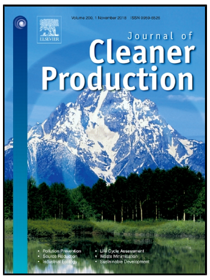

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Evolution of collaborative networks of solar energy applied technologies

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Evolution of collaborative networks of solar energy applied technologies

Abstract: This paper proposes to investigate solar energy applied patents published between 1997 and 2016. Social network analysis and Source path link count algorithms are used as a method to identify technological routes, trends, promising technologies, cooperation features and market of interest protection. Patents applied in Japan and Brazil were selected for analysis of several issues, showing two different contexts when it comes to innovation in solar energy. Mapping these issues can support governments, companies and universities in their decisions about solar energy applications, offering data of the most relevant technologies, their owners, relationships between them, as well as their marketing protection coverage through reliable and replicable metrics. It enables an analysis of competitive technological intelligence and can be used as a tool for Research and Development manager’s decisions of future efforts and investments. Companies can observe in a simplified way, standards that are followed and adopted by scientists and market, bringing a possibility of increasing technological knowledge that previously had only empirical means. In addition, government can understand the dynamic of solar energy development from/to their countries and propose policies that improve the use of solar energy in an urban environment. Also, a set of recommendations based on findings was provided to construct a better environment for cooperation and to improve solar energy researches.

Keywords: Technological Cooperation, Technological Routes, Emerging Technology, Sustainable Technologies, Solar Energy.

1 Introduction

The challenge to mitigate the environmental degradation, mainly related to climate change, has led to an increase in interest about mechanisms to encourage the development and adoption of green technologies (Hall and Helmers, 2010). In this context, innovation fostering and development of green technologies essentially has become important and necessary for environmental and business sustainability (OECD, 2011). One of the greatest potential for green technologies refers to the exploitation of energy by solar radiation since it is a clean and renewable resource (Dong et al., 2012). A set of competencies to provide low-carbon transitions is proposed by Holtz et al. (2017) and solar energy technologies are essential to provide clean energy, mainly to develop infrastructure. The impact on disruptive technology development, such as solar energy that proposes to change the energy matrix can also influence positively all innovation ecosystems and bring environmental, financial and social benefits (BID, 2014).

There is no doubt about the importance of patents in determining the innovative effort directed towards a technology or a market. Cities and urban areas have been known to be society's predominant engine of innovation. So, the intensity of technological innovation (patent per capita) is strongly related to the density of jobs in highly urbanized areas (Carlino, Chatterjee and Hunt, 2007). Some patent researches show that cities are essential for innovation activity and knowledge spillovers (Crescenzi, Rodríguez-Pose and Storper, 2007). But it is noteworthy that studies that correlate urban environments and innovation use specific data about cities of patent inventors and assignees that, for most offices, are data with low reliability. In a general way, as cities are real dynamic laboratories, their continuous evolution is directly related to the technologies that are developed to be applied in urban environments, especially those with sustainable purposes. Among these technologies, those related to solar energy have been the object of recent intense studies.

So, what are these technological trends on solar energy from Japan and Brazil and that can be applied to sustainable cities? Trend identification can be made using different methods, quantitative, qualitative or mixed. One of these ways is based on tracing the most promising technological routes analyzing patent citations whose principle is that a patent cited several times tends to get greater technological impact and can generate complementary technologies in a technological area (Verspagen, 2007). Unlike bibliometric studies that calculate the index of patent citation and other statistics, research on technological routes (TR) have a potential for quantitative exploration of knowledge, but mainly allows qualitative analysis of the flow of technological knowledge, temporal technology evolution, which are the main actors and partners in the development of technology and allows to indicate which technologies are more promising and emerging.

In addition, are emerging solar energy technologies for urban environments protected on Japan and Brazil? Is there any technological development cooperation and what is the profile of cooperation efforts? Companies are looking for more frequently to collaborate with universities and research centers, and there is a notable increase in the technological cooperation and know-how exchange between the companies (Etzkowitz and Leydesdorff, 2000). The strategic importance of exploring potential technology partners has been marked in recent years because of the growing trend of collaborations for innovation across organizational boundaries (Petroni, Venturini and Verbano, 2012). Thus, technological cooperation tends to be a mechanism to find the key players and influencers to a technology type as well as can help to accelerate technological development (Abulrub and Lee, 2012).

There are several studies on cities and patents that analyze the region's innovative potential versus socioeconomic aspects: major innovation cycles are generated to sustain growth of population (Bettencourt et al., 2007) and a high innovation output is directly associated with large labs and the number of small firms (Agrawal et al., 2014). However, current studies don’t address features such as interest in technological development, market protection, relevant technologies or analyze the implications of technologies for sustainable cities, neither analyze in depth the relationship between main players and technologies. Based on these gaps, this paper answers the follow questions: (i) “Collaborative development is a strong issue for these kind of solar energy innovations deposited in Brazil and Japan?” and (ii) “What are the emergent technologies and their features?”. The choice of these two countries is related to a call for researches[1] on renewable energies between Brazil and Japan promoted by the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Japan Society for the Promotion of Science (JSPS), from which this research resulted. So, in the next sections, it presents theoretical background that supports this manuscript: review of solar energy technologies, technological cooperation, technological routes and emerging technologies. After, the results and conclusions of this study are discussed.

2 Theoretical background

2.1 Solar energy technologies overview

The breadth of solar energy technologies and their applications is vast. The most common and that has been object of studies, implementations and continuous improvement, are technologies for photovoltaic energy and use of solar heat. Guo, Huang and Porter (2010) point to nanotechnology-enhanced thin-film solar cells as emerging solutions in solar energy, taking India and China as leaders in the development of this technology. Luan, Hou and Wang (2012) have mapped the evolution of solar energy technologies, highlighting emerging technologies such as “Solar energy power generation and Solar photovoltaic cells”, “Solar Water Heater and Layered Products” e “Solar Power Heating and Refrigeration”, but this study is limited to a macro analysis of trends and it doesn’t cite aspects concerning actors (assignees and inventors). Dincer (2011) proposes an analysis of photovoltaic issues to address how countries can lead in solar energy. Devabhaktuni et al. (2013) point out in an overview that photovoltaic technologies are the most relevant sources of solar energy exploitation. The effect of absorption heat pumps integrated with solar systems and thermal energy storages is an interesting alternative in cooling systems and a discussion about it are proposed by Leonzio (2017). However, these authors didn’t go into details about the most important solar energy technologies, their features and relationship between them.

As a typical emerging technology, dye-sensitized solar cells (DSSCs) have attracted much attention because of their ease of production and low cost when compared to silicon (Ileperuma, 2013). A network-based citation analysis of organic photovoltaic cells developed by Choe et al. (2013) points to the United States (USA), Japan and Germany as important centers of citation; Boeing, Konarka Technologies, Eastman Kodak and Sharp as the most relevant institutions in the network; and the most emerging innovations are “Batteries: thermoelectric and photoelectric”, “Active solid-state devices” and “Stock material or miscellaneous articles”. However, this study was limited to patents on organic photovoltaic cells and to applications in offices of South Korea, USA, Europe, China and Japan. In an analysis of technological routes from green patents, Porto, Kannebley Jr and Baroni (2014) state that there are indications that many of the patents are associated with energy optimization, with energy technology trends focused on “electric power control systems” with predominantly Japanese companies such as Toshiba, Mitsubishi and Honda in development this type of innovation. Lewis (2016) points out that the technologies are focused on materials that can reduce costs, extend equipment lifecycles, and increase the storage capacity of systems.

