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An algorithm-based approach to map the global players' network for photovoltaic energy businesses

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ABSTRACT

Due to economic, social, and environmental factors that influence businesses related to renewable energy sources, such as photovoltaic energy (PV), several players are acting on these business models, forming a complex network of interrelations. In this sense, this paper aims to identify the players involved in PV businesses considering a global perspective, mapping the main relations between the players, contextualizing and discussing how these interactions develop in the context of PV businesses and help to the development and diffusion of the PV market. A systematic review (SR) based on the Preferred Reporting Items for Systematic Reviews and a Meta-Analyses (Prisma) statement was used to identify who the players were and to group them into clusters. The Apriori algorithm was used to build a players' network and a clusters' network, enabling a detailed discussion, based on a Political, Economic, Social, Technological, Legal, and Environmental (PESTLE) factors analysis, of these relationships. 35 players were identified, being grouped into 7 clusters, which can be related to the PV's businesses. 20 players achieved relevance through Apriori rules, appearing in the players' network. With the players' network related to the PV businesses, business models can be defined or improved, exploring the conditioning, and limiting factors to improve business processes.

Keywords

Solar Energy;
Photovoltaic Energy;
Apriori;
Players;
Stakeholders;

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1. Introduction

Renewable energy sources are clean, free [1], and contribute to a variety of sustainable development goals [2]. A high level of renewable energy introduced in electricity grids implies the most cost-efficient energy systems [3] generating environmental, social, and economical benefits. Moreover, the interest of companies and consumers in increasing participation in the renewable energy market has increased rapidly, bringing new challenges to stakeholders [4]. Besides, companies are also facing pressure from regulators, the media, and creditors to adopt strategies related to renewable energies [5]. Therefore, proper management of technological, financial, and human resources is necessary to achieve good competitive levels in this business sphere.

Energy markets should be competitive regardless of who owns or controls the grid [6]. Photovoltaic energy (PV) is inserted in this globally competitive market, forcing companies to carry out processes relevant to their competitiveness with maximum efficiency [7]. Contributing to the popularity of PV systems, residential consumers are becoming part of the electricity market technically and commercially [8], thus, acquiring the status of prosumer [9]. However, the high initial investment due to the positive relationship between capital and solar energy capture still proves to be limiting for the population [10,11]. In this sense, it is possible to highlight the policies implemented by governments around

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the world [12] that aim to reduce the costs of installing renewable energy generation systems, such as PV [13].

Business areas, such as PV, have several challenges for researchers and managers, such as information technology, engineering, business management, and public management [14]. Considering this, it is possible to highlight the importance of the players that can be considered as those stakeholders or agents in a business process or network. They can represent an individual or collective entity, having heterogeneous attributes, preferences, goals, and behavioral rules through which they make their decisions in the face of certain situations interacting with each other and with the environment in which they operate [15].

Considering the concept of the principal-agent theory, the stakeholders who represent institutions often maximize their utility privileging their interests [16,17]; however, partnerships between different organizations can form a solid basis, being the starting point for stronger networks to be established over time [18], which leads to a need to balance the interests of organizations so that the community can benefit. In short, the behavior of players in everyday situations depends on several factors and social connections [19], or even their ability and technical knowledge about the theme in question [20]. Therefore, it is important to evaluate the context of the business carried out, considering social, economic, and business relationships and the information flows.

Regarding this context, the businesses related to the PV market have their characteristics, with several players interacting in this environment. Previous research has shown important relationships in the PV market. The integration of the public administration with other players to choose and define decision variables can help in the integration of renewable energy sources into the energy system [21]. [2] states that both private enterprise and government need to cooperate playing each one his role to improve the adoption of renewable energy technologies. For [22], another example of collaborative management of energy production and supply of renewable energy occurs in communities.

[11] says that the private sector has a vital role in the transformation of the power sector in Nigeria and similar countries with the end-users being the key part of the power supply and demand process. For [23], policy makers and energy experts should be precursors in the planning of energy capacities to provide energy sustainability for countries. [24] say that in the energy transition environment, prosumers, whether from homes in cities or rural areas, are the main drivers for the decentralization of energy systems. In developed countries, there is a predominance of small and medium scale solar PV systems that benefit from policy support schemes [25].

The energy transition considering the insertion of renewable sources, such as PV, involves players and policy structures leading to interactions and networks that are difficult to assess and predict [26]. Thus, it becomes important to research networks and interactions between players in the PV market, mapping and contextualizing their connections in this dynamic environment.

1.1. Research motivation

This paper aims to identify the players involved in PV businesses considering a global perspective, mapping the main relations between these players, contextualizing, and discussing how these interactions develop in the context of PV businesses and help to the development and diffusion of the PV market.

The players were chosen as the object of study in this article because of the heterogeneity of attributes, objectives, and preferences in the most different businesses, including those related to renewable energies, such as PV. The network of players related to PV businesses is complex and has a broad dimension. This business modality, in turn, has several political, economic, financial, social, technological, legal and environmental factors, which are conditioning and limiting influences on innovative technological aspects with significant expansion potential, which requires the performance of several different entities to integrate and properly coordinate business.

1.2. Academic and managerial contributions

This research seeks to contribute to the improvement of the existing business models or the establishment of new ones. This becomes possible because, by establishing the main interconnections between players and the contextualizing their relations, it is possible to show how the main information flows happen, as well as what are the support trends for joint action in certain situations within the PV market. As a result, flows between players in a business model can occur in such a way that there is no unnecessary interference or loss. Thus, even with a broad context and a complex players' network, it will be possible to efficiently address and exploit the conditioning and limiting factors to improve the business processes related to PV.

The remainder of the paper is organized as follows: Section 2 details the methodological procedures used, Section 3 presents the results obtained, Section 4 brings a Political, Economic, Social, Technological, Legal, and Environmental (PESTLE) factors analysis of the findings, and Section 5 presents the conclusions of the paper.

