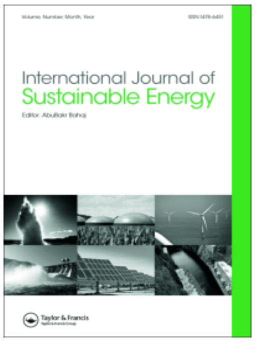

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Social impacts of energy resource planning: assessment methodology and case study

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ABSTRACT
This paper presents an Accounting and Valuation (AV) method within the scope of Integrated Resource Planning (IRP) to analyze social impacts when implementing new energy resources. The method is based on a critical analysis from existing assessments regarding the IRP and its design is based on algorithms that convert qualitative information of social attributes into absolute values. These values feed the subsequent stages of the IRP to select the best energy resource (among available options) to be implemented. The method has been applied and tested as a pilot case in a rural region in Peru. This work provides extremely valuable information for decision-makers to assess, with real and quantitative data, investment decisions regarding energy planning.

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KEYWORDS
Integrated resource planning; social impacts; energy resources; case study

1. Introduction

Until the beginning of 1970, given the continuous growth in electricity demand and tariffs' stability, energy planning consisted of simple projection techniques, very similar to economic planning: meeting demand at minimum cost (Da Costa 2001). This type of planning was almost always restricted to a few specific segments of the energy sector, such as electricity, coal and oil. The concern of energy planning was focused on resources' supply at a minimum cost, in order to ensure the growing demand (Codoni, Park, and Ramani 1985).

In the mid-1970s, political and environmental events, such as the Arab Oil Embargo and the adoption of gas emission regulations from thermoelectric plants, began to change the scenario (Gimenes et al. 2004). More complicated systems, such as energy portfolios, were required to respond to variations in energy demand, diversifying supply while reducing technical and economic risks and putting a greater emphasis on social and environmental considerations.

Based on this search to reduce the social cost of energy services and to postpone or avoid the construction of large generating plants, the Integrated Resource Planning (IRP) was presented as a management strategy for those with the greatest energy supply needs (Deshun, Youhong, and Aiming 1997).

Numerous definitions and analysis of IRP, or, as applied to the energy sector, Integrated Energy Planning (IEP), are available in the literature on the subject. As explored by Bauer and Eto (1992), IRP involves more complex issues including participating in competitive businesses, managing risk, accounting for externalities (social and environmental), in addition to encouraging lower planning cost and demand-side management use.

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Bajay and Leite (2004), for example, argue that IRP is an important planning tool as it allows to take into consideration the concerns and priorities of all agents involved, including the government, the regulatory agency, environmental groups and the consumer himself. Shrestha and Marpaung (2006) define IRP as a planning approach capable of identifying a set of energy generation options from clean centralised sources, decentralised renewable sources and efficiency measures, ensuring lower electricity costs for society and lower environmental impacts in energy production. Also, Reddy and Sumithra (1997) discuss IRP as a way of planning based on the need to obtain energy to serve society, evaluating electricity supply and an adequate level of service.

We can summarise that the objective of IRP is to maximise the contribution of a set of energy resources (ER) in favour of social and environmental development in a sustainable way, in a specific period of time and in a defined region (Udaeta 1997; Wang and Min 1998). In general terms, the IRP technique differs from strategic supply planning as it should consider not only individual/organisational costs, but also societal costs, such as resource selections to mitigate the environmental impact (D'sa 2005). However, this evaluation can be very complex, especially considering that most social impacts are relative or qualitative, which makes it very hard for an equal assessment of all energy resources (Cicone et al. 2008).

In Latin America, IRP applications are limited to initiatives conducted in higher education institutions and research institutes. Contributions to the topic can be found in academic publications such as Jannuzzi (1995), Jannuzzi & Swischer (1997), Bajay et al. (1996), Fadigas, Sauer, and Udaeta (1996) and also in the IRP proposal prepared by the Energy Company of Minas Gerais, in Brazil (Udaeta 1997). In addition, a theoretical foundation has been developed at the University of Sao Paulo (USP) (Udaeta et al. 2003), also in Brazil, since the 1990s. This IRP developed at USP is aimed for broad applications, without restrictions to different locations and has already been applied in the countryside of the State of São Paulo, Brazil (Galvao et al. 1999) and in the Amazon region (Inatomi and Udaeta 2005).

This paper presents an evolution of the work developed at USP by proposing a transparent procedure capable of accurately interpret and measure data from social impacts of the implementation of new energy resources in a regional environment.

Despite the relevance of social impacts to research on social entrepreneurship and economics, both theoretically and empirically, there is a lack of standards for evaluating social impacts of different stakeholders or organisations (Rawhouser, Cummings, and Newbert 2019). The same applies for the energy market.

Therefore, the objective of this paper is to improve and apply an Accounting and Valuation (AV) method within the scope of Integrated Resource Planning (IRP) to compute and evaluate social impacts of implementing new energy resources into a determined region. The first evolution is to take into consideration not only environmental aspects, but also other social attributes not previously assessed, such as employment rates, economic and human development, comfort perception and spacious impacts. Secondly, the method also takes this qualitative assessment and converts it into measurable grades so all energy resources options can be ranked.

Our literature review contained a sample of 50 articles from more than 20 different top journals that investigate how to assess social impact conceptually or empirically. The use of different data sources proves that the methodology proposed here has a much broader and more complex approach to the issues dealt with obtaining and using energy, when compared to traditional planning.

This study identifies two research gaps that are related. First, there is a scarcity of meta-analyses of relevant papers in this field. Because the social component is typically just a small factor in comparison to the economic and environmental dimensions (Amber and Aslam 2018; Li and Liu 2019), the samples of articles remain rather restricted. The second study gap is that all of the listed literature reviews agree that quantitative modelling is extremely undeveloped in terms of social implications and needs a clear and rigorous strategy.