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[1] Workshop on “Towards Sustainable Urban Energy Systems: Experiences from Asia and Latin America”, 01-03 February 2018, hosted by Institute of Advanced Energy, Kyoto University, Kyoto, Japan and orgazanized by FAPESP and JSPS. Access on http://www.ceac.iae.kyoto-u.ac.jp/JointWorkshop.html

A study based on patented inventions between the years 2010 to 2015, Reuters (2016) points out that among the main innovations for power generation, photovoltaic patents grew 160% and solar thermal, 10% in the same period. Specifically, for photovoltaic, the organizations which leads the inventions are: Sharp, Mitsubishi, Kyocera, Fujifilm, LG, Samsung, Konica Minolta and Chinese Academy of Science. Not even important, the latest innovations are focused on inorganic, organic and silicon technologies, both technologies for solar cells. Some studies describe collaboration features in technological development. Despite giving an important reference on energy generation technologies as well as their main developers, these studies do not point out the relationship between the organizations and uses a classification based only on the counting of patents by technology to show which emerging technologies and organizations involved, which requires a greater depth of analysis.

Last, Malinowski, Leon and Abu-Rub (2017) discussed in their studies that the future of solar energy are focused on technologies tahat can increase the efficiency of solar modules and batteries and reduce their cost, such new materials to create multijunction solar cells, multilevel converter topologies and new high-energy density batteries. However, it depends of a strong support of governments to develop and implemente them.

2.2 Technological cooperation

In between the development of technologies, there are some inherent aspects of its development that must be observed, as technological cooperation for example. Technology cooperation can be conceived in different ways: acquisition, merger, licensing, minority participation, joint venture, bilateral Research and Development (R&D) agreements, research funding, alliances, consortia, relationship networks or outsourcing and the choice of collaboration model depends on factors such as the strategy, time expectation, control level and costs involved. (Chiesa and Manzini, 1998).

The importance of cooperation to expand scientific and technological development can be reinforced by pointing out that: partnerships accelerate the transfer of knowledge from university to industry (Villarreal and Calvo, 2015); the Enterprise-University technological cooperation initiated tends to broaden the bonds of cooperation between companies and other educational and research institutions (Althoff Philippi et al., 2015); the development path of industry, for example Photovoltaic (PV) in China, indicates that innovation in cleaner energy technologies is a combination of global and national innovation processes (Gallagher, 2014); governments should encourage cooperation between research centers and companies from different countries to expand technological internationalization (De Paulo and Porto, 2017). An additional point of view is introduced by Zou et al. (2017) based on China's PV industry. They affirms that a poor connectivity in innovation networks is one of the most serious threats facing the solar energy industry. Last, Chen and Su (2018) point out the importance of partnership agreements to strength competitiveness in the PV supply chain. On this same direction, Creutzig et al. (2017) affirm that a rapid technological learning are crucial to solar technology deployment and cooperation agreemments can be a important catalyzer for it.

It is common to use analysis based on co-authorship to identify the cooperative relationships. Thus, this analysis to identify academic collaboration is already consolidated and it is also used to knowledge management and flow. When collaboration results in the patenting of innovation, there is a credited source of technological information. Co-ownership of patents, thus co-authoring the analysis of scientific publications, is a relevant indicator of technological collaboration (Sternitzke, Bartkowski and Scharamm, 2008). For both trend identification and cooperation, social network analysis (SNA) has been used as an important visualization and analysis tool. SNA is the object of study by several authors because it is a method that offers resources for both qualitative and quantitative analysis (Fontana, Nuvolari and Verspagen, 2009). SNA has applications in many fields of knowledge, such as web navigation (Laura et al., 2003), epidemic spread analysis (Keeling and Eames, 2005) or to compare industrial changes in China and Japan (Li et al., 2017).

When analyzed through the network citation approach, SNA can provide interesting results as showed by Egghe and Rousseau (2002). Collaborative networks produced by Batagelj and Cerinšek (2013) demonstrate the potential for exploration of SNA-based relationship analysis. This same method allows a better understanding and visualization of the cooperation links and allows to identify the organizations (companies, research centers, universities, government, etc.), predominant technology areas, relationships between these organizations to analyze the competition or identification of partners and identification of key patents (Sternitzke, Bartkowski and Scharamm, 2008).

2.3 Technological routes and emerging technologies

The identification of emerging technologies and new fields of knowledge has become essential for researchers, scientists and the industry itself (Prabhakaran, Lathabai and Changat, 2015). Studies on technological routes have allowed to point out the emerging technologies, the interdependence between the different technologies as well as the main actors involved.

For this, the use of patents and analysis of their citations has been used as an important source of data for the identification of promising technologies in different technological areas (Linares and Porto, 2016). One of them is the cross-impact matrix (Choi, Kim and Park, 2007) proposes to identify relevant technologies when analyzing the interdependence between them. However, this method gives a macro view of the technology area and may have limitations of analysis as to the size of the matrices generated. Another method based on the pathways of patent development, k-core analysis, and trend modeling identifies technologies with disruptive potential as technology is path dependent (Momeni and Rost, 2016). But it has some points of attention: information is lost during the analysis because the algorithm neglects smaller paths in the network; there is a limitation on the number of patents that can be analyzed by the proposed algorithm and method needs to be tested on a wider range of technologies. Another method based on the Pagerank algorithm evaluates the dynamics of citations from different classes of "precursor" patents and makes it possible to make predictions about future technological development, but this method does not give an evolutionary or technological chain view (Bruck et al., 2016). Another study based on patent technology forecasting uses technologies such as life cycle, diffusion speed, and expansion (Altuntas, Dereli and Kusiak, 2015). However, this proposal has serious limitations in using only patent title data, in addition to the complexity and computational effort to manipulate citations and patent codes.

Based on Hummon and Doreian's (1989) mapping of scientific routes, Verspagen (2007) proposed a methodology that uses network analysis and patent citation to identify better paths and point out the main routes for a technology. The proposed measures are known as Search Path Node Pair (SPNP) and Search Path Link Count (SPLC) and both are based on the construction of a directed patent's network that, when placed in an orderly sequence, it points to the different technological routes. Thus, Verspagen (2007) suggests that it is possible to identify technological trends. Although the SPLC focuses on link counting and SPNP counts the node pairs, the results of both algorithms are mostly similar, and the choice of the algorithm is an arbitrary decision of the researcher (Verspagen, 2007; Bekkers and Martinelli, 2012).

