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Article

Photovoltaic Energy in Colombia: Current Status of Supply Chain

Mateo Valderrama Mendoza [1], Pablo César Ocampo Vélez [2], Camilo Mejía Moncayo [3] and Leonardo Rodríguez Urrego [4]

[1] EAN University; mvalderr6602@universidadean.edu.co
[2] EAN University; pabloc.ocampo@universidadean.edu.co
[3] EAN University; cmejiam@universidadean.edu.co
[4] EAN University; lrodriguezu@universidadean.edu.co

Abstract: This article makes a general analysis of the supply chain of photovoltaic systems in Colombia, taking as a starting point a conceptual base and the current situation of the country in this sector. This article especially will contemplate the non-interconnected areas (ZNI) to the electricity grid in the national, due to its complexity in the logistics issues. Likewise, the work performs a graphical representation of the stages and processes of the supply chain using a powerful-modeled tool such as the Petri Nets (PNs). Finally, it identifies some of the flaws in the operation and the joint of all the links of the logistic part and from there it is based the importance of the strategy of orientation to the supply chain (SCO) as a possible alternative to improve and to enhance the logistic processes of this type of systems.

Keywords: Photovoltaics systems in Colombia, Supply chain, non - interconnected areas (ZNI), Supply chain orientation (SCO), Petri Nets.

1. Introduction

In Colombia, the industrial development and the environmental awareness have transformed the way to think and to act of the people and the companies. Currently we are looking for friendly processes with environment and that entail to diminish the carbon footprint throughout the processes and supply chain. For that reason, the concept of environmental, that is a fundamental pillar in the globalized world receives importance, where the sustainability of socio-economic organizations in an aggregate level depends fundamentally on three dimensions: environmental, social and economic [1].

The change of conventional energy to energy of renewable sources, is a subject that comes in increasing of exponential form in Colombia, has grown thanks to the creation of standards at global and local level, in addition to the environmental awareness.

Photovoltaic solar energy comes from a renewable source, the processes that are used to install, capture, maintenance and transportation, must be the least polluting potential, so this power generation system brings benefits, from the conception of its supply chain and the use of sustainable logistics and management approaches internal to a proper joint. Photovoltaic systems have special characteristics that provide them benefits as electricity energy production system; in particular, standing out among them is modularity [2].

Focusing these concepts in the supply chain of the photovoltaic solar system, which from the point of view of logistics has a series of immersed stages, which in Colombia is beginning to evolve, as they

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are it the planning, management and execution, based on the processes of the management of the supplying chain, such as: planning, sourcing, production, delivery and reverse logistics [3].

According to the foregoing, the supply chain of this type of system requires a synchronization in all areas and processes, in addition to the support by the State with the generation and creation of government policies for the expansion and growth of This type of energy. Currently in Colombia there is a very limited regulatory framework on the issue of solar energy and in general in renewable sources of energy, developed from the increase in the power requirements of the country, the problems of supply and reliability in energetic terms, facing difficulties in the network of interconnection of the country, the influence of the natural phenomena, the climatic variety and the security, among others.

2. Supply chain Concepts

2.1 Supply chain

A propose definition is that the supply chain "is formed by all those involved parts of direct or indirect way in the satisfaction of a request of a customer. The supply chain not only includes to the manufacturer and the supplier, but also to the carriers, warehouse-men, retail salesmen (or retail) and even to the same customers" [3].

In general terms, supply chains look for indicators that allow them to support their advance and the impact that the changes in their processes have, in the search of a sustainable development, being this last science, the science of the sustainability, that explores relations and interactions of the human activity with the ecosystems that support the life to find a way towards the sustainable human development [4].

2.2 Supply chain orientation (SCO)

Supply chain orientation is defining as "the extent to which there is a predisposition among the chain members to view the supply chain as an integrated entity and to meet the needs of the chain in an integrated way" [5]. It can be said that distinction between SCM and SCO is that the supply chain orientation is a sort of prerequisite for supply chain management. [6].

The first strategic perspective characterized by the importance that companies have to adopt the concept of supply chain management, seen as a single system, as well as a strategy that competes on the basis of the logistics network's capabilities and in turn, that drives the performance of the business units through an optimal coordination within the companies is also characterized by determining the implications of the management of supply chain flows.

