Research Article

A Novel Method for Technology Forecasting and Developing R&D Strategy of Building Integrated Photovoltaic Technology Industry

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Because of global warming, renewable energy technologies have become more essential currently, with solar energy technology advancing worldwide. Therefore, interdisciplinary integration is an important trend, and building-integrated photovoltaic (BIPV) is an emerging technology involving the photovoltaic and building fields. The purpose of this study is to understand the technology evolution of BIPV and to determine the R&D planning direction. This paper proposes a hybrid approach to explore the life cycle of BIPV technology and develop the R&D strategy of related industries. The proposed approach comprises the following submodules. First, patent analysis is employed to transform patent documents into structured data. Second, the logistic growth model is used to explore the life cycle of BIPV technology. Third, a patent matrix map analysis is used to develop the R&D strategy of the BIPV industry. Through the analysis by the logistic model, the BIPV technology is transformed from the emerging stage to the growth stage of a long-term life cycle. The other important result is created by the three-dimensional matrix for R&D strategies in this paper.

1. Introduction

Issues of energy conservation and prevention of global warming have been of great concern in recent years. For energy shortages, the development of renewable energy technologies is an inevitable trend and includes solar, wind, hydro- and bio-mass energy. There are advantages to solar energy, including that it is natural, nonpolluting, inexhaustible, noiseless, and not subject to geographical constraints. Solar energy contains few moving parts, and therefore, needs almost no maintenance. The cost of solar energy is fixed at the initial investment stage.

It is the parity technology in the long-term operation. Solar energy technology can be divided into the ground-based system, rooftop system, and building-integrated photovoltaic (BIPV) system. Since the ground-based system needs considerable land and the rooftop system is restricted to a limited number of building roofs, this study focuses on the BIPV system, which is used to construct three-dimensional space to create the largest possible photovoltaic power generation with less area. In addition, solar energy technology can be embedded in various ways of designed buildings, which not only has the ability to improve the use of renewable energy but is also by far the oldest and the most cleanly green energy worldwide. BIPV will gain increasing attention of the building energy efficiency market in the twenty-first century.

Consequently, the ability to manage intellectual property plays a critical role in the R&D process or new product development. The report of the World Intellectual Property Organization (WIPO) shows that 90%–95% of the world's inventions can be found in patent documents, and 80% of these technologies do not appear in other resources, such as journals, magazines, and encyclopedias [1]. Moreover, a WIPO investigation showed that a company can save up to 60% of time in R&D and 40% of research budget if it can use patent documents efficiently. Patents contain substantial information including practical and specific technological content, technical reporting, technological trends of firms, and technological development trends [2]. Patent information is a sufficient source of technical knowledge, and the patent contains characteristics of the technology and market because it fulfills a clear standard and originality, technical feasibility, and commercial value [3]. It can also be the basis of technical competitive analysis and technology trends analysis [4], and it can be regarded as an important indicator of technological changes [5]. Therefore, to master the technology development trend and competitive advantage of enterprises, we must rely on detailed patent intelligence to fully achieve maximum value from patent analysis [6].

The analysis of patent databases can provide the latest information technology and product. The growth of the number of patents may represent a national or industrial development of technology. It is a leading indicator of competitiveness, allowing one to grasp the message of patent data and analysis of industry trends to trace an evasive technology or technological innovation development strategy.

Many experts and scholars used patent analysis to investigate different levels as follows:

(1) discussion of national economic growth or innovation activities: Barroso et al. [7] studied 21 Latin American countries, including analysis of patents as a source of technical information to improve scientific and technological research and development and innovation in their own countries; Abraham and Moitra [8] used patent analysis to accurately assess the technical progress and technical innovation;

(2) discussion of enterprise technology ability: Liu and Shyu [1] used patent analysis of Taiwan LED and TFT industry technology development, strategy, and technology planning and forecasting. Ernst [9] analyzed the German mechanical engineering industry and four patent strategies of performance associated with the company;

(3) discussion of distribution of industries or enterprises: Guo [10] analyzed Taiwan national patent database (TWPAT) for the number of applications and development trend. Chen and Cheng [11] analyzed the US patent database (USPTO) in patent classification and UPC solar patent analysis research;

(4) an analysis of patent citation data: Hu [12] studied the USPTO citation data seeking knowledge of the East Asian regional traffic. Tijssen [13] related to patent

citation analysis of global and domestic industry of interaction between science and technology and knowledge flows.

Technology forecasting is the theory and practice of technology development strategy. Many researchers have combined patent analysis with different technology prediction methods to identify future development trends and strategies. Trappey et al. [14] constructed the multitechnology cluster to analyze the RFID (radio frequency identification) technology forecasting model. They discussed future development strategies of industry by analyzing RFID patent clustering, which has reached the saturation stage of the technology life cycle. This model provided systematic quantitative analysis of technology development and supported expert intuition and judgment [15]. Chen et al. [16] considered the time dimension of technology forecasting. He stated that the S-curve was an effective quantitative technology forecasting model for cumulatively analyzing patents. However, researcher ability limited patent data analysis, and the accuracy and reliability of the data also affected analysis accuracy. Therefore, Cheng et al. [17] used the FAHP (fuzzy analytic hierarchy process) method as a technology forecasting method to evaluate and select novel material fields in a rapidly changing environment.

However, it is more important for an R&D manager to know how to master the market of technology imports and the exit market of time. If an enterprise wants to keep a competitive advantage, it must establish a technology forecasting system [18]. According to technology life cycle displayed by S-curve, we can effectively understand the technology development track.

Technology forecast is through text or digital form to describe future machinery, entity program, and the application of program and development [19]. Technology forecasters must focus on changes of technology function, the significance of innovation, and the implementation of time points. Technology forecasting of content contains technology ability of growth, replacement rate of old and new technology, situation of technology diffusion, market penetration, and future possibilities [20]. There are three types of technological prediction methods. They are direct forecasting, correlative forecasting, and structural forecasting. However, as the technology industry competition intensifies and technology development continues in the globalized world, technology forecasting must master the principles of accurate, fast, and simple to achieve the desired results. Therefore, we use the direct forecasting method by reliable patent data in this study.

We are interested in the BIPV's development and aim to explore its evolution. This study examines the viewpoint of patent analysis and hopes to offer some useful recommendations for BIPV's technology development. Thereby, we use a logistic model to explore the life cycle of BIPV technology development. The patent database of the United States Patent and Trademark Office (USPTO) is by patent number. We combine logistic growth model analysis of embryonic development of BIPV technology trends and forecasts to allow industry R&D managers to develop technology strategies for future planning.

2. BIPV Technology and Industry

All energy consumption in a building includes raw-material production, construction process, decoration, and the final usage stage. Through the combination of solar power technology and building itself, the building can function as a power generator. Here, photovoltaic modules are fabricated as building material and facilitate the building to convert
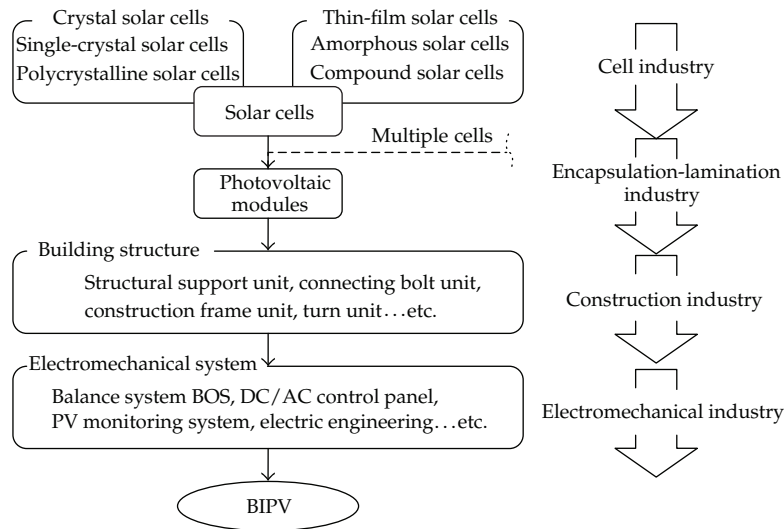
Figure 1: BIPV technology industry chain.

solar energy into electricity. Therefore, BIPV can be called a static generator as well as the new generation of photovoltaic building [21].