2. Methodological procedures

A systematic review (SR) was developed to identify the players that are part of the PV businesses, and an approach based on the Apriori algorithm was applied to map the existing relationships between these players. Thus, the construction of this paper can be divided into two stages:

Stage 1 – systematic review
Stage 2 – meta-analysis
In the following, these two stages are detailed.

2.1. Stage 1 – systematic review

SRs are intended to answer formulated research questions [27]. A research protocol needs to be established to develop the SR [28], and in this article, the Prisma statement was used. The Prisma statement consists of a checklist with four phases focusing on ways in which authors can ensure transparency and reliable reporting of results [29].

In the Prisma identification phase, search strings need to be defined based on a research question. The research question to be answered in this research was: "Who are the players involved in PV businesses?" Therefore, the keywords to be searched were defined as ("solar energy*" OR "photovoltaic energy*") AND ("management*" OR "business*"). These keywords were tested on different scientific databases to find databases that encompass more studies in this area. Through this process, it was found that Scopus and Web of Science were the most appropriate databases to find articles on this subject.

The research aimed to verify who are the main players considered in the literature after the adoption of higher incentive policies by a group of several countries. Thus, the period considered was from 2009 to the present because the European Parliament approved, in 2009, Directive 2019/28/CE on the promotion of the use of energy from renewable sources [30]. Table 1 summarizes all the search filters used to retrieve articles from the Scopus and Web of Science databases.

Still, in the identification phase, the searches were carried out and resulted in 2523 articles, and after removing the duplicate records, 2268 remained. In the screening phase, titles and abstracts were analyzed and 107 were screened, and considering the scope of this research related to the players in the PV business, 2161 articles with the scope of the subject focused on other activities related to PV, such as issues related to PV generation technology, were excluded.

In the eligibility phase, the full texts were assessed, with 36 articles excluded because their theme was not related to PV businesses. In the fourth phase, 64 articles were included in the qualitative and quantitative synthesis because, in addition to their theme being related to the PV businesses, they also indicated at least one player related to these businesses. Figure 1 shows the Prisma Statement flow diagram used in this stage.

Table 1: Search filters used in the systematic review

Filter	Scopus	Web of Science
Document type	Articles	Articles
Search in	Title, abstract or keywords	Topic
Subject areas	Energy; Engineering; Decision Sciences; Business, Management and Accounting; Economics, Econometrics and Finance	Energy Fuels; Engineering Electrical Electronic; Green Sustainable Science Technology; Engineering Industrial; Engineering Environmental; Engineering Manufacturing; Engineering Multidisciplinary; Business; Economics; Management
Years	2009 – Present	2009 – Present
Search terms	("solar energy*" OR "photovoltaic energy*") AND ("management*" OR "business*")	("solar energy" OR "photovoltaic energy") AND ("management*" OR "business*")

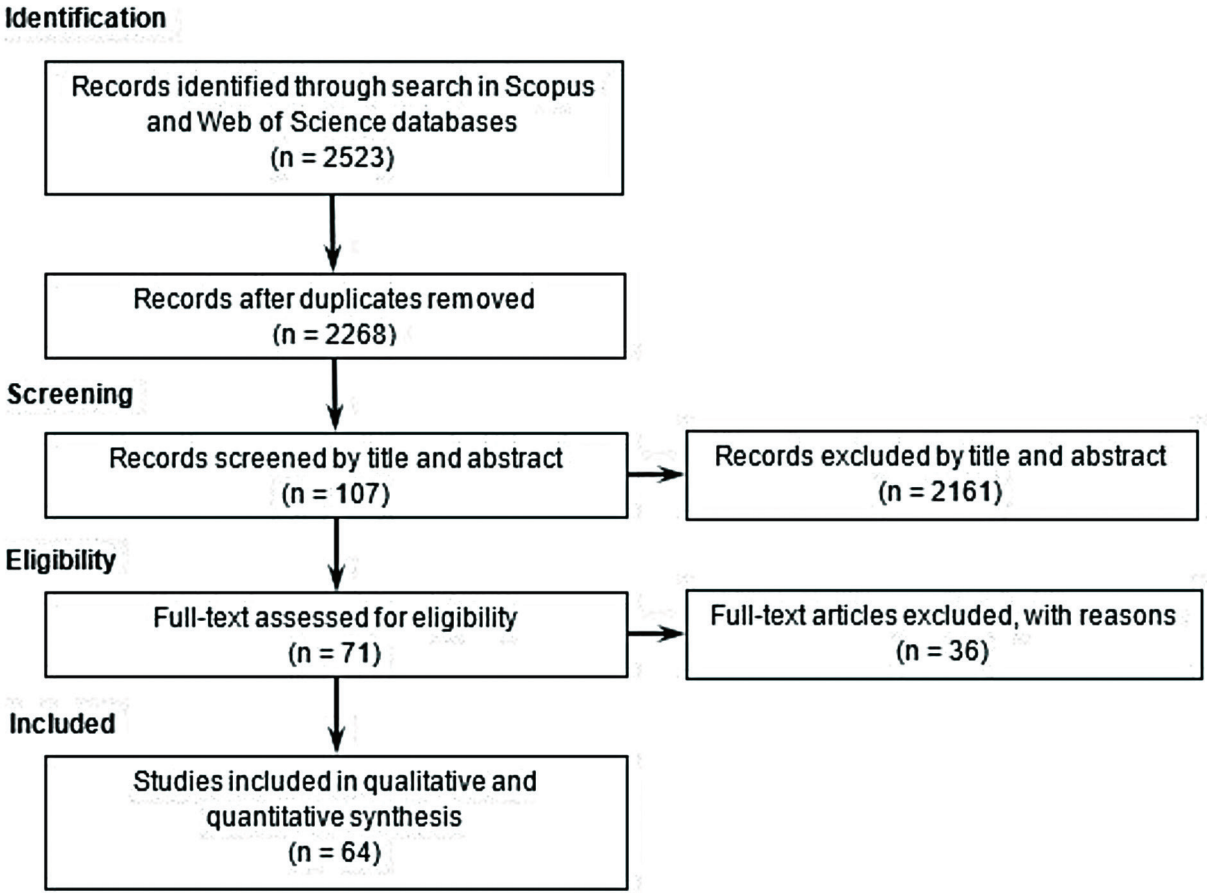

Figure 1: Prisma flow diagram used to include studies in the systematic review

The 64 articles included in the SR were read, catalogued and numbered. A table was created to identify all the players mentioned in the articles. In the columns, the players were placed, and in the lines the articles that cited them, resulting in a matrix with 35 columns (one for each player) and 64 rows (one for each article retrieved from the SR) where it was indicated in each cell the occurrence or non-occurrence of citation of each player.

