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Assessment of Energy Sustainability Issues in the Andean Community: Additional Indicators and Their Interpretation

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Abstract: To achieve sustainable development goals (SDGs), it is necessary to solve the problem of assessing and measuring energy sustainability performance. A popular indicator used for this purpose is the World Energy Council (WEC) energy sustainability index, or the Energy Trilemma Index, which is based on such key metrics as energy security, energy equity, environmental sustainability, and country context. Each of the four metrics, or dimensions, includes many indicators that depend on both internal and external factors. By combining a variety of indicators into integral ones, WEC ranks countries in terms of energy sustainability. However, what is not taken into account is how countries differ in terms of economic development, income, energy mix, renewables use, ownership in the energy sector, and other factors, and neither is the methodology itself disclosed by the developers. As a provider for all other sectors of the economy, the energy sector plays an important role in developing countries. Ecuador, Colombia, Peru, and Bolivia, being members of the Andean Community, are neighbors and have similar economic conditions but lack transnational power grid interconnections, which hinders the development of a common energy market. In terms of energy sustainability, these countries' ranks range from 45 to 101, according to the Energy Trilemma Index. The aim of the study is to develop a new methodology for assessing energy sustainability performance that will factor in the specific features of developing countries with a high share of hydroelectricity generation, and to calculate energy sustainability index indicators taking into account contemporary requirements for sustainable development, which include developing green and renewable energy and fostering decarbonization. This research reveals whether the countries' energy sustainability indices correspond to their actual performance in energy development and identifies the factors influencing the values of the metrics in the Energy Trilemma Index. The methodology can be used to integrate the energy sectors of countries, as it allows for evaluating the state of the energy sector of several countries (for example, those of the Andean Community) as a whole.

Keywords: energy sector; Andean Community countries; Energy Trilemma Index; energy efficiency; environmental sustainability; energy equity; hydroelectric power

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1. Introduction

The energy sector supports the whole economy, which makes its sustainable development a prerequisite for the growth of the country's key industries and GDP [1–3]. While the problem of measuring the level of sustainable development is yet to be solved for many sectors of the economy [4–6], the energy sector has a sustainable development assessment tool, which is the Energy Trilemma Index. This index was proposed by the World Energy Council [7] in 2011 and allows for ranking individual countries.

In the World Energy Council Energy Trilemma 2020 Report, 108 countries were ranked and assigned grades ranging from AAA to DDD. The AAA (top) grade signals that the country has a stable economy and a high-quality energy policy.

Aggregate indices have become very popular due to the fact that it is difficult to objectively compare the level of development of very different energy systems around the world. Ranking based on aggregate indices is more realistic than using separate benchmarks in the assessment process [8].

From 2011 to 2020, adjustments were made to the methodology for calculating the Energy Trilemma Index, with the number of categories and metrics changing in order to improve the comparability of the results obtained for individual countries [9–11]. This raises the question of whether the metrics and their weights are valid, which is important to understand as it is these parameters that make it possible to correctly assess the level of energy sustainability of an individual country and its changes over time in comparison with other countries.

The Energy Trilemma Index is a tool for making annual assessments of the development of the energy sector of a particular country in comparison with other countries. It also helps to draw a conclusion about the effectiveness of the country's energy policy, ensure balanced management in the energy sector, analyze competing priorities and development opportunities, and learn from the experience of the leaders in energy policy, energy development, and green energy [8]. At the same time, there is still an unresolved problem of how to identify factors determining the level of the country's energy sustainability and explain their influence. The energy sustainability index includes assessments of energy security, energy equity, environmental sustainability, and energy management in country-specific contexts. Next we will discuss how countries are ranked by these metrics.

In terms of energy security, the top ten countries are those that either hold significant oil and gas reserves or are focused on energy diversification and green energy [12]. Examples of such countries include Canada, Finland, Romania, Denmark, Latvia, Sweden, Brazil, Czech Republic, United States, Bulgaria, and Hungary. Often, the level of energy security is predetermined by the uneven distribution of fuel and energy resources on the planet. Countries that lack their own fuel and energy reserves become dependent on countries or regions exporting energy resources [13].

In our opinion, a big amount of oil and gas reserves is not as much of an indicator of energy security as it is a key that opens doors to export routes. As decarbonization has become a popular trend, hydrocarbon reserves in themselves are becoming less important than technologies that make their use efficient and environmentally friendly [14]. A lack of such technologies can lead to a decrease in the efficiency of energy generation. The diversification of energy resources should be supported by the diversification of energy capacities, with energy security being ensured by a balance between the facilities running on fossil fuels and those powered by renewable energy sources. All these factors make the issue of energy security a topic for discussion since there is no unanimous agreement as to what assessment parameters should be used. As for countries where hydroelectricity generation plays an important role, they have their specific features. On the one hand, they enjoy the benefits that are brought by using renewables, but, on the other hand, relying on one source of energy is associated with risks. Despite these risks, Brazil features in the top ten energy security list due to large-scale hydroelectricity production and having the largest hydropower plants in the world.

The top ten countries in terms of energy equity are those that have low energy costs. Access to reliable and affordable energy makes it possible to achieve economic prosperity, but at the moment there is an increasing focus on the quality of energy supply [12]. Examples of countries ranking high in this dimension are Luxembourg, Qatar, Kuwait, UAE, Oman, Bahrain, Iceland, Saudi Arabia, Iran, Singapore, Ireland, Hong Kong, China, Netherlands, Trinidad and Tobago, Switzerland, and Israel. This list does not include South American countries where hydroelectric power dominates. Although the costs of hydroelectric power generation are among the lowest in this region, such a problem exists because of power supply interruptions, due to the influence of hydrological and geographical conditions, and seasonal decreases in the hydropower potential of even the largest rivers.

It is understandable that having low costs associated with energy production and fossil fuel processing (primarily oil processing) is extremely important both for energy companies and the entire national economy as it influences the economic efficiency of production, the well-being of the population, and the prices for all other types of products. For example, Latin America has a well-developed metallurgy sector producing such energy-intensive products as copper, aluminum, nickel, pig iron, and other metals [15]. Energy security, reliability, and quality are influenced by the activities of both energy producers and the government, and determine energy equity for both businesses and citizens.

In terms of environmental sustainability, top performers are countries that focus their policies on reducing greenhouse gas emissions, improving energy efficiency, decarbonization, and energy system diversification [12]. Accelerating climate change and growing resource scarcity are putting unprecedented pressure on the global community and have potentially serious implications for the future well-being of nations and the stability of key ecosystems [16–18]. As a result, a lot is spoken about the fourth energy transition, which implies the widespread use of renewable energy sources and the elimination of fossil fuels [19–21]. In addition to renewable energy sources, a significant impact on countries' energy mixes is made by distributed energy generation, digitalization of the economy [22], decarbonization of the energy sector and other industries [23], innovations in smart energy systems, novel energy materials and low carbon technologies [24], the introduction of energy storage systems (batteries, fuel cells), the utilization of new CO_2 sequestration technologies [25–27], the transition to electric vehicles, all of which significantly changes the structure of the energy market, stimulating energy saving and improving energy efficiency [28]. The examples of countries include Switzerland, Sweden, Norway, Albania, France, Panama, Costa Rica, Uruguay, Colombia, Brazil, and Denmark [12]. In WEC's rankings, five large and small countries of Latin America are classified as leaders by their environmental indicators. However, while hydropower generation produces low carbon dioxide emissions, hydroelectric power plants with impoundment facilities produce major emissions of methane, which is a greenhouse gas.

As countries differ from each other in terms of economic, historical, political, geographic, and institutional conditions, it limits their comparison. To obtain results in a sustainable energy performance assessment that can be used to improve energy policies in both individual countries and their unions, it is advisable to select regions with comparable conditions and influencing factors.

This study analyzes the countries belonging to the Andean Community in Latin America, namely Ecuador, Peru, Colombia, and Bolivia. The activities of the Andean Community are aimed at developing a common economic policy, the harmonization of law, and establishing close ties between regions and governing bodies [29].

At the same time, the energy sectors of the countries are not integrated into one system. To integrate them in a rational and efficient manner, a research problem should be solved for the economic assessment of the state and the performance of the countries' energy sectors, for which reasonable indicators should be selected. Comparing the countries' rankings will help to create conditions for the successful integration of all participating countries.

Limited access to the detailed description of the methods and the database used to calculate the World Energy Trilemma Index (WETI) means that they cannot be analyzed in detail or have a broad scope of application. It makes the WETI of very limited interest for research as it is difficult to explain why countries differ in terms of their ranks or use the information the index provides for improving the energy policy of individual countries, let alone solving integration problems [8].