BIPV is a new concept of converting solar energy into electrical energy. In addition to developing self-efficient zero-energy buildings (ZEB) with the use of BIPV, heat load within the building can be reduced via the thermal resistance of the photovoltaic module and then achieve the dual effect of energy saving and carbon reduction. At the same time, the excess of clean energy can be sold back to the commercial electricity providers to sell to other customers, thus creating a multiple effect of energy saving and carbon reduction. In the future, the integrated distribution of BIPV electricity network will form the solar power grid of a metropolitan area that we might call a photovoltaic city.

The methods of integrating photovoltaic and building can be distinguished into two kinds of technology: installed PV module above a building and PV module integrated with the building. BIPV's technology industry chain can be divided into four flows, including solar cells, photovoltaic modules, building structure, and electromechanical system (Figure 1). The industry chain goes from the most upstream raw material of the silicon, a seed crystal puller rod for growing silicon boule, and then cuts into a silicon wafer, which is the main source of solar cells. After being made into solar cells that can be converted into energy, the solar cells are linked together in modules. Later, these solar modules are combined with a balance system (balance system BOS) into a form such as the converter, current breaker, building support structures, power cables, and monitoring instrumentation and then finally installed.

Figure 1 shows technology and market chain relationships for the BIPV industry. It is possible to clearly understand technology and market relationships in the BIPV industry. For example, PV manufacturers must consider and consistently comply with national building codes when developing products; the construction and electromechanical industries in the wiring and installation of PV modules; electrical and mechanical piping interface design, integration, and coordination when building a high-performance, high-security system; visual appeal. Finally, BIPV building systems are handed to market users after completion and achieve effective energy savings and carbon reduction, furthering the realization of zero-energy buildings.
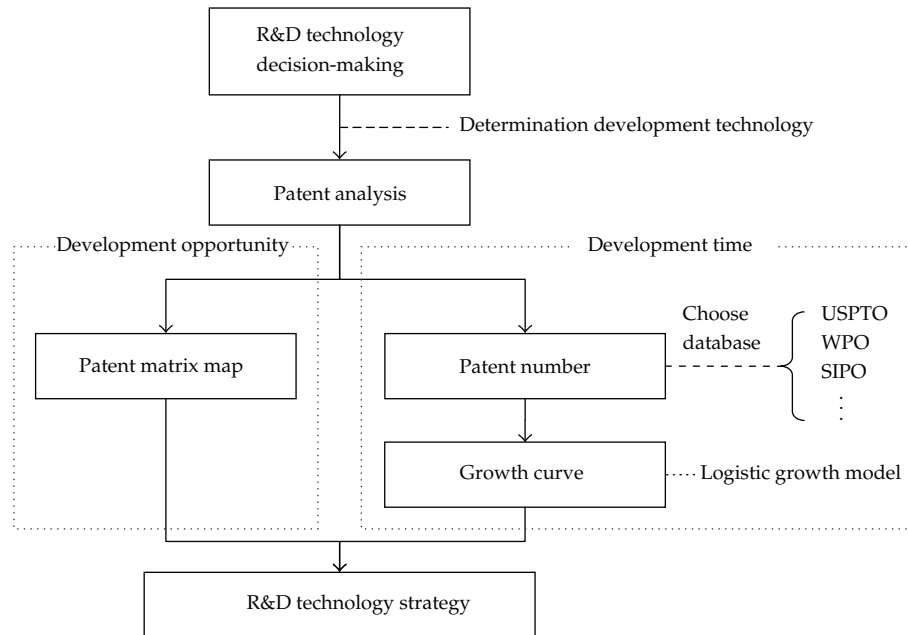
Figure 2: R&D technology strategy model.

Since BIPV is integrated into the three-dimensional space with the building structure and does not take up any additional ground space, BIPV is the best model of applying renewable energy in the highly urbanized area. However, its installation cost is high, which affects the development of market demand. Therefore, when developed countries are promoting renewable energy, they rely on the government's four policy factors, including incentive policy, subsidies, low installation cost, quick approval process, and lending policies for financial institutions, which sustain the promotion of the BIPV industry and market development. In the future, the key factor in reducing the impact on market development is the continuity of technology development. The installation cost, meaning the economies of scale of the BIPV industry, could flourish unimaginably when the cost of solar photovoltaic electricity and cost of commercial electricity are balanced.

3. Methodology

For this study, we intend to explore completed lifecycle evolution of BIPV technology. The quantity and quality of data acquisition are priorities and explicitly defining the industry technology is necessary to avoid forecasting bias. For the above reasons, we adapt the expert opinions and growth curve to develop the forecasting models. Therefore, we combined patent analysis, growth curve, and expert opinions to analyze the development of BIPV technology and construct the R&D strategy. The framework of this study is presented in Figure 2. These are summarized below.

3.1. Patent Searching

Patent searching is based on a specific field of study, through the relevant patent documents issued by relevance of patent data search, application for the analysis, and followup of
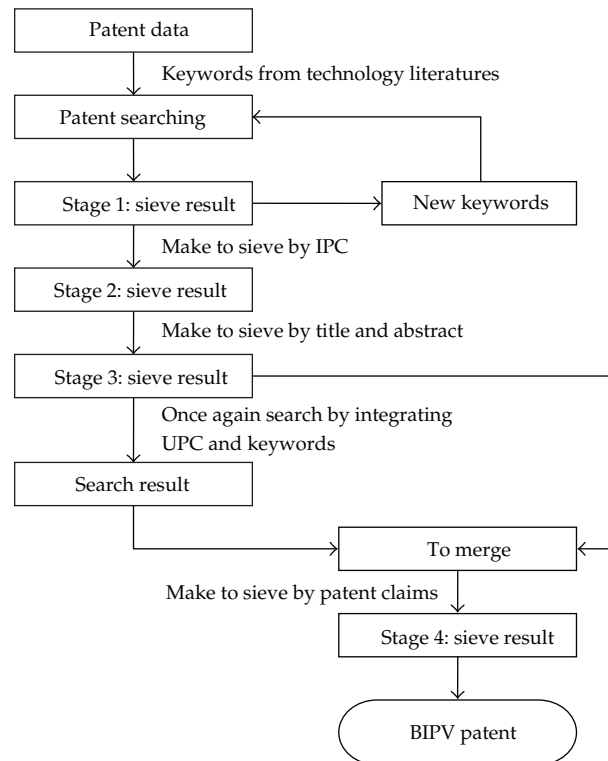
Figure 3: Process of BIPV patent searching.

research. We must understand its retrieval application purpose, scope, search method, and search tools before patent searching. This research through the patent analysis is to predict technology trends and use the BIPV technologies as scope, and then to group Boolean searches through the USPTO patent database of keywords (Boolean Search), its use of the retrieval tools patented analysis software developed for Lian Ying Technology Patent and Patent Guider 2008 Tech tools for analysis. The patent searching strategies for this study are the main access point to keywords and to supplement, patent classification (international patent classification (IPC)), to achieve the accuracy and integrity of the retrieval processes in Figure 3.