Therefore, this work presents two great contributions filling the gaps described above: providing an improved and robust quantitative method to measure social externalities, which can be easily adapted and replicable in any region, testing the method proposed with a relevant study case; and contributing to the literature on this field.

Furthermore, the case study developed here has a significant contribution to Brazil's and Peru's energy planning. The Peruvian government has been planning an expansion in the country's unexplored hydroelectric potential to attend rising energy demand. Government officials and energy companies are increasingly looking for rivers on the eastern flank of the mountains, where steeper slopes and more stable flows mean greater generating capacity. However, many of their efforts have met with resistance from communities that would be displaced by the floods and from environmentalists who say current regulations do not adequately account for the impacts of the dams in Amazonian ecosystems.

The method successfully assisted in the valuation of social impacts of the potential energy resources for the region. This result is highly relevant to assist stakeholders in decision-making not only to select the most socially positive energy resources, but also to assess the strengths and weaknesses of each resource regarding its social impacts, helping to respond and adapt to the urge of local communities that would be affected by the impacts of the dams in the local ecosystems.

The organisation of the paper is as follows. Section 1 presents the Introduction of the article, including a subsection with a more extensive overview of the IRP background. Section 2 presents the method and calculations for the new methodology presented. Section 3 provides the case study applied in the Peruvian energy market. Section 4 presents the results and discussions, and, finally, Section 5 concludes the paper and presents the limitations of the study and future work suggestions.

2. Method

The results produced by the Accounting and Valuation (AV) method transcend the monetisation of externalities and must also take into consideration less tangible accounting, such as, for example, visual impacts. In fact, some attributes are difficult to quantify because they are quite relative and vulnerable to human perception, which makes this analysis even more important, as it tries to bring the social dimension into quantitative and comparable data that will then be ranked at the subsequent stage of the IRP, the Resource Ranking, and the best energy resources will be positioned at the top.

The social dimension connects different impacts of the energy system with society. In this case, there is heterogeneity in the calculation of indicators since human development or occupational health attributes can be estimated more easily through financial indicators. However, when it comes to attributes related to comfort, for example, their subjective content makes it difficult to quantify (Verán-leigh and Vázquez-rowe 2019).

Therefore, the starting point of the method was to identify the best attributes that could robustly assess social impacts regardless of the energy resource chosen, taking into account the fundamental premise of this study that this method should fit in any analysis and in every study region.

We start by recognising that there are other fields from which the Integrated Resources Planning can learn since social impacts can take many different forms, such as management and entrepreneurship. Consequently, we conducted an electronic search in the ABI/Inform database to find articles from the 20-year period (2001–2021) that examined social impacts. Given that the FT50 journals publish papers in a variety of business disciplines, including accounting, economics, entrepreneurship, ethics, finance, information systems, management, marketing, and operations, they were our primary focus.

Table 1. Summary Statistics of article sample review by fields.

Field	Number
Economics	13
Management	7
Operations	2
Entrepreneurship	4
Marketing	3
Accounting	1
Energy Related	20

Source: Prepared by Author.

Also, electronic research was conducted on the top 20 journals ranked by Scimago Journal & Country Rank on the categories: Renewable Energy, Sustainability and the Environment and Energy (Miscellaneous), to consider research also conducted on the energy field regarding social impacts.

We select a sample of 30 pertinent articles from top (FT50) business journals and 20 articles from top Scimago energy journals that investigate how to assess social impacts conceptually or empirically. We begin by outlining the variety of social impacts definitions, data sources, and operationalisations. Then, we created a typology of four categories of social impact literature based on this study, and we use it to arrange our findings and suggestions for a better way to quantify social impacts on energy resource planning (Tables 1 and 2).

In this context, according to our findings on the literature review, this paper proposes a list of four social impact categories, some of which are detailed in sub-attributes, that can complete a social impacts assessment of energy generic energy resources, they are Job Creation (Quantity and Quality), Development Influence (Economic Activities, Human Development), Social Impact due to land occupation and Comfort Perception (Sound and Visual Impact).

To finalise this study, this article tests the proposed method in a study case to validate it.

2.1. Job creation: quantity

According to 69% of the reviewed articles, the creation of is, by far, the most significant of the social factors studied. In most cases, this refers to the total number of jobs produced. Only a few publications differentiate between directly and indirectly created jobs, as well as induced jobs (Chazara, Negny, and Montastruc 2017).

The initial step in the evaluation of job creation is the identification of potential employment opportunities at the various stages of the energy chain analysis involved in each energy resource – planning, production, construction and others.

The employment factor is also influenced by the productivity and efficiency of local business processes based on the level of local technological and economic development. This impact is represented by a regional or local employment multiplier, which can be calculated locally – depending on the experience of implemented projects - or using productivity indicators from different studies, adapted to the reality of the region studied (Bartelmus and Vesper 2000).

Table 2. Summary Statistics of article sample review by type.

Type	Number
Qualitative	29
Quantitative	5
Modeling	2
Descriptive	3
Conceptual	4
Theoretical	7

Source: Prepared by Author.

In summary, the calculation of the achievable potential to generate jobs results from two components: the multiplication of the installed capacity of each resource by the correction of the employment factor with the regional multiplier, as stated in Equation (1).

$$\mathrm{AV(Quantity\ of\ Jobs)} = \mathrm{IC}\left(\sum_{i=1}^{n} (\mathrm{EF}_i \times \mathrm{RM}_i)\right) \tag{1}$$

where

- IC: Installed Capacity of Energy Resource (in MW)
- EF: Employment Factor of Energy Resource (in jobs/MW);
- IN: Index of nationalisation of production and/or services (%);
- RM: Regional Multiplier (dimensionless)
- n: number of stages in the energetic chain

2.2. Job creation: quality

Other work-related aspect considered in the literature is the employment quality, which includes mainly qualification and availability of workforce (Allaoui et al. 2018; Jakhar 2015) and its wage structure (Das and Shaw 2017).