The aim of the study is to propose a method for assessing energy sustainability performance based on the WEC methodology that can be applied to countries with hydropower as the key element in their energy mix, and to compare the economic, environmental, and social indicators of the energy sectors of the Andean Community countries, calculated in accordance with the proposed methodology with their WETI ranks, and to analyze the results for the purposes of government regulation and possible integration.

The main objectives of the study are:

1. To adapt the WEC methodology and select indicators for calculating energy sustainability indices for the members of the Andean Community that rely on hydroelectric power;
2. To select and calculate additional indicators and to explain the WETI ranks of the Andean Community countries;
3. To identify the factors influencing the energy sectors of the Andean Community members and such characteristics as energy security, energy equity, environmental sustainability, and country context, with the aim of integrating them into one system in the future.

2. Materials and Methods

2.1. The System of Indicators Developed by the Authors Is Based on the World Energy Trilemma Framework and the Energy Sustainability Index of the World Energy Council

The conceptual basis of both energy indices (WETI in particular) and energy future scenarios is the concept of the energy trilemma. This concept focuses on three key vectors of energy development: energy security, energy equity, and environmental sustainability, which cannot be balanced without international cooperation at different levels, and integration at the systems level and in the field of information exchange. The Energy Trilemma provides a framework for dialogue that serves as an innovative tool for building a future with fairer, more sustainable, and accessible energy systems [30].

Energy security (30%) reflects a country's ability to meet current and future energy needs and withstand internal and external risks. This dimension shows the efficiency of energy sector management, as well as the reliability and sustainability of the energy infrastructure, and covers such aspects as the security of energy supply and demand (12%) and the resilience of energy systems (18%).

Energy equity (30%) assesses a country's ability to provide universal access to reliable and affordable energy sources, clean fuels and technologies, and energy for domestic and commercial use. This dimension reflects the level of well-being associated with the consumption and availability of electricity, gas, and fuel, and is comprised of such indicators as energy access (12%), quality energy access (6%), and energy affordability (12%).

Environmental sustainability (30%) represents the ability of the country's energy sector to prevent potential environmental damage and climate change. This criterion focuses on the efficiency of production, transmission, and distribution of energy, and covers such aspects as resource productivity (9%), decarbonization (9%), and emissions and pollution (12%).

In 2019, a new dimension—country context—with a share of 10% was proposed to reflect the institutional and macroeconomic differences between countries. It assesses energy policies, regulatory framework, incentives for R&D and innovative technologies, and investment policies, including macroeconomic environment (2%), governance (4%) and stability for investment and innovation (4%) [9,31].

We used Energy Outlook of Latin America and the Caribbean reports by Latin American Energy Organization (OLADE) for years 2017 to 2019 [32–34] as the sources of initial data.

2.2. The Proposed Methodology for Assessing Energy Sustainability

Based on the World Energy Trilemma framework, twelve indicators are proposed for the following four dimensions: energy security, energy equity, environmental sustainability, and government regulation.

In general, it is very difficult to be objective in comparing the level of development of energy systems as they are very different. Taking into account regional and national indices can give a more realistic idea of the trends and prospects of their energy sectors for political, investment, and integration purposes. Taking into account the specific features of both the energy systems of the countries under consideration, their economic opportunities, political and social orientation, and similar geographic features will make it possible to create a realistic assessment of whether the energy systems of the region being discussed are developing in a sustainable manner. It can be done if countries are compared in terms of different dimensions.

The first dimension includes the following indicators: percentage of imports, diversity of electricity generation, and energy storage (petroleum reserves, gas reserves, and carbon reserves). Percentage of imports shows the extent to which countries depend on primary energy imports, which determines their dependence on the conditions set forth by suppliers and the need to accumulate sufficient financial resources. Diversity of electricity generation shows how much primary resources a country uses (or can use) to generate electricity, which improves the reliability of energy generation and ensures uninterrupted electricity supply. Energy storage (petroleum reserves, gas reserves, and carbon reserves) reflects how long the members of the Andean Community will have sufficient supplies of oil, gas, and coal, which are the key types of fossil fuels. It is important to note that we add to the WEC methodology the evaluation of coal reserves as it is expected that environmentally friendly and efficient technologies for fossil fuel processing, in particular new methods for coal processing, will be developed in the near future.

An issue here is that the first dimension focuses primarily on fossil fuels (hydrocarbons). This is why we argue that such additional indicators can be used as hydropower potential, hydropower nominal capacity, and hydropower generation.

The second dimension of energy equity should include the following indicators: access to electricity (% of the population), electricity prices, and gasoline prices. Access to electricity is influenced by economic, energy, and technical factors. Access to electricity is a key indicator that shows the percentage of the country's inhabitants having access to energy sources, which is an important indicator for Latin America. When analyzing energy equity, we considered electricity prices (USD/kWh) and gasoline prices (USD/L) to be of equal importance. In our opinion, the growing demand for cars in Latin America is accompanied by the growing demand for gasoline, which is the most popular vehicle fuel [35]. In our opinion, an additional indicator here can be the amount of energy that can be bought with an average salary, which can be critically important for low- and middle-income countries.

The third dimension includes such indicators as final energy intensity, low carbon electricity generation, and CO_2 emissions per capita. Energy intensity characterizes the energy efficiency of national production (USD/kWh). Low carbon electricity generation is a modern trend in the energy sector that serves as the driving force behind not only environmental but also economic and social progress of the 21st century. CO_2 emissions per capita can be viewed as both a key environmental sustainability indicator and an economic development indicator, and it reflects whether Latin American countries follow the global decarbonization trend or not. As it was noted, hydroelectric power plants can be assessed in terms of their methane emissions, which will complement the data on the emissions of CO_2, the key greenhouse gas.

The fourth dimension includes the following indicators: macroeconomic stability, effectiveness of government, and innovation capacity. Macroeconomic stability is characterized by economic development, the effectiveness of government policy, and the country's level of economic security. Macroeconomic stability reflects whether the government creates attractive investment conditions, which is important for Latin American countries due to the lack of funds coming from domestic investors and the fact that per capita income in these countries is lower than average [36–38]. Government control in the energy sector takes the form of measures aimed at improving power generation, power supply, and power consumption systems. Effectiveness of government is associated with the regulatory instruments that ensure the implementation of decisions taken, reduce risks, generate resources for the implementation of energy strategies, and contribute to the sustainable development of the country's energy sector. It is greatly influenced by the institutional environment, which is a set of legal, social, and economic rules and models according to which the fuel and energy sector functions. The institutional factors of such areas as developing norms and standards, improving the regulatory framework, research and information exchange, coordination of actions in the field of economic relations, innovation capacity, opportunities in the consumer sector, and management quality. For low- and middle-income developing countries, subsidies and grants are critical and can be measured both quantitatively and qualitatively and used as additional indicators.

Tables with initial data are compiled for the twelve indicators in the four dimensions. The indicator values in the analysis are based on data obtained from [33–35] for four Andean Community members. Additionally, the maximum and minimum values for all countries of Latin America are taken into account.

To ensure that the values of indicators measured in different units can be compared, the values for each indicator are converted into scores. First, it is determined whether the indicator should be maximized (i.e., the higher the value of the indicator, the better result it reflects) or minimized. Conversion to scores is made using the formulas:

Intermediate values of indicators:

$$Q\ max = (Act.\ Val. - Min.\ Val.)/(Max.\ Val. - Min.\ Val.) \quad (1)$$

$$Q\ min = (Max.\ Val. - Act.\ Val.)/(Max.\ Val. - Min.\ Val.) \quad (2)$$

where Max. Val. is the highest value of the indicator for all countries of Latin America, Act. Val. is the value of the indicator in the country under consideration, and Min. Val. is the lowest value of the indicator for all countries of Latin America.

The weights of all twelve indicators (12) in all four dimensions (4) are assumed to be equal, i.e., their weighting factors in each dimension are 0.33 (three indicators in each dimension). The only exception is the energy storage indicator (in energy security dimension), which includes three types of non-renewable energy sources (petroleum, natural gas, and coal) with a weighting factor of 0.11 each. The total weight of the indicator is still 0.33. The results are presented in the tables.

The resulting values are compared with those published in the WEC report. Deviations and factors influencing the values of indicators are revealed, and the results are interpreted.

Additional indicators are then determined, factors influencing the values of indicators produced by the proposed methodology are analyzed, and an interpretation of the results is given.