2.2. Stage 2 – meta-analysis

A meta-analysis was developed through the use of statistical techniques to integrate and summarize the results of studies considered as included in an SR [29]. In this article, the meta-analysis used was based on association rules to show the main relationships among the players identified in the SR. Based on these relationships, a PESTLE analysis was carried out to discuss the aspects related to the context of these players' relations.

Association rules are a data mining technique that extracts frequent associations in a set of items from a database [31], and if two keywords appear in the same document, they are considered relevant to being part of a network [32]. Networks of citations were the first complex networks studied [33]. Da Costa et al. [34] created a network of industry 4.0 technologies through the identification of associations rules and relations among these technologies in related papers. However, only the formatting of networks does not provide enough information to conclude the level of relevance of a theme [35]. Therefore, it is important to seek theoretical, technical, and practical support that corroborates or not the associations presented in the network.

In this study, the meta-analysis was based on the Apriori algorithm. Apriori was chosen because it makes it possible to check the dependency and the level of confidence between keywords, easily identifying the relationships between them [34]. Apriori was the first

algorithm to extract patterns from a database to determine Boolean association rules [36]. To run the Apriori algorithm, the data mining software WEKA was used, which is an open-source software that supports tasks such as association, classification, clustering, and regression [37].

The players' occurrence matrix created in stage 1 was used and edited to consider "1" for a player citation and "?" for a non-citation. The "?" was used because if "0" had been used, it would be interpreted by WEKA as an association rule about not-occurrences, and this was not the focus to building a player's network. Then, the file with the matrix was converted to *.arff to be read in WEKA.

The identification of association rules through Apriori is defined as follows [38,39]: Considering I a set of items: (I_1, I_2, ..., I_n). D is the database containing the transactions T represented as a binary vector with $T[k] = 1$ if T bought the item I_k, and $T_{[k]} = 0$ otherwise. For each transaction, there is one tuple in database D. Each transaction $T \rightarrow$ I has an identifier k. Let A be a set of some items in I. Transaction T contains A if and only if $A \square T$. An association rule is an implication of the form $A \rightarrow B$, where $A \square I$, $B \square I$ and $A \cap B = \Phi$.

Support: The rule $A \rightarrow B$ holds in the set D with support, where s is the percentage of transaction in D that contains $A \cup B$. The probability in this rule is $P(A \cup B)$.

$$Support\ (A \rightarrow B) = P\ (A \cup B) \quad (1)$$

Confidence: The rule $A \rightarrow B$ has confidence c in set D, where c is the percentage of transactions containing A that also contains B, then there is the conditional probability $P(B \mid A)$.

$$Confidence\ (A \rightarrow B) = P\ (B \mid A) \quad (2)$$

Lift: This metric evaluates the correlation measure between item occurrences.

$$Lift\ (A, B) = [P\ (A \cup B) / (P\ (A) * P\ (B))] \quad (3)$$

When the result is less than 1, the occurrences of A and B are negatively correlated, when the result is greater than 1, the occurrences of A and B are positively correlated, and when the result is equal 1, then A and B are independent [34]. Thus, to build the players' network, it was established that the confidence should be equal or greater than 0.75 and that the lift should be equal to or greater than 1.0 showing on the networks only dependency relations between players and clusters. These metrics were thus established to structure a network with the most relevant and most dependent players' connections considering the businesses involving the PV.

With the relationships established, a detailed analysis of the articles was made seeking subsidies that explain and support the relationships found. Therefore, a PESTLE analysis was developed. PESTLE stands for Political, Economic, Social, Technological, Legal, and Environmental factors, providing a broad view of the complete environment [40,41] of the PV businesses market. PESTLE analysis allows managers to identify ways in which their companies can define their strategies, reflecting on its internal tactics and resources to ensure survival in a dynamic business environment [42]. This analysis enabled a better understanding of the interrelationships, highlighting the roles of the players in each link of the PV market business network.

3. Systematic review and Apriori results

Figure 2 shows the geographic distribution of the articles included in the SR. The approach proposed in the article seeks to map players and clusters with a global scope, however from this figure, it can be seen that there was a predominance of articles from Europe, Asia, and North America. With that, it can be said that the analyzes of the subsequent sections end up tending the countries of these continents.

Through the SR, 35 players related to business in the PV market were identified considering a global scope.