Therefore, the method proposed here for the evaluation of the quality of created jobs involves identifying the potential of workers in the many fields related to the energy chain. The distribution of these potential employees is evaluated in light of the qualifications required for the job, which can be valued by its wage structure.

Therefore, to compare the quality of the job of different energy resources, its necessary to compare its wage structure (Buchmayr et al. 2022). To simplify it, it is possible to calculate an average monthly salary of an average employee, according to the following equation:

$$\mathrm{AV(Quality\ of\ Jobs)} = \mathrm{PE}\ /(\mathrm{EMP} \times 12) \tag{2}$$

where:

- AV (Quality of Jobs): Accounting and Valuation (of quality of job) for Energy Resource ($/Months);
- PE: Payroll Expenses by Energy Resource ($/Year)
- EMP: Number of Employees by Energy Resources (on that year)

2.3. Development influence

Another major aspect cited in 47% of articles assessed are related to the region affected by the energy resource planning decisions. The economic development of a region is frequently used to refer to the prioritisation of those regions with a lower level of development, which can be measured using the Human Development Index (HDI) (Babazadeh et al. 2017; Anvari and Turkay 2017; Das and Shaw 2017) or population density (Mota et al. 2018) and also economic indicators such as the gross domestic product (Mota et al. 2015; Costa, Duarte, and Sarache 2017; Habibi et al. 2017) or unemployment rates (Mota, Gomes, and Barbosa-Póvoa 2013).

Therefore, the development influence assessment proposed here consists of two components: economical and human. The first one is evaluated according to the contributions that the energy resources can provide to the local economy. This can be measured by changes in the internal gross product and other economic indicators, such as changes in the commercial balance. As for the human development, it can be based on the criteria of housing conditions, health, education, and others (Sheikh, Kocaoglu, and Lutzenhiser 2016).

Therefore, the Accounting and Valuation method for economic and human development of energy resources are obtained by the following equations:

$$AV(\text{Development Influence}) = \text{FIncome} \times IC \tag{3}$$

$$\Delta AV = AV(\text{Development Influence})/\text{Local\_GDP} \tag{4}$$

where

- AV (Development Influence): Accounting and Valuation (of economic development) for Energy Resource ($);
- FIncome: Annual salary of a given enterprise ($/MW);
- IC: Installed Capacity of Energy Resource (in MW)
- Δ AV: Accounting and Valuation of economic development of Energy Resource (%).

$$\Delta AVH = \Delta AV/3 \tag{5}$$

where

- Δ AV HD: Accounting and Valuation of human development of Energy Resource (%).

2.4. Comfort perception: visual impact

The least commonly addressed component is comfort perception. Visual and sound impacts are frequently determined by the technology used and are considered in eight research (Marinakis, Papadopoulou, and Psarras 2017).

Visual pollution is measured by the aesthetic change caused by an energy system in relation to the previous situation (Carrera and Mack 2010). In this context, the impact is measured by the contrast between the occupied area of the introduced element in the landscape or visual field and the other elements of this field before its installation.

This evaluation can range from 0 to 1, between minimal impact and profound impact. Visual impact assessment considers visibility coefficients: (a) from the power plant to the affected area and (b) from the affected area to the power plant. It also has two other variables: (PA) total population of the affected area and (TP) total population of the city or region, according to the following equations:

$$AV(\text{Visual Impact}) = APC \tag{6}$$

$$APC = \sum (axbxPA)/TP \tag{7}$$

where

- AV (Visual Impact): Accounting and Valuation (of visual impact) for Energy Resource (%);
- APC: Affected people coefficient

2.5. Comfort perception: sound impact

Noise pollution in energy systems is associated with excess operating noise from machines, turbines and other equipment. The noise level varies depending on the power and size of equipment (Araujo 2004). Thus, noise pollution can be measured by the sound pressure level (SPL) at different points.

$$AV(\text{Sound Impact}) = \frac{SPL_{\text{(after energy resource)}} - SPL_{\text{(before energy resource)}}}{SPL_{\text{(before energy resource)}}} \times 100 \tag{8}$$

$$\mathrm{SPL} = 20\log\left(\mathrm{p}/\mathrm{p0}\right) \tag{9}$$

where

- AV (Sound Impact): Accounting and Valuation (of Sound Impact) for Energy Resource (%);
- SPL: Sound Pressure Level (dB)
- p0 is the reference sound pressure of 0.00002 pascals = 0 dB the threshold of hearing, in air at 1 kHz.
- p: sound pressure measured at a determined point

2.6. Social impact due to land occupation

Finally, the valuation of social impacts due to land occupation of energy resources is also mentioned as one important attribute in energy research articles. It considers, in essence, the total amount of people displaced based on the population density of the affected area.

$$\mathrm{AV(Land\,Occupation)} = \mathrm{PD}/\mathrm{IC} \tag{10}$$

where

- V (Land Occupation): Accounting and Valuation (of Social Impact due to Land Occupation) for Energy Resource (People/MW);
- PD: People Displaced
- IC: Total Installed Capacity (MW)

3. Case study

The electricity sector in Peru has experienced amazing improvements in the last 20 years. Access to electricity has grown from 45% in 1990–96% in June 2019, which also increased demand for electricity. In this context, the Peruvian government has been planning an expansion in the country's unexplored hydroelectric potential to attend rising energy demand.