The strategic perspective of the SCO is to encourage the company's personnel to act in a way that manages flows from supplier to client, adopting a systemic approach to view the supply chain holistically and not as constituent parts and seeking integration, firm operational and strategic capacity [7] [8]. On the other hand, the second structural perspective of the SCO, emphasizes the organizational artifacts that facilitate the management of the supply chain. For example, [9], they suggest SCO consists it of constructing and maintaining internal behavior elements that facilitate the relational exchange.

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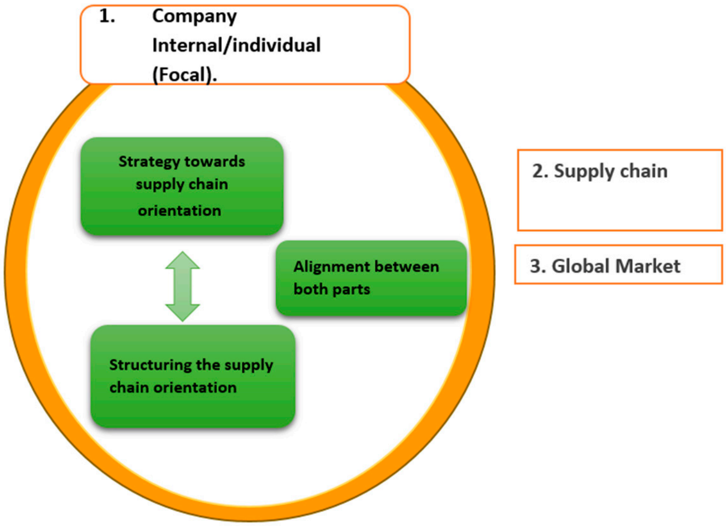

Figure 1. Elements of supply chain orientation [8]

In the fig. 1, explain general structure of SCO, have three main parts, the strategy, the structure and the union of the two, the model occurs inside the company, to manage the logistics from the interior, a subject important to work to develop the chain of supply of inside out.

3. World-wide Solar Energy

One of the most widely used and implemented systems is the PV (photovoltaic), with a significant growth, the world-wide capacity of photovoltaic solar energy in the annual market of the 2016 duplicate global capacity in 2013 [10].

The increase of global energy demand is a factor to consider, the rate of growth average of electricity consumption since 1974 has been 3.4% per year [11]. According to demand, an increase in the production of electrical energy is required to replace the existing and future necessities, in which its obtaining occurs from the coal, natural gas, hydroelectric and nuclear energy in that order respectively [12].

Overall, 85% of the total commercial energy is generated by fuels fossil, about 36% comes from oil, 38% of coal and natural gas 23% [13].

On the other hand, of all the renewable energies, the one that presents a greater rate of growth it is the photovoltaic solar energy with 46,2% [14], which indicates that it is an energy alternative to which is being bet to him to world-wide level.

In the country, the sources available of information of solar resource indicate that the country counts on an irradiation average of 4.5 kWh/m2 /d [15], which exceeds the world-wide average of 3.9 kWh/m2 /d, and is well above the average received in Germany (3.0 kWh/m2 /d) country that makes greater use of the solar energy PV to world-wide level, with approx. 36 GW of capacity installed to 2013 [16].

4. Photovoltaic Solar Energy in Colombia

Colombia energy consumption is linked to the climatic change, specifically phenomena such as "La niña" (rain) or "El niño" (drought) that can affect the supply and generation of the National electricity network. In the same way the GDP of the country and the economic situation has an impact in the energy demand. According to the "Energy-Mining Planning Unit (UPME) the projection is that between the years 2010 and 2020 one appraises average of growth of 3,4%, and of 3,1% for period 2020 to 2030 [17].

The implementation of photovoltaic systems in Colombia has enabled 2% of the population in areas that do not have access to electric energy to meet their lighting, refrigeration and leisure needs, allowing them to expand their capacities and improve their quality of life [18].

The growth in energy demand in Colombia is illustrated in Fig. 1, in which a projection is made up to the year 2030, classifying the demand by sectors.