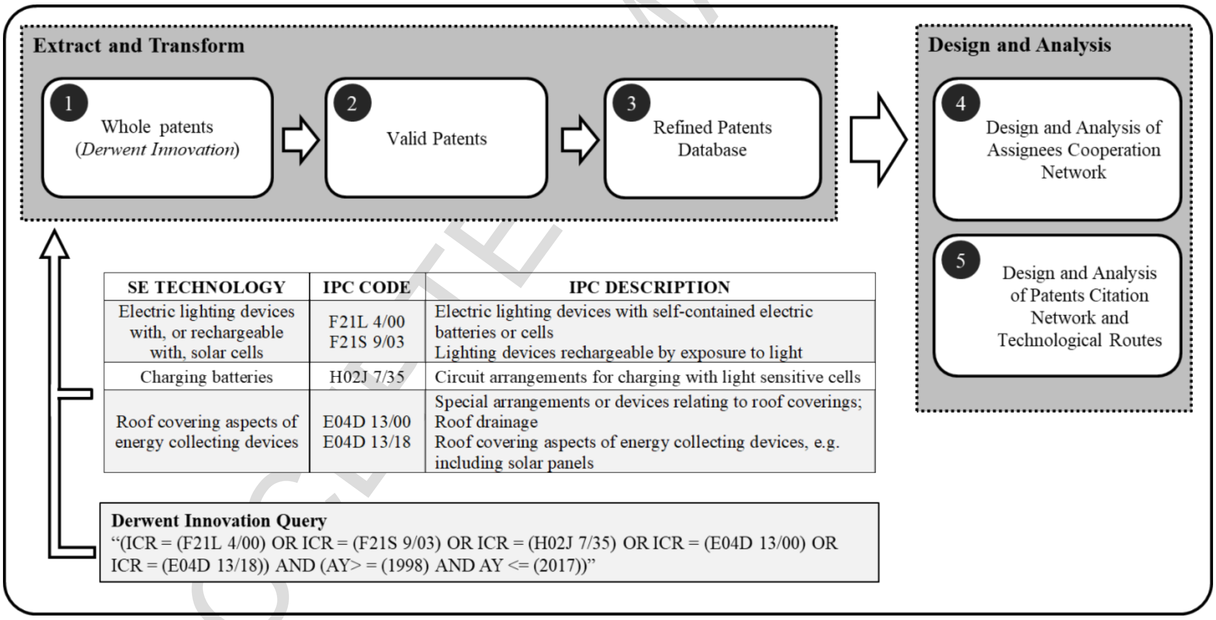
Several works and applications were developed based on the SPLC and SPNP algorithms for identification of technological trajectories: identification of routes for fuel cells (Verspagen, 2007), route mapping for data communication technologies (Fontana, Nuvolari and Verspagen, 2009), trajectories, patterns and strategies in high-tech markets (Bekkers and Martinelli, 2012), detection of emerging technologies on Radio Frequency Identification - RFID (Prabhakaran, Lathabai and Changat, 2015), mapping the cooperation network and showing emerging technologies on biotechnology (Pereira et al., 2018). Based on previous researches, Pereira and Porto (2018) update the TR concept. They propose TR as a process that map and understand a technological path to identify temporal evolutions and various players who have developed technological contributions. Also, the latest technologies can called emerging technologies.

3 Methods

3.1 Model specification

Patents haves been widely used for studies of competitive technological intelligence, to point emerging innovations and to assist organizations, especially R&D areas, with strategic information for decision making (Porto et al., 2013). In addition to pointing out technological innovations, patents have the advantages of covering several technological fields, are not duplicating scientific data and being classified in a coherent way, according to their technological application, thus gives greater credibility to this type of data source.

The methodology presented in this manuscript is based on SNA method. This method is a powerful approach to get answers about behavior between individuals or organizations as well as for understanding patterns and key influencers from the subject (Wasserman and Faust, 1994). SNA depicts the interaction between players. The method can be used to analyze a different range of variables, such as relationships between companies and universities, the spread of a disease, which languages spread faster, the social position of an individual and their professional opportunities, among others (INSNA, 2016). Figure 1 sumarizes the methodology used in this research.



SE TECHNOLOGY	IPC CODE	IPC DESCRIPTION
Electric lighting devices with, or rechargeable with, solar cells	F21L 4/00 F21S 9/03	Electric lighting devices with self-contained electric batteries or cells Lighting devices rechargeable by exposure to light
Charging batteries	H02J 7/35	Circuit arrangements for charging with light sensitive cells
Roof covering aspects of energy collecting devices	E04D 13/00 E04D 13/18	Special arrangements or devices relating to roof coverings; Roof drainage Roof covering aspects of energy collecting devices, e.g. including solar panels

Derwent Innovation Query
“(ICR = (F21L 4/00) OR ICR = (F21S 9/03) OR ICR = (H02J 7/35) OR ICR = (E04D 13/00) OR ICR = (E04D 13/18)) AND (AY> = (1998) AND AY <= (2017))”

Figure 1 - Methodology synthesis

3.1 Data collection

This study uses solar energy patents applied between 1997 and 2016 in Brazil and Japan. The choice of technologies for solar energy was based on International Patent Classification by Green Inventory IPC-GI (WIPO, 2017), which makes this classification appropriate for researches on green technologies (Porto et al., 2012). Three technological groups were selected that were applied in sustainable urban areas, because these are field of technology that have not been extensively explored in solar energy studies and are widely applicable. The patents for the technologies above were selected from Derwent Innovation (DI) database by Clarivate. This database provides the world's most comprehensive collection of global patent data in English - more than 50 authorities covering over 30 languages.

The first three steps are considered to extract and to transform patent data (figure 1). In step 1, patent data applied between 1997 and 2016 were selected. In the query showed in figure 1, ICR means IPC Current field and AY refers to patent application year. Only first patent of each INternational PAtent DOCumentation (INPADOC) was recovered in such a way to avoid redundant data for the same invention. Also, these selected data included a condition that each patent must be applied in Brazil, Japan or in both countries. The fields collected: Publication Number, Title, IPC Current, Application Year, Application Country, Priority Country, Assignee - Standardized, Assignee - Original w/address, Cited Refs - Patent, INPADOC Status Legal, INPADOC Family Members, Abstract and Claims. This paper didn't consider data relating to inventors because the objective is to analyze the behavior of organizations engaged in solar energy innovations. In this step, 4,252 INPADOCs were recovered.

In step 2, a data refinement was applied where removed the rejected patents (86) in such a way to consider only patents with "granted" or "under analysis" status. Thus, the valid patent database has 4,166 patents. Third step, names of assignees were refined to get a better standardization, since there are syntax variations of the same names. It was used the OpenRefine tool, a free software developed by Google, for messy data cleaning and transforming, to group and standardize common names (Verborgh and De Wilde, 2013). This step is not intended to exhaust all inconsistencies, but will minimize them, especially for assignees names that occur most frequently in valid patent database.

3.2 Data processing and network construction

The next steps are Design and Analysis (figure 1). Step 4 consisted of the design and analysis of the cooperation network between assignees. For this, it is used patents with more than one assignee were as a proxy for technological cooperation. Thus, the patent with a single assignee can be assumed as a result of internal R&D efforts or can be assumed as proprietary technology. Gephi software, a free tool for visualization and analysis of social network was used (Bastian, Heyymann and Jacomy, 2009). After importing the data to Gephi, the statistical analysis was started. A bipartite network was transformed into a cooperation network, which the nodes were assignee and edges were patents.

Step 5 was used to build networks and to identify technological routes (Verspagen, 2007). Nodes refer to patents and edges refer to links obtained through patent backward citations. There are many definitions to term "emerging technology" (Rotolo, Hicks and Martin, 2015, p.1841). In this paper, we define the most promising and emerging technologies (MPET) as those patents which are most recent applied and which are in the top of each TR. Using a SPLC plug-in, MPET for each technology were obtained. The number of patents on a route may vary for each IPC. Therefore, in this step were also made sensitivity tests to calibrate parameters of SPLC algorithm and thus to get the best route for each technological group. It was used SNA statistics like: betweenness and closeness centrality (Brandes, 2001), pagerank (Brin and Page, 1998), weighted average degree, eigenvector centrality and edge betweenness (Newman, 2010). These statistics allow to obtain a better understanding of each actor's relevance in the networks as well as their relationships.