Also, in 2009, Peru and Brazil established an agreement to promote the construction of hydroelectric plants and transmission lines to serve Peru as a priority and sell the surplus to Brazil. However, since them, great opposition arose from indigenous tribes, local population, and regional workers, claiming an expressive concern with social impacts in the region, which complicated all negotiations at the time.

Therefore, Peru's agreement with Brazil and its emerging need to expand electricity supply has motivated several studies in this subject (Verán-Leigh and Vázquez-Rowe 2019; Israel and Herrera 2020; Cherni and Preston 2007; Meier et al. 2011), mainly evaluating environmental impacts. However, the literature review shows that there is almost no data identifying and evaluating social impacts of expanding hydroelectric projects to the western region of Peru.

In this context, the Accounting and Valuation method was applied to evaluate the social impacts of implementing new energy resources in the region of the Republic of Peru, to export available energy to Brazil (without affecting internal demand).

Historically, the hydroelectric development in Peru took place mainly on the occidental coast of the country since this region had the highest population concentration and the most built infrastructure. Therefore, recent studies (Isral and Herrera 2020; Minen 2019; Abastos 1987) have highlighted the great potential of unexplored regions of the oriental coast of Peru.

3.1. Peruvian electricity market

The development of Peru's water resources began more than a hundred years ago, at the beginning of the 20st century. Initial developments took advantage of the rugged topography that occurs primarily in the rivers that drain the western slope of the Andes Mountains. The purpose of hydropower plants was to meet the local demand for electricity and, increasingly, the mining industry (Huber and Joshi 2015).

During the second half of the twentieth century, regional power grids emerged, and hydroelectric development began to include large-scale projects. Throughout this period, hydroelectric generation contributed to a very important share of the country's energy supply, generally above 80% (Hommes 2019).

After a period in which the expansion of electricity generation through gas plants predominated, the interest in hydroelectric generation grew back. It is important to note that interest for developing hydro power plants follows historical trends, focusing on projects located on the western coast basins (in high places in the Andes) that are located closer to major load centres and that are also known to their challenging technical characteristics (high hydrostatic loads, underground structures, limited water flows) (OSINERGMIN 2012; COES SINAC 2012; ANA 2013).

However, government officials and energy companies are increasingly looking for rivers on the eastern flank of the mountains, where steeper slopes and more stable flows mean greater generating capacity. Many of their efforts have met with resistance from communities that would be displaced by the floods and from environmentalists who say current regulations do not adequately account for the impacts of the dams in Amazonian ecosystems.

3.1.1. Total hydroelectric theoretical potential

Based on a study by the World Energy Council (WEC 2001), it can be estimated that the potential available for hydraulic exploitation, said total resource, in Peru is 1578 TWh/year, as shown in Figure 1.

However, not all the theoretical potential can be converted into energy from hydroelectric plants and, therefore, it is necessary to consider for this study the technically usable hydroelectric potential. In this case, the same study carried out by the World Energy Council (Figure 2) presents potential for this dimension of 260 TWh/year in Peru.

3.1.2. Total installed capacity

During 2019, according to data presented by the Ministry of Energy and Mines of Peru [35], the total electricity generated in the country was 56,969 and 60 GWh were imported from Ecuador. Of the total energy generated in the country, 54,449 GWh (96%) corresponds to companies in

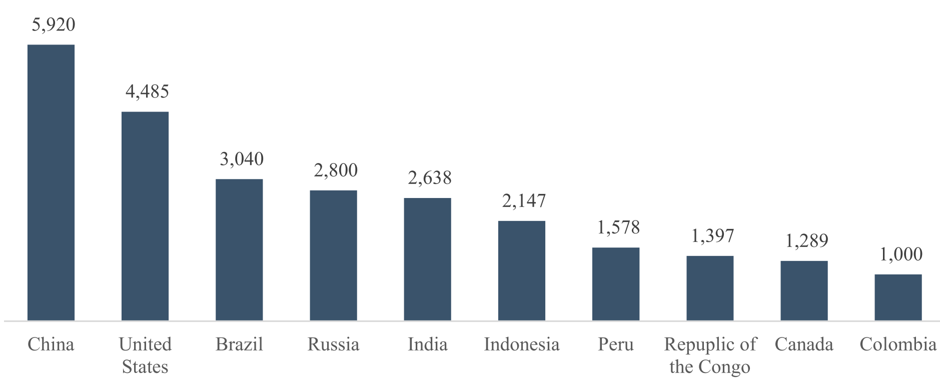

Figure 1. Theoretical hydropower potential in the world (in TWH/year) – total resource. Source: EPE (2007); Prepared by Author.

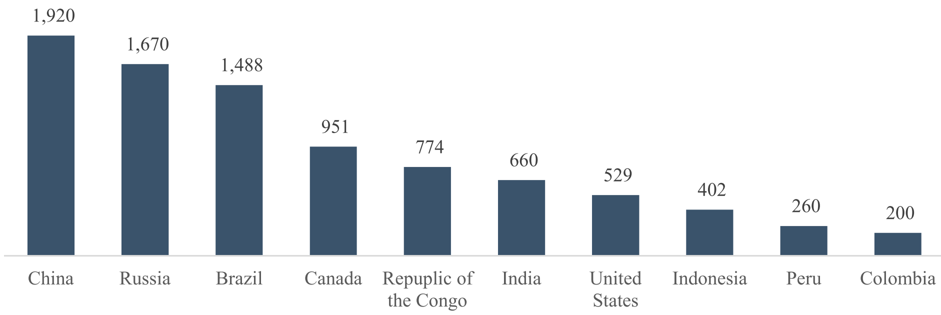

Figure 2. Technically usable hydroelectric potential in the world (in TWH/year). Source: EPE (2007); Prepared by Author.

Table 3. Peruvian installed capacity.