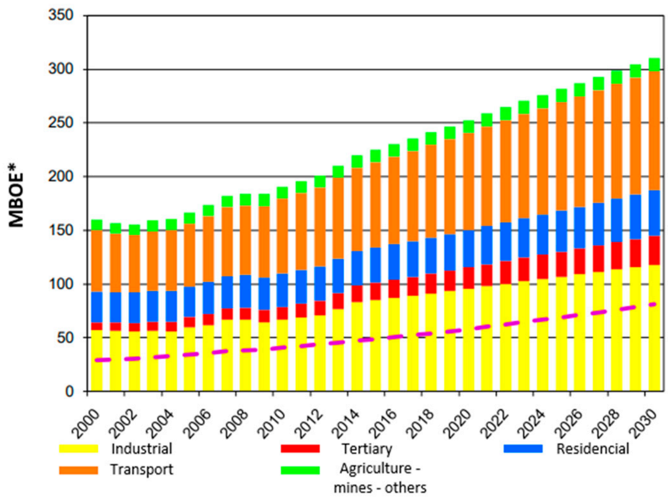

Figure 2. Energy demand in Colombia by sectors, historical and projection [19]

Consequently, the environmental problems that bring the generation of energy from conventional sources and the exhaustion of the resources encourage the country to follow the global trend of the use of alternative sources of generation, since its energy demand increases (fig. 2) and the resources available are increasingly being consumed especially from fossil sources. For that reason, this type of systems must be encouraged, already have taken the first steps, but greater support on the part of the state beings added to a work makes lack to guarantee a traceability in the supply chain and a sustainable development. Fossil fuels are the main source of energy in today's world. However, the world is changing its conception, to have alternative energy generation more economical and respectful with the environment [20]. In contrast to fossil fuels, renewable energy can be utilized as a remedy for solving the global warming problem. The development of renewable energy technology will promote sustainable development and reduce environmental impacts [21], alternative energies have great benefits, becoming an attractive option for the transformation of supply chains, especially photovoltaic energy, which is being implemented to a greater extent, a statement justified by figures already mentioned.

4.1. Non-interconnected Zones

The so-called not-interconnected zones (ZNI) are difficult access areas, in which for "the effects related to the provision of the public service of electric energy, is understood by ZNI to municipalities, townships, localities, and villages not interconnected to the national interconnected system (SIN)" [22].

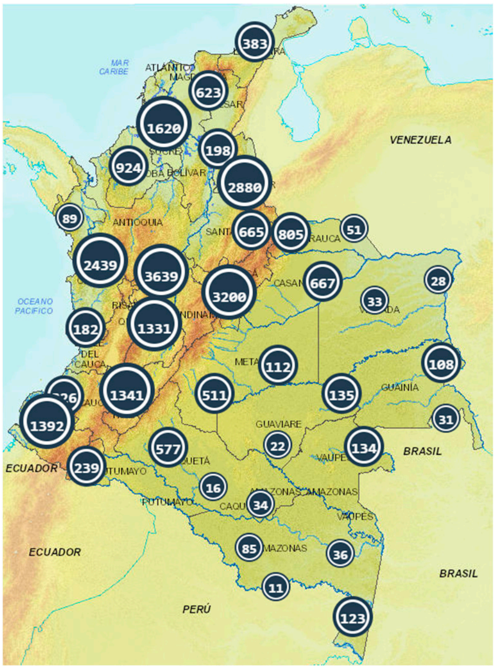

Figure 3. Places without access to electrical power [23]

Usually this type of areas has a dispersed population, with a low population density approximately 52% of the national territory are catalogued like ZNI [17]. As can be show in Fig. 3, In Colombia there are approximately 25,000 places without access to the national electrical Network, although most of these places are in the northeast by the concentration of the population, the lowest level of coverage is southeast of the Colombia.

Currently, to replace the energy demand of these communities, and to replace the firewood or fossil fuel use, some small projects in selected zones are carried out. Nevertheless, it is insufficient and the remote populations suffer difficult to mount an infrastructure that replaces its power necessities and of potable water.

Is important also to keep in mind the legislative part, since from laws and norms are developed there that promote renewable energies, an important issue to mitigate the disconnection of some areas of the country is created. Among them is the Law 1715 of 2014 (13 of May of 2014), “By means of which the integration of nonconventional the renewable energies to the National Power System is regulated”. Its main objective is to promote the development and use of non-conventional energy sources, especially renewables, for their integration in non-interconnected areas, to achieve sustainable development, ensure energy supply and finally reduce greenhouse gas emissions [24].

