
|-------------|------|
| Economic variables and electricity consumption in Northern Cyprus | 2001 [23] |
| Renewable energy resources as an alternative to modify the load curve in Northern Cyprus | 2005 [24] |
| A framework for evaluating WTP for BIPV in residential housing | 2014 [25] |
| A framework for evaluating WTP for BIPV in residential housing design in developing countries: A case study of North Cyprus | 2015 [26] |
| A parametric study on the feasibility of solar chimney power plants in North Cyprus conditions | 2016 [27] |
| Estimating higher education induced energy consumption: The case of Northern Cyprus | 2017 [28] |
| Solar Thermal System Analysis of Northern Cyprus | 2018 [29] |
| The Serhankoy photovoltaic power plant and the future of renewable energy on the Turkish Republic of Northern Cyprus | 2019 [30] |
| Evaluation of the potential of solar energy utilization in Famagusta, Cyprus | 2020 [31] |
| Freestanding PV solar system-example of Lefke town in Northern Cyprus | 2021 [32] |
| The Evaluation of Single-Family Detached Housing Units in terms of Integrated Photovoltaic Shading Devices: The Case of Northern Cyprus | 2022 [33] |
| The Possibility of Generating Electricity Using Small-Scale Wind Turbines and Solar Photovoltaic Systems for Households in Northern Cyprus: A Comparative Study | 2023 [34] |
| Solar Energy Technology for Northern Cyprus: Assessment, Statistical Analysis, and Feasibility Study | 2024 [35] |

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Table 3. Pairwise comparison scale.

| Importance | Explanation |
|------------|-------------|
| 1          | When comparing two elements, the importance is the same |
| 3          | When comparing two elements, the former is slightly more important or advantageous than the latter |
| 5          | When comparing two elements, the former is more important or advantageous than the latter |
| 7          | When comparing two elements, the former is absolutely more important or advantageous than the latter |
| 2,4,6,8    | The middle values between the above scales |
CI is the consistency index and RI is the random index given in Table 4 [63], produced for a random matrix of order n. The results are considered reliable if the CR ratio is less than 0.10 [64]. The whole process is repeated for each group or factor separately so that the group elements are sorted in a relative priority order [65].

2.3.3. Hybrid structure: A SWOT analysis studies
The qualitative nature of SWOT analysis does not allow a quantitative analysis of the factors. This is the main disadvantage of this method [66]. For this reason, many researchers have integrated SWOT analysis with eigenvalue calculations in the AHP. According to [67], if the AHP method and SWOT factors are used together, the factors can be systematically evaluated and measured. This hybrid method is known in the literature as A’WOT [68]. Pairwise comparisons force decision-makers to consider the weights of factors and analyze the situation more accurately. The numerical results obtained by this method are also used to formulate alternative strategies [69]. In the literature, there are examples of SWOT-AHP integration to produce sustainable energy strategies and policies [70, 71, 72, 73, 74].

2.3.4. TOWS analysis
This matrix is the next step of the SWOT [75]. TOWS is one of the best-known methods in the literature for identifying alternative strategies based on strengths, weaknesses, opportunities, and threats. Developed by Weithrich [76], this method aims to achieve the following explanations.

- WT strategies (Min-Min): Minimizing both threats and weaknesses;
- WO strategies (Min-Max): Minimizing weaknesses by taking advantage of opportunities;
- ST strategies (Max-Min): Avoiding threats by taking advantage of strengths;
- SO strategies (Max-Max): Maximizing both strengths and opportunities.

SWOT-AHP-TOWS methods can be used together [41, 62, 77, 78, 79, 80, 81]

2.4. Data collection and study framework
The selection and assignment of experts at the time of a decision should not be random. Instead, decision makers should consist of people with both knowledge and practical experience. A valid decision can be made even by a single expert. In this case, several expert opinions may be sought if available [82].

The expert group that contributed to the study consisted of people who have been serving in the energy sector for many years and have knowledge. Two of the five members of the group are university academics with numerous scientific studies on energy, one is a board member of the Renewable Energy Board, the other is a board member of a company that makes important infrastructure investments in the field of energy, and the last is a senior manager working in a public institution responsible for electrical energy. All the experts are also members of the board of the chamber of electrical engineers and take an active role in producing energy policies for society.