3.2. Keywords Extraction

To construct our patent map, keywords are required first. It forms important patent search methods by technical or patent documents for keywords, and keywords in groups to a logical combination of relevance. Therefore, the processes of keywords extraction are including literature review, compile keywords, re-searching and find out new keywords, and establish the keywords pool (Figure 4). After literature review, the three parts keywords of BIPV industry chain can be extracted. The new keywords found in the retrieval process to establish more complete keywords pool of BIPV (Figure 5).
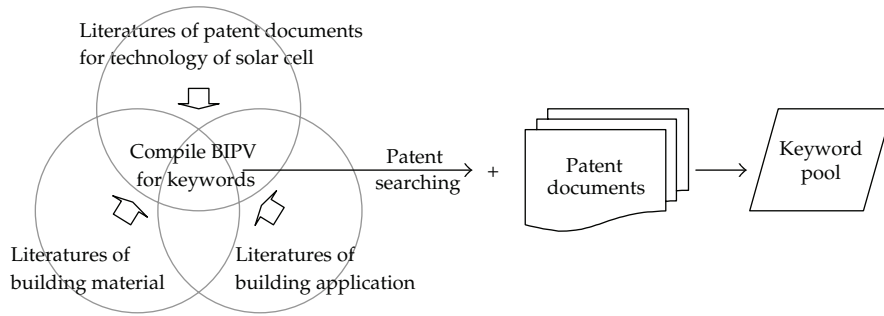
Figure 4: The process of keywords extraction.
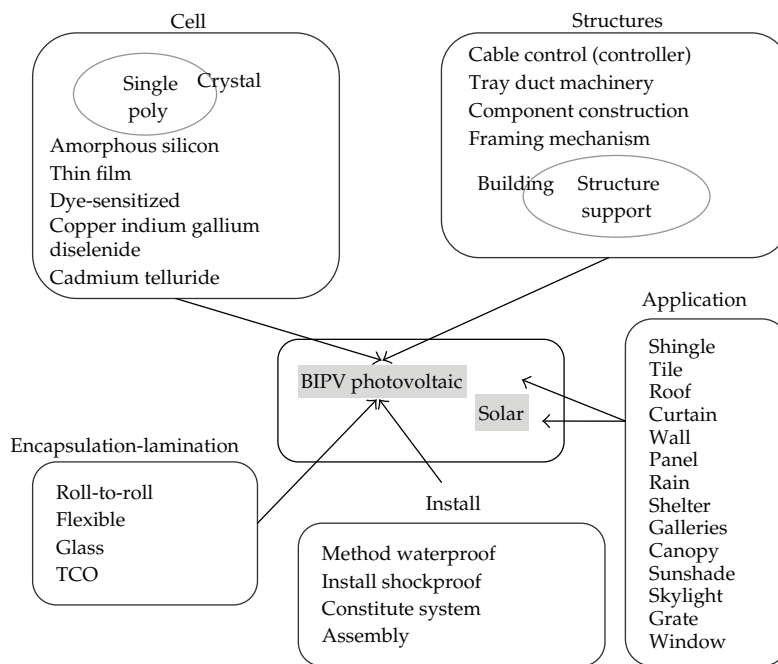
Figure 5: Keywords pool of BIPV.

3.3. Patent Map

The main purpose of a patent map is easy and effective understanding of patent information and analysis on a wide range of complex data and to represent them through measures such as tables or schemata. Figure 6 explains the process and related information of the patent map.

3.4. Matrix Map

A matrix map is two-dimensional array, and the array matrix is a simple data structure. Two-dimensional array is by x, y two-axial plane, and we can construct a spatial distribution of the state that through the display of the spatial distribution can clearly see the correlation
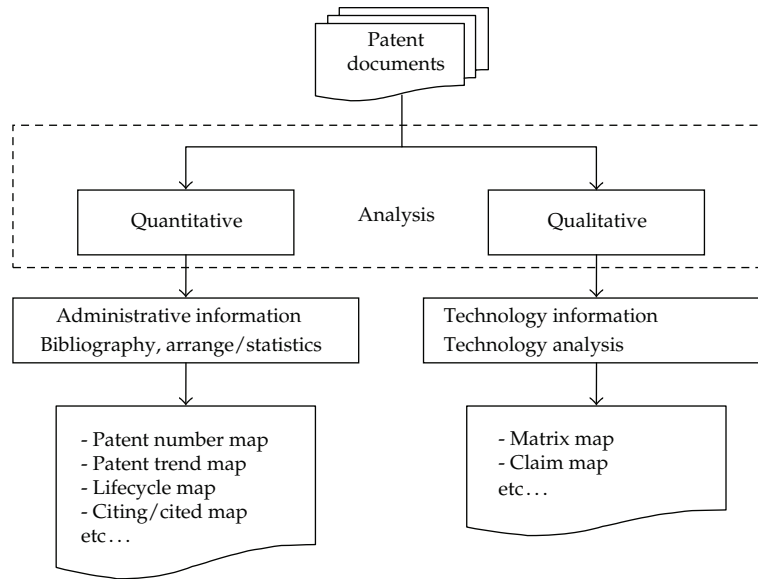
Figure 6: The process of patent map.

between the x-axis items with the y-axis items and the trends. Therefore, we can understand the relationship of its elements and functions in a two-dimensional array matrix notation as shown in Table 1. This study uses this two-dimensional array matrix to represent the technology function matrix, as shown in Table 2. A matrix map shows patent intelligence with the correlation between technical information, including technology sort and purpose sort. The matrix can be used to teach important technology and development trends. Therefore, R&D managers can use patent matrix maps to develop related technologies and preventive strategies.

3.5. Logistic Growth Model

The study supposes technology growth with the property of S-curve. We adopt the Loglet Lab 2, which is a kind of analysis software developed by Rockefeller University in 1994. There is a great advantage in setting all the parameters related to time series into analysis and the result presents as an S-curve [22]. S-curve can be classified into two types of symmetry and unsymmetry. The symmetry type represents the growth curve with inflection point, which can be presumed by the following equation:

$$P(t) = \frac{k}{1 + e^{-\alpha(t-\beta)}},$$

(3.1)

where $P(t)$ means the patent numbers change with the time t; α means the slope (growth rate) of S-curve; β means the inflection point of growth, which is the turning point of time spent into technique; k means the saturation level of growth; e means nature log. Based on the practice consideration, $[k * 10\%, k * 90\%]$ is defined as the growth interval. The period time from 10% of technology with maximum utility value to 90% presents by Δt. To proper

Table 1: Arrays of two dimensions.

		Row-Major					
			n				
	m	R_1	R_2	R_3	$\cdots$	$\cdots$	R_n
	C_1	$Q[1][1]$	$Q[1][2]$	$Q[1][3]$	$\cdots$	$\cdots$	$Q[1][n]$
	C_2	$Q[2][1]$	$Q[2][2]$	$Q[2][3]$	$\cdots$	$\cdots$	$Q[2][n]$
Column-Major	C_3	$Q[3][1]$	$Q[3][2]$	$Q[3][3]$	$\cdots$	$\cdots$	$Q[3][n]$
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	C_m	$Q[m][1]$	$Q[m][2]$	$Q[m][3]$	$\cdots$	$\cdots$	$Q[m][n]$

Table 2: Matrix map of patent.