	National installed power
Hydropower	36%
Thermal	60%
Solar	2%
Wind	2%
Total (MW)	15,122.84

Source: MINEM (2019).

the electricity market and 2520 GWh (4%) corresponds to industrial companies that generate for their own use.

In addition, the country, in 2019, had a total of 15.1 GW of installed power, with 60% of the matrix formed by thermoelectric plants and 36% by hydroelectric plants. This portion of the hydroelectric source in the matrix was responsible for 55% of the country's total energy generation, that is, 31.3 GWh. The data is presented in more detail in Tables 3 and 4.

3.1.3. Energy export

According to data provided by the International Energy Agency (IEA 2021), Peru, in 2018, had a total electricity consumption of 49 TWh. Growth in demand in Peru is based mainly on the development of mining and industrial projects and the development of the country's main cities. Therefore, the estimated GDP growth scenario of the country was used as a projection index (MINEN 2015).

An estimated GDP growth rate of 2% was applied, as projected by the Ministry of Economy and Finance of Peru (MEF 2021). Due to the impacts of Covid-19, a negative impact of -10% was estimated in 2020, followed by a recovery of 11% in the following year. Therefore, the Useful Energy Volume grew from 49.0 TWh in 2018–95.3 TWHh in 2051.

To calculate the Useful Export Energy to Brazil, it is important to consider some points. The first one is the energy demand that the country will have in the next 30 years (time period considered for the study). As calculated previously, the expectation is that, in 2051, demand for electricity will be

Table 4. Peruvian power generation.

	National power generation
Hydropower	55%
Thermal	41%
Solar	1%
Wind	3%
Total (MW)	5696.85

Source: MINEM (2019).

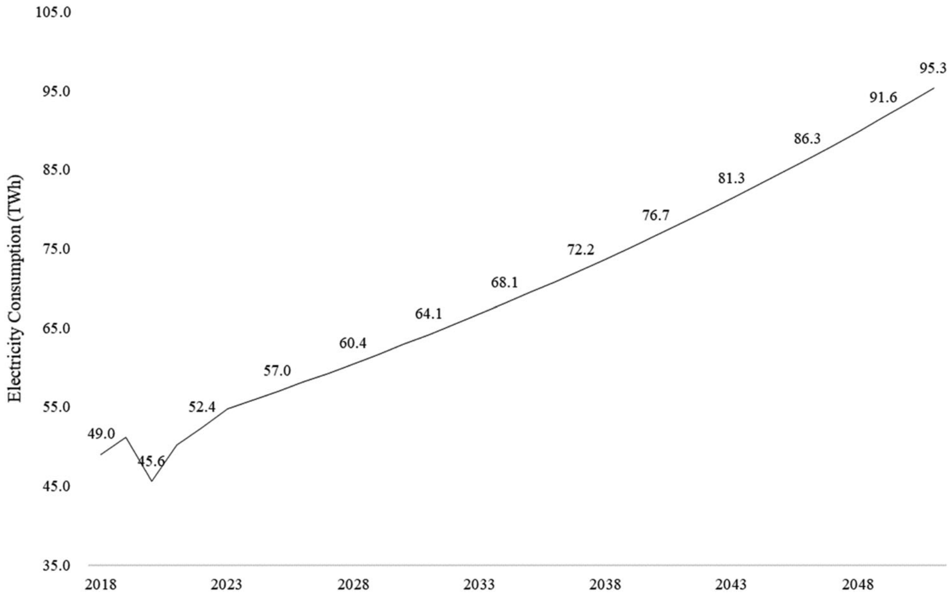

Figure 3. Useful electricity volume projection until 2051. Source: MEF (2021); MINEM (2015) Prepared by Author.

95.3 GWh, which corresponds to 38.3 GWh more than what is produced today in the country (Figure 3). Therefore, it is concluded that the country should invest in new generation projects to meet this growing demand.

When analysing the country's theoretical power generation potential (Figure 2), it is observed that this potential is considerably higher than the forecast demand until 2051. When considering that other sources can also be used to meet this demand (mainly thermal), it is concluded that the country has enough potential to export energy without compromising domestic demand.

Added to these points, it is important to analyse more specifically the region in question, the Madre de Dios Basin. Two factors contribute to the utilisation of the region's potential for energy exports. The first fact is its proximity and ease of access with Brazil since it is directly connected to the border of Brazil, which contributes to the establishment of transmission lines. Also, it is important to consider that, as pointed out in previous sections, the west coast has always been the country's first option for the construction of hydroelectric plants, which explains the lack of exploration in the Madre de Dios region until then.

Therefore, it was considered in the study that the entire potential of the selected energy resources in the Madre de Dios region could be exploited for energy export, without compromising domestic demand. That is, the volume of useful energy for export is 14,583 GWh (as shown in Table 3).

3.2. Region of study

Madre de Dios is one of Peru's 25 regions, located in the South American continent, extending from southwestern Peru to the extreme north of Bolivia. The Madre de Dios basin is also characterised by being a sub-basin of the Madeira River basin, which originates in the eastern Peruvian mountain range (Abastos 1987). Despite some work carried out by oil companies in the region, there are still very few exploratory data about it. (Carvalho 2007).

To obtain more data regarding energy generation in the unexplored regions of the oriental coast of Peru, a study[1] was carried out by the government in partnership with a private consultancy (MINEM 2014), which aimed precisely at obtaining a portfolio of hydroelectric projects resulting

Table 5. Energy resources description.

	N° of Possible Power Plants	Total Installed Capacity (MW)	Average Energy Production (GWh)
SHP with reservoir	Zero	Zero	Zero
SHP without reservoir	46	664.9	3006.5
UHE with reservoir	9	732	3721.8
UHE without reservoir	27	1544	7855.8
Total	82	2940.8	14,583.1

Source: Prepared by Author.

from the optimisation of water resources in some unexplored Peruvian basins such as the Apurimac, Madre de Dios, Purús, Grande, Chili, Tambo and Titicaca.