The research was carried out after approval of the European University of Lefke ethics committee’s decision No: 07.05.2021, UEK/61/02/05/2021/01, and after obtaining the consent of all participants. Due to the pandemic, face-to-face meetings were held with experts in the virtual environment. Two questionnaires were sent to the experts in the study. The return of information took about two months. In the first survey, they were requested to develop suggestions and contribute to the SWOT analysis. In the second survey, they were requested to determine the absolute relative priorities of the SWOT factors with the AHP method (Surveys 1 and 2 are available in the Supplementary data 1).

The research framework consisted of five stages (Figure 3). This approach is applied to formulate strategic alternatives within the framework of sustainable energy planning.

- First stage: A draft SWOT analysis, which determines SWOT factors and sub-factors, is performed by scanning the literature and documents.
- Second stage: A group of energy experts added their views on the draft SWOT analysis through a questionnaire sent to them, adding and subtracting feedback from the analysis when necessary. Thus, the relevant factors of the internal and external environment are re-determined, and the SWOT analysis is given its final shape.
- Third stage: Absolute priority values of the SWOT factors and sub-factors are determined.
- Fourth stage: While performing TOWS analysis, the third-stage data are evaluated together, and strategy formulation is attempted.
- Fifth stage: Alternative energy strategies are determined.

Figure 4 shows the flowchart of the five-step framework to determine the best result using the hybrid method.

To apply the AHP method in the third stage, a decision hierarchy was created [83]. This hierarchy included the purpose of the problem, factors, sub-factors, and alternative strategies (Figure 5).

3. Results and discussion

3.1. SWOT factors and sub-factors
Experts identified 19 factors using the SWOT analysis. Below is a description of internal factors (strengths and weaknesses) and external factors (opportunities and threats). Using SWOT analysis, experts identified 19 factors. Below is a general description of the internal factors (strengths and weaknesses) and external factors (opportunities and threats) specific to Northern Cyprus.

Strengths
- S1. Solar energy potential: The country is in a very advantageous position in terms of geography, total sunshine hours, and radiation. Due to these climatic conditions, it can benefit from solar energy in almost all months of the year, this period is approximately 340 days a year [84].
- S2. Geostrategic position in energy transmission: The island of Cyprus is located in the middle of the center of the world’s proven oil and natural gas reserves. In addition, it is the last point where the interconnected electrical energy connection with Europe is completed. Therefore, the island is almost like a window to the Mediterranean, the Aegean, the Black Sea, the Red Sea, and the Atlantic. This location of the island of Cyprus creates a geostrategic advantage in both hydrocarbon and electrical energy transmission.

Weaknesses
- W1. Energy efficiency policies are Insufficient: In sustainable energy, production of efficiency is equally important. First, any activity that increases consumption and leads to wasted use must be terminated. Although the energy efficiency strategy document has been published, neither the public nor the private sector has implemented it.
- W2. Insufficient installed power: The installed power in the NC electricity generation facilities is 404 MW, and the available power is 336 MW [17]. Retrospective statistical data show that the annual increase
in energy consumption is approximately 5%. An energy deficit is soon expected.

- **W3. Dependency on the use of fuel oil**: 94% of electrical energy production is from fossil fuel oil [19]. This situation is far from being a sustainable energy source. On the contrary, in the international energy market, electricity generation from fuel oil will be banned entirely by 2030.

- **W4. Renewable energy sources are solar only**: Currently, only solar energy is used from renewable energy sources. Other renewable energy sources such as wind energy and bioenergy, which have increased rapidly in recent years and are likely to be applied in NC, are not utilized.

- **W5. Insufficient energy management**: There is an inadequate institutional and human infrastructure to formulate energy policies and manage decisions for sustainable energy planning. Legislations that contribute to energy management, such as the energy law, the energy office establishment law, and the energy market regulatory board, are not yet in force.