		Purpose sort					
		P_1	P_2	P_3	$\cdots$	$\cdots$	P_n
	T_1	PDQ $[1][1]$	PDQ $[1][2]$	PDQ $[1][3]$	$\cdots$	$\cdots$	PDQ $[1][n]$
	T_2	PDQ $[2][1]$	PDQ $[2][2]$	PDQ $[2][3]$	$\cdots$	$\cdots$	PDQ $[2][n]$
Technology sort	T_3	PDQ $[3][1]$	PDQ $[3][2]$	PDQ $[3][3]$	$\cdots$	$\cdots$	PDQ $[3][n]$
	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
	T_m	PDQ $[m][1]$	PDQ $[m][2]$	PDQ $[m][3]$	$\cdots$	$\cdots$	PDQ $[m][n]$

Notes: PDQ (patent document quantity).

represent the growth process and make it with more fitness, α is replaced by (3.2) in practice [23]. Therefore, the $P(t)$ is proposed as (3.3) as follows:

$$\Delta t = \frac{\ln 81}{\alpha}, \tag{3.2}$$

$$P(t) = \frac{k}{1 + e^{[-(\ln 81/\Delta t)-(t-t_m)]}}. \tag{3.3}$$

This research is through the BIPV technology growth model calculation and describe technical development trend.

4. BIPV Technology Development

This model of research in technology forecasting and strategy for research and development is under construction by the world's major advanced countries such as the United States, Japan, and Germany, plus positive development of a PV industry in China. The BIPV technology and applications are as the empirical techniques in the study.

4.1. Patent Map Analysis

Using the keyword pool to begin the patent searching based on USPTO database, the date from the BIPV technology patents in the field of data begins on July 26, 1977 and runs to October 31, 2011. Through the patent searching process, results of 263 valid patents in this study are obtained. The results of patent numbers in every year and accumulative patent
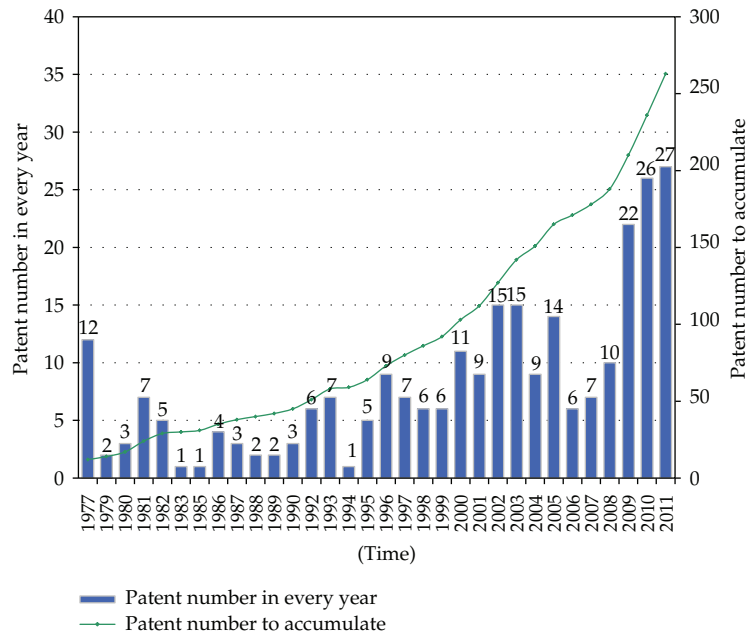
Figure 7: Patent number and accumulative numbers of BIPV.

numbers are shown in Figure 7. Global warming and near-future energy crisis results show an increase in related patents since early 2000.

Analyzing the number of patents for technology, purpose, and application (Figure 8) can determine the BIPV technology development level of a country. The patent output of United States (US) is the first; Japan (JP) is the second. Germany (DE) accounted for approximately 5% of BIPV technology in Europe. Results show that countries most focused on R&D of BIPV technology are the United States, Japan, and Germany.

Results of the firm-level analysis show major manufacturers and product applications. Table 3 shows PV module technology directions and strategies in the BIPV industry. The table shows that most manufacturers continue developing roof technology and its applications. However, some manufacturers have changed R&D strategies to focus on glass curtain walls and external walls.

4.2. Matrix Map

The results of technology effect analysis, the matrix map is shown in Figure 9. According to the complex BIPV technology, we can classify the functions into two groups: main function and subfunction. The main functions of BIPV are generating electric, building materials to diversify quality and reliability, install and maintain, and keeping cost down. The main function map presents the development of BIPV from 1977 to 2011. A larger pie chart means a large number of patents and represents the technology development center. On the contrary, a smaller pie chart means fewer patents, which is worthy of note by research and development personnel. BIPV derives technologies corresponding to the early functions in the field of
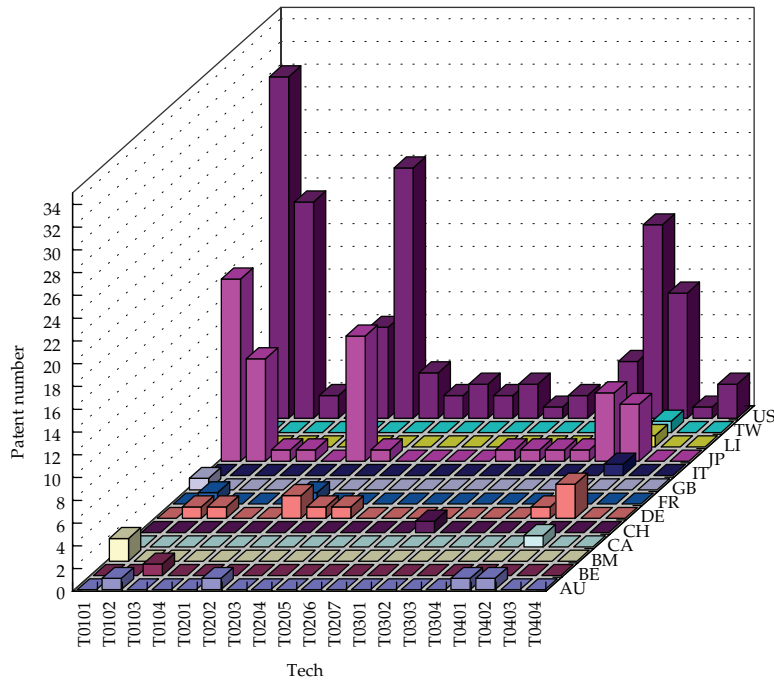
(a) The number of patents in the focus on technology
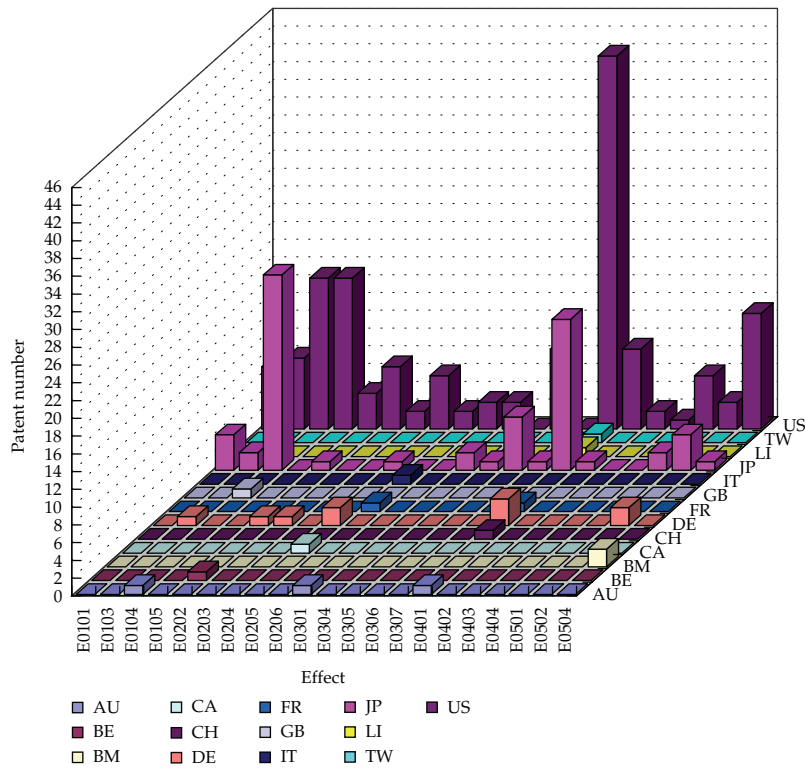
(b) The number of patents in the focus on the purpose