The study includes the determination of the technical hydroelectric potential of the river basins mentioned above, as well as the development of an optimisation methodology that maximises the use of natural resources. As a result of the partnership and the study carried out, a digital tool was created in which a series of detailed information was mapped for the hydroelectric potential of each of the analysed rivers, as well as transmission lines and highways.

Focusing on the region of Madre de Diós, its hydroelectric potential totals approximately 2.9GW of power and 14,583 GWh of hydroelectric generation. However, despite the high theoretical generation potential, the analysed region did not have any installed hydroelectric generation capacity until 2019, according to official government reports (MINEM 2019). This information is in accordance with the scenario presented in earlier since the major hydroelectric development in Peru took place on the western coast, closer to the large population facilities.

Based on the Prosemer study (MINEM 2014), it was possible to analyse in detail that Small Hydroelectric Power Plants (SHPs) and Hydroelectric Power Plants with more than 30MW of installed power (UHEs) are the only energy resources considered viable for the region. Therefore, this article also adopted both hydro energy resources for this study, with and without reservoirs. Table 5 presents additional information on the selected energy resources, according to the regions' capacity as described in (MINEM 2014).

3.3. Detailed analysis

Once the method had been defined, to validate it, it was applied to the specific case of the region of Madre de Dios.

3.3.1. Job creation: quantity

According to (Rutovitz, Dominish, and Downes 2015) and (Tiago et al. 2008), job generation for UHEs presents an average of 7.4 jobs/MW for the construction and installation of plants, 3.5 jobs/MW for equipment manufacturing and 0.2 jobs/MW for operation and maintenance, totalling 11.1 jobs/MW. SHPs, however, totals 31.6 jobs per MW, where construction and installation correspond to 15.8jobs/MW, manufacturing 10.9 jobs/MW and operation and maintenance 4.9 jobs/MW.

Combining these employment rates with theoretical power capacity of energy resources, the total number of jobs generated can be calculated according to Equation (1) and the results are presented in Table 6.

3.3.2. Job creation: quality

According to the methodology developed by the Economic Department of the National Bank for Economic and Social Development of Brazil (BNDES) (Tiago et al. 2008), Table 7 presents an average of monthly salary for every energy resource and how it can be distributed in all different types of jobs related to UHEs and SHPs.

Table 6. Job creation quantity.

Energy resource	Total installed capacity (MW)	Job creation rate (Job/MW)	Job creation
SHP with reservoir	0	31.6	0
SHP without reservoir	664.9	31.6	21,011
UHE with reservoir	732	11.1	8124
UHE without reservoir	1544	11.1	17,138
Total	2940.8		46,273

Source: Prepared by Author.

The numbers provided in the study were adjusted by accumulated inflation until 2021 using consumer price index data, measured by the Brazilian Institute of Geography and Statistics (IBGE 2021). According to Tiago et al. (2008), the generation of jobs by hydro power plants is concentrated in the civil construction and production, absorbing 82% of the total jobs.

3.3.3. Development influence

The analysis of economic development due to the implementation of hydro resources considers previous attributes of jobs creation to determine the annual revenue contribution from each energy resources, according to Equations (2) and (3).

Based on a regional GDP of approximately BRL 3.3 billion (CEPLAN 2019) in 2019, the energy resources considered can be responsible for a considerable variation of the economic development of the region due the expressive installed capacity being considered.

According to Equation (4), assigning a weight of 1/3 to the economic development component calculated, an expressive positive variation in human development can also be obtained for UHEs and SHP, also pointed out in Table 8.

3.3.4. Comfort perception: visual impacts

The assessment of comfort perception for UHEs and SHPs focuses on visual and sound impacts. Since there are no examples of UHEs or SHPs in the region, all coefficients were estimated based on research of similar cases with the same energy resources (Başkaya, Başkaya, and Sari 2011; Rodrigues, Montañés, and Fueyo 2010; Melo et al. 2021). Table 9 presents all values considered for the coefficients and the results calculated for the Affected Population Coefficient (CPA), which represents what percentage of the population is visually impacted.

3.3.5. Comfort perception: sound impacts

For sound impact, existing practical examples referring to the energy resources in question are used as reference.

As there are no record of practical examples of UHE or SHP projects in the region of Madre de Dios, this sub-attribute uses as reference recent studies from Baitelo (2010); Paula, Alencar, and Moura (2002) and Zampar Filho (2014) that analyses sound impact for the same hydro resources in other regions.

Table 7. Monthly salary by energy resource (R$/month) (Exchange Rate reference for 2021: 1 R$ = 0.18527 USD. Source: Bloomberg, 2022).

(R$/month)	UHEs with reservoir	UHEs without reservoir	SHPs with reservoir	SHPs without reservoir
Project (1%)	19,744	17,346	18,545	15,345
Construction and Production (82%)	7142	5714	7142	5714
Operation (17%)	3398	3398	3398	3398
Average	6632	5437	6620	5428

Source: Prepared by Author.

Table 8. Development influence variables.

	UHEs with reservoir	UHEs without reservoir	SHPs with reservoir	SHPs without reservoir
Δ AVERFP	19.4%	33.6%	0%	41.1%
Δ AVERFP HD	6.47%	11.2%	0%	13.7%

Source: Prepared by Author.

Table 9. Visual impact assessment.

Energy Resources	a	b	PA	TP	CPA
UHE with reservoir	0.85	0.85	500	1000	36.1%
UHE without reservoir	0.7	0.7	500	1000	24.5%
SHP with reservoir	0.6	0.6	500	1000	18.0%
SHP without reservoir	0.5	0.5	500	1000	12.5%

Source: Prepared by Author.