- **W6. Limited uses of solar energy**: The country’s geography can benefit from sunshine duration and radiation amount for 340 days a year. However, the current power generation network structure (a small-island network) has some disadvantages. The contribution of renewable energy generation cannot exceed 20% because the current system is not integrated into another robust generation system. Otherwise, the energy production quality of the existing grid deteriorates.

**Opportunities**

- **O1. Switching to LNG fuel use**: The use of liquefied natural gas (LNG) as an energy source has accelerated in recent years. This energy fuel is more economically beneficial than fuel oil and has fewer carbon emissions.

- **O2. Hydrocarbon potential in the Eastern Mediterranean**: There are 1.7 billion barrels of oil and 3.5 trillion cubic meters of natural gas reserves in the Levant region of the Eastern Mediterranean. It has been estimated that there may be 70.2 million tons of undiscovered natural gas liquid in the region [7].

- **O3. Interconnected connection in energy transmission**: In the globalizing world, many countries are interconnected with electrical cables. These connections cause the sharing of excess production, reduce costs, and ensure supply security. With the interconnected connection to be established between NC and mainland, it will create the opportunity to benefit from unlimited renewable energy sources.

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**Figure 4.** Flow diagram of the five-stage framework for the identification of the best outcome using the hybrid method.
**O4. Decrease in energy investment costs:** In recent years, expenses such as restructuring, production, and storage in the field of energy have been decreasing. This situation can be evaluated as an opportunity for sustainable energy planning.

**O5. Increasing awareness in energy efficiency:** Today, in addition to reducing the burden of energy costs, awareness of the need to use energy efficiently for the protection of the environment has increased. In the global world, bringing efficiency to the forefront in the entire energy process, from production to consumption, is an opportunity for sustainable energy management.

**O6. Strong university infrastructure:** NC has a vital university infrastructure due to academics who continue their studies on energy in many universities.

**Threats**

**T1. Energy supply security:** In recent years, continuing energy production with old technology and primary energy sources, or at least renewing obsolete technologies in this direction in sustainable energy supply, seems unlikely. A highly dependent country on energy imports should turn to energy diversity in production to ensure sustainable energy supply security sustainable [85]. In NC, 95% of energy is imported. This is a significant threat.

**T2. Geopolitical risks:** Hydrocarbon resources discovered and waiting to be found in the Eastern Mediterranean are a new threat to the global energy map [86]. These resources are a threat to the already complex Eastern Mediterranean coastal states. If cooperation, trust, and stability cannot be established, a crisis may arise first among neighboring countries and then globally.

**T3. Climate change and environmental obligations:** In addition to its commitment to reduce greenhouse gas emissions, the EU is taking decisive steps to meet its obligations to provide safe, affordable, and sustainable energy for its citizens. The EU and its member states aim to achieve their 2030 goals and carry out a climate-neutral economy transition program by 2050. For this reason, planning and implementing studies are socially fair and cost-effective [87].

**T4. International legislations:** The international community has made it mandatory to comply with any legal regulations for sustainable energy management. These are issues related to climate and energy policies such as reducing greenhouse gases, increasing energy efficiency and the renewable energy rate, and increasing the biofuels used in the transportation sector [88].

**T5. Unprepared entry of electric vehicles into the market:** In a report prepared by the EU, the transport sector is responsible for 28% of the total carbon dioxide (CO2) emissions, and road transport for 70% of the transport sector emissions. The goal is for all cars, vans, and buses to be zero emissions by 2050 [89]. The view held by many automotive experts is that there will be an explosion in electric vehicle sales very soon because the critical point in this regard has been exceeded. Promoting electric vehicles, one of the most important options for reducing carbon emissions, will lead to scattered renewable energy storage [90]. However, the fact that the current network is unprepared for this situation is dangerous.