3. Literature Review

Sustainable development indicators are of particular interest to modern interdisciplinary research. For example, the UN Agenda for the 21st century contains the requirement that countries and organizations should develop systems of sustainable development indicators that can serve as a foundation for making decisions at all levels [39]. The sustainable development of the energy sector is in Sustainable Development Goal 7 (SDG 7), established by the United Nations General Assembly. SDG 7 aims to ensure access to affordable, reliable, sustainable and modern energy for all [40]. Reasonable and well thought out indicators of sustainability can provide valuable information for monitoring progress or regress in a given sector of the economy.

Studies on the sustainable development of the energy sector cover a wide range of issues, and there is no unanimous agreement as to what methods should be used for a sustainable development assessment. A large number of authors from around the world give their interpretations of various methods, indicators, and tools for calculating/measuring the sustainable development of the energy sector. The goals, aims, and indicators taken into account, as well as the methods for calculating the sustainability of the energy sector, differ depending on the country, but the common denominator is that adherence to the energetic trilemma framework is considered to be the key principle as sustainable energy development contributes to social and economic well-being while ensuring environmental friendliness and the rational use of resources [41].

An analysis of major publications on the topics related to the energy trilemma index showed that they propose making adjustments to methods for calculating individual components of the index or changing the ways experts assess some indicators of the index in order to factor in the specific features of the country. This is understandable, since many researchers are well aware of the regional or other individual features of the energy sector they are studying, so they try to incorporate them in their works.

The study titled "Managing the Energy Trilemma: The Case of Indonesia" examines the challenges of the energy sector in Indonesia through the prism of the Energy Trilemma Index [42]. The authors of the article titled "Comparative analysis of trend of change of Azerbaijan's energy sector functioning stability at the current development stage" [9] use the methodology for calculating the energy sustainability index proposed by the World Energy Council and propose indicators for calculating the level of sustainable development of the energy sector in Azerbaijan, arguing that it is difficult to assess all countries using the indicators proposed by WEC as there is limited information for some of the indicators. From our point of view, it is advisable to assess sustainable development in individual regions or countries by using a combination of indicators that will reflect the specific features of their economic conditions, social environment, environmental issues, and the productivity of the energy sector.

The study titled "Energy Trilemma Based Prioritization of Waste-to-Energy Technologies: Implications for Post-COVID-19 Green Economic Recovery in Pakistan" [43] examines waste-to-energy (WTE) conversion as an alternative green fuel for Green Economic Recovery (GER). The seven WTE technologies presented in the article are prioritized based on the concept of the energy trilemma, which implies energy security, energy equity, and environmental sustainability. For the assessment, a decision support system based on the energy trilemma was developed using the most famous multi-criteria decision-making (MCDM) methods. The authors conclude that a transition to sustainable energy is necessary to limit carbon emissions and prevent a future crisis.

The authors of the article "The Swiss Energy Transition: Policies to Address the Energy Trilemma" [44] present an electricity market model that simulates the Swiss energy transition. The study shows the importance of understanding the interactions between policy and market participants to effectively achieve decarbonization goals. The authors simulate three national development scenarios (Reference, RES +, NUC +), which differ in plans to support renewable energy sources and to phase out nuclear energy. The authors of the study compare them in terms of the dimensions of the Energy Trilemma prism: sustainability (CO_2 emissions), affordability (costs for the consumer), and security of supply. All scenarios prove the need for a strategic reserve to ensure compliance with the security criteria.

The article titled "Review of indicators for sustainable energy development" [45] notes that the sustainable development of the energy sector has become an international policy goal, which reflects various problems faced by energy systems, among which are the depletion of fossil fuel reserves, growth in energy consumption, and climate change. The authors emphasize that it is of paramount importance to develop ways for tracking progress, or lack thereof, towards sustainable development in the energy sector and assessing government policies that contribute to the desired development.

The article titled "An evaluation framework for future integrated energy systems: A whole energy systems approach" [46] discusses the issue of energy system integration, including such elements as gas, heat, and transportation systems, which is one of the possible ways to ensure smooth economic and energy transitions that are driven by the need to achieve the goals of the energy trilemma, namely decarbonization, acceptability, and security. This study argues that the already existing methods are unable to assess the performance of integrated energy systems because they lack one or more characteristics or indicators. The authors present a novel holistic evaluation framework based on the System-of-Systems approach for systems analysis coupled with an indicator-based approach for evaluation. The proposed approach allows for making such an assessment that factors in multiple points of view and goals at different levels of the energy system. In our opinion, it is important that this approach can factor in future changes in the entire energy system and identifies the interdependencies between the systems. This approach can also be used for evaluating different scenarios.

In the article "Measuring National Energy Performance via Energy Trilemma Index: A Stochastic Multicriteria Acceptability Analysis" [47], the authors propose to use an alternative ranking framework for the parameters of the Energy Trilemma Index based on interval estimates and composing interval decision matrices for ranking countries by the components of energy security, energy equity, and environmental sustainability. The authors of "Resolving Society's Energy Trilemma Through the Energy Justice Metric" [48] and "Balancing the Energy Trilemma Through the Energy Justice Metric" [49] propose an Energy Justice Metric and show how this can balance the competing goals of the energy trilemma.

The study titled "The dynamic role of energy security, energy equity and environmental sustainability in the dilemma of emission reduction and economic growth" [50] examines the relationship between energy security, energy equity, and environmental sustainability in terms of economic growth and CO_2 emissions. The main finding of this study is that all other things being equal, a higher energy price will indicate a higher degree of energy scarcity, stimulating the search for cheaper and renewable alternatives and ultimately affecting the supply. Measuring carbon emissions will reduce greenhouse gas emissions, creating incentives for energy efficiency. This will change patterns in energy consumption and make it cleaner in order to maximize profits. The need for a transition to sustainable energy to limit carbon emissions and prevent future crises is also highlighted in [43].

Of interest is the study titled "Energy quadrilemma and the future of renewable energy" [51], as it proposes a new concept of quadrilemma. This concept, in comparison with the energy trilemma, considers four dimensions—cost, environment, security, and job opportunities. As the author believes, such a system covers more aspects in the movement towards 100% renewable energy sources.

The study "An Extended GRA Method Integrated with Fuzzy AHP to Construct a Multidimensional Index for Ranking Overall Energy Sustainability Performances" [52] proposes a foundation for developing an index that measures the energy sustainability of countries. Thirty-five OECD member countries are considered. The authors propose changes and adjustments regarding the normalization procedure of the GRA method. We believe that the authors made an important contribution to the literature on MCDMs.

In the study titled "A Step to Clean Energy–Sustainability in Energy System Management in an Emerging Economy Context" [53], the authors present and evaluate the indicators of sustainable development and energy system management in emerging economies using the example of India. The authors used a gray based Decision-Making Trial and Evaluation Laboratory technique to understand the causal interactions among indicators and segregate them. In our opinion, this study can be used by energy companies to implement and monitor strategies aimed at developing energy systems and achieving sustainable development goals in the field of green energy at the national level.

It is also important to assess the sustainability of power plant projects (hydroelectric power plants, nuclear power plants), tracking their environmental, economic and social aspects in the context of assessing the sustainability of energy systems. The authors of the article "Integrated approach for sustainability assessment in power plant projects using Building Information Modeling" [54] suggest using Building Information Modeling (BIM) to develop a plugin for the proposed rating system to determining the level of sustainability of power plant projects.

Not everybody in the scientific community supports the Energy Trilemma Index framework, making it a topic for debate. For example, the article titled "Energy security in decision making and governance—Methodological analysis of energy trilemma index" [55] assesses the methodological parameters of the energy sustainability index proposed by the World Energy Council. The assessment of the methodological setting of index reliability was made using a set of statistical methods: principal component analysis (whose additional interpretation was carried out using the following tests: Pearson correlation test, Kaiser–Meyer–Olkin measure of sampling adequacy, and Bartlett's test of sphericity). The final assessment of reliability was made using the Cronbach's Alpha test. Based on the results of the analysis, it was established that the Energy Trilemma Index can in no way be considered reliable due to a number of disadvantages, of which the most important is the end indicator of Cronbach's Alpha value (0.694), which stands at the very margin of reliability (0.600) [55].

This literature reviews brings us to a conclusion that while there is an obvious need to measure and assess energy sustainability, the choice of indicators remains a debatable issue and should be made taking into account both the energy trilemma principles and the specific features of the countries being assessed.