Currently efforts are underway to connect the isolated areas with electricity service, through Sustainable Rural Energization Plans (PERS), which consist of plans structured from an analysis of the regional elements relevant in the field of entrepreneurship, productivity and rural energizing that identify, formulate, and structuring guidelines and strategies of rural energy development as well as integral and sustainable supply and exploitation projects of supply and use of energy for a period of at least 15 years, where not only their object is to provide the service, but that support the growth and development of the rural communities of the regions objective.

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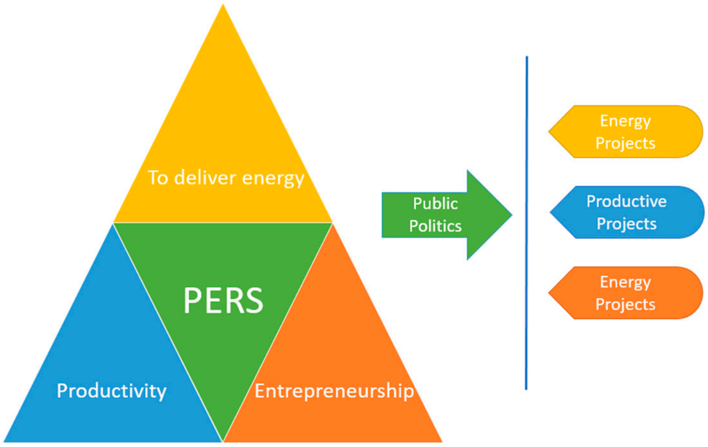

Figure 4. Structure of PERS [25]

5. Transport as a backbone of the supply chain

Historically the country has been evolving in its networks from transport, although the geography of the country makes difficult the expansion and construction of new channels, at the moment efforts have been made to manage projects that lead to the improvement of the infrastructure of the country through state agencies like the National Infrastructure Agency (ANI), the Ministry of Transport, among others, all under the direction of the National Government.

5.1. Road Infrastructure

The Colombian Road network to year 2016 is of 206.500km corresponds to the National Primary Network, 45,137 km correspond to the National Secondary Network and 142,284 km correspond to the National Tertiary Network. Also, it has 5,097 bridges national level and 1,266, 80 km in a Double carriageway, 10 viaducts and 40 tunnels [26].

5.2. Railway Infrastructure

Colombia's railway network is divided into two main areas, the Atlantic and Pacific. The first formed by the routes, with an extension of 1,493 km crossing the departments of Cesar, Magdalena, Santander, Boyacá, Antioquia, Cundinamarca, Caldas. The second is the Pacific rail network covers 498 Km in the departments of Caldas, Quindío, Risaralda and Valle. In the loading part, the following products are highlighted: pulp and paper inputs, sugar, sheets, sleepers, chemical products and inputs, spare parts, scrap, maize, raw materials, piping and cargo in general containerized.

5.3. Maritime infrastructures

On the other hand, it is the harbor network, it connects more than 4,200 shipping roads of export in good condition to regulate, direct and with connection, offered by 40 shipping ones to more than 590 cities in the world, in addition to 198 million tons mobilized more by the Colombian ports in 2015 [27], The main ports belong to the regional port companies (TCBUEN, SPR Buenaventura, SPR Cartagena, SPR Santa Marta, SPR Barranquilla) [28]. The Colombian river system comprises a total length of 24,725, of which 18,225 Km are navigable. Likewise, it has 32 ports of national interest and 52 ports providing local and regional transport services. It is important to note that this system is an alternative especially in areas of difficult access. For the year 2014 something more than 3.4 million tons of cargo were transported by this medium [29].