The results of this study were generally similar to studies examining the energy sector of Southern Cyprus. In the study based on SWOT analysis, Sangas et al., identified the country’s solar energy potential, natural gas reserves, and interconnection potential as strengths and opportunities. On the other hand, the risk of conflict, the dominance of fossil fuels in the energy system, and the low penetration of solar energy came to the foreground as weaknesses and threats [91]. Another study identified interconnected connectivity and natural gas, due to its environmental benefit over fossil fuel, as strengths [92]. Similarly, the risk of conflict identified in threats was defined as a problem for Cyprus.
The different striking result in this study is that Southern Cyprus considers EU membership as a strength and opportunity factor in both studies. The fact that NC is not a member of the EU explains this difference. On the other hand, although NC is not a member of the EU, the expert decision emphasized the necessity of complying with environmental obligations and international legislation as threats. The new SWOT factor that came to the fore for the first time in the study was electric vehicles. Experts evaluated the unprepared entry of electric vehicles into the market as a threat.

3.2. Priorities of the SWOT factors and sub-factors

Forty-seven pairwise comparison questions were asked to the members of the expert group in order to determine the importance levels of the SWOT factors and sub-factors. Six of the survey questions are for the SWOT factors, and 41 are for determining the relative priority of the SWOT sub-factors (see Supplementary data 1-S1). The geometric mean of the pairwise comparison responses given in the questionnaires by the experts was taken. This process was repeated for each pairwise comparison of the SWOT factor and its sub-factors (Geometric means are available in the Supplementary data 2-S2).

As an example, Table 5 shows the answers given by the experts after the pairwise comparison to the SWOT factors and the calculated geometric mean.

The resulting values obtained as a result of the geometric mean take their place in the matrix as the relative values of the SWOT factors. These processes can be solved by using the Microsoft Excel program, which can be prepared according to the AHP decision hierarchy structure. However, there are also software programs developed by Thomas L. Saaty. In this study, the Super Decision program was used [93].

First, a pairwise comparison of the four main factors constituting the SWOT group was made. Table 6 shows the relative order of importance of the strengths, weaknesses, opportunities, and threats in the pairwise comparison matrix of the SWOT factors. Experts determined "opportunities" as the most important criterion with a weight value of 0.359, while "strengths" and "weaknesses" were ranked very closely with weight values of 0.250 and 0.231, respectively. Experts put NCs "threats" to the energy sector in the last place in importance with a weight value of 0.158. Thus, the priority order was determined as (O) > (S) > (W) > (T).

Subsequently, a pairwise comparison of the sub-factors in the SWOT group was made. The priority vector and consistency ratios of each SWOT group are shown in Tables 7, 8, 9, and 10. CR of all groups was valid and below 0.1. The matrix is considered consistent if the CR is less than 0.1 [64].

The overall weights of the SWOT sub-factors were obtained by multiplying the SWOT factor priority weight by the sub-factor priority weight. The results are listed in Table 11.

The graph created according to the priority of the SWOT factors and the overall priority of the sub-factors was created in Figure 6.

The "strengths" criterion ranks second in importance within the SWOT group. However, in the overall prioritizing of the sub-factors, the highest weights were attributed to the criteria in the "strengths" group. The sub-factors of this criteria had weight values of 0.136 and 0.113, and the ranking was (S1) > (S2). This prioritization may imply the following interpretation: Although "strengths" only have two sub-factors, they rank in the top two with weighted values from other sub-factors. "Solar energy potential (S1)" is quite high in NC. Currently, out of different renewable energy sources, penetration into the power system in NC is provided only by solar energy. However, the potential of this renewable energy is not utilized sufficiently. For this reason, experts saw solar energy as the primary viable renewable alternative in their aspiration to transition from fossil energy to clean energy. “Geostrategic position in energy transmission (S2)” is a very important factor for both sides of the island of Cyprus. As a matter of fact, in two separate studies on the energy sector of the Southern Cyprus, the location of the island of Cyprus in the eastern Mediterranean came to the foreground, and the interconnected connection and natural gas pipeline options were brought to the plan [92, 94]. In this study, experts could not have ignored the advantageous position of Northern Cyprus in energy transmission compared to Southern Cyprus, especially in terms of distance to the mainland, in their decisions.