The analysis of WETI applicability gives grounds to conclude that this index was created in the interests of businesses and analytical agencies for solving energy industry management problems and making decisions, but it is not for use in scientific research. It is confirmed by the fact that the methodology for calculating the index is not disclosed by the WEC structure (according to the official website, 7% of WEC members are government representatives, 38% are business representatives, and 25% belong to the expert community [7]).

4. Results

The analysis of the key economic indicators of the Andean Community members showed that there are both commonalities and differences. The countries are located close to each other, have some primary energy reserves, and rank low in terms of energy per unit of GDP and renewable sources/GDP (Table 1). In all countries of the Andean Community, energy consumption and production are balanced, i.e., the former does not exceed the latter. The countries under consideration differ in terms of population. For example, Colombia's population is estimated at 50.3 million, while that of Bolivia is four times smaller. Bolivia's GDP is also significantly smaller than that of other Andean Community members. Colombia has the biggest oil and coal reserves, while Peru and Bolivia have the biggest gas reserves. Colombia is a leader in energy production and consumption.

Table 1. Key development indicators of the Andean Community members as of 2019.

Indicators/Country	Ecuador	Colombia	Peru	Bolivia
Population, mln.	17.37	50.33	32.51	11.47
GDP, USD thous. of mln.	108	323	230	41
GDP per capita, USD	6261	6419	7098	3578
Oil reserves, mln. of USA barrels	1303	2041	345	190
Natural gas reserves, Gm^3	4	90	299	253
Coal reserves, Mt	0	5912	7	0
Primary energy production, Mtoe	31.02	137.41	62.71	17.24
Energy per unit of GDP, kep/USD 2011 PPA	0.08	0.06	0.08	0.09
Renewable sources/GDP, kep/USD 2011 PPA	0.01	0.01	0.02	0.01
Total energy consumption, Mtoe	13.38	32.14	21.51	6.79

Compiled by the authors based on [34].

Table 2 shows the Andean Community members' rank in terms of energy sustainability.

Table 2. Energy sustainability indices of the Andean Community members.

Country/Year		2017		2018		2019	
		Rank (Out of 125 Countries)	**Grade**	**Rank (Out of 125 Countries)**	**Grade**	**Rank (Out of 128 Countries)**	**Grade**
Ecuador		64	BBC	62	CBB	45	ABBd
Colombia		45	BCA	48	BCA	49	BCAc
Bolivia		101	CCD	99	CCD	84	BCCd
Peru		55	BCB	51	BBA	58	ACBb
Latam countries	Highest	Uruguay (35)	CBA	Uruguay (28)	BBA	Uruguay (17)	ABAb
	Lowest	Honduras (108)	DDD	Honduras (109)	DDD	Nicaragua (102)	DCCd

Compiled by the authors based on data from the World Energy Council [11,56,57].

Table 2 shows that the countries under consideration vary in their ranks, which mainly range from 50 to 100. Among the four countries, Colombia had the best indicators in 2017 and 2018. In 2019, Ecuador took the lead as a result of significant improvements in energy security and energy equity. It should be noted that all countries have low values of the indicator reflecting government regulation in the energy sector. During the period under review, Ecuador improved its energy security (B-C-A) and environmental sustainability (C-B-B). In Colombia, all three indicators remained unchanged. Bolivia improved its energy security (C-C-B) and environmental sustainability (D-D-C) in 2019. Peru improved its energy security (B-B-A) in 2019.

It should be noted that there are certain contradictions between ranks and grades. For example, in 2017, Ecuador and Peru had similar grades but were given different ranks (55 for Peru and 64 for Ecuador). In 2018, Peru had a better grade (BBA) than Colombia (BCA), but its position in the ranking was slightly lower. In 2019, Colombia had a worse grade (BCAc) than Peru (ACBb) but its rank was higher. Based on this comparison, it can be stated that the ranks and the values of indicators in individual dimensions of energy sustainability do not always correspond to each other and do not allow for drawing conclusions about trends in the energy sector.

The analysis showed that the governments of the Andean Community members support the development of green energy, which goes along the global views on what today's electricity generation should look like. Each of the countries under consideration has primary energy reserves, which has a positive effect on the energy security of the countries. However, despite the fact that the countries border each other, their energy systems do not form a common system and there are no cross-border electricity interconnections, which negatively affects the prospects for selling surplus electricity.

In the countries of the Andean Community, hydropower generation is the dominant source of energy (90% of energy supply in Ecuador and about 65% in Colombia) or an important source (48% in Peru). It is only in Bolivia that it has a significantly smaller share compared to heat energy (35%). At the same time, in terms of absolute indicators, hydropower generation in Colombia exceeds that in Peru and Ecuador by a factor of 2–2.5 and that in Bolivia by a factor of 20.

The analysis also shows that the government of Ecuador aims to create a sustainable energy sector. The country faces a major problem, namely limited oil reserves that are being depleted. This is reflected in the Ecuador Strategy Plan for years 2017 to 2021, which strives to ensure uninterrupted and safe energy supply using a diversified, efficient, sustainable, and independent energy system as the foundation for industrial and social transformation [58]. A lot of attention was paid to the development of the hydropower sector in the country, which resulted in an increase of 2.8 GW in the total power capacity by adding eight large projects. In 2019, 88% of electricity produced in the country came from hydropower plants. The share of non-traditional renewable energy sources is still less than 1% in annual accumulated electricity [59].

Colombia is an oil and natural gas producer with the largest coal reserves in South America. The country uses a lot of renewable energy sources to generate electricity, including solar energy, wind, and biomass, with hydropower accounting for 65% of total energy output [60]. The focus on green energy enables Colombia to provide affordable, clean, and reliable energy while keeping carbon emissions low. In 2019, the Colombian government launched a green auction, signing contracts to add 1077 MW of wind power and 297 MW of solar power by 2022 [60]. Apparently, this is what helped Colombia rank quite high in the energy sustainability index.

Peru traditionally produces hydroelectric power and belongs to the countries where the share of renewable energy sources in the energy mix is big. Good examples are the Gallito Ciego hydroelectric power plants in Lambayeque and Mantaro, which have a capacity of more than 1 GW and produce about 20% of electricity [61]. In recent years, there has been an increase in the use of hydrocarbons in energy production, but the new government has ensured that the necessary repairs have been carried out and investments have been made to maintain hydropower as the main source of electricity production. On average, 48% of electricity comes from hydroelectric power plants and 51% comes from burning hydrocarbons. This ratio changes throughout the year as the water level in the dams can vary.

Bolivia has the weakest position among the members of the Andean Community in the energy sustainability index. It has a deficit in oil and imports petroleum products. At the same time, the country ranks fifth in terms of proven natural gas reserves in South America and has significant potential for the development of renewable energy sources, in particular, sugar cane by-products and hydropower generation. The government has launched a program to produce biofuels from sugar cane. The country has a significant surplus of electricity [34] from new thermal power plants and new hydroelectric projects that are underway [62].

The percentage of imports was calculated by the formula:

$$\text{Iimp} = \text{Qimport.}/\text{Qconsum.}, \quad (3)$$

where Qimport. is the volume of imports of petroleum products into the country, and Qconsum. is the volume of domestic consumption of petroleum products in the country.

Energy security is reflected by the indicators presented in Tables 3 and 4 in absolute terms and scores, respectively. Despite the fact that the countries have balanced energy budgets, they still require some imports. In Colombia they are low, which results in a high score. Peru and Ecuador import more energy. The diversification pattern of primary energy sources is the same for all the countries under consideration and consists of oil, gas, hydropower, solar energy, and wind energy. All four countries have oil and gas reserves, but there are no coal reserves in Ecuador and Bolivia. Table 5 shows the total scores in the energy security dimension.

Table 3. The key indicators of the energy security dimension in the members of the Andean Community (in absolute terms).