For both steps 4 and 5, it was used an algorithm implemented on Gephi called Modularity. This algorithm allows to group the nodes that are more densely connected together than to the rest of the network (Blondel et al., 2008). So, when it applied to patent networks, the colors indicate different communities and show assignees (nodes) which are more interconnected with other. Consequently, it can indicate a high or exclusive partnership to develop some kind of solar energy technology.

4 Results

4.1 Characteristics of cooperation networks

Figure 2 shows the evolution of patent deposits made in cooperation over the analyzed period. It is observed that from 1997 to 2006, patents were requested for the most part with a single assignee. Cooperation (co-ownership) rates increased from 2007 to 2012, reaching 53% of patents. After 2013, there is a tendency for the development of innovations to be the result of internal effort and no longer in cooperation with other organization. This behavior may show trends for companies to prioritize the development the proprietary technology (no cooperation). This may also include the acquisition of technological development projects without the sharing of patent ownership. It was also found that the patents applied in both countries had a much higher average of cooperation than applied in a single country.

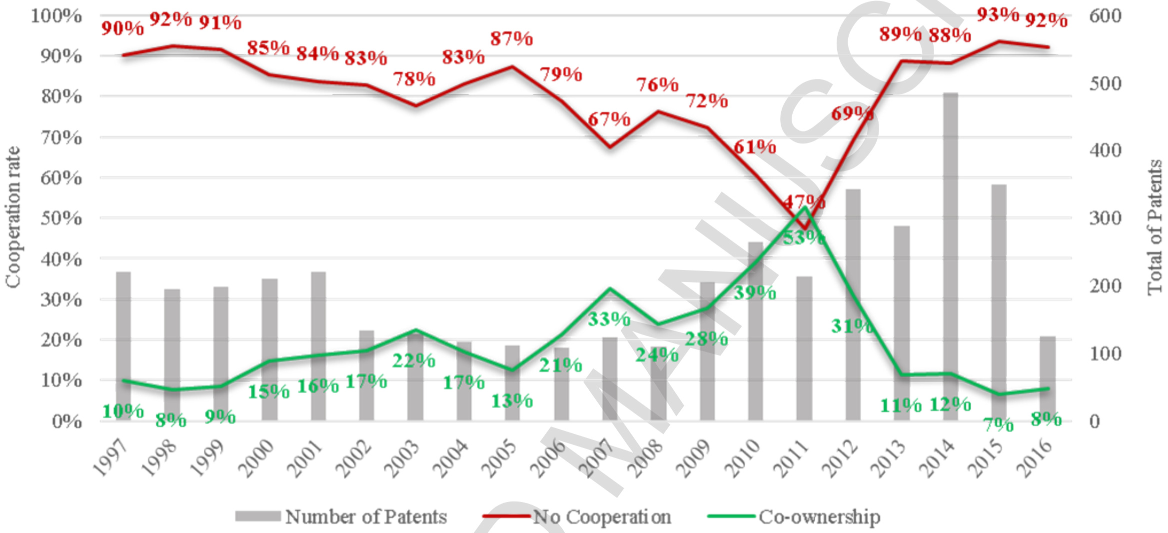


Figure 2 - Cooperation technology development from 1997 to 2016

From the bipartite network (patents and assignees) the cooperation network was obtained (Figure 3-a), which represented a collaboration between assignees who shared the development of a certain technology. This network has 1017 nodes (assignees) and 2518 patents represented at 1119 edges, whose thickness shows the strength of the bond between two assignees. When using the modularity statistic, the formation of assignees communities is obtained, and consequently the identification of stronger cooperation links represented by the thickness of the edges in the network. The top 5 clusters were selected (Figure 3-b), used the best statistics of medium degree, centrality, proximity and relevant links.

A characterization of each cooperative cluster is shown in figure 4. The yellow cluster, has 18 assignees and 47 patents developed in cooperation. These technologies were protected primarily in Japan, but also protected in the USA (44%), European Patent Office - EPO (28%) and China (21%). It is interesting to note that these patents protected in markets other than the Japanese were applied after 2010. Patents prior to this year were restricted to the Japanese market. No patents from this community were protected in Brazil. In a text clustering analysis, the main topics addressed are: "switch, circuit, voltage", "unit, discharge, power storage unit", "panel, light, battery". The main assignee is Sanyo Electric with 42 patents. This assignee polarizes any development of this cluster. As can be seen from the thickness of the edges, its main development partners are Hagihara Ryuzo (6), Sankyo Alu (3) and Sanyo Consumer Electronics (2). The green cluster has 16 assignees and 22 patents developed in cooperation. The main covered topics are: "cell, cell module, member", "supply, bus, device", "light, panel, photoelectric". The assignee hub is Sharp with participation in all patents of this community, that polarizes any development of this cluster. The main partnership was with: "Ohkoshi Yasushi" (4), "Matsui Ryoji" (2) and "Yoshida Akihito" (2). These technologies were protected in Japan (100%), USA (52%), China (37%) and EPO (35%). Again, there are no patents protected in Brazil.

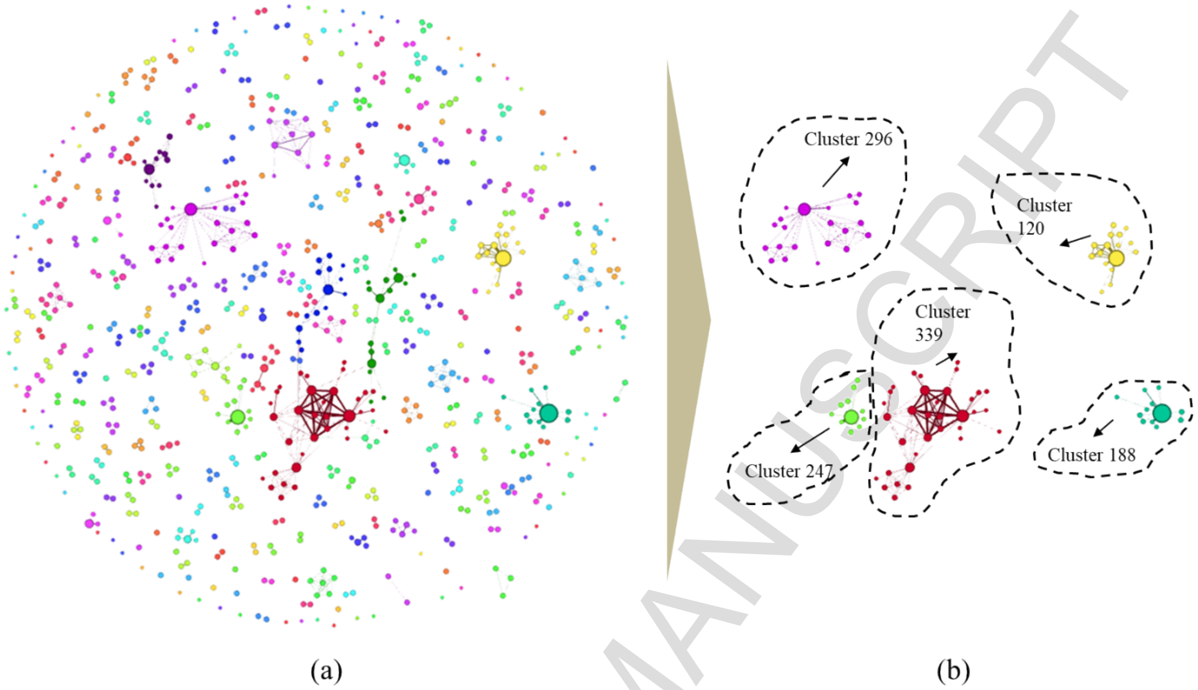


Figure 3 - Cooperation network: (a) full network and (b) main clusters

The light green cluster has 13 assignees and 20 patents developed in cooperation. The central actor is Panasonic whose strongest collaboration is with the Panahome (6). The main topics in this cluster are: "light, air, element", "power, stand alone, ac power", "current, energy, storage". Japan is the priority country in protecting the technologies of this cluster. However, such patents are also protected in EPO (48%), USA (36%) and China (32%). Again, Brazil is not priority market. The pink cluster has 22 assignees and 9 patents developed in cooperation. These technologies were protected primarily in the USA and Europe, but were also protected in Japan and China (100%), South Korea (87%), Canada and Taiwan (75%), Brazil and Russia (37%). The main subjects developed are: "Light, Source, Device", "Power, Adapt, Arrange", "Produce, Illuminate, Electric". The main assignee is Koninkl Philips and their cooperative relations has equal weight.