Figure 8: Continued.
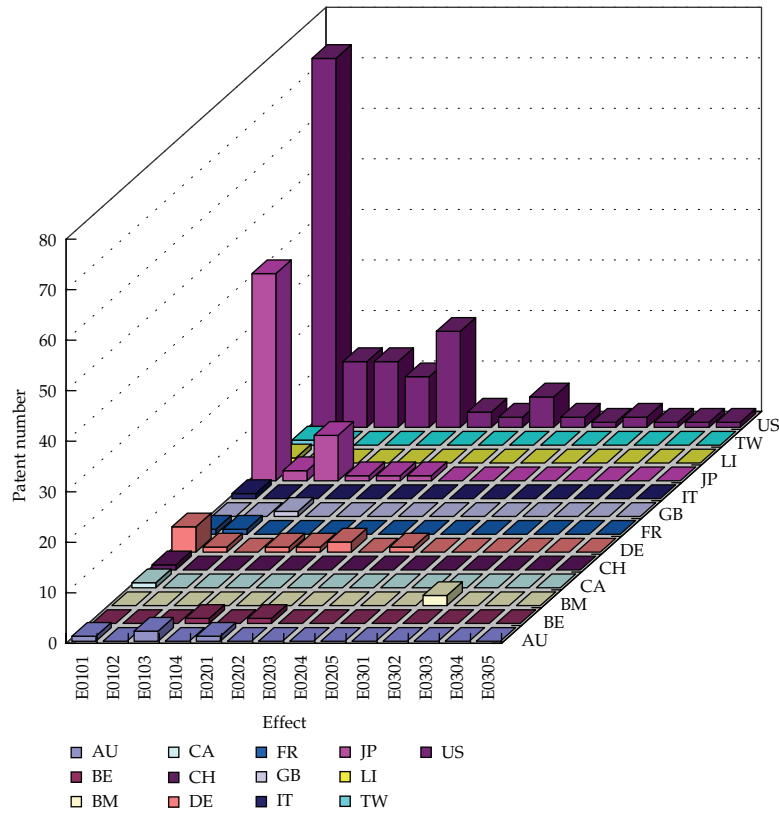
(c) The number of patents in the focus on the application

Figure 8: BIPV technology three-dimensional (technology, purpose, and application) map in country level.

Table 3: BIPV manufacturers and product applications.

Manufacturer	Country	Product name	Application
Uni-solar	US	Photovoltaic Laminate	Various shapes of roofs in commercial buildings
		Power Tilt	The flat roofs in commercial buildings
		EnerGen	Residential roofs
		PowerShingle	Residential roofs
Power Film Solar	US	N/A	Commercial building roof
First Solar	US	N/A	Commercial building roof
Ascent Solar	US	WaveSol	Roof
Global Solar Energy	US	Power FLEX	Roof
Solyndra	US	100/200 series	Commercial building roof
Konarka	US	Power Plastic	Roofs and external walls
Sharp	JP	ND/NU series	Roof
		NA series	Roofs and external walls
Kaneka Solartech	JP	Hybrid silicon	Roof
		SOLTILEX, VISOLA, GRANSOLA	Tile style roof in a residential
		See-Through	Glass curtain wall
Honda Soltec	JP	HEM series	Roof
Würth Solar	DE	GeneCIS series	Roofs and external walls
Dyesol	AU	Sun2	Roofs and external walls

Purpose / Technology	Generate electric	Building materials to diversify	Quality and reliability	Install and maintain	Cost down
Photovoltaic module	16(39)	12(24)	7(11)	10(13)	12(23)
Building structure	7(9)	7(9)	9(11)	20(66)	3(3)
Electric and controller	6(7)			7(11)	
Engineering technology	11(27)	8(9)	5(5)	10(12)	5(6)

Figure 9: Main purpose matrix map of BIPV. $Y(Q)$: patent number of years (in accordance with this technology and the effectiveness of patent). The pie chart represents the number of patents. Patent number of the more means larger the pie chart, and vice versa smaller.

Apply / Technology	Roof of building	Outside wall of building	Sole function of structure
Photovoltaic module	18(66)	14(42)	4(4)
Building structure	24(69)	9(19)	5(5)
Electric and controller	11(16)	1(2)	
Engineering technology	24(52)	3(3)	

Figure 10: Main apply matrix map of BIPV. $Y(Q)$: patent number of years (in accordance with this technology and the effectiveness of patent). The pie chart represents the number of patents. Patent number of the more means larger the pie chart, and vice versa smaller.

technology development from 1977 to 2011. The technical function matrix gives a more precise formulation of the future direction of development policy.

We can understand the technology development trends by analyzing the effect of the technology and the application of BIPV. After further study through a combination of two oriented analyses, we will be better able to judge technology trends and liquidity phenomena. According to technology mapping from 1977 to 2011, the main applications of BIPV are in the roof of the building (Figure 10), especially in USPTO patent pieces in the United States, Japan, and Germany.
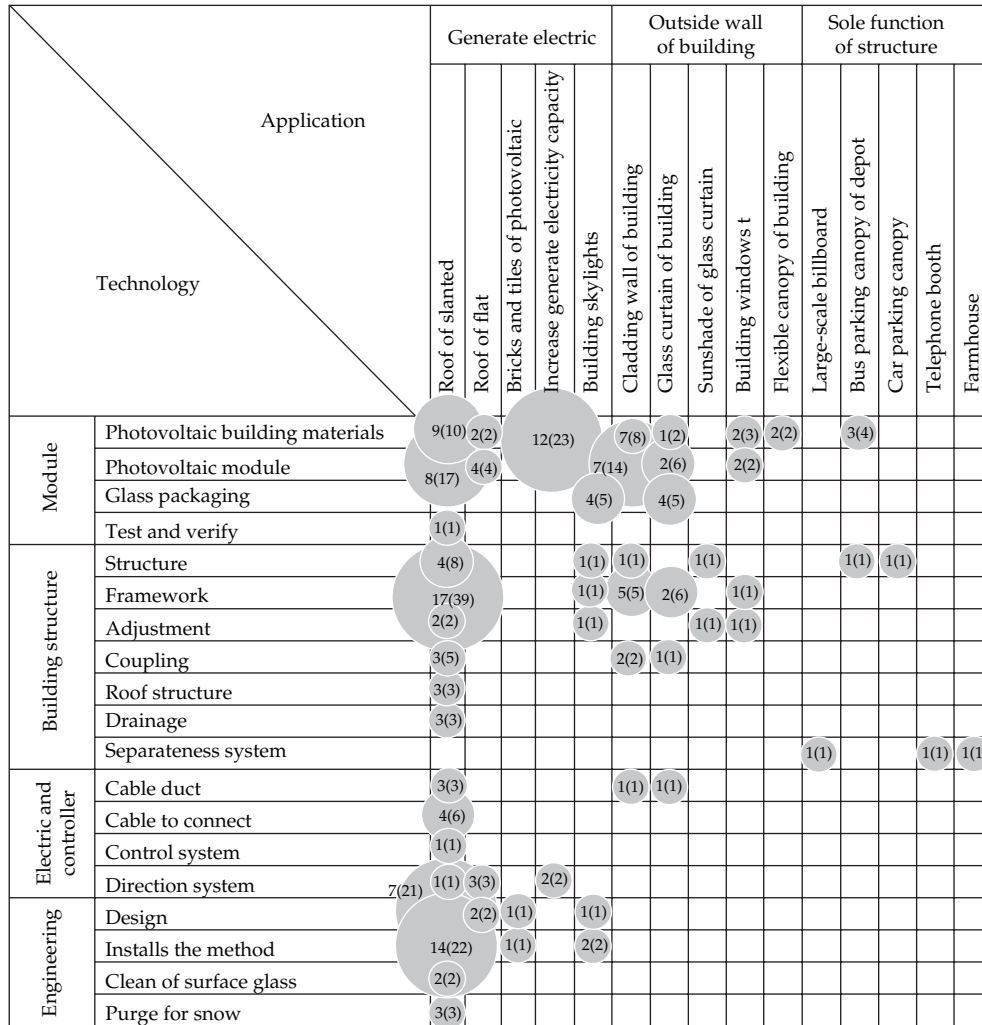
Technology		Generate electric					Outside wall of building					Sole function of structure				
	Application	Roof of slanted	Roof of flat	Bricks and tiles of photovoltaic	Increase generate electricity capacity	Building skylights	Cladding wall of building	Glass curtain of building	Sunshade of glass curtain	Building windows t	Flexible canopy of building	Large-scale billboard	Bus parking canopy of depot	Car parking canopy	Telephone booth	Farmhouse
Module	Photovoltaic building materials	9(10)	2(2)		12(23)		7(8)	1(2)		2(3)	2(2)		3(4)			
	Photovoltaic module	8(17)	4(4)				7(14)	2(6)		2(2)						
	Glass packaging						4(5)	4(5)								
	Test and verify	1(1)														
Building structure	Structure	4(8)				1(1)	1(1)		1(1)				1(1)	1(1)		
	Framework	17(39)				1(1)	5(5)	2(6)		1(1)						
	Adjustment	2(2)					1(1)		1(1)	1(1)						
	Coupling	3(5)						2(2)	1(1)							
	Roof structure	3(3)														
	Drainage	3(3)														
	Separateness system											1(1)			1(1)	1(1)
Electric and controller	Cable duct	3(3)					1(1)	1(1)								
	Cable to connect	4(6)														
	Control system	1(1)														
	Direction system	7(21) 1(1)	3(3)		2(2)											
Engineering	Design	2(2)	1(1)			1(1)										
	Installs the method	14(22)	1(1)			2(2)										
	Clean of surface glass	2(2)														
	Purge for snow	3(3)														