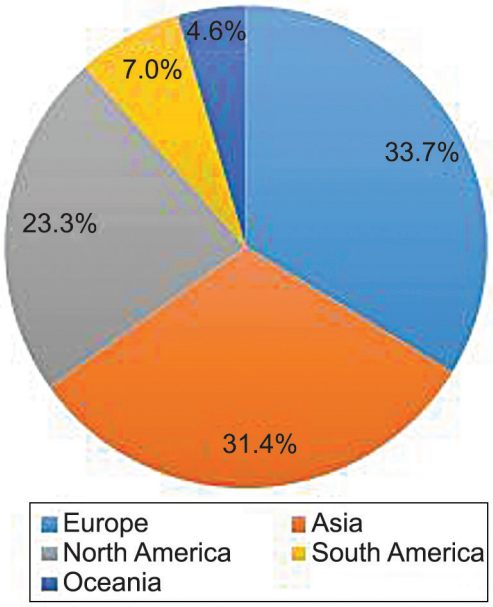

Figure 2: Geographical distribution of articles included in the systematic review

Table 2: Players associated with photovoltaic energy businesses identified in the systematic review

CLUSTER	CODE	PLAYER	CITATIONS	PERCENTAGE
NATIONS	P1	Nations Organizations	7	10.9%
	P2	Nations	46	71.9%
AGENCIES	P3	International Agencies	7	10.9%
	P4	Non-Governmental Organizations (NGOs)	6	9.4%
	P5	Policy Makers	30	46.9%
	P6	Associations, National Agencies, and Pro-Renewable Energy Programs	17	26.6%
KNOWLEDGE	P7	Universities, Educational and Research Institutions, and Researchers	20	31.3%
FINANCES	P8	Public Financial Agents	24	37.5%
	P9	International Donors	1	1.6%
	P10	Equity funds	2	3.1%
	P11	Private Financial Agents	11	17.2%
	P12	Investors	26	40.6%
	P13	Insurers	1	1.6%
SUPPLY CHAIN	P14	Raw Material Manufacturers	6	9.4%
	P15	Manufacturers and Developers of Solar Panels and Equipment	35	54.7%
	P16	Startups	2	3.1%
	P17	Component Distributors	4	6.3%
	P18	Installers	15	23.4%
	P19	System Integrators	3	4.7%
CUSTOMERS	P20	General Prosumers	23	35.9%
	P21	Enterprises Prosumers	24	37.5%
	P22	Residentials Prosumers	34	53.1%
	P23	Shared Community Prosumers	10	15.6%
	P24	Public Illumination Prosumers	1	1.6%
	P25	Rural Prosumers	9	14.1%
	P26	Public Services Prosumers	4	6.3%
	P27	Society	2	3.1%
	P28	Others customers	4	6.3%
SERVICES	P29	Advisory Services	4	6.3%
	P30	Third-Party Ownership	8	12.5%
	P31	Others Enterprises	24	37.5%
	P32	Power Generation Companies	30	46.9%
	P33	Utilities	31	48.4%
	P34	State Owned Enterprises	7	10.9%
	P35	Transmission and Distribution System Operators	9	14.1%

Table 2 shows these 35 players identified with the number of citations and the percentage that these citations represent considering the 64 articles included in SR. To help their identification, they were codified from P1 to P35.

Those players were also clustered in 7 groups: Nations, Agencies, Finances, Knowledge, Supply Chain, Customers, and Services. This clustering was done through the reading and interpretation of the context described for each player in each article, and so the

player was framed in the cluster with the greatest possible similarity to the situation described considering the businesses in the global PV market.

In this clustering, some points deserve to be explained, for example, the players that form the Nations cluster: P1- Nations Organizations were so considered the organizations of countries mentioned in articles such as the European Union, Mercosur, and others; and P2- Nations is formed by nations and their direct governors itself.

It is also worth mentioning the Agencies cluster, where, in addition to P3 and P4, the following players were also included: P5- Policy Makers, formed by the agencies, secretariats, and bodies responsible for formulating policies related to PV; P6- Associations, National Agencies, and Pro-Renewable Energy Programs, formed by all other organizations that play a relevant role to the insertion of PV at the national level.

The P16- Startups were placed in the Supply Chain cluster due to the context addressed in the SR articles, a similar situation to the P27- Society that was placed in the Customers cluster. P34- State Owned Enterprises was characterized as a player in the Services cluster because, according to SR articles, it has a similar function to utilities but they are companies controlled by governments.

This way, in addition to an analysis of the players, it was also possible to develop and analyze a network of clusters of players in the PV businesses.

Figure 3 presents the players' network built considering the best rules found among these players, which are described in Table 3. For the relationship to be represented in the network, the confidence level must be greater than or equal to 0.75 and the lift greater than 1.0. This way, it can be seen that 20 of the 35 players identified in SR are presented in this network. The numbers displayed within the arrows are the confidence values between the two players.

To exemplify the data association rules calculation, the association between the players P12- Investors and P2- Nations can be used. In this case, P12- Investors is the antecedent (A), and P2- Nations is the successor (B). To calculate the support of the association between A and B, it is necessary to establish the relationship between the number of times A and B are cited in the same article (22 times according to Table 3 in the column "Apparitions as the successor") and the total number of articles (64). Therefore:

$Support\ (A \rightarrow B) = P\ (A \cup B) = 22\ /\ 64 = 0.344 = 34.4\%$

Confidence association rule is obtained through the relation between the transactions containing A (26 times according to Table 3 column "Apparitions as the antecedent") that also contains B (22 times according to Table 3 column "Apparitions as the successor").

$Confidence\ (A \rightarrow B) = P\ (B \mid A) = 22\ /\ 26 = 0.85 = 85\%$

Lift association rule is obtained through the relation between the $Support\ (A \rightarrow B)$ (previously calculated as 0.344) and the multiplication of the probabilities of occurrence in the hole itemset of A (it occurs 26 times according to Table 2) and B (it occurs 46 times according to Table 2). Thus:

Table 3: Best association rules found among players associated with photovoltaic energy businesses

Associations				Rules	
Antecedent	**Apparitions as the antecedent**	**Successor**	**Apparitions as the successor**	**Confidence**	**Lift**
P14– Raw Material Manufacturers	6	P15– Manufacturers and Developers of Solar Panels and Equipment	6	1	1.83
P3– International Agencies	7	P2– Nations	7	1	1.39
P34– State Owned Enterprises	7	P2– Nations	7	1	1.39
P21– Enterprises Prosumers	24	P22– Residentials Prosumers	23	0.96	1.8
P6– Associations, National Agencies, and Pro-Renewable Energy Programs	17	P2– Nations	16	0.94	1.31