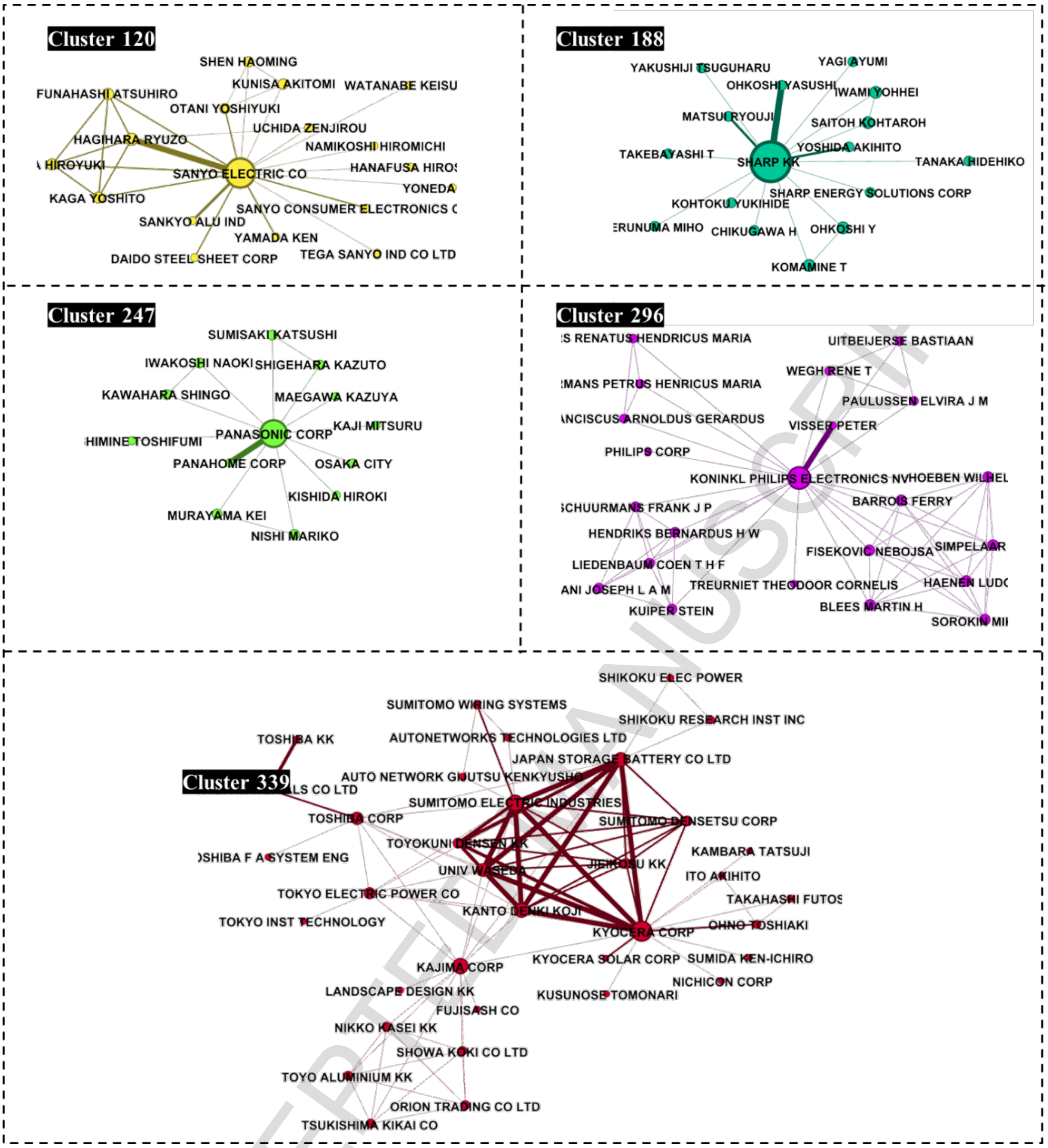
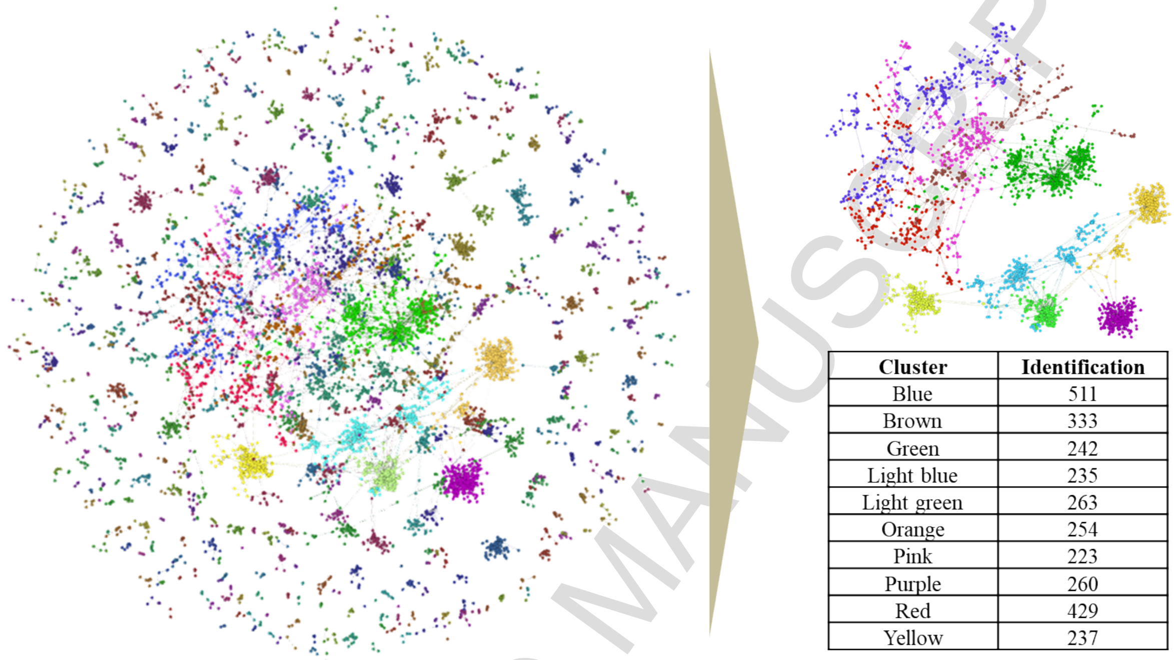


Figure 4 - Top 5 clusters and assignees in cooperation network

The last and largest cluster is red has 35 assignees and 36 patents. The most influential assignees are Kyocera. (17), Sumitomo Electric (7 patents), Kanto Denki Koji (6 patents), Japan Storage Battery (5 patents), Univ Waseda, Kajima and Toshiba (4). All patents were primarily applied in Japan. However, 39% were protected in the USA and 28% in China and EPO. The most relevant subjects covered are: “Power, Solar, System”, “Supply, Electric, Cell”, “Module, Generate, Unit” and “Control, Storage, Battery”. It is important to highlight, the assignees that have a greater breadth of collaboration, which can be shown by the number of triangulations of each node. In descending order: Kyocera (38), Sumitomo Electric (38), Japan Storage Battery (37), Kanto Denki Koji (36), Univ Waseda (36) and Kajima (31). Unlike the others, it is connected to other clusters of the cooperation network. The assignees who make this “bridge” are Univ Waseda which connects to the Nippon Telegraph and Telephone assignee community, the holder Kanto Denki Koji who cooperates with the assignee Shoden belonging to another grouping led by NEC, and the assignee Sumitomo Electric that cooperates directly with Toyota.