The "weaknesses" criterion ranks third in importance. Sub-factor weights explaining this criterion were prioritized between 0.073 and 0.013: (W5) > (W6) > (W1) > (W2) > (W3) > (W4). "Insufficient energy management (W5)" ranked first in the group with a weight value of 0.073 and ranked fifth in the overall ranking. Experts may have thought that all of the liabilities in the energy system, such as limited uses of solar energy, energy efficiency policy insufficiencies, insufficient installed power, were caused by inadequate energy management and placed it in the rankings accordingly. The remarkable point is that the "Renewable energy sources are solar only (W4)" sub-factor is in the last place both within its group and in the general ranking. This can be explained by the fact that experts consider it optimal to concentrate primarily on solar energy during the transition period.

The "opportunities" criterion ranks first in importance. However, its sub-factors could replicate this in the general ranking. Sub-factors of this criteria were given weight values of 0.08 and 0.04 and ranked as the following: (O3) > (O5) > (O1) > (O4) > (O6) > (O2). It is pleasing that the third priority in the general ranking is in this group: “Interconnected connection in energy transmission (O3)”. Because the opportunity for interconnected connection to the mainland is important for islands, it provides a sustainable solution for the decarbonization of the electricity sector [95, 96]. Experts could not ignore this factor, which will create an opportunity for the penetration of renewable energy into the energy system.

The “threats” criterion was seen as the least important in this study on sustainable energy planning. The sub-factors defining this criterion had weight values of 0.05 and 0.02, in the following order of importance: (T1) > (T2) > (T5) > (T4). Experts saw “Energy supply security (T1)” as the primary threat. This is an expected assessment. Energy security in NC is in jeopardy; often, the energy system loses its functionality owing to significant disruptions in energy supply or price changes [97]. Experts evaluated the "International legislations (T4)" factor as the least important threat. This decision can be explained as follows: Although the entire territory of the island of Cyprus belongs to the European Union (EU), only the southern part of the island is a member of the EU and is subject to the EU regulations. In other words, the EU acquis is not applied because the NC is not a member of the EU. Experts may have made their decision considering this atypical situation in their evaluations.

Known as the early stage of strategic planning, SWOT analysis cannot identify the priorities of each factor and sub-factor. The application of the AHP determines the importance of each factor. Factor priorities are used for decision-makers to develop new strategies in the strategy formation process [98].

According to the results obtained, 8 and 11 sub-factors were determined for the internal and external environment, respectively, in the sustainable energy planning of NC. As shown in Figure 7, the location of the current energy sector highlights taking advantage of strengths and opportunities. Among the SWOT groups, the highest scores on strengths and opportunities encouraged decision-makers to consider factor prioritization in formulating strategies. In this context, the S1 and O3 factors, which have the highest priority among strengths and opportunities, are the main factors to be considered when creating a strategy (especially SO, ST, WO). The process continued the same for each group, meaning W5 and T1 priorities had the same role in the process.

3.3. Alternative strategies

In the alternative strategy formulation, the general principles of the TOWS and AWOT analysis data were considered. While applying the TOWS analysis, answers were sought for questions such as "How can I make more use of opportunities by using strengths?" "How can I improve weaknesses by using opportunities?" and "How can I avoid threats using..."
In this framework, eight strategic alternatives are identified, as listed in Table 12.

In the next part of the discussion, since there is no other energy planning study for Northern Cyprus, studies specific to Southern Cyprus were given priority.

The first strategy is SO1 (natural gas pipeline laying). The strategy of laying a natural gas pipeline between NC and the mainland has geostrategic importance beyond just connecting to the mainland. At the same time, this line can be used to transport potential gas reserves from the Eastern Mediterranean to Europe. As a matter of fact, NC may be the closest and lowest cost bridge in energy transmission between Asia and Europe. NC’s geostrategic location can be seen as the main reason why experts consider natural gas reserves an important strategy for sustainable energy planning. Environmental benefits of natural gas is better than fossil fuels [99]. Experts decided to lay a natural gas pipeline as a strategic tool for sustainable energy planning. Tsangas et al. [92], similarly, in their study covering the Southern Cyprus energy sector, could not ignore the natural gas potential around the island of Cyprus for a pipeline interconnection and accepted that Cyprus’ hydrocarbon sector could be sustainable.