Table 3: Best association rules found among players associated with photovoltaic energy businesses (*continued*)

Associations				Rules	
Antecedent	**Apparitions as the antecedent**	**Successor**	**Apparitions as the successor**	**Confidence**	**Lift**
P11– Private Financial Agents	11	P2– Nations	10	0.91	1.26
P30– Third-Party Ownership	8	P33– Utilities	7	0.88	1.81
P30– Third-Party Ownership	8	P22– Residentials Prosumers	7	0.88	1.65
P31– Other Enterprises	24	P2– Nations	21	0.88	1.22
P1– Nations Organizations	7	P2– Nations	6	0.86	1.19
P12– Investors	26	P2– Nations	22	0.85	1.18
P8– Public Financial Agents	24	P2– Nations	20	0.83	1.16
P6– Associations, National Agencies, and Pro-Renewable Energy Programs	17	P15– Manufacturers and Developers of Solar Panels and Equipment	14	0.82	1.51
P23– Shared Community Prosumers	10	P22– Residentials Prosumers	8	0.8	1.51
P15– Manufacturers and Developers of Solar Panels and Equipment	35	P2– Nations	28	0.8	1.11
P5– Policy Makers	30	P2– Nations	24	0.8	1.11
P23– Shared Community Prosumers	10	P2– Nations	8	0.8	1.11
P21– Enterprises Prosumers	24	P2– Nations	19	0.79	1.1
P25– Rural Prosumers	9	P22– Residentials Prosumers	7	0.78	1.46
P25– Rural Prosumers	9	P15– Manufacturers and Developers of Solar Panels and Equipment	7	0.78	1.42
P25– Rural Prosumers	9	P2– Nations	7	0.78	1.08
P30– Third-Party Ownership	8	P12– Investors	6	0.75	1.85
P30– Third-Party Ownership	8	P32– Power Generation Companies	6	0.75	1.6
P31– Other Enterprises	24	P15– Manufacturers and Developers of Solar Panels and Equipment	18	0.75	1.37
P7– Universities, Educational and Research Institutions, and Researchers	20	P15– Manufacturers and Developers of Solar Panels and Equipment	15	0.75	1.37
P7– Universities, Educational and Research Institutions, and Researchers	20	P2- Nations	15	0.75	1.04

$P(A) = 26 / 64 = 0.406$

$P(B) = 46 / 64 = 0.719$

$Lift(A, B) = [P(A \cup B) / (P(A) * P(B))] = [0.344 / (0.406 * 0.719)] = 0.344 / 0.292 = 1.18$

Figure 4 presents the network of clusters built based on the best association rules found between clusters and is described in Table 4. The numbers displayed within the arrows are the confidence values between the two clusters. To obtain the association rules between clusters, it was considered that a cluster is cited in an article when at least one of its players is cited in this article.

Considering the lift rule, there is a dependency relation in all the rules shown in Figures 3 and 4, because in all cases shown the lift is greater than 1.0. Following the Apriori confidence rule, in Figures 3 and 4, the arrow always points to the successor, ie indicating the confidence level that the predecessor appears, the successor will also appear in the same article. Therefore, for example, in the rule Agencies and Customers, the confidence 0.80 means that in 80% of the articles where a player from the Agencies cluster is cited, a player from the Customer cluster is cited too.

Figure 3 shows P2– Nations in a central role having 14 other players, from all clusters, linked to it and being cited in 71.9% articles. This fact also led the Nations cluster to have significant relevance in Figure 4, having a dependency relationship with five other clusters. The second role-centred player in Figure 3 is P15– Manufacturers and Developers of Solar Panels and Equipment being connected to 6 other players, from the other five clusters, and cited in 54.7% of the articles. This player is part of the Supply Chain cluster that has a direct and dependent connection with the Nations, Services, and Knowledge clusters. The third role-centred player in Figure 3 is P22– Residentials Prosumers that is connected to 4 other players, with three connections internally in the Customers cluster and just one with a player from the Services cluster. P22- Residentials Prosumers is cited