Indicators	Country	Unit	2017	2018	2019
Percentage of imports (petroleum products)	Ecuador	%	51	50	54
	Colombia	%	12	6	9
	Peru	%	58	59	46
	Bolivia	%	19	21	26
	Max.	%	Grenada (138)	Dominican R. (135)	Panama (134)
	Min.	%	Colombia (12)	Colombia (6)	Colombia (9)

Table 3. *Cont.*

Indicators	Country	Unit	2017	2018	2019
Diversity of electricity generation sources	Ecuador	№	5	5	5
	Colombia	№	5	5	5
	Peru	№	5	5	5
	Bolivia	№	5	5	5
	Max.	№	Argentina (8)	Argentina (8)	Argentina (8)
	Min.	№	Haiti (3)	Haiti (3)	Haiti (3)
Energy storage: petroleum reserves	Ecuador	Years	16	9	7
	Colombia	Years	5	5	6
	Peru	Years	29	29	28
	Bolivia	Years	12	11	11
	Max.	Years	Venezuela (282)	Venezuela (282)	Venezuela (282)
	Min.	Years	Costa Rica (0)	Costa Rica (0)	Costa Rica (0)
Energy storage: gas reserves	Ecuador	Years	3	5	3
	Colombia	Years	9	9	6
	Peru	Years	19	20	16
	Bolivia	Years	15	17	15
	Max.	Years	Bolivia (15)	Bolivia (17)	Bolivia (15)
	Min.	Years	Belice (0)	Belice (0)	Belice (0)
Energy storage: carbon reserves	Ecuador	Years	0	0	0
	Colombia	Years	67	71	70
	Peru	Years	28	36	40
	Bolivia	Years	0	0	0
	Max.	Years	Colombia (67)	Colombia (71)	Colombia (70)
	Min.	Years	Ecuador (0)	Ecuador (0)	Ecuador (0)

Compiled by the authors based on [63,64].

Table 4. The key indicators of the energy security dimension in the members of the Andean Community (scores).

Indicators	Country	2017	2018	2019
Import dependence for petroleum products (0.33)	Ecuador	0.69	0.65	0.64
	Colombia	1.00	1.00	1.00
	Peru	0.63	0.59	0.70
	Bolivia	0.94	0.88	0.86
Diversity of electricity generation (0.33)	Ecuador	0.40	0.40	0.40
	Colombia	0.40	0.40	0.40
	Peru	0.40	0.40	0.40
	Bolivia	0.40	0.40	0.40
Energy storage: petroleum reserves (0.11)	Ecuador	0.06	0.03	0.02
	Colombia	0.02	0.01	0.02
	Peru	0.10	0.10	0.10
	Bolivia	0.04	0.04	0.04

Table 4. *Cont.*

Indicators	Country	2017	2018	2019
Energy storage: gas reserves (0.11)	Ecuador	0.16	0.25	0.19
	Colombia	0.47	0.45	0.38
	Peru	1.00	1.00	1.00
	Bolivia	0.79	0.85	0.94
Energy storage: carbon reserves (0.11)	Ecuador	0.00	0.00	0.00
	Colombia	1.00	1.00	1.00
	Peru	0.42	0.51	0.57
	Bolivia	0.00	0.00	0.00

Compiled by the authors.

Table 5. The total scores in the energy security dimension in the Andean Community members.

Country	2017	2018	2019
Ecuador	0.26	0.27	0.25
Colombia	0.58	0.57	0.56
Peru	0.51	0.52	0.55
Bolivia	0.43	0.43	0.45

Compiled by the authors.

The total values were calculated, taking into account the scores and equal weighting factors for the selected indicators. Colombia has the highest score and Ecuador has the lowest one.

Table 6 shows the initial data for the energy equality dimension.

Table 6. The key indicators of the energy equity dimension in the members of the Andean Community (in absolute terms).

Indicators	Country	Unit	2017	2018	2019
Access to electricity (% of population)	Ecuador	%	99.20	98.70	100.00
	Colombia	%	98.50	98.50	99.70
	Peru	%	94.80	95.20	98.34
	Bolivia	%	91.80	92.80	96.30
	Max.	%	Chile (100)	Chile (100)	Ecuador (100)
	Min.	%	Cuba (83)	Nicaragua (88)	Bolivia (96.30)
Electricity prices	Ecuador	USD/kWh	0.10	0.09	0.09
	Colombia	USD/kWh	0.13	0.13	0.12
	Peru	USD/kWh	0.14	0.13	0.13
	Bolivia	USD/kWh	0.09	0.11	0.10
	Max.	USD/kWh	Brazil (0.22)	Chile (0.26)	Mexico (0.25)
	Min	USD/kWh	Cuba (0.03)	Cuba (0.04)	Cuba (0.06)
Gasoline prices	Ecuador	USD/L	0.52	0.53	0.55
	Colombia	USD/L	0.85	0.80	0.75
	Peru	USD/L	0.90	0.92	0.90
	Bolivia	USD/L	0.55	0.54	0.54
	Max.	USD/L	Chile (0.92)	Costa Rica (0.95)	Costa Rica (0.93)
	Min.	USD/L	Ecuador (0.52)	Ecuador (0.53)	Cuba (0.49)

Compiled by the authors based on [65–67].

The energy equity dimension covers three indicators: access to electricity (% of population), electricity prices, and gasoline prices. Access to electricity is quite good (Table 6), with Peru and Bolivia lagging behind. Electricity prices in the members of the Andean Community are almost the same and tended to decrease in 2019. The lowest gasoline prices are found in Ecuador and Bolivia (Table 7).

Table 7. The key indicators of the energy equity dimension in the members of the Andean Community (scores).

Indicators	Country	2017	2018	2019
Access to electricity (% of population) (0.33)	Ecuador	0.95	0.89	1
	Colombia	0.91	0.86	0.96
	Peru	0.69	0.6	0.79
	Bolivia	0.52	0.4	0.58
Electricity prices (0.33)	Ecuador	0.63	0.77	0.84
	Colombia	0.47	0.59	0.68
	Peru	0.42	0.59	0.63
	Bolivia	0.68	0.68	0.79
Gasoline prices (0.33)	Ecuador	0.98	1	0.86
	Colombia	0.17	0.35	0.41
	Peru	0.05	0.07	0.69
	Bolivia	0.92	0.98	0.89

Compiled by the authors.

Table 8 shows the total scores in the energy equity dimension.

Table 8. The total scores in the energy equity dimension in the Andean Community members.

Country	2017	2018	2019
Ecuador	0.85	0.89	0.9
Colombia	0.52	0.60	0.68
Peru	0.39	0.42	0.70
Bolivia	0.71	0.69	0.75

Compiled by the authors.

The total values were calculated, taking into account the scores and equal weighting factors for the selected indicators. Ecuador has the highest score, with Columbia and Peru having the lowest.

The environmental sustainability dimension is characterized by three indicators: final energy intensity, low carbon electricity generation, and CO_2 emissions per capita. Table 9 shows these principal indicators of the environmental sustainability dimension in the members of the Andean Community in absolute terms.

Table 9. The key indicators of the environmental sustainability dimension in the members of the Andean Community (in absolute terms).

Indicators	Country	Unit	2017	2018	2019
Final energy intensity	Ecuador	MJ/USD 2011 PPP GDP	3.34	3.41	3.62
	Colombia	MJ/USD 2011 PPP GDP	2.42	2.34	2.26
	Peru	MJ/USD 2011 PPP GDP	2.46	2.78	2.79
	Bolivia	MJ/USD 2011 PPP GDP	5.15	5.17	4.95
	Max.	MJ/USD 2011 PPP GDP	Haiti (10.09)	Haiti (9.95)	Haiti (10.11)
	Min.	MJ/USD 2011 PPP GDP	Panama (2.27)	Panama (2.27)	Panama (2.17)
Low carbon electricity generation	Ecuador	TWh	16	20	21
	Colombia	TWh	50	62	61
	Peru	TWh	26	31	33
	Bolivia	TWh	2	2	3
	Max.	TWh	Brazil (478)	Brazil (507)	Brazil (526)
	Min.	TWh	Haiti (0.09)	Haiti (0.09)	Haiti (0.09)
CO_2 emissions per capita	Ecuador	Tons of CO_2 per c.	2.39	2.48	2.38
	Colombia	Tons of CO_2 per c.	1.58	1.58	1.74
	Peru	Tons of CO_2 per c.	1.68	1.71	1.71
	Bolivia	Tons of CO_2 per c.	2.15	2.15	2.15
	Max.	Tons of CO_2 per c.	Tri.Tob. (24.7)	Tri.Tob. (3.76)	Tri.Tob. (23.81)
	Min.	Tons of CO_2 per c.	Haiti (0.32)	Haiti (0.33)	Haiti (0.32)

Compiled by the authors based on [68–70].

Bolivia has high energy intensity, while Colombia and Peru rank low in this domain, based on the results of Tables 9 and 10. Colombia demonstrates good results in low carbon electricity generation, while Bolivia ranks low. The lowest CO_2 emissions per capita of the countries under consideration are found in Colombia and Peru, with the best result demonstrated by Ecuador.

Table 10. The key indicators of the environmental sustainability dimension in the members of the Andean Community (scores).