Another strategy, SO2 (installation of solar energy storage systems), has been commonly used to obtain hot water by utilizing solar energy, especially in residences, since the 1950s on the island. Due to its climatic conditions, Cyprus can benefit from solar energy almost year-round. However, the limited capacity of the existing grid prevents the use of high-energy potential from sunlight. There is widespread use of storage methods in many countries [100, 101]. Energy storage is an integral part of renewable energy and is necessary for sustainable economic development [102]. However, since the grid of NC is not connected to a large

Table 5. Evaluation results of the SWOT factors by five experts.

| Pairwise Criteria      | 1st    | 2nd    | 3rd    | 4th    | 5th    | Geometric Mean |
|------------------------|--------|--------|--------|--------|--------|----------------|
| Strengths vs. weaknesses | 0.3333 | 0.3333 | 3.0000 | 2.0000 | 3.0000 | 1.14870        |
| Strengths vs. opportunities | 0.3333 | 0.3333 | 5.0000 | 0.3333 | 1.0000 | 0.71971        |
| Strengths vs. threats   | 2.0000 | 2.0000 | 1.0000 | 0.3333 | 5.0000 | 0.46144        |
| Weaknesses vs. opportunities | 0.5000 | 0.3333 | 4.0000 | 0.3333 | 0.3333 | 0.59420        |
| Weaknesses vs. threats   | 4.0000 | 4.0000 | 0.5000 | 0.3333 | 5.0000 | 1.67876        |
| Opportunities vs. threats | 5.0000 | 3.0000 | 0.5000 | 2.0000 | 3.0000 | 2.14113        |

Table 6. Pairwise comparisons of SWOT factors (S2-1).

| SWOT group   | Strengths | Weaknesses | Opportunities | Threats | Priority vector |
|--------------|-----------|------------|---------------|---------|-----------------|
| Strengths    | 1.00000   | 1.14870    | 0.71371       | 1.46144 | 0.25059         |
| Weaknesses   | 0.87055   | 1.00000    | 0.59420       | 1.57876 | 0.22180         |
| Opportunities| 1.40113   | 1.98293    | 1.00000       | 2.14113 | 0.35905         |
| Threats      | 0.68426   | 0.59568    | 0.46704       | 1.00000 | 0.15856         |
| CR           | 0.00370   |            |               |         |                 |

Table 7. Priority vector and consistency analysis of the pairwise comparison matrix of the strengths (S2-2).

| Strengths | S1       | S2       | Priority vector |
|-----------|----------|----------|-----------------|
| S1        | 1.00000  | 1.20112  | 0.54569         |
| S2        | 0.83255  | 1.00000  | 0.45431         |
| CR        | 0.00000  |          |                 |

Table 8. Priority vector and consistency analysis of the pairwise comparison matrix of the weaknesses (S2-3).

| Weaknesses | W1 | W2 | W3 | W4 | W5 | W6 | Priority vector |
|------------|----|----|----|----|----|----|-----------------|
| W1         | 1.00000 | 1.05920 | 1.21290 | 2.72407 | 0.47818 | 1.03693 | 0.16229 |
| W2         | 0.94411 | 1.00000 | 1.08447 | 2.60517 | 0.52961 | 0.54928 | 0.14327 |
| W3         | 0.82447 | 0.92211 | 1.00000 | 2.35216 | 0.50000 | 0.69883 | 0.13680 |
| W4         | 0.36710 | 0.38385 | 0.42514 | 1.00000 | 0.20069 | 0.34657 | 0.05929 |
| W5         | 2.09128 | 1.88818 | 2.00000 | 4.98292 | 1.00000 | 2.26793 | 0.31553 |
| W6         | 0.96439 | 1.82056 | 1.43097 | 2.88540 | 0.44093 | 1.00000 | 0.18282 |
| CR         | 0.000805 |        |       |       |       |       |                 |

Table 9. Priority vector and consistency analysis of the pairwise comparison matrix of the opportunities (S2- 4).