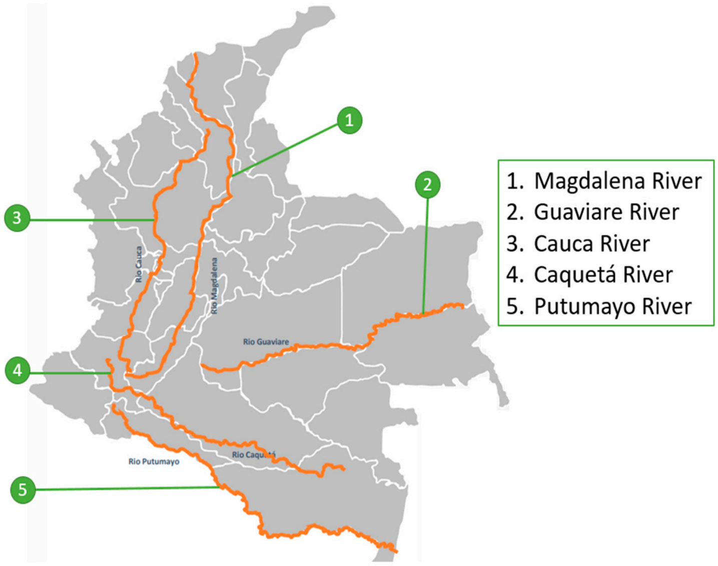

Figure 5. Principal Rivers for transport in Colombia [27]

5.4. *Aerial infrastructure*

In the aerial part, they were mobilized more than 735,000 tons of cargo exported via aerial in 2015, through more than 2,200 routes of export for cargo, direct and with connection provided by 32 airlines of cargo. The Main international airports as it is possible to be seen in the fig. 5, (Bogotá, Cali, Medellin and Barranquilla) and other international (Cúcuta, Bucaramanga, Pereira, Armenia, Riohacha, Leticia, San Andrés, Cartagena and Santa Marta [28]

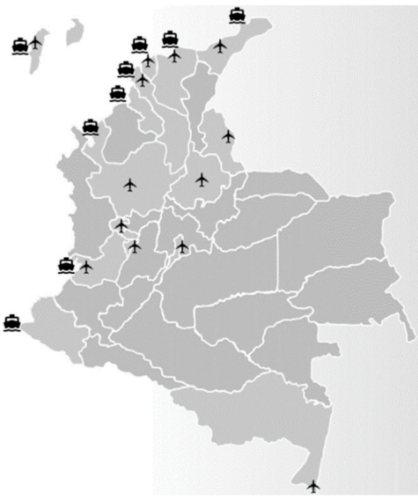

Figure 6. Primary network of airports and ports in Colombia [27]

6. **Logistics in Colombia.**

The situation of Colombia, figures can show through the following indicators, according to the World Economic Forum.

Table 1. Global Competitiveness and Infrastructure Index 2017 [30]

Global Competitiveness Index		
1	Switzerland	5.8
2	Singapour	5.7
3	U.S.	5.7
42	Panama	4.5
51	Mexico	4.4
1	Colombia	4.3

Global Infraestructure Index		
1	Hong Kong	6.7
2	Singapore	6.5
3	Holland	6.4
36	Panama	4.9
44	Chile	4.7
47	Uruguay	4.5
84	Colombia	3.7

Colombia is a country that is progressing in logistic terms, according to the previously presented indicators of competitiveness and transport infrastructure, there is still a lot to do and to improve, and currently we are working on road and airport infrastructure.

6.1. Master Logistic Plan (PML)

On the part of the road infrastructure there are going ahead to the works of the denominated routes of fourth generation 4G, project to modernize the road infrastructure, which began in 2013 by the National Government to improve the competitiveness, in total are 19 projects which they try to improve the time and the quality of the routes to travel through the national territory with double carriageways that in average would diminish the time of transfer in a 30% [31].

The project is divided into two parts called "primera ola" and "segunda ola" [32]. These highways are concentrated mainly in strategic important points of the center, the north and the West of the consequent country with the location of the ports and sites of greater flow and entrance of product and merchandise to the country.

To increase competitiveness in Colombia, in October of the 2015, director of The National Planning Department (DNP), Simón Gaviria, presented the Logistic Masterful Plan for the 2016, in agreement with the thrown thing by the Logistic National Survey, made by the DPN, between its indicators it is that the cost of logistic as percentage of products of the companies is of 15%, with greater participation of the headings of transport and storage with 57% of the total.

Similarly, customs standards happened from 15,000 to 25,000, being logistic a point in which there is much to improve and work to achieve better results, the innovation in the companies of the logistic sector is low, 37% of the industrialists have an operator solely to take care of their requirements logistic [29]. The PML seeks to have a positive impact in the competitiveness of the country, by means of strategies to give answer to the main present necessities in the logistic sector, integrating several aspects around the foreign trade, urban and regional, logistic the distribution sustainable, promotion of the intermodality, among others [33].