Indicators	Country	2017	2018	2019
Final energy intensity (0.33)	Ecuador	0.86	0.85	0.82
	Colombia	0.98	0.99	0.99
	Peru	0.97	0.93	0.92
	Bolivia	0.63	0.62	0.64
Low carbon electricity generation (0.33)	Ecuador	0.03	0.04	0.04
	Colombia	0.1	0.12	0.11
	Peru	0.05	0.06	0.062
	Bolivia	0.004	0.004	0.004

Table 10. *Cont.*

Indicators	Country	2017	2018	2019
CO_2 emissions per capita (0.33)	Ecuador	0.91	0.91	0.91
	Colombia	0.95	0.95	0.94
	Peru	0.94	0.94	0.94
	Bolivia	0.92	0.92	0.92

Compiled by the authors.

Table 11 shows the total scores for the environmental sustainability dimension. Colombia and Peru rank highest and Bolivia ranks lowest.

Table 11. The total scores in the environmental sustainability dimension in the Andean Community members.

Country	2017	2018	2019
Ecuador	0.6	0.6	0.59
Colombia	0.68	0.69	0.68
Peru	0.65	0.64	0.64
Bolivia	0.52	0.51	0.52

Compiled by the authors.

The country context dimension is characterized by three indicators: macroeconomic stability, effectiveness of government, and innovation capacity. Table 12 demonstrates these principal indicators of country context dimension in the members of the Andean Community in absolute terms.

Table 12. The key indicators of country context dimension in the members of the Andean Community (in absolute terms).

Indicators	Country	Unit	2017	2018	2019
Macroeconomic stability	Ecuador	Ranking	91/137	87/140	92/141
	Colombia	Ranking	62/137	56/140	43/141
	Peru	Ranking	37/137	1/140	1/141
	Bolivia	Ranking	82/137	84/140	88/141
	Max. Latam	Ranking	Chile (1)	Chile (1)	Chile (1)
	Min. Latam	Ranking	Venezuela (137)	Venezuela (140)	Venezuela (141)
Effectiveness of government	Ecuador	Scale −2.15; 2.15	−0.32	−0.26	−0.4
	Colombia	Scale −2.15; 2.15	−0.07	−0.09	0.07
	Peru	Scale −2.15; 2.15	−0.13	−0.25	−0.07
	Bolivia	Scale −2.15; 2.15	−0.38	−0.32	−0.7
	Max. Latam	2.15	Chile (0.84)	Chile (1.08)	Chile (1.06)
	Min. Latam	−2.15	Haiti (−2.07)	Haiti (−1.91)	Haiti (−2.02)
Innovation capacity	Ecuador	Ranking	111/137	88/140	88/141
	Colombia	Ranking	73/137	73/140	77/141
	Peru	Ranking	113/137	89/140	90/141
	Bolivia	Ranking	X	122/140	124/141
	Max. Latam	Ranking	Mexico (50)	Mexico (56)	Mexico (52)
	Min. Latam	Ranking	Haiti (138)	Haiti (137)	Haiti (139)

Compiled by the authors based on [71–73].

The Table 13 presented the same indicators of country context dimension in scores.

Table 13. The key indicators of country context dimension in the members of the Andean Community (scores).

Indicators	Country	2017	2018	2019
Macroeconomic stability (0.33)	Ecuador	0.33	0.38	0.35
	Colombia	0.55	0.6	0.7
	Peru	0.73	1	1
	Bolivia	0.41	0.4	0.37
Effectiveness of government (0.33)	Ecuador	0.45	0.43	0.4
	Colombia	0.48	0.47	0.51
	Peru	0.46	0.44	0.48
	Bolivia	0.41	0.42	0.33
Innovation capacity (0.33)	Ecuador	0.3	0.64	0.58
	Colombia	0.73	0.79	0.71
	Peru	0.27	0.59	0.56
	Bolivia	X	0.19	0.17

Compiled by the authors.

Peru and Colombia have the highest macroeconomic stability values, with Ecuador ranking the lowest based on the results of Tables 12 and 13. Effectiveness of government is the indicator that has the highest value in Colombia. Innovation capacity is not pronounced in the members of the Andean Community. In this domain, they rank lower than 50, with Colombia performing better and Bolivia performing worse than the rest of the countries under consideration.

Table 14 demonstrates the total country context scores. Colombia and Peru rank the highest and Bolivia ranks the lowest.

Table 14. The total scores in the country context dimension in the Andean Community members.

Country	2017	2018	2019
Ecuador	0.36	0.48	0.44
Colombia	0.59	0.62	0.64
Peru	0.49	0.68	0.68
Bolivia	0.33	0.34	0.29

Compiled by the authors.

Table 15 presents the summarized results for the four members of the Andean Community for the period from 2017 to 2019. It can be concluded that there are differences between the data presented by WEC, and the values of the indicators that were obtained in the course of this study. For example, in the energy security dimension, Ecuador ranked at approximately the same level for three years, but according to WEC, there is an upward trend to Grade A (Appendix A). There is also a difference in terms of assessing energy equity in Peru, where a significant increase is noticeable in 2019, while grade C indicates a decrease (Appendix A).

Table 15. Total score for all individual indicators and the average values of the energy sustainability indicator.

Indicators/Country	**Ecuador**			**Colombia**			**Peru**			**Bolivia**		
Years	**2017**	**2018**	**2019**	**2017**	**2018**	**2019**	**2017**	**2018**	**2019**	**2017**	**2018**	**2019**
Energy security	0.26	0.27	0.25	0.58	0.57	0.56	0.51	0.52	0.55	0.43	0.43	0.45
Energy equity	0.85	0.89	0.9	0.52	0.6	0.68	0.39	0.42	0.7	0.71	0.69	0.75
Enviromental sustainability	0.6	0.6	0.59	0.68	0.69	0.68	0.65	0.64	0.64	0.52	0.51	0.52
Country context	0.36	0.48	0.44	0.59	0.62	0.64	0.49	0.68	0.68	X	0.34	0.29
Average	0.549	0.576	0.566	0.593	0.62	0.64	0.514	0.542	0.635	X	0.523	0.545
Rating	64	62	45	45	48	49	50	51	58	101	99	84
Additional indicators (Absolute values)												
Hydropower nominal capacity, MW	4.500	5.000	5.000	11.650	11.700	11.800	4.700	4.900	5.100	550	650	750
Hydropower generation, TWh	19.7	20.5	24	59	58.5	57	29	30	31	2.2	2.8	3.4
The amount of electricity purchased for the average salary, MWh	8.14	8.72	9.35	10.63	10.65	10.66	8.61	9.01	7.19	7.07	6.23	6.42

Compiled by the authors based on [74–78].

Water resources are the most important natural wealth of Latin America: 60% of the region's area is taken up by the basins of the world's largest rivers, with the Amazon River flowing through seven countries and the La Plata River Basin crossing five countries. In terms of the availability of water resources, Latin America (the region accounts for about 1/4 of the global river discharge) ranks first in terms of river discharge per 1 square kilometer and per capita. In this regard, it is important to take into account the hydropower potential of the countries under consideration in the context of sustainable development of the energy sector.

Having analyzed the additional indicators for assessing energy sustainability, we can conclude that the hydropower sector in Colombia is developed at a quite high level, with the capacity and hydropower generation two times higher than those in Ecuador and Peru, and 15 times higher compared to Bolivia. The large-scale application of water resources means that power generation sources are diversified, which has a positive effect on the country's energy security. We believe that for developing countries, access to electricity is the most important indicator reflecting energy equity. Bolivia has the lowest indicators of energy production and access to electricity, which negatively affects energy equity.

Unfortunately, data on methane emissions (an additional indicator of environmental sustainability) in the countries under consideration are not available in open sources, which can be explained by the dependence of the amount of emissions on the type of hydroelectric power stations (with or without a large reservoir). During the construction of a hydroelectric power station in the Republic of Ecuador, innovative technologies were used that do not require reservoirs as they provide energy through diversion tunnels. This means a reduction in methane emissions compared to traditional projects.

The additional indicators verify Colombia's high scores for energy security and energy equity. The low level of the development of the hydropower sector in Bolivia explains limited access to energy. At the same time, a high level of energy security has been achieved by means of regulating electricity and gasoline prices.

5. Discussion

The results obtained in the study require additional comments.