Figure 11: Subapplication matrix map of BIPV. Y(Q): patent number of years (in accordance with this technology and the effectiveness of patent). The pie chart represents the number of patents. Patent number of the more means larger the pie chart, and vice versa smaller.

Due to high latitudes, the technology development is mainly to oblique roof. We also can find out technology application and purpose in the field of BIPV technology development by Figures 11 and 12. The subtechnology matrix can provide more accurate positioning and development of the strategic direction of future research and development.

We can use dynamic trend analysis, technology research, and development activities to watch the technology development of the whole picture through patent maps. The cross-analysis by purpose and applications of technology can help us to grasp the accurate R&D direction.

After analyzing the technology purpose and application matrix map, it was combined with time to show the evolution of BIPV purposes and applications over time. This study proposes a patent number weight over time concept. In Figure 13, there are five major purposes of BIPV technology on the *x*-axis and three major applications of BIPV technology
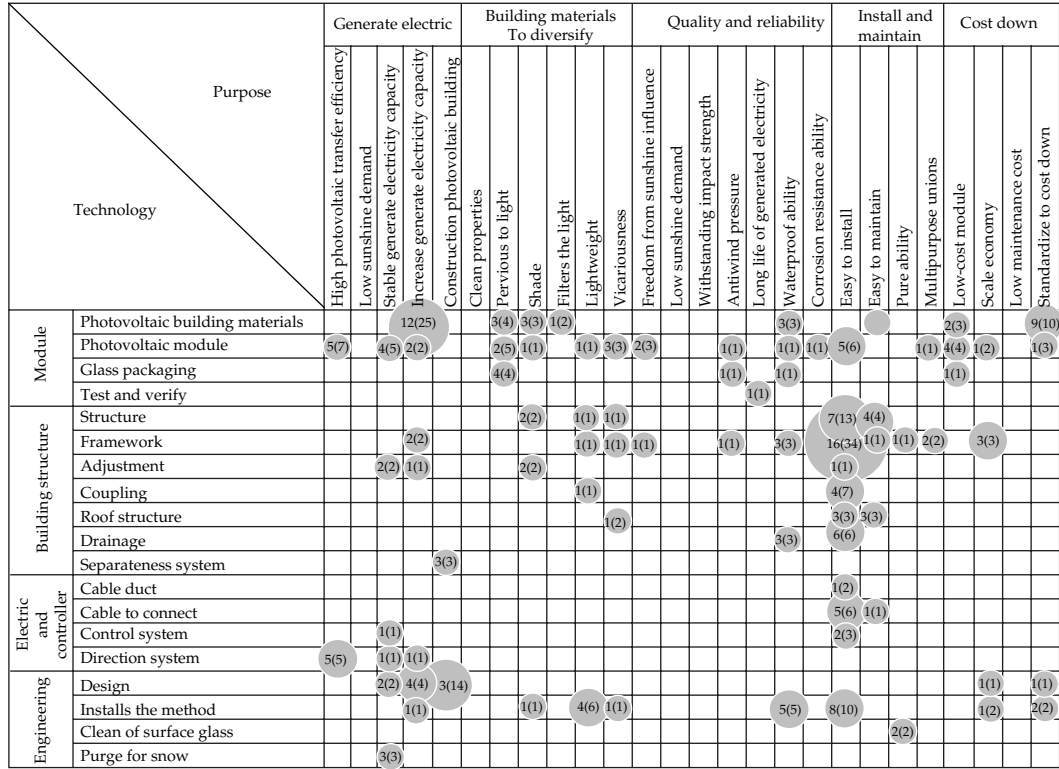
		Generate electric					Building materials To diversify						Quality and reliability							Install and maintain				Cost down			
Purpose / Technology		High photovoltaic transfer efficiency	Low sunshine demand	Stable generate electricity capacity	Increase generate electricity capacity	Construction photovoltaic building	Clean properties	Pervious to light	Shade	Filters the light	Lightweight	Vicariousness	Freedom from sunshine influence	Low sunshine demand	Withstanding impact strength	Antiwind pressure	Long life of generated electricity	Waterproof ability	Corrosion resistance ability	Easy to install	Easy to maintain	Pure ability	Multipurpose unions	Low-cost module	Scale economy	Low maintenance cost	Standardize to cost down
Module	Photovoltaic building materials				12(25)			3(4)	3(3)	1(2)								3(3)						2(3)			9(10)
	Photovoltaic module	5(7)		4(5)	2(2)			2(5)	1(1)		1(1)	3(3)	2(3)			1(1)		1(1)	1(1)	5(6)			1(1)	4(4)	1(2)		1(3)
	Glass packaging							4(4)								1(1)		1(1)						1(1)			
	Test and verify																1(1)										
Building structure	Structure								2(2)		1(1)	1(1)								7(13)	4(4)						
	Framework				2(2)						1(1)	1(1)	1(1)			1(1)			3(3)	16(34)	1(1)	1(1)	2(2)		3(3)		
	Adjustment			2(2)	1(1)				2(2)											1(1)							
	Coupling										1(1)									4(7)							
	Roof structure											1(2)								3(3)	3(3)						
	Drainage																		3(3)	6(6)							
	Separateness system					3(3)																					
Electric and controller	Cable duct																			1(2)							
	Cable to connect																			5(6)	1(1)						
	Control system			1(1)																2(3)							
	Direction system	5(5)		1(1)	1(1)																						
Engineering	Design			2(2)	4(4)	3(14)																		1(1)			1(1)
	Installs the method				1(1)			1(1)		4(6)	1(1)							5(5)		8(10)				1(2)			2(2)
	Clean of surface glass																						2(2)				
	Purge for snow				3(3)																						