The noise measurement procedure is concentrated in the engine room and in the surroundings of the power plants to observe the noise emission in the environment and, in the studied cases, the measurement of noise pollution for SHPs varied between 5.5 and 7.7% of the values prescribed by law. For larger hydropower plants, the sound impact observed is higher, ranging from 9.5% and 12.6% (Table 10).

No studies were found to prove the variation in sound impact for hydroelectric plants with and without reservoir and, therefore, it was considered that the impact would be equivalent for both energy resources.

3.3.6. Social impact due to land occupation

The valuation of this attribute considers impacts such as population displacement as a result of hydroelectric power plant projects. Taking into account that the installation of local power plants has not been identified, the impact of the displaced population is estimated according to studies carried out in other regional experiences.

According to Marsilio (2012) and Serra (2010), in Inambari and Pakitzapango, in Peru, (a close region to Madre de Dios, with similar population density), discussions regarding the implementation of UHEs with reservoir have already been the subject of many discussions and also great opposition from indigenous tribes since a hydroelectric project, of approximately 1500 MW, would have an enormous economic, environmental and social impact for all Peruvians. The project would make all agriculture and gold mining in the area unfeasible, as well as displacing approximately 10,000 people, which corresponds to a rate of 6.67 people displaced per MW.

For the case study, SHP with reservoir is not being assessed; therefore, there is no need to collect date for this case.

No study was found in the literature that evaluated the displacement of people quantitatively in relation to hydroelectric plants without reservoirs in the region. However, due to the absence of a reservoir, a considerably smaller flooded area can be considered. Therefore, insignificant displacement of people in the region was considered for UHEs and SHPs without

Table 10. Sound impact percentage difference between the identified value measured and the value allowed by law.

Energy Resources	Sound Impact (%)
UHEs with reservoir	9.5–12.6
UHEs without reservoir	9.5–12.6
SHP with reservoir	5.5–7.7
SHP without reservoir	5.5–7.7

Source: Prepared by Author.

Table 11. People displacement rates.

Energy resources	Displacement rate (People/MW)
UHEs with reservoir	6.7
SHP with reservoir	Not available
UHEs without reservoir	~Zero
SHP without reservoir	~Zero

Source: Prepared by Author.

reservoirs. Table 11 summarises the displacement rates considered for each energy resource in this case study.

It is noteworthy that the estimate of displacement by occupied area and rural population density in the region has limitations due to the variability of this area for each SHP or UHE project - considering the elimination of reservoir in most of the plants - and the relationship between displacement and the occupied area – considering that the expropriation does not refer only to the reservoir area, but also due to multiple factors, such as the alteration of river flows and the loss of its multiple benefits to riverside populations.

3.4. Consolidation and ranking of energy resources

The set of information worked in AV method quantifies the sub-attributes so that energy resources can be compared between themselves in each sub-attribute. The comparison of this set of information between resources makes it possible to rank or classify energy resources according to their performance in the sum of all these attributes.

Table 12 shows a summary of all sub-attributes' values of the AV method for the case study. In this case, all sub-attributes were given the same weight, as there was no specific information to drive this decision to change; however, depending on the case study, this variable can be adjusted to reflect a better scenario that is being evaluated.

Then, it is necessary to convert the results of the attribute and sub-attributes calculation algorithms to numbers of the same base. Each sub-attribute will receive a grade of 1, 0.5 or 0, in which the best-evaluated energy resource will receive grade 1 and the worse will receive a zero score. In the case of sub-attributes whose ERs have the same value, same grade will be assigned to both. The result can be seen in Table 13.

Table 15 presents the final ranking of energy resources based on the standardised assessment provided by Table 13 and also taking into consideration the weights of each evaluated sub-attribute (Table 14). The weights were calculated according to the Best-Worst Method (Rezaei 2015), which is a decision method based on a systematic pairwise comparison of the decision criteria. The best criteria selected by the author is Direct Jobs and the worst is Visual Impact. The optimal result of the pairwise comparison is presented in Table 14.

Table 12. Resource assessment according to the AV method.

Attribute	Sub-attribute	UHEs with reservoir	UHEs without reservoir	SHPs without reservoir
Job Generation	Direct Jobs (Jobs/MW)	8124	17,138	21,011
Job Generation	Job Quality (R$/month)	6632	5437	5428
Social Impact due to Land Occupation	People displacement (People/MW)	6.7	0	0
Development Influence	Economic Activities (%)	19.4	33.6	41.1
Development Influence	Human Development (%)	6.47	11.2	13.7
Comfort Perception	Visual Impact (%)	36.1	24.5	12.5
Comfort Perception	Sound Impact (%)	9.5 - 12.6	9.5 - 12.6	5.5 - 7.7

Source: Prepared by Author.

Table 13. Standardisation of sub-attribute assessments.

Attribute	Sub-attribute	UHEs with reservoir	UHEs without reservoir	SHPs without reservoir
Job Generation	Direct Jobs (Jobs/MW)	0	0.5	1
Job Generation	Job Quality (R$/month)	1	0.5	0
Social Impact due to Land Occupation	People displacement (People/MW)	0.5	1	1
Development Influence	Economic Activities (%)	0	0.5	1
Development Influence	Human Development (%)	0	0.5	1
Comfort Perception	Visual Impact (%)	0	0.5	1
Comfort Perception	Sound Impact (%)	0.5	0.5	1

Source: Prepared by Author.