In terms of the first group of indicators, Ecuador ranks the lowest, which is explained by factoring in only fossil fuel reserves (oil, gas, and coal). Along with fossil fuels, hydropower is also important in the Andean Community. The assessment of additional indicators by the criterion of energy security by country (2019) shows the following: Colombia produced 11,800 MW of hydroelectricity, while Ecuador and Peru produced approximately 5000 MW, and the output was only 750 MW in Bolivia. These values are not comparable with the output in Brazil (109,143 MW), the leading country, but the countries demonstrate an upward trend, with an increase ranging from 32% in Colombia and 147% in Ecuador [79]. Hydropower production was taken into account only when assessing energy diversification. At the same time, all countries received 5 points each, which indicates a variety of sources, but does not allow for taking into account their structure. As already noted, the share of hydropower in Ecuador's energy mix is 90%, i.e., the country is almost fully dependent on one source. In other countries, diversification is more pronounced. However, this is not reflected by the indicator.

If it had been taken into account in the assessment of energy security, the scores would be higher. Another reason for the low score is petroleum product imports which still play an important role in the energy sector of Ecuador. If the country's electricity imports and exports had been factored in, the score would be much higher (in Ecuador, energy production exceeds consumption by 20%). The sharp growth in this indicator within the WEC framework is explained by a significant increase in hydropower generation in 2019.

The second group of indicators characterizes energy sustainability in terms of its social aspect. Therefore, such indicators as access to electricity, electricity prices, and gasoline prices are analyzed. Changes in the energy mix towards hydropower generation will lead to a decrease in energy costs and prices. This explains Ecuador's high performance by this criterion.

By the amount of electricity purchased for an average salary (2019), the countries of the Andean Community range from 753 kWh (Bolivia) to 1290–1381 (other countries) [65]. In this respect, they differ greatly from European countries, where the values are 10 times higher: 13,031 kWh (France), 19,689 kWh (Norway), and 31,307 kWh (Liechtenstein) [80]. Another important point is differences in population density in Latin America and the need to create equal conditions for the population. That is, these countries are characterized by a lack of energy equity, which sets them apart from European countries but is not reflected in the indicators. When these additional factors and indicators are taken into consideration, the ranks will be lower.

All the countries under consideration have quite high ranks in the third dimension of indicators. This is also explained by the choice of indicators that reflect the final energy intensity, low carbon electricity generation, and CO_2 emissions per capita. The additional indicator is methane emissions by country (2019) associated with hydropower production. It should be noted that while hydropower generation does not produce large CO_2 emissions, it has a substantial negative impact on river systems which results in floods, bottom sediments, weakening of the current, soil erosion, changes in morphodynamics, and natural system disruptions [81–83]. However, this impact was not taken into account due to its complex nature. If it had been factored in, the total score would be lower.

The fact that Ecuador ranks low in the fourth dimension of indicators can be explained by relying on the information provided by the global rankings, which cover such aspects as macroeconomic stability, effectiveness of government, and innovation capacity. In our opinion, this system should be supplemented by taking into account government regulation in the energy sector. This area includes attracting investments, participation of the government in international interactions with developed countries, and developing policies in the field of renewable energy sources with an emphasis on small-scale hydropower plants. Currently, Ecuador is constructing eight large hydropower plants, but some countries with well-developed energy sectors (Brazil, for example) are gradually moving to small-scale hydropower plants. If these aspects had been taken into account, the score would probably be higher. The additional quantitative indicator is subsidies for the energy sector and consumers.

The resulting estimates of the indicators reflecting the energy sustainability of countries with a significant share of hydroelectricity in their energy mix show that the energy sustainability index does not fully reflect the specific features of individual countries. Therefore, in order for each country to solve such energy management problems as designing strategic energy development programs, providing a rationale for engineering solutions, assessing the impact on the environment and society, and making decisions on the size and form of subsidies, the index should be applied along with additional indicators. The results obtained are in line with the results produced by other researchers who emphasized the specificity of regional energy (for example, in such countries as Pakistan, Azerbaijan, and Indonesia). To integrate the energy sectors of individual countries into one system, it is not enough to take into account technical parameters. Economic indicators should also be analyzed when agreeing the terms of contracts and agreements. An example of integration in Latin America is the joint construction and operation of hydropower plants by Brazil and Paraguay, which is a large-scale investment project with long-term effects.

6. Conclusions and Implications

As a result of the study, the following conclusions were made:

1. Energy sustainability indicators that are used to assess energy security, energy equity, and environmental sustainability that were proposed by the WEC as part of the Energy Trilemma framework provide for comparing countries but do not produce detailed results that can be explained. The situation with country context assessment

is even more complicated as countries differ significantly from each other in many characteristics.

2. WEC indicators can be adjusted when analyzing groups of countries in such a way that takes into account their economic and geographical conditions, the availability of fossil fuels, and the potential of using renewable energy sources, including hydropower. It will make it impossible to compare countries using global ranks, but it allows for comparing countries that are similar in their socio-economic and geographic parameters, which will help to develop energy policies for both individual countries and their unions.
3. The analysis of the WEC methodology using open sources revealed that many indicators in the methodology are interconnected and the assessment of individual indicators should be supplemented by taking into account their interconnections. For example, the shortage of fossil fuels stimulates the use of renewable energy sources, which requires significant investments from the state. An increase in generation volumes leads to a decrease in costs and prices, which makes energy more available. The complex impact of energy facilities on the environment is manifested in different types of emissions, impact on soils, and landscape disturbances, even in the case of hydropower.
4. The proposed adapted methodology for calculating energy sustainability indices in countries with a dominant role of hydropower (Latin America, Andean Community) includes twelve main indicators and six additional ones. The energy security dimension includes the following indicators: the percentage of imports, diversity of electricity generation, and energy storage (petroleum reserves, gas reserves, and carbon reserves); the energy equity dimension comprises access to electricity (% of the population), electricity prices, and gasoline prices. The environmental sustainability dimension includes final energy intensity, low carbon electricity generation, and CO_2 emissions per capita. The country context dimension includes macroeconomic stability, effectiveness of government, and innovation capacity. Additional indicators include hydropower nominal capacity, hydropower generation, and the amount of electricity purchased with an average salary, which have been analyzed in this article. Three more additional indicators—hydropower potential, methane emissions associated with hydropower generation, and governmental subsidies and grants for hydropower generation—are important to take into account; to calculate them, special information is required. This system allows for obtaining detailed assessments, comparing the performance and development results of countries with similar economic, geographic, and political characteristics, and explaining the results.
5. The values of the selected indicators and indices for the four dimensions of energy sustainability in the proposed methodology characterize the state of the energy sector of the Andean Community countries and correspond to their grades in the WEC ranking.
6. The resulting average scores for the members of the Andean Community are approximately equal and do not correspond to the countries' Energy Trilemma ranks. This is explained by averaging and the fact that integral metrics consist of a variety of indicators which influence each other. It also proves that rankings are not informative enough. Columbia and Peru score higher according to the new methodology (0.64 and 0.635 in 2019, respectively), which is explained by their better developed economies and policies and more powerful energy sectors (11,800 and 5100 MW, respectively). This is confirmed by the hydropower generation indicators (57 and 31 TWh). At the same time, Ecuador has a significant potential for hydropower generation and greatly grew in this area over the period of three years (19.7–20.5–24 TWh).
7. As the example of the Andean Community shows, being ranked as an outsider does not reflect such characteristics as the economic and production results of the energy sector, energy accessibility, and the environmental impact of the energy sector, as well as the government's efforts to improve management in the industry.

8. The study revealed the factors that influence the energy sector of the Andean Community, which include the following: hydropower potential, hydropower nominal capacity, hydropower generation, the availability of energy for the population in terms of per capita income, the anthropogenic impact of hydroelectricity on natural ecosystems in terms of methane emissions, as well as state programs in areas of hydroelectricity, including projects for small-scale hydroelectric power plants and subsidies for the population.
9. By taking into account additional indicators related to hydropower in the countries of the Andean Community, it becomes possible to supplement the previously obtained estimates on the levels of energy sustainability with information on hydropower generation, which allows for making better conclusions.
10. Hydropower has a number of great advantages, including low production costs, the use of renewable energy sources, and zero emissions, which makes it more competitive in comparison with other energy sources and, in general, ensures an increase in energy sustainability. However, the challenges that this sector is associated with should be assessed. They include hydrographic requirements, human impact on water resources, and vast investments.

The limitations of the study are that indicators were selected and calculated for only four countries that form an economically integrated system (the Andean Community). The choice of indicators is based on the importance of hydropower for these countries and requires collecting information on six additional indicators over several years. This can be difficult to do when using open sources. In addition, governmental plans and programs on the topic should be taken into account. If such data are available, the number of indicators can be increased, and the resulting scores can be better explained. For other countries and their unions, other indicators can be chosen on the basis of which additional effects of integration can be identified.