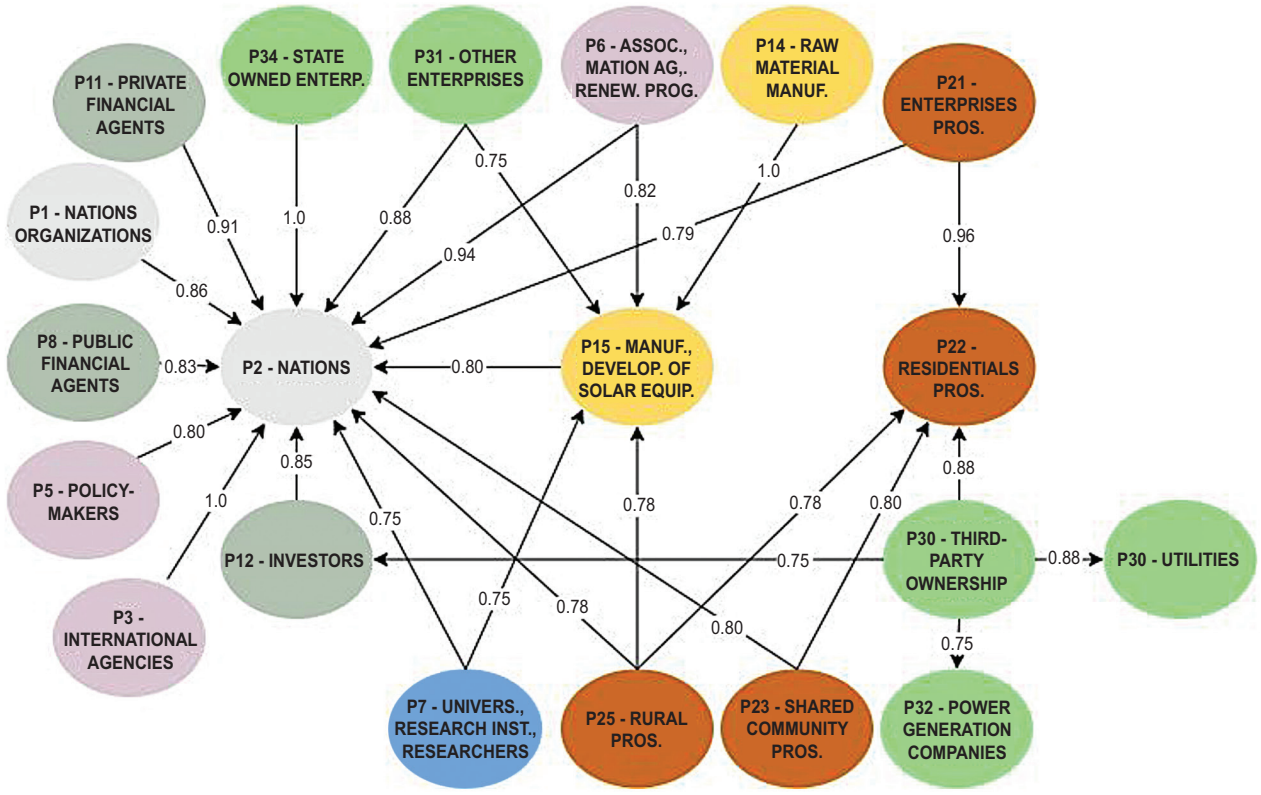

Figure 3: Players' network of photovoltaic energy businesses

Table 4: Best association rules found among clusters of players from photovoltaic energy businesses

Associations				Rules	
Antecedent	Apparitions as the antecedent	Successor	Apparitions as the successor	Confidence	Lift
Agencies	41	Services	35	0.85	1.05
Supply Chain	40	Services	34	0.85	1.05
Finances	36	Services	30	0.83	1.03
Agencies	41	Nations	33	0.82	1.12
Supply Chain	40	Nations	33	0.82	1.12
Nations	47	Services	38	0.81	1
Agencies	41	Customers	32	0.80	1.11
Knowledge	20	Nations	16	0.80	1.09
Knowledge	20	Supply Chain	16	0.80	1.28
Finances	36	Customers	28	0.78	1.08
Finances	36	Nations	28	0.78	1.06
Knowledge	20	Agencies	15	0.75	1.2

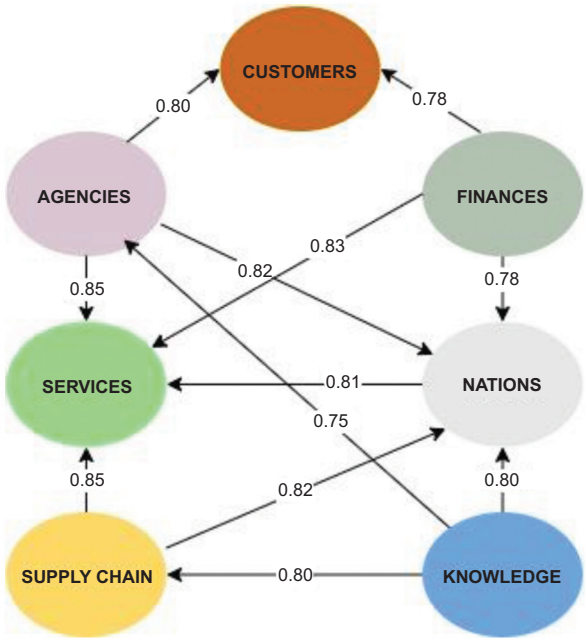

Figure 4: Clusters' network of photovoltaic energy businesses

in 53.1% of the articles. This player composes the Customers cluster, and even with this players' relations, it has a dependent rule relation just with Agencies and Finances clusters.

4. PESTLE analysis of the networks of players and clusters

In this section, the relationships between players and clusters shown in Figures 3 and 4 are discussed and contextualized in the light of the six types of aspects of the PESTLE analysis: political, economic, social, technological, legal, and environmental.

4.1 Political aspects

Considering a political perspective, it can be highlighted the dependent relationship between the Nations and Finances clusters. There are three links between players of these clusters, P8– Public Financial Agents, P11– Private Financial Agents, and P12– Investors, all related to the player P2- Nations as the successor. This shows the close role of these players in the PV market.

Governments such as the Lebanese, Indian, and Chinese have made efforts by using grant funds to provide low-rate financing and lending to PV systems [43–45]. On the other hand, the effect of government subsidies on investment by private agents is apparent [46], and with the opening to the investment of these agents, there is the possibility of governance in the sector as well as diversification in the energy mix [47]. Another effort made by governments is the establishment

of policies to attract investors [45] to the PV market in business models such as Third Party Ownerships.

Another dependent relation between clusters and players with a political perspective is between the clusters Nations and Customers, and between the players of these clusters, P21- Enterprise Prosumers, P23- Shared Community Prosumers, and P25- Rural Prosumers, all related to the player P2- Nations as the successor. These relations are guided by incentives granted by governments such as tax exemption, tax credits, low-cost financing, and assistance in technological, economic, financial, and administrative aspects [48,49]. Shared Community Prosumers still benefit from the division of costs and government subsidies for PV installation [50]. All these incentives provide savings on the energy bill [51] of prosumers.

Considering these aspects, it is clear that the governments play an intermediary role between public and private financial agents and prosumers to the diffusion of PV and, consequently, having a coordinating and governance role over the PV sector. While, on the one hand, financial agents press for more favorable policies for their profit, on the other, consumers seek to benefit from financial and technological advantages when generating their energy, with the ease of incentives intermediated by governments with financial agents.