Figure 12: Subpurpose matrix map of BIPV. $Y(Q)$: patent number of years (in accordance with this technology and the effectiveness of patent). The pie chart represents the number of patents. Patent number of the more means larger the pie chart, and vice versa smaller.

on the y-axis. Over three periods ($s_1 - s_3$), the growth in patent number weights of outside wall building materials and the installation and maintenance of solar panels can be identified. The patent number weights include technical application and purpose over three periods. Technical purposes include electricity generation, diversified building materials, quality and reliability, installation and maintenance, and cost reduction. Technical applications are structure function, outside building wall, and building roof. The weights for the technical purpose and application of the patent number are calculated using (4.1):

$$w_{x_i,s_j} = \frac{p_{x_i,s_j}}{\sum_{i=1}^{m} p_{x_i,s_j}} \times 100\%$$

$$w_{y_i,s_j} = \frac{p_{y_i,s_j}}{\sum_{i=1}^{n} p_{y_i,s_j}} \times 100\%,$$

(4.1)

where w_{x_i,s_j} is the patent number weight for different technical purposes (x_i) in a different stage (s_j). p_{x_i,s_j} is the patent number for different technical purposes (x_i) in a different stage (s_j). w_{y_i,s_j} is the patent number weight for different technical applications (y_i) in a different stage (s_j). p_{y_i,s_j} is the patent number for different technical purposes (y_i) in a different stage (s_j).
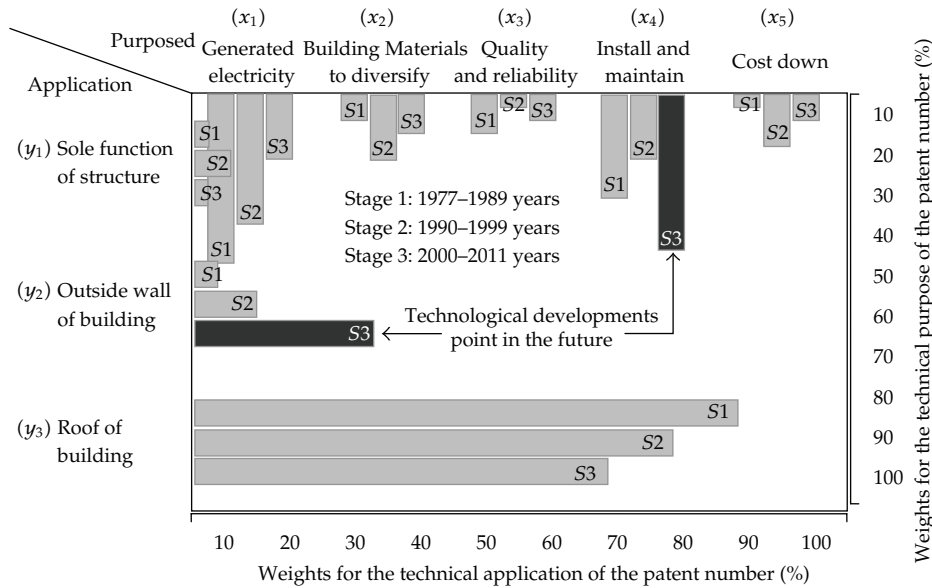
Figure 13: BIPV technology development trends.

The objective of installation and maintenance is to ensure that diverse building materials in the outside walls of high-rise buildings are of high quality and reliable. The technical purpose weights of the number of diverse building material patents are low (Figure 14). Other than R&D into photovoltaic panels, they emphasize future methods of engineering and installing photovoltaic panels on the outside walls of high-rise buildings. However, safety and durability must be considered when developing diverse building materials. Indoor comfort must be considered when installing and maintaining buildings because people are central to BIPV. Key BIPV R&D factors are insulation, daylight penetration, visual appeal, wind and rain proof, earthquake proof, fireproof, national technical building regulations, compliance with building rules, and compliance with construction material tests (Figure 15 and Table 4).

4.3. Technology Forecasting: Logistic Growth

This study uses Loglet Lab developed by Jason Yung, Perrin S. Meyer, and Jesse Ausubel as a tool to predict future development of BIPV technology trends. Technology start time, transition time, and saturation time are shown through the S-curve to depict the message (Figure 16). Up to October 31, 2011, a total of 263 pen announcement patents were approved by the USPTO patent database since July 26, 1977. The logistic growth curve diagram shows the technical saturation point for the 1881 patents. Defined according to the value of k [$k \times 10\%$, $k \times 90\%$], it corresponds to the growth point in time in February 2008. The turning point from growth to maturity is in January 2032. To close to 90% saturation point in time through the system to calculate the growth time of 49.4 years in June 2057, its BIPV technology patent saturation point is about 1881 cumulative patents. From the phenomenon of technology development at the application level, many patents focus on roof of building. However, the number of patents in the outside wall of building applications has grown well above the roof of building. This means that focus has moved to outside wall of building
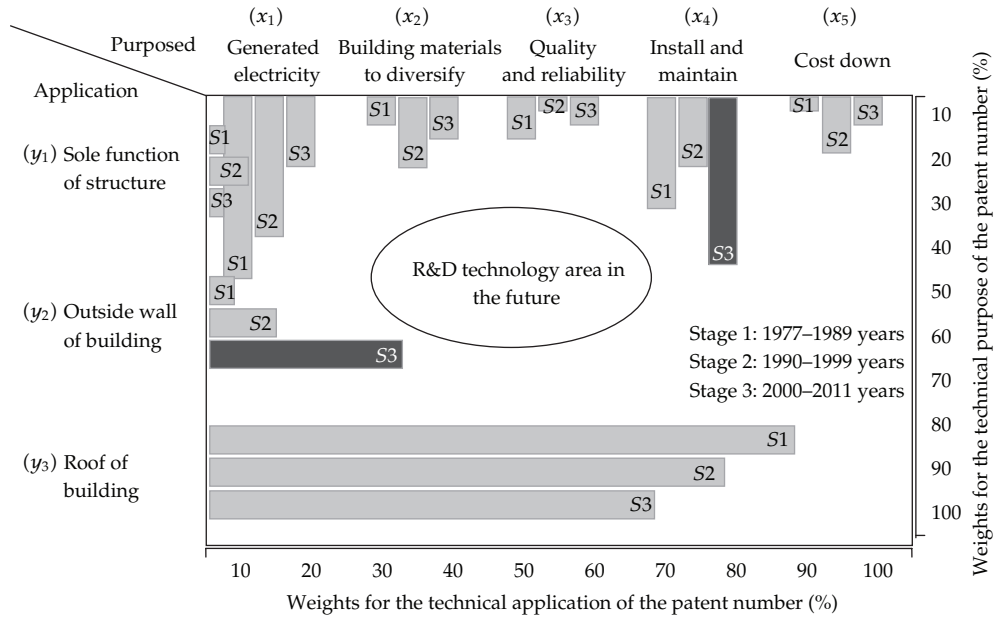
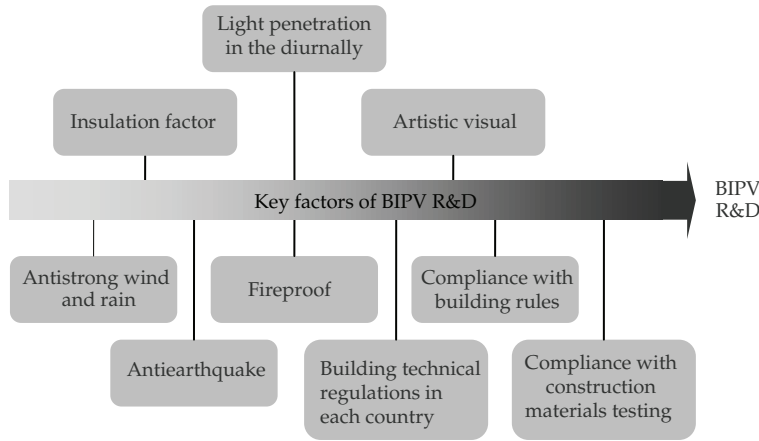**Figure 14:** BIPV technology R&D areas in the future.