4.3 Analysis of technological routes and emerging technologies

The citation network is based on the relation between patents and has the purpose of analyzing the knowledge flow and the most relevant technologies. It identifies the most relevant technological routes (TR) and their most influential patents. The citation network has 8853 nodes (patents) and 9726 edges (backward citations). In applying the modularity statistic, the citation network was divided into 539 clusters (figure 5-a). The top 10 citation clusters were selected to start the identification of TR and MPET (figure 5-b).



Cluster	Identification
Blue	511
Brown	333
Green	242
Light blue	235
Light green	263
Orange	254
Pink	223
Purple	260
Red	429
Yellow	237

(a) (b)

Figure 5 - Citation network: full network (a) and top 10 citation clusters (b)

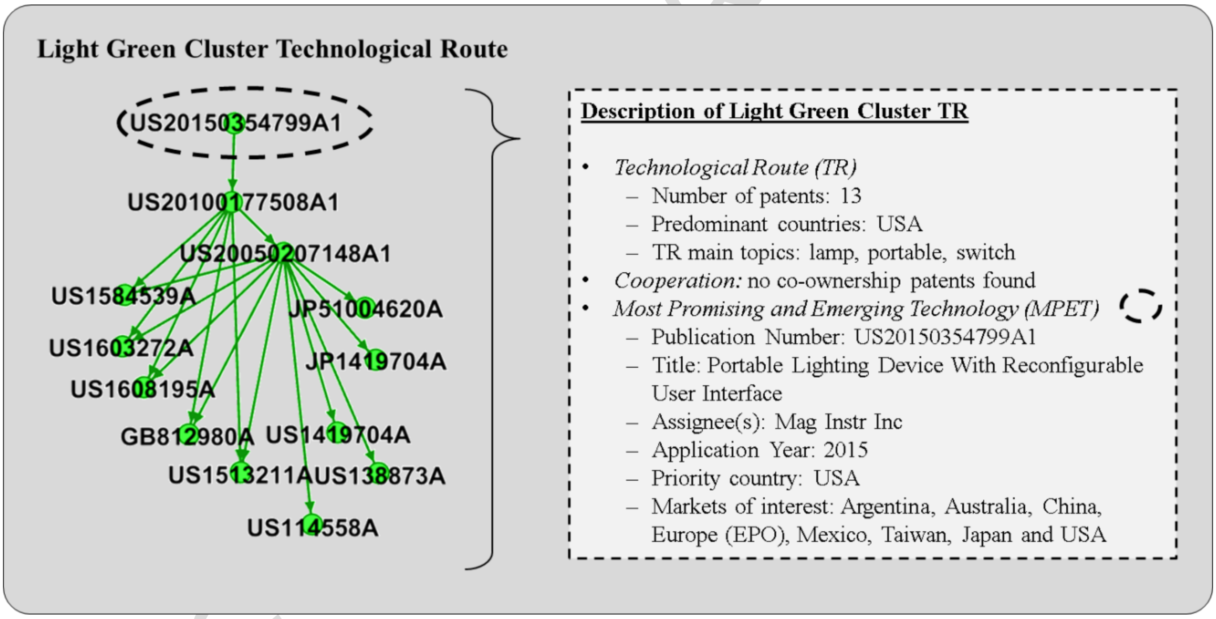
Table 1 - Citation network statistics of main 10 citation clusters

CLUSTER		NODES		EDGES		AWD	APL	NSP	EVC	EB	RANK
NAME	ID	N	%	N	%						
Light Green	**263**	201	2,27%	545	5,60%	2,711	1,392	859	0,3114	1196	**1**
Green	**242**	445	5,03%	738	7,59%	1,685	1,714	1236	0,0475	3068	**2**
Pink	**223**	248	2,80%	280	2,88%	1,129	1,179	341	0,0559	402	**3**
Blue	511	37	3,81%	375	3,86%	1,113	1,163	448	0,0603	521	4
Light Blue	235	297	3,35%	334	3,43%	1,125	1,026	343	0,0977	352	5
Brown	333	174	1,97%	199	2,05%	1,144	1,194	247	0,0401	295	6
Red	429	235	2,65%	259	2,66%	1,102	1,094	286	0,0405	313	7
Orange	254	304	3,43%	311	3,20%	1,023	1,000	311	0	311	8
Purple	260	253	2,86%	252	2,59%	0,996	1,000	252	0	252	9
Yellow	237	204	2,30%	205	2,11%	1,005	1,000	205	0	205	10

Legend: N=amount; AWD=Average Weighted Degree; APL=Average Path Length; NSP=Number of Shortest Paths; EVC=EigenVector Centrality; EB=Edge Betweenness

Among the main SNA statistics, this research used closeness and betweenness centrality are resulted of network functions Average Path Length (APL) and Number of Shortest Paths (NSP). The main 10 clusters represent 30.5% of all network nodes and 35.9% of edges, and these statistics are showed on table 1. The clusters with the highest amount of high-value statistics were marked in bold and are described in the table below.

The TR of light green cluster has patents deposited with priority in the USA (figure 6), totaling 13 patents on this route. Main subjects of this route are: a) “Electric lighting devices with self-contained electric batteries or cells”, b) “Arrangement of electric circuit elements in or on lighting devices the elements being transformers or impedances” and c) “Electric lighting devices characterized by provision of a light source housing portion adjustably fixed to the remainder of the device”. The interest of market protection in this TR are Argentina, Australia, China, Europe, Mexico, Taiwan, Japan and USA. An interesting point is that in all routes analyzed, only this route has a patent protected in Brazil (US20050207148A1, assignee Mag Instr). In addition, this is the only route among the analyzed in this study with no patent on the route developed in cooperation. Based on a text clustering analysis, top subjects covered are “lamp, portable, switch”. This TR initializes with technologies on electrical flash lamp, improvements relating to electric battery lamps, light source aligning apparatus for use in a portable lighting device that culminated in the MPET about “Portable Lighting Device” which electronics configured to provide power to the light source and to acknowledge when user disengages power switch after a certain number of blinks.