| Opportunities | O1      | O2      | O3      | O4      | O5      | O6      | Priority vector |
|---------------|---------|---------|---------|---------|---------|---------|-----------------|
| O1            | 1.00000 | 1.64375 | 0.87055 | 0.97365 | 0.65071 | 1.36851 | 0.16713         |
| O2            | 0.60836 | 1.00000 | 0.53649 | 0.87055 | 0.57292 | 0.83255 | 0.11441         |
| O3            | 1.14870 | 1.86396 | 1.00000 | 2.35216 | 1.14870 | 2.22064 | 0.24703         |
| O4            | 1.02707 | 1.14870 | 0.42514 | 1.00000 | 0.713771 | 0.14870 | 0.13859         |
| O5            | 1.53678 | 1.74544 | 0.87055 | 1.40113 | 1.00000 | 1.43097 | 0.20695         |
| O6            | 0.73072 | 1.20112 | 0.45032 | 0.87055 | 0.69883 | 1.00000 | 0.12590         |
| CR            | 0.00865 |        |       |       |       |       |                 |
and powerful grid, the solar energy capacity cannot be increased above 20% of the installed power capacity of the base plants. Therefore, the continuity of PV investments above a certain capacity in NC points to the necessity of storage.

Heavy fuel oil, and diesel power plants are used as energy sources in the current system. With the WO1 (conversion of fuel plants to LNG and capacity increase) strategy, instead LNG can be an important energy source alternative and existing power plants can be converted into LNG. Experts have suggested this strategy to improve old and inadequate power plants and ensure an uninterrupted energy supply. LNG is considered an environmentally friendly fuel compared to other fossil fuels. Because it has lower carbon dioxide and local air pollutants, it is a transitional source for countries between fossil fuels and renewable energy sources, as emphasized in Chavez-Rodriguez et al., [103]. A combined-cycle power plant to be built with the combination of gas and steam turbines will be meaningful with the supply of natural gas to the country in the future.

The geostrategic location of the island of Cyprus in the Eastern Mediterranean makes Cyprus important in electrical energy transmission. Therefore WO2 (establishing the interconnected connection) strategy is an alternative that is expected to be recommended by experts. The interconnected connection between the mainland and NC also means a connection to the European powerline. While the strategy will maximize the electricity quality in the existing grid, it will also result in the security of supply. It can also remove the limitations on renewable energy sources to be installed in the system and pave the way for the energy transition. It will be able to connect Asian and European energy transmission lines with future submarine interconnections. The strategy was similar to the results of a study for southern Cyprus; emphasizing that priority should be given to pipelines and electricity cable interconnections with area countries [99].

ST1 (Establishment of a regional cooperation policy), Cyprus problem is seen as a weakness and threat to the energy sector. On the other hand, Çayır et al. discussed this strategy in terms of energy use, prevention of losses and reduction of energy density and handled it in the energy planning process [105].

Table 10. Priority vector and consistency analysis of the pairwise comparison matrix of the threats (S2-5).

| Threats | T1   | T2   | T3   | T4   | T5   | Priority vector |
|---------|------|------|------|------|------|-----------------|
| T1      | 1.00000 | 2.16894 | 2.45951 | 2.99256 | 2.35216 | 0.37646         |
| T2      | 0.46105 | 1.00000 | 1.24573 | 2.09128 | 1.51572 | 0.20709         |
| T3      | 0.40659 | 0.80274 | 1.00000 | 0.80274 | 1.24573 | 0.14711         |
| T4      | 0.33416 | 0.47818 | 1.24573 | 1.00000 | 0.87055 | 0.13036         |
| T5      | 0.42514 | 0.65975 | 0.80274 | 1.14870 | 1.00000 | 0.13907         |
| CR      | 0.01315 | | | | | |

Table 11. Overall priority of the SWOT sub-factors.