Another link that fits under a political perspective is between P2– Nations and P34– State-Owned Enterprises. Even though it has been the object of a government monopoly in the past, in some countries the energy sector has not yet been decentralized, which is still strategic in countries like China for their power to approve large-scale projects, their ability to set energy prices, and their influence on subsidy regulation [44]. In South Africa, state-owned enterprises have a negative moderating effect that discourages new investments [51]. It can be seen that the State-Owned Enterprises are still a means that some governments use to maintain control over a highly strategic sector such as the energy sector.

4.2 Economical aspects

Turning the discussion to the economic dimension, it can be started with the dependent relationship between the Agencies and Nations clusters. Within this clusters' relation is the relation of P3– International Agencies with P2 – Nations, and the relation of P6– Associations, National Agencies, and Pro-Renewable Energy Programs linked with P2– Nations.

While the International agencies work to ensure the implementation of renewable energy projects, triggering expectations in the energy market for further adoption by nations [43], the National agencies work to help governments achieve sustainable development goals by bringing donors and investors closer to the PV sector [43]. However, there are critical stakeholders regarding the number of agencies and the complexity of these interactions for PV projects approval [52]. This shows that the moderating and coordinating role played by governments on political issues can also be extended to moderate and coordinate national and international agencies in order to simplify the processing of PV projects aiming at the PV market expansion.

Other relations that fit under the economic dimension are the internal relations in Customers cluster between P22– Residentials Prosumers and P23– Shared Community Prosumers, between P22– Residentials Prosumers and P25– Rural Prosumers, and between P22– Residentials Prosumers and P21– Enterprises Prosumers.

In a shared community, energy generation does not occur at the customer's home; this customer is entitled to a portion of the facility located elsewhere, providing for the expansion of PV availability to more consumers [15], and the aggregation of more families into a single facility allows for scale economies, helping to reduce the cost of PV systems for consumers [53]. There is also a different economic reality among rural and residential prosumers, with rural residents with lower average incomes than urban residents, so it is important to focus on cost reductions, increased earnings, and operational reliability of PV systems [54]. Thus, the common point for these prosumers is the need to reduce the installation costs of PV systems, making the option of generating their own energy more attractive.

Residentials and enterprises prosumers seek energy savings by installing PV systems [51], so PV generation is growing for both [55]. But the advantages may vary; for example, in California, non-residential clients receive subsidies based on the performance of their system, while for residential clients, the subsidies are higher [56]. In China, the price of residential electricity is much lower than commercial electricity, which leads to a lack of interest from residential consumers for PV systems

[57] Thus, it can be seen that there is no unanimity regarding the economic incentives for adherence to PV, and the assignment of these incentives sometimes follows the strategies of the governments of the countries.

Still, under the economical dimension, the Services and Finances clusters have a dependent connection through the link between P30– Third-Party Ownership and P12– Investors. Third-Party Ownership (TPO) can also be understood as a business model and, in this paper, it is characterized as a player in which it is one modality of energy generation enterprise [58]. TPOs are one of the most important and profitable PV business models with a tendency to increase long-term investors' profit [58]; thus, investors along with banks are the ones who own the most TPOs [59]. Thus, this business model presents itself as a trend for the PV market.

4.3 Social aspects

The relation between P2– Nations and P25– Rural Prosumers has some important social aspects. Rural prosumers are becoming an important player once the installation of PV plants in rural areas has increased due to marginalization and even abandonment of agriculture in these areas [60] Thus, new business models must be established that can address the challenges and needs of rural facilities [61], so that PV can address problems of lack of access to energy in rural areas of different countries [62,63] Besides, efforts can be made to promote partnerships with farmers to lease land and install PV plants, generating a source of income from sometimes degraded land.

Another social aspect comes from the dependent connection between the Supply Chain and Knowledge clusters. P15– Manufacturers and Developers of Solar Panels and Equipment and P7- Universities, Research Institutes, and Researchers collaborate in research and development to study PV materials and modules [55,64]. Therefore, developing the infrastructure necessary for the development of PV technology requires specialized training leading to additional investments in the academic sector [65], resulting in the formation of human resources with the necessary skills to work in the PV sector, thus supplying shortages labor force, improving the population's employment and income conditions.

4.4 Technological aspects

Regarding the technological aspects involved in PV businesses, a dependence relationship can be seen forming a triangle in Figure 3 between the players P7– Universities, Research Institutes, and Researchers, P15– Manufacturers and Developers of Solar Panels and Equipment, and P2– Nations. These players are the principal partners in business models applied to renewable energies [66], and this approach with these three players, also called the triple helix, has the government as its central point exerting extreme influence on the other two [65]. This triple helix can also be view in Figure 4, between the clusters Knowledge, Supply Chain, and Nations.

Governments and developers of solar panels pointed out that it is extremely important to make investments and give incentives to support the PV industry [44,52,67]. However, these subsidies may lead to an oversupply of solar modules, which may lead to some technological turbulence [64] and, due to possible market instability, PV technology companies are migrating to large markets with consistent government policies to develop and improve their products [49]. These turbulences and instabilities demonstrate the need for PV consolidation from a technological point of view in emerging countries.

P35- Transmission and Distribution System Operators does not appear in Figure 3 however this player is cited in 14.1% of the articles from SR. Transmission and distribution system operators have faced economic and technical challenges from the growing installation of distributed generation of renewable energy units and the increased amount of energy feed into the distribution network [43,68]. There is also a concern regarding generation instability associated with varying availability of sunlight or wind, so the transmission and distribution system operators suggest the installation of ancillary services to manage this instability between production and consumption [69]. In the view of this perspective, it would be interesting to coordinate the installation of new units of distributed generation of PV, so that the electrical system can be adapted as the number of new installations grows.

Another technological aspect that can be highlighted comes from the relationship between P25- Rural Prosumers and P22- Residentials Prosumers. Comparing with residentials prosumers, an advantage of rural

consumers is the space available for PV system installation, while the main disadvantage is the difficulty of flowing the energy feed in the grid [63]. This brings the need for new technological solutions and investments in infrastructure for the disposal of this energy, which, together with the cost reductions previously suggested for these rural consumers, can considerably leverage the diffusion of PV in rural areas.