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Appendix A

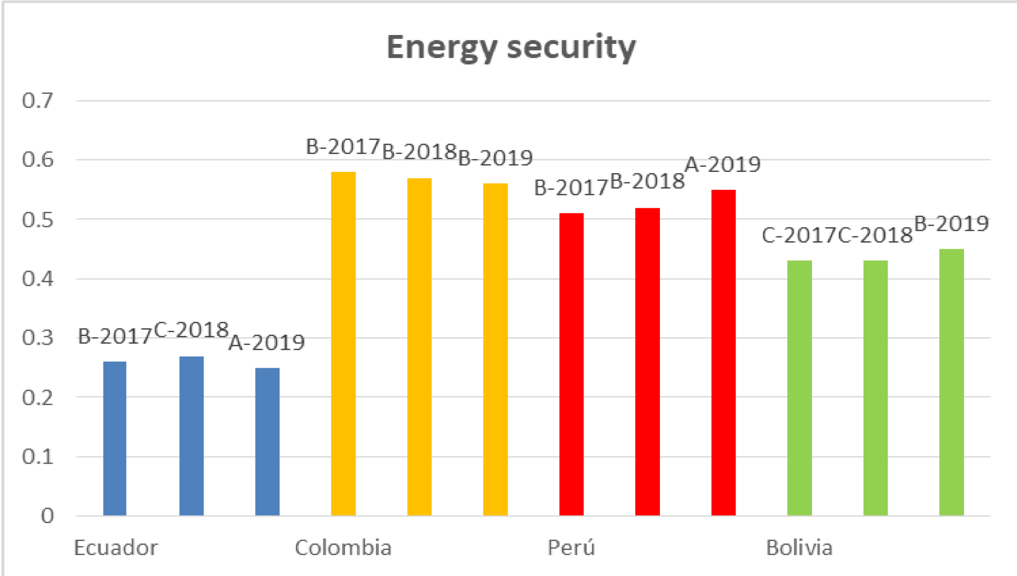

Figure A1. Energy security dimension by countries in period from 2017 to 2019. A,B,C,D—letter indices according to the WEC methodology: The letter A indicates the highest grade, the letter D—the lowest for each of the dimension.

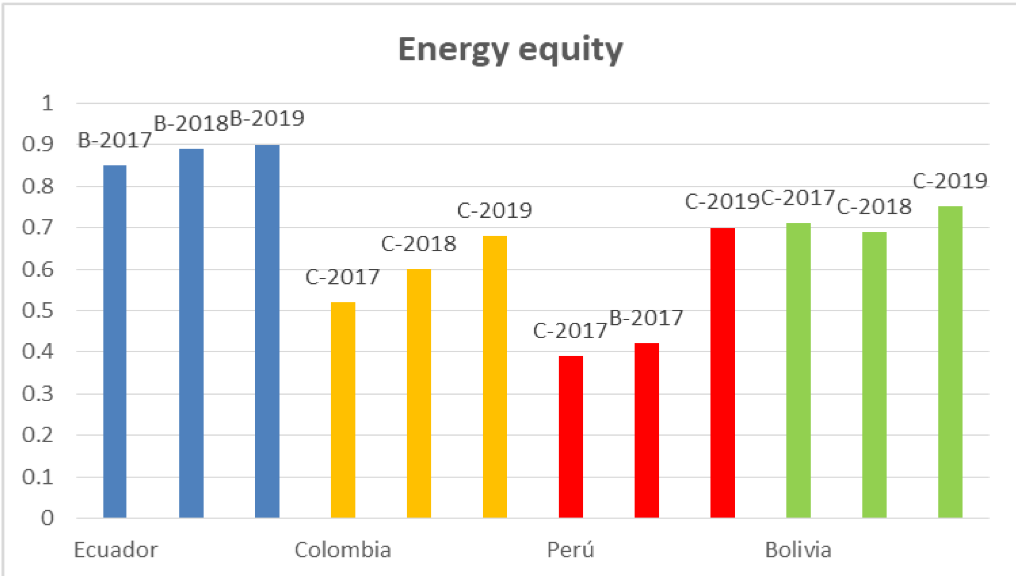

Figure A2. Energy equity dimension by countries in period from 2017 to 2019. A,B,C,D—letter indices according to the WEC methodology: The letter A indicates the highest grade, the letter D—the lowest for each of the dimension.

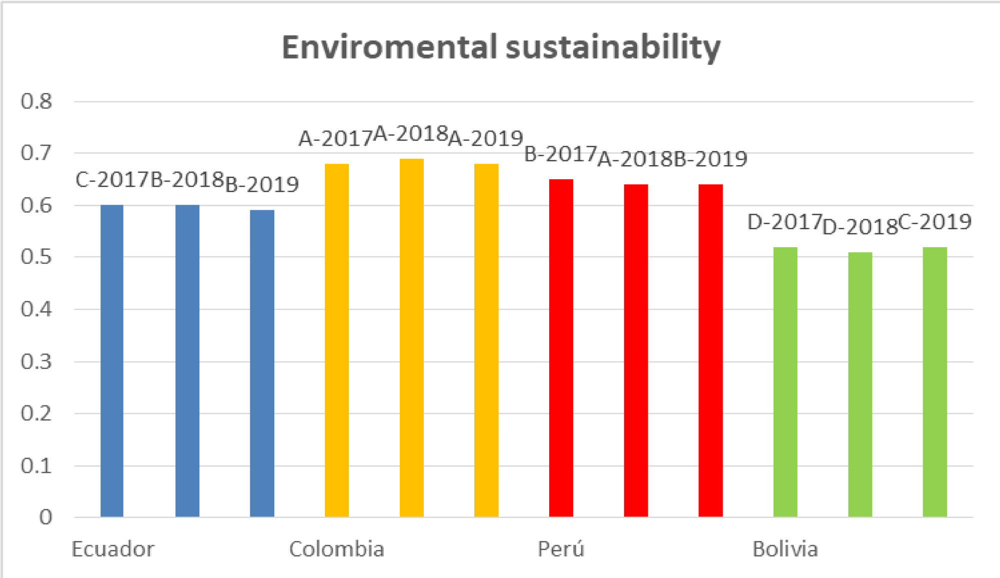

Figure A3. Environmental sustainability dimension by countries in period from 2017 to 2019. A,B,C,D—letter indices according to the WEC methodology: The letter A indicates the highest grade, the letter D—the lowest for each of the dimension.

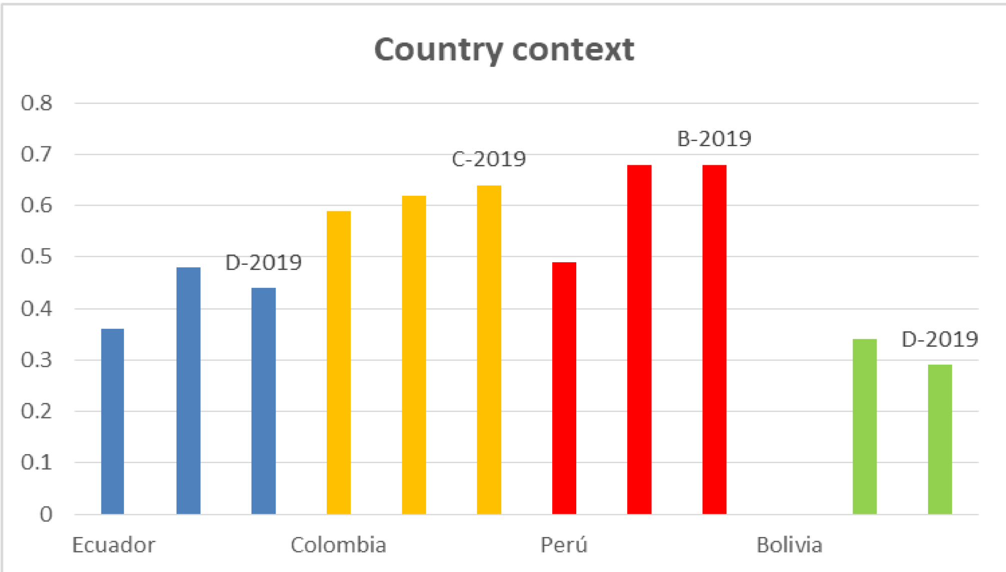

Figure A4. Country context dimension by countries in period from 2017 to 2019. A,B,C,D—letter indices according to the WEC methodology: The letter A indicates the highest grade, the letter D—the lowest for each of the dimension.

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