Table 14. Sub-attribute weight

Attribute	Sub-attribute	Sub-attribute weight
Job Generation	Direct Jobs	32%
Job Generation	Job Quality	19%
Social Impact due to Land Ocupation	People Displacement	10%
Development Influence	Economic Activities	13%
Development Influence	Human Devolopment	19%
Confort Perception	Visual Impact	3%
Confort Perception	Sound Impact	4%

From Table 15, it is possible to conclude that Small Hydro Power Plants without reservoirs are the most recommended Energy Resource to be implemented in the region of Madre de Dios among those evaluated, mainly due to their lower environmental and social impacts.

It is possible to conclude that SHPs without reservoirs are the most suitable resource for implementation in the region in order to export energy to Brazil without compromising domestic demand when compared to UHEs with or without reservoirs. It is also important to highlight that power plants with reservoirs should be the last option, considering the social impacts, as pointed out in Table 15.

4. Results and discussions

This study allows the identification of two interdependent research gaps. First, there is a lack of meta-analyses of pertinent studies in this area. The samples of revisited articles continue to be somewhat limited because the social dimension is frequently only a minor consideration in comparison to the economic and environmental ones. Although it is one of the most complex components of the interface of a sustainable energy resource planning, almost none of the selected articles (Table 2) assessed the quantitative side of incorporating social indicators in mathematical models. The majority of them are still restricted mainly to a qualitative and/or theoretical analysis.

The second research gap concerns the fact that all cited literature evaluations agree that the subject of quantitative modelling is highly underdeveloped in terms of social impacts and lacks a defined and robust approach. Therefore, more research must be dedicated to the quantification of social impacts, the identification of significant social indicators, and appropriate modelling

Table 15. Final energy resources ranking.

Energy resources	Final standardised grade	Final ranking
SHPs without reservoir	0.81	1
UHEs without reservoir	0.55	2
UHEs with reservoir	0.26	3

Source: Prepared by Author.

methodologies, especially when it comes to the field of energy resource planning, where literature is even scarcer.

Our literature review contained a sample of 30 relevant articles from top (FT50) business journals and 20 articles from top Scimago energy journals that investigate how to assess social impact conceptually or empirically. From this database, no article includes all of the relevant information into a single model. Therefore, the method proposed here of Accounting and Valuation of energy resources sought to fill the above gaps and mature the IRP research in the field of quantification of social attributes. The use of different data sources proves that the methodology proposed here has a much broader and more complex approach to the issues dealt with obtaining and using energy, when compared to traditional planning.

This is significant because the energy sector can offer a variety of environmental, economic and social impacts for all associated stakeholders. In most cases, however, importance is given to the measurement and assessment mainly of the environmental and economic impacts, leaving behind the investigation of social impacts. Beyond the restricted measurement of project costs, an energy project needs an in-depth examination of broader social impact on communities (DOE 1997; OECD 2003) to enhance projects' acceptance throughout its lifecycle (Cataldi 1997; Stirling 2014) (planning, construction, and operation). It is very important that investors, policymakers, local governments, and residents ensure social approval of the project.

Therefore, this work provides extremely valuable information for decision-makers to assess, with real and quantitative data, investment decisions regarding energy planning, which is believed to be greatest contribution of this work. Social and environmental externalities are difficult to price but they need to be evaluated in a cost–benefit analysis and, when possible, monetised.

The AV method is also highly relevant to assist these stakeholders in decision-making not only to select the most socially positive energy resources, but also to assess the strengths and weaknesses of each resource regarding its social impacts.

When applied to the case study in Peru, the method successfully assisted in the valuation of social impacts of the potential energy resources for the region. This result can be a strong ally for decision-makers such as government institutions to respond and adapt the urge of local communities that would be affected by the impacts of the dams in the local ecosystems.

Also, the method presented is very adaptable. The indicators can be calculated using real data or also literature review in search for case studies for similar existing practical examples in other regions.

5. Conclusion and future work

The AV methodology consistently processed the previous information collected, offering potential and reliable indicators for the assessment of the social dimension of hydro resources in the region of Madre de Dios in Peru.

The development of this work improves the existing steps of the traditional IRP and adds changes to the structure and complexity of the complete process of resource planning by changing it into a modular characteristic, in which the social dimension can be analysed separately without harming the quality of the analysis. Also, the results transcend the monetisation of impacts and also take into consideration less tangible accounting such as visual impacts and development influence impacts.

Therefore, this work provides extremely valuable information for decision-makers to assess, with real and quantitative data, investment decisions regarding energy planning, which is believed to be the greatest contribution of this work. Social and environmental externalities are difficult to price, but they need to be evaluated in a cost–benefit analysis and, when possible, monetised.

Also, the study case shows great success in testing the method proposed as implementing new projects of UHEs or SHPs in Peru has already been the focus of a very complex social-environmental discussion in the country and has been placing barriers to the evolution of the agreement between Brazil and Peru for the export of energy. It is believed that the results achieved could help improve discussions regarding this matter.

However, the exercise conducted for the case study in the Madre de Deus region showed some limitations regarding access to data. Given that the region analysed has not yet been much explored, it was hard to find studies and analysis conducted in the region that could support the quantification of the impacts analysed by the sub-attributes. This is one limitation for this method, once it frequently necessary to support calculations with data. In these cases, an alternative is to perform a literature review in search for case studies for similar existing practical examples in other regions, as it was done for the attribute of comfort perception, for example.

Finally, for future work, it is important to consider the complete analysis of the four dimensions of the IRP for this study. The evaluation of the four dimensions provides a complete perspective of the relationship between each energy resource and its interdependence with the social, environmental, geographic, political, and cultural elements of a region. The social dimension alone, even though provides extremely valuable information, cannot be used to define which energy resources will be implemented in a certain region.

Note

1. *Programa para la Gestion Eficiente y Sostenible de los Recursos Energéticos del Perú* (Prosemer). it was not possible, from the documents made available by the government, to identify the company private person who performed the work.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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