4.5 Legal aspects

Considering the legal perspective, the relationship with the higher impact on PV development occurs between P2- Nations and P5- Policy Makers, and Nations and Agencies clusters. The increase of the share of renewable energy in the energy matrix is a desire for governments, policy-makers, and populations [48,67,70], and PV policies are different in each country [64]. In this sense, governments and policy-makers are encouraged to take a leading role in implementing policies, laws, and recommendations that help overcome renewable energy challenges [22,63].

4.6 Environmental aspects

Regarding the PV business environmental aspects, the link between P1– Nations Organizations and P2– Nations in the cluster Nations has an important role. Among the retrieved articles that connect these two players, the main group of nations active in the PV issue is the European Union (EU), where the development of renewable energy is one of the principal objectives of all members [66]. To achieve this objective, the strategy is to increase the proportion of renewable energy consumed to 27% by 2030 [68]. However, there is a certain lack of incentives from nations organizations other than the EU, since coordinated action by several organizations of nations could create a favorable environment at a global level for PV businesses.

The connection between P15- Manufacturers and Developers of Solar Panels and Equipment and P31– Other Enterprises also fits under the perspective of developing a favorable environment at a global level for PV businesses. This occurs because enterprises from various segments are under pressure to redesign and adapt their concepts, policies, planning, and operations to meet the carbon reduction goals that have been set [70].

The Supply Chain cluster internally has an important connection between P15- Manufacturers and Developers of Solar Panels and Equipment and P14- Raw Material Manufacturers. The diffusion of PV technology depends on abundant and cheap capital for raw material manufacturers to increase production, thus mitigating the financial risks of technology propagation [49]. In addition to cheap capital, reduced manufacturing costs, lower energy, and material consumption have accelerated the development of these enterprises [71], characterizing the sector as a scale economy to match production [67].

Product modularity and production costs suffer from operational leverage due to tradeoffs associated with supply chain integration [72] The characterization as a scale economy can help in the consolidation of the PV segment in emerging countries and the integration of the supply chain may reduce instability in the PV market.

The Supply Chain and Agencies clusters have no dependent connection. However, there is a connection between P15- Manufacturers and Developers of Solar Panels and Equipment and P6– Associations, National Agencies, and Pro-Renewable Energy Programs. In countries such as Tunisia, energy agencies certify equipment produced by manufacturers [47], while in China, provincial commissions mediate government interventions on solar panel manufacturers [44]. The positive point of this is the guarantee of installing certified quality equipment, favoring the development of a more reliable business environment.

P30– Third-Party Ownership is connected with the P33– Utilities. TPOs help to promote renewable energy consumption, reducing users' dependence on the electricity grid [58]. California was the first American state to state that TPOs are not utilities, but a distinct model of power generation companies [50,56] and as such, TPOs began to work with utilities to fund the expansion of the American solar matrix [53]. Thus, TPOs must work to meet the challenges regarding the flow of energy produced as well as to provide a systemic view of the electrical network to assist in its management.

Installers do not appear in the players' network, however, they meet the needs of a variety of customers such

as government offices, commercial and residential installations by creating local and even international supplier networks [49], some of which offer aggregate maintenance plans [73].

5. Conclusion

The purpose of this paper has been achieved with the identification of the players involved in PV businesses considering a global perspective, establishment the networks of players and clusters of players, and through the contextualization and discussion, based on a PESTLE analysis, of how these interactions develop in the context of PV businesses and help to the development and diffusion of the PV market.

It is worth mentioning the use of the Apriori algorithm for mapping the network of business players related to PV. Apriori algorithm can be used in other scientific and practical approaches to map networks on different topics. In this article, this mapping made it possible to focus efforts objectively to search the retrieved articles for relevant information that would explain the relevant and dependent relationships, showing how each players' engagement in practice develops. The study of these relationships presented in the previous section led to some conclusions from the academic, managerial, and policy-making points of view.

Academically, there can be realized a need to establish or improve clear business models that present, in addition to the technical aspects of the business, all existing and necessary interrelations between players because of the real changes from country to country due to political, economic, financial, social, technological, legal, and environmental particularities that need to be studied and defined. With the network of players and clusters, it could be identified and contextualized what is the relationship and importance of each player in the business context of PV.

From a managerial point of view, it can be said that the establishment of good governance practices in companies in the sector can leverage the investments of public and private financial agents. There could also be identified a tendency to spread TPO companies, but there are still challenges to be overcome for this, including the understanding of the investment capabilities of this type of business model as well as providing consumers with an understanding of the possibilities related to it.

This paper also identified a growing trend and spread of PV facilities in rural areas. This is partly due to the evolution of government incentives, but there is still a need for not only financial investments but also technological development to adapt this technology to the conditions found in rural areas.

From a policy-making point of view, it can be seen that nations' governments centralized actions to support PV development. This is due to the need and commitments made by international entities to replace the energy sources that increase the greenhouse effect with renewable sources. This requires the establishment of governance in the sector as well as forms of coordination and modifications and standardizations at certain policy points, to attract investors and investments from public and private agents.

Another important point to consider is the migration of solar panel manufacturing companies to markets with consolidated economic and regulatory aspects in the PV segment. In this way, to attract companies and investments, emerging markets must seek to consolidate their regulatory aspects to international standards as well as to provide relevant subsidies that can compete with those of already consolidated markets.

This study was limited to establishing the relationship between two players at a time, studying direct links between them from the network elaborated with the aid of the Apriori algorithm rules. For future research, it is expected to establish more complex business networks, studying the relationships between more than two players in each situation, or to test the applicability of these rules in a real context of a region or country with experts that can also be characterized as players with representativeness in the mapped networks.

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