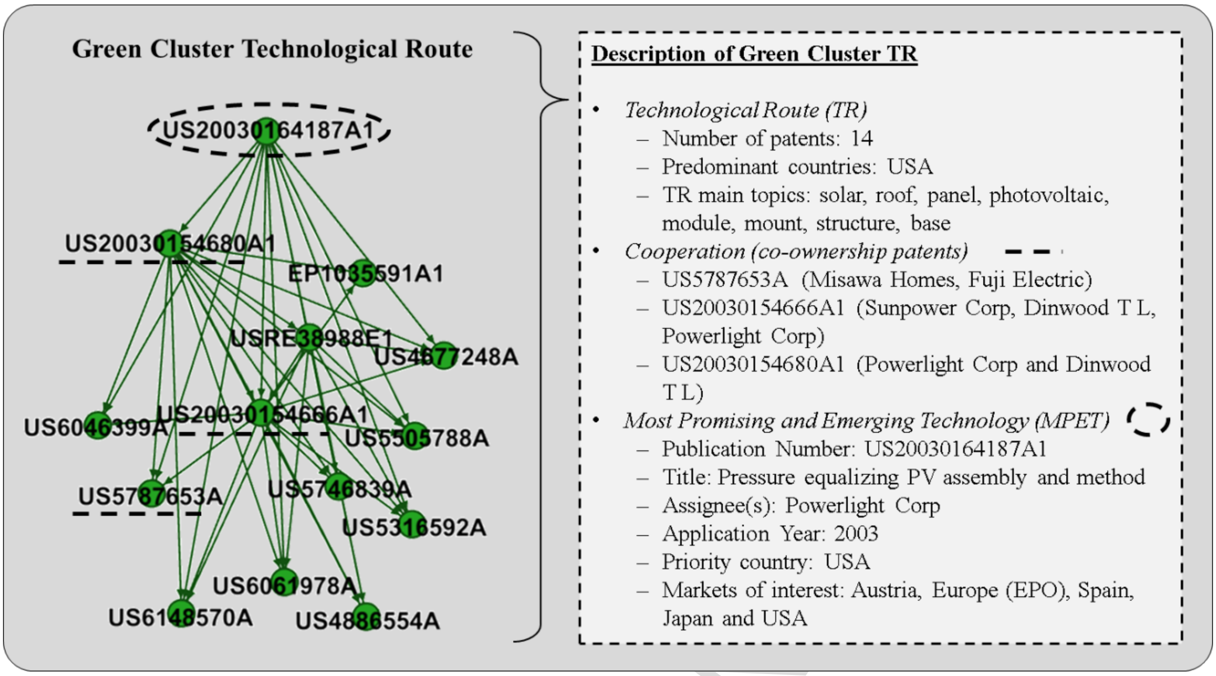
Description of Light Green Cluster TR

- *Technological Route (TR)*
  - Number of patents: 13
  - Predominant countries: USA
  - TR main topics: lamp, portable, switch
- *Cooperation:* no co-ownership patents found
- *Most Promising and Emerging Technology (MPET)*
  - Publication Number: US20150354799A1
  - Title: Portable Lighting Device With Reconfigurable User Interface
  - Assignee(s): Mag Instr Inc
  - Application Year: 2015
  - Priority country: USA
  - Markets of interest: Argentina, Australia, China, Europe (EPO), Mexico, Taiwan, Japan and USA

Figure 6 - TR and MPET of Light green cluster

The TR from green cluster has 14 patents (figure 7). These were prioritized in USA but part of them are also protected in Japan e Europe (71%), Australia (57%), Germany and Spain (36%), Austria (29%) and China (21%). Main keywords are: solar, roof, panel, photovoltaic, module, mount, structure, base. TR Green pointed out innovations in fields a) “Encapsulation of modules adapted as PV conversion devices”, b) “PV modules or arrays of single PV cells” and c) “Roof covering aspects of energy collecting devices”. This TR begins with technologies about apparatus for mounting solar cells, solar roofing assembly usable with flat roof, solar cell roofing assembly with several insulation blocks disposed on top, roofing panels with integral brackets for accepting inclined solar panels that resulted in the development of a MPET

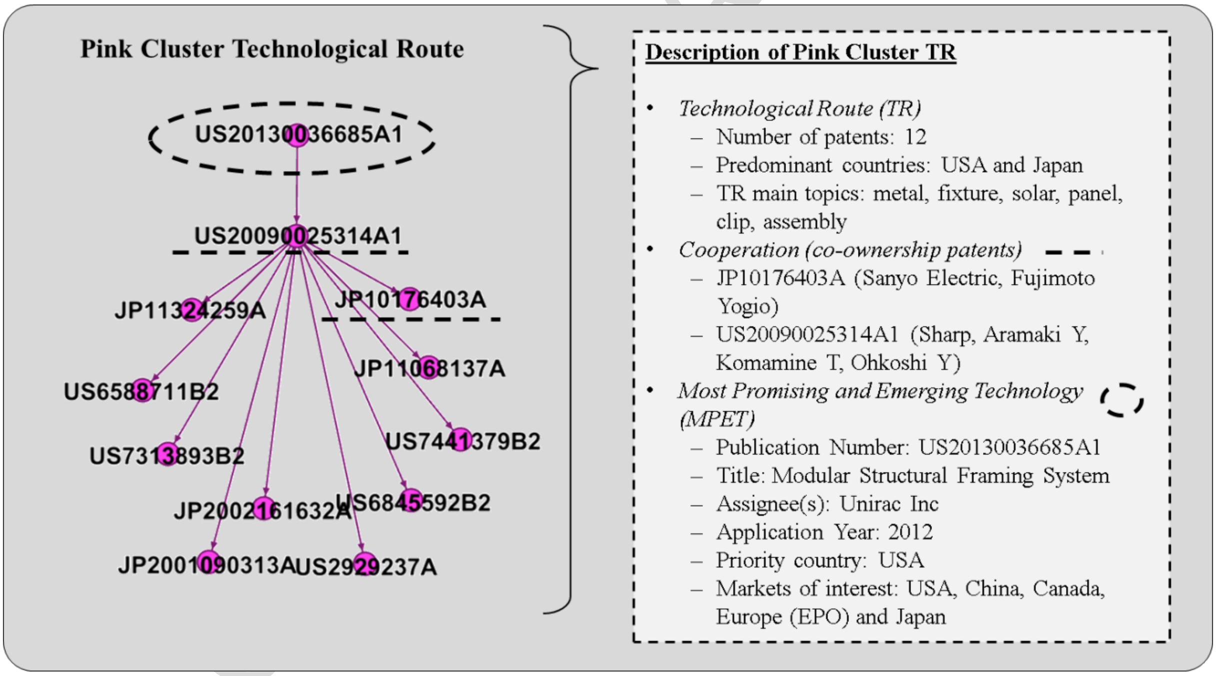
"Pressure equalizing PV assembly and method" which proposes equalizing PV assembly for minimizing wind uplift forces.