6.2. Intermodal Transport Master Plan (PMTI) (Colombia)

This plan was raised in 2015 by the national Government and in the Ministry of Transport of Colombia, is to organize in an efficient and strategic way the growth of the country, through an infrastructure network that manages to connect to the cities, regions, Frontiers and ports, prioritizing the projects that will have the greatest impact for the national economy [26]

This plan is one of the most important, since according to figures of the Vice presidency of the Republic the annual investment is approximately 10 billion of Colombian pesos, a considerable figure and that is expected to have its fruits in terms of improvement of the indicators and that can Integrate and connect all areas of the country in one form or another.

The idea is to integrate the 32 departments of the country the national government and the private entities, to carry out a joint work that allows to promote the mobility and the trade through the optimization and repowering the transport networks.

6.3. Logistical Problems in Photovoltaic Solar Systems

In Colombia, there are difficulties in different aspects that affect the expansion of this type of systems, which are the following:

- ✓ The majority of components are not manufactured in the country, the big problem is in distributing the product to the different zones, by the conditions, the limitations of speed and capacity of the road network mainly, in the same way the lack of other means of Transport that could expedite the transfer as the railroads.
- ✓ The energy projects of this type in the country are focusing on areas with problems of connection to the national electricity grid ZNI, for example, in the year 2014 in the Department of La Guajira, in the townships of Puerto Estrella and Nazareth, a project was carried out RO 330kW bust of installed capacity with 1,300 solar panels and 480 lead-acid batteries to supply energy to these populations, approximately 2000 inhabitants. This project had many logistical problems for transport, because it is located in a desert area of difficult access, because of the social culture of the ethnic Wayuu and the lack of technical personnel in the area. Likewise, this year 2017 is completing three projects in the Department of Amazonas, specifically in the communities of Puerto Nariño, San Martín de Amacayacu and Macedonia. In these populations, 2376 photovoltaic panels were mounted for an installed capacity of 594kW.

The projects had major drawbacks in the logistics by river transport, as well as some of the imports were made by Manaus, Brazil, as the batteries which increased the time of transfer by the Amazon River and lost time in the Nationalization by the regulations between the two countries in terms of importation of products with dangerous elements (lead acid batteries).

7. Proposed model for the supply chain of photovoltaic solar systems in Colombia.

Solar PV systems are an alternative to reduce costs and have reliability in the delivery of energy, currently several companies are venturing into the design and planning of new strategies in the supply chain for the treatment of Different elements that compose a system of this type.

The dynamism of the market today, forces companies to change their process model. Boost business growth through innovation in the supply chain, not only through products and services, but also with business models [34]. The implementation of the technology allows streamlining and improving the tasks of recognition, organization and response in the supply chain.

The supply chain of solar systems in Colombia is made up of several actors; in Fig. 7, it shows at a general level each one of them and the interaction of some significant processes, which are part of the flow of products and materials. This process is illustrated through a Petri Net's, which graphically and logically shows the evolution and behavior of the chain. The Petri Nets (PN) introduced in the literature thanks to the doctoral thesis of Carl Adam Petri [35], Petri nets are a tool for modeling dynamic event systems and it is used to simulate the dynamic properties of complex systems by means of graphic models of concurrent processes, ideal in logistic systems. His study has had a major boom over time thanks to the large number of applications that have been found. These Nets are very efficient in modeling discrete event systems, characterizing the behavior and interaction of different sub-processes that cooperate in the objectives of a system.

The formalism provided in concepts such as synchronism, concurrence, mutual exclusion, and sharing of resources are of special interest and have provided a greater capacity and power of representation in the resulting models. Some important applications in discrete models for the green purchasing process or in the diagnosis of complex system failures can be seen in [36] [37], respectively.

In Fig. 7 A Petri network is presented in which the so-called places (P) in which the actions occur are circulated, and represented by a thick black line the transitions (T) in which the conditions are detected. The arcs represented by arrows represent the direction of the actions and the marks represented by black points the state where the process is located, in this case the logistic process.