| SWOT Factors | Priority of the Factors | SWOT Sub-Factors | Consistency Ratio | Priority of the Sub-Factors | Overall Priority of the Sub-Factors | Rank |
|--------------|-------------------------|------------------|-------------------|-----------------------------|------------------------------------|------|
| Strengths (S) | 0.25059 | S1 | 0.00000 | 0.54569 | 0.13674 | 1 |
|              |           | S2 | 0.45431 | 0.11385 | 2 |
| Weaknesses (W) | 0.23180 | W1 | 0.00805 | 0.16229 | 0.03762 | 12 |
|              |           | W2 | 0.13427 | 0.03221 | 13 |
|              |           | W3 | 0.12680 | 0.03171 | 15 |
|              |           | W4 | 0.05929 | 0.01374 | 19 |
|              |           | W5 | 0.31553 | 0.07314 | 5 |
|              |           | W6 | 0.18282 | 0.04238 | 10 |
| Opportunities (O) | 0.35905 | O1 | 0.00865 | 0.16713 | 0.06001 | 6 |
|               |           | O2 | 0.11441 | 0.04108 | 11 |
|               |           | O3 | 0.24703 | 0.08870 | 3 |
|               |           | O4 | 0.13859 | 0.04976 | 8 |
|               |           | O5 | 0.20695 | 0.07431 | 4 |
|               |           | O6 | 0.12590 | 0.04520 | 9 |
| Threats (T)   | 0.15856 | T1 | 0.01315 | 0.37646 | 0.05969 | 7 |
|               |           | T2 | 0.20701 | 0.03282 | 14 |
|               |           | T3 | 0.14711 | 0.02333 | 16 |
|               |           | T4 | 0.13036 | 0.02067 | 18 |
|               |           | T5 | 0.13907 | 0.02205 | 17 |

Figure 6. Priority of the factors and overall priority of the sub-factors.
If relations and security dynamics improve, joint energy projects can be realized by ensuring political stability. Spatial proximity, shared infrastructure and cooperation by regional actors are considered the most important drivers of energy development in regional environments [106]. With this strategy, the threat of geopolitical conflict will be disappeared [107].

WT1 (Preparation of an energy policy and legal regulations), the energy policy implemented in NC is far from sustainable. This strategy will be a driving force for energy policymaking and compliance with international legal regulations. Research has shown that energy policies and regulations for sustainable development impact poverty reduction, energy security, equitable access to energy, and the transition to a more efficient and environmentally friendly energy system [102].

The eighth and final proposed strategy is WT2 (Diversification of renewable energy source alternatives). In NC, only high potential solar energy unique to islands is used as a renewable energy source. However, each grid has a unique renewable capacity, and it is assumed that renewable energy sources cannot be used above this capacity. This is particularly relevant for solar energy. However, alternatives such as biofuels, wind, and hydrogen energy, which will contribute to the pool of sustainable renewable energy resources, can increase this rate. Despite the potential to harness wind power [21], wind plants have yet been installed in NC. In recent years, WT2 strategy has been frequently recommended by policymakers in energy planning and management, especially in societies with small grids [108]. The study for Southern Cyprus has shown that in sustainable development, efficient use is provided from the photovoltaic park, wind park and biogas unit [109].

4. Conclusion and future perspective

Some of the strategies obtained in this study are similar, but their effects are NC-specific. Regional cooperation policy is a commonly proposed strategy. However, the risk of conflict in the Eastern Mediterranean will affect not only the northern part of the island but also the entire island of Cyprus and, due to its hydrocarbon potential, the energy welfare and security of other neighboring countries. The effects of interconnected connection and natural gas pipeline laying strategies to the mainland are also unique. Both strategies will lead to the link of the island of Cyprus to the European energy transmission network. In the future, the island could play a crucial role in energy transmission due to potential undersea links between Asia and Europe.

This study has the potential to become a foremost source in providing energy strategies to energy planners and academics during the energy transition period, specifically for NC. However, qualitative research results form the limits of this study. The study can be carried forward in the next step, and qualitative strategy alternatives can be ranked using the multi-criteria decision method. In addition, the research can be accompanied by analysis with numerical optimization tools, especially on specific issues such as integrating renewable energy sources into the energy system. The study results may also be of interest to policymakers.
and academics of other Eastern Mediterranean countries due to their potential hydrocarbon reserves.

**Declarations**

**Author contribution statement**

Soley Akçaba: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Fehimân Eminer: Conceived and designed the experiments; Wrote the paper.

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**Data availability statement**

Data will be made available on request.

**Declaration of interest statement**

The authors declare no conflict of interest.

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