Description of Green Cluster TR

- *Technological Route (TR)*
  - Number of patents: 14
  - Predominant countries: USA
  - TR main topics: solar, roof, panel, photovoltaic, module, mount, structure, base
- *Cooperation (co-ownership patents)* – –
  - US5787653A (Misawa Homes, Fuji Electric)
  - US20030154666A1 (Sunpower Corp, Dinwood T L, Powerlight Corp)
  - US20030154680A1 (Powerlight Corp and Dinwood T L)
- *Most Promising and Emerging Technology (MPET)*
  - Publication Number: US20030164187A1
  - Title: Pressure equalizing PV assembly and method
  - Assignee(s): Powerlight Corp
  - Application Year: 2003
  - Priority country: USA
  - Markets of interest: Austria, Europe (EPO), Spain, Japan and USA

Figure 7 - TR and MPET of Green cluster



Description of Pink Cluster TR

- *Technological Route (TR)*
  - Number of patents: 12
  - Predominant countries: USA and Japan
  - TR main topics: metal, fixture, solar, panel, clip, assembly
- *Cooperation (co-ownership patents)* – –
  - JP10176403A (Sanyo Electric, Fujimoto Yogio)
  - US20090025314A1 (Sharp, Aramaki Y, Komamine T, Ohkoshi Y)
- *Most Promising and Emerging Technology (MPET)*
  - Publication Number: US20130036685A1
  - Title: Modular Structural Framing System
  - Assignee(s): Unirac Inc
  - Application Year: 2012
  - Priority country: USA
  - Markets of interest: USA, China, Canada, Europe (EPO) and Japan

Figure 8 - TR and MPET of Pink cluster

TR based on pink cluster consists of 12 patents with deposits prioritized in Japan and USA (figure 8) which were also subsequently protected in the markets of China, Canada and Europe. In this TR, patents of the assignees Sharp (2), Sanyo Electric and Extech Inc (2) are more frequent than other assignees. In this route, 75% of patents technologies are about: a) roof covering aspects of energy collecting devices, b) Devices adapted for the conversion of radiation energy into electrical energy" and c) "Special arrangements or devices in connection with roof coverings". The main topics on patents of this TR are: metal, fixture, solar, panel, clip, assembly. This TR begins with the unveiling of technologies on metal sill installation devices, installation apparatus for the solar battery module, panel clip assembly for use with skylight or roof panels, mounting structure of solar cell module that culminated in the development of a MPET on "Modular structural framing system" which is provided for connecting one flange of I-beam structural element by engaging flange.

5 Discussion and conclusions

The importance of discussions about the use of solar energy is uncontested. Thinking about its use in urban systems, there is clearly an interest of universities, industry and market for photovoltaic and solar heat technologies due to their applicability (Devabhaktuni et al., 2013). However, other innovations also associated with solar power have relevance in urban energy context. Although they are not directly used to capture solar energy potential, technologies evaluated in this manuscript – "Electric lighting devices with or rechargeable with solar cells", "Charging batteries" and "Roof covering aspects of energy collecting devices", are important derivations of solar technologies and applied in different urban subsystems such as buildings, transportation or general infrastructure.

First, we find a clear superiority of Japan in these kind of technological production, compared to Brazil. Obviously, this situation is potentialized by socio-economic, and even political, conditions that differs these two countries. Nevertheless, patents that could gain market on a larger scale are limited to the Japanese market, wasting all potential consumption and applicability in a vast market such as Brazil and other emerging markets. Despite the clear advantage of technological know-how obtained from Japan, the establishment of agreements between these two countries for technology transfer is a big opportunity that can expand the use of such technologies in urban systems. This implication is confirmed in studies by Villarreal and Calvo (2015) and Althoff Philippi et al. (2015). Specially for Brazil is necessary to develope specific regulatory mechanisms to encourage development of solar energy technologies either by government programs or by financial and/or tax incentives, as proposed by Ferreira et al. (2018). Corroborating, Salter and Martin (2001) argue that universities and research centers tend to focus on dense urban. Thus, companies can more easily experiment with different production methods, collaborate with other companies, and establish a network with various knowledge providers. In both countries, there are urban environments with high population density, surrounded by universities and public / private research centers. However, except for one of cooperation cluster (light green), other communities may have very close profile and at a ratio of one enterprise assignee to several individual assignees. This point shows that cooperation development is not a strong feature for solar energy innovations analyzed here. For those cases which partnership is a relevant issue, European countries and the USA have a greater adhesion. In contrast, an evolution would be to establish market conditions through subsidies to partnerships between large companies and technology-based companies whose capacity for innovation is high. In this way, a more dense and connected collaboration network will lead to a greater transit of knowledge and consequently a greater possibility of using one technology.

Second, cooperation is not a strong feature found in these patent developments (19.2%). However, when applied to both countries, this index up to 45.3%. We conclude which cooperation between patent assignees points to a dispersed, poorly connected network with small and well-defined communities. If the cooperation can provide a greater technological and market reach, Japanese technologies may be losing market share to American or European innovations that already use cooperation on a larger scale. In summary, technologies for urban systems protected in the Japanese market can broaden their scope of development partnerships and market protection to effectively produce innovations that are massively applied in urban systems. This research identified ten main clusters and these communities indicate partnerships in the development of a technology. Some of partnerships take place between corporate and individual assignees. It is worth mentioning the role of hub for some assignees such as Sanyo Electric (yellow), Sharp (green), Panasonic (light green) and Koninkl Philips (pink). All analyzed clusters have technologies protected in Japan, USA, Europe and China, in this order of interest. Only the pink cluster has a single patent protected in Brazil. It is worth highlighting the red cluster that has the largest variety of assignees in cooperation. Highlight in this community for the holders Kyocera, Sumitomo Electric and Kanto Denki Koji that have a greater breadth of collaboration, which can be shown by the number of triangulations of each assignee.

Third, technological routes were made and key technologies pointed out for key communities. All of them are composed of prioritized patent and protected in the USA. The exception is the blue cluster which is based on Japanese patents. These patents, which trace most relevant knowledge paths for each technology, are characterized by internal R&D efforts that have opted out of cooperation. Also, we can conclude that most of technological routes and all emerging technologies are exclusively developed by internal R&D and cooperation is not a strong issue of emerging technologies too. The main features for emerging technologies are: proprietary technologies, primarily protected in the USA, Japan and Europe markets and most of knowledge or technological routes are from the USA.

Although efforts to strengthen cooperative studies and projects between Brazil and Japan in field of solar energy, it seems that this will be a long way to go until we can find technologies developed with a focus on both markets. It should be noted that Japanese assignees do not perceive or chose the Brazilian market as relevant to protect their technologies. Perhaps, they do not perceive real demands of these technologies in this market or because they evaluate that the export to the same would not be threatened by potential copies due to the lack of technological capacity of the local actors to use the technology.

Additionally, we propose a set of recommendations based on previous results to promote improvements in solar energy technology: (i) to establish a technological cooperation program between Brazil and Japan, combining all Japanese expertise with Brazil's exploration and consumption potential; (ii) provide special funding for Brazilian and Japanese firms to transform innovation in technology applied; (iii) TRs imply in a non-collaborative development profile and possibly firms prefer to create technologies by themselves or acquire them from individual researchers; (iv) emerging technologies identified in this research can support several R&D and market decisions based on data on technological cooperation efforts, most relevant technologies, their owners, relationships and interest of market protection; (v) it enables an analysis of competitive technological intelligence and can be used as a tool for future investment decisions and investments related to solar energy technologies; (vii) to allow innovation studies in a city-level granularity, it is needed to standardize patent data of assignees and inventors cities in the Japan Patent Office.

A limitation of this study is due to the time of patent secrecy up to 18 months, then such patents could not be used to their full potential. As future work, evolutionary studies may focus on additional countries besides Brazil and Japan. Moreover, socioeconomic data of cities could be included and the origin city of each type of solar energy invention could be evaluated. This will allow a better granularity analysis to be identified results on cooperation, routes and emerging technologies at the city level. It will generate complementary insights that could enrich sustainable urban systems and innovation literature.

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Highlights

- Patents with two or more assignees was adopted as cooperation proxy
- Cooperation features are clearly identified and discussed
- Technological routes and most relevant technologies are pointed out.
- A competitive technological intelligence based on these results enables R&D managers address efforts and investments.
- Findings support governments, companies and universities in decisions about solar energy development and applications