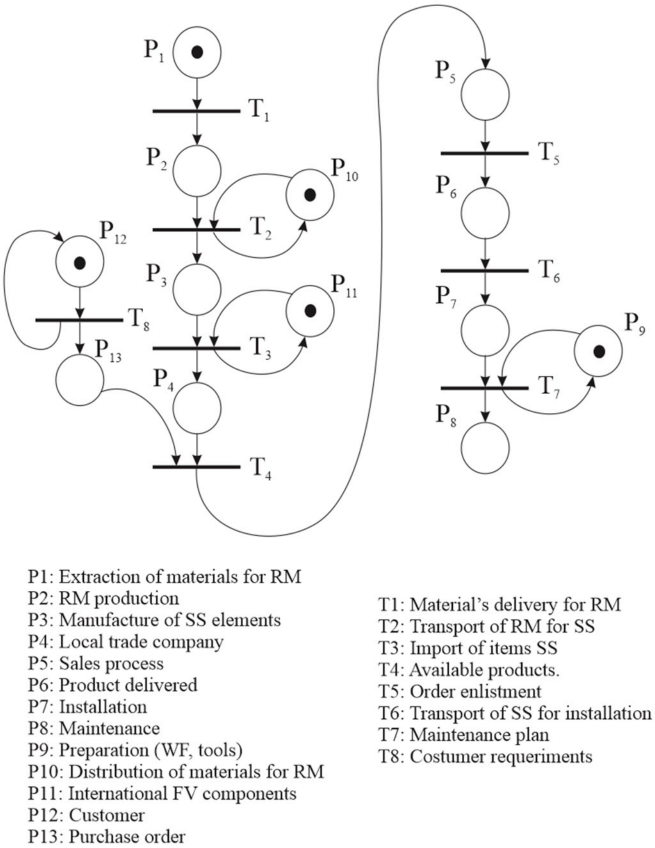

Figure 7. General Supply Chain of solar PV systems in Colombia

The supply chain is part of the extraction of materials and raw material (RM) processing, which are elements such as: silicon, glass, aluminum, and plastic, among others. They are then transferred and delivered to the companies responsible for manufacturing solar systems (SS), which are composed of solar panels, batteries and investors, among others. After that, companies located in Colombia import products from different parts of the world, to market them locally, this allows them to have a stock available for sale. When a customer buys a solar system or one of its components, according to their requirements, the company generates the purchase order and verifies the stock to end the sales process. In the event that there is not enough stock of the product, we proceed to request the supplier and import the necessary elements. With the order ready, it is finally delivered.

The power generation system must be transported to the installation site, a work that requires special care with the parts to avoid their affectation. With all the equipment and elements on the site, we proceed to install the Solar PV system. The last step is to carry out the necessary maintenance according to the maintenance plan developed before the start-up.

For the articulation, a rigorous logistical scheme is required because the photovoltaic systems must be handled in a special way, in their transfer they travel long distances and are in constant movement. For example, the solar panels must be packaged, transported and handled properly, is a critical element within the photovoltaic systems, about 10% are damaged during transport, often only discover the breakdowns in these modules After assembly [38].

8. Conclusions

- ✓ Through the construction of the Petri Net's is understood the interaction and evolution in all phases of the supply chain of PV systems in Colombia, as a first step to propose a structured logistic model that includes the SCO concept as a first step to improve and enhance their development. This mathematical model is being developed for a future publication.

- ✓ The country is working to improve the competitiveness indicators through the plans PML or the 4g pathways and the PMTI for intermodal transport, with a great economic investment, the government of Colombia is giving importance to this issue of Transport and logistics, which directly benefits the supply chain of the PV systems to be more easily traceable.

- ✓ Achieving the supply chain articulation of these systems is not an easy task; it is required to have an efficient logistic and infrastructure model, which is not currently very strong, not only in terms of bringing products from suppliers. To the customers, but also to the end users (installation of the PV systems), which many times are located in areas of difficult access.

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Author Contributions

All authors contributed substantially to the ideas, concepts, and work presented in this paper. Mateo Valderrama was responsible for the preparation of the manuscript and have approved the submitted form. Leonardo Rodríguez Urrego provided the data in solar PV area and Petri nets model. Pablo Ocampo and Camilo Mejía designed the SCO model and analyzed to supply chain.

Conflicts of Interest The authors declare no conflict of interest

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