Figure 15: Key factors of BIPV R&D.

technology development. Therefore, this field of research for BIPV technology is in line with the number of patents in the outside wall of building development trend forecast in this study (Figure 17). Through the logistic growth, the curve graph shows the technical saturation point for the 449 patents. Defined according to the value of k, $[k \times 10\%, k \times 90\%]$ corresponds to the growth point in time, in February 2010. The turning point from growth to maturity is in January 2022. To close to 90% saturation point in time through the system to calculate the growth time of 23.6 years in August 2033, its BIPV technology patent saturation point about cumulative to 449 patents.

Table 4: The definition of the key factors of BIPV development.

| Key factor	Definition
Insulation	Block thermal radiation heat from the sun and reduce indoor heat loads
Daylight penetration	Increase PV module light penetration and reduce interior lighting power demands
Artistic visual	PV fusion of the exterior of a building improves architectural aesthetics
Antistrong wind and rain	Resistant to strong wind and rain, thereby increasing building security
Antiearthquake	Resistant to earthquakes, thereby increasing building security
Fireproof	Resistant to fire, avoiding fire spreading from inside a building to adjacent buildings and avoiding external fires spreading inside
National technical building regulations	Must comply with national standards
Compliance with building rules	Must comply with construction technique rules
Compliance with construction material tests	Must comply with specifications for inspection and testing
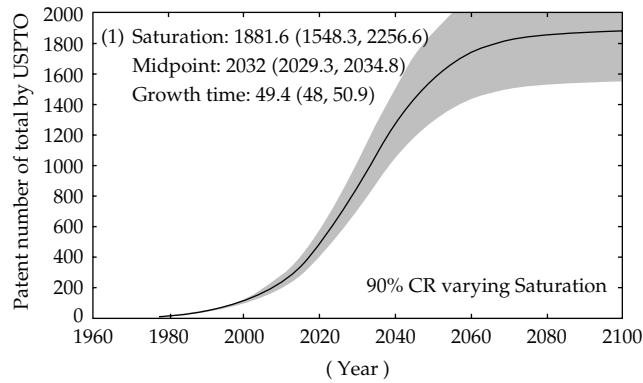
Figure 16: Technology growth curve of BIPV.
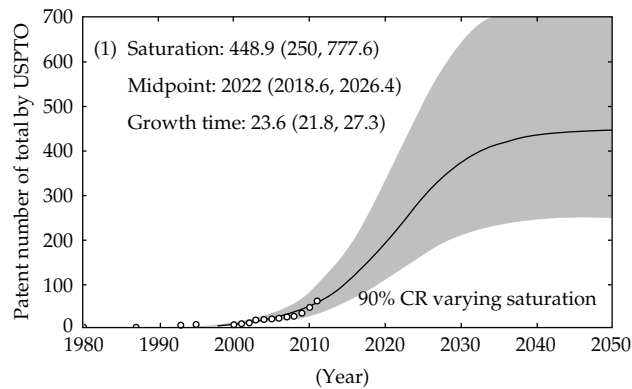
Figure 17: Technology growth curve of BIPV for outside wall of building.

Table 5: Life cycle phases of BIPV.

Life cycle	Introductory stage	Growth stage	Maturity stage	Saturation stage
Beginning time	1977.07	2008.02	2032.01	2057.06

Table 6: Life cycle phases of BIPV on outside wall of building.

Life cycle	Introductory stage	Growth stage	Maturity stage	Saturation stage
Beginning time	1987.05	2010.02	2022.01	2033.08
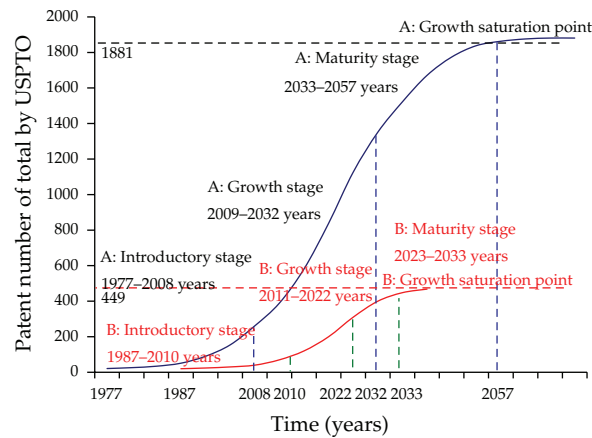
Figure 18: *S*-curve of BIPV. *S*-curve A: BIPV technology develop forecasting. *S*-curve B: BIPV on outside wall of building technology develop forecasting.

By Loglet Lab statistics describing logistic growth curve diagram out BIPV technology life cycle in Table 5 and BIPV technology application in the outside wall of building development of the technology life cycle in Table 6.

Figure 18 shows the BIPV technology *S*-curve. *S*-curve A refers to BIPV technology developing forecasting, and *S*-curve B refers to BIPV outside wall building technology developing forecasting. *S*-curve A shows that the introductory BIPV stage was from 1977 to 2008; the growth stage is from 2009 to 2032; the maturity stage is from 2033 to 2057; the growth saturation point is near 2057. *S*-curve B shows that the introductory stage of BIPV outside wall building technology was from 1987 to 2010; the growth stage is from 2011 to 2022; the maturity stage is from 2023 to 2033; the growth saturation point is near 2033.

5. R&D Strategy

BIPV technology functions through the research and technical application of matrix state space dimensions, combined with the logistic growth curve that takes on a timeline surface. It shows BIPV technology patents in the field focused on the building roof assembly and installation techniques and applications. In the vertical plane of buildings, the technology and application of patents clearly show the phenomenon of loose or blank. This one-block technology for three-dimensional space of the buildings shows the use of maximum power generation area in the world's major countries to actively develop the future generation of

Table 7: BIPV technology key point in the future.

Technology node	Description
Durability	When PV modules are used in construction, the difference between the PV module and the building lifespan must be considered. The life of an average building is more than several decades or even centuries, but the life of a PV module is only 10–20 years. Therefore, in addition to enhancing photoelectric conversion efficiency, PV module durability should be a major focus in the future
Ease of maintenance	When faced with replacing PV modules of BIPV modules in high-rise buildings, consider (1) speed and ease of replacing the PV module (2) when PV modules become more popular, original specification sizes may be discontinued and replacement components may be difficult to find. New specifications must be developed to be compatible with previous specifications. BIPV installation and maintenance will become more important in the future
Security	Global warming has recently caused intense thermal radiation from the sun and frequent earthquakes and hurricanes. Therefore, BIPV glass in high-rise buildings must be antiradiative and resistant to strong wind, earthquakes, and fire. Research should also focus on developing building materials with these qualities
Customization	PV modules must be able to meet a wide range of building installation requirements. R&D should focus on methods of changing the production process to produce novel PV modules with different architectural designs. This will allow for a new industry in the future. It will be able to generate a new industry, that is, in the future producing a PV module will require semifinished products. A PV template will be cut according to a building shape and returned to the plant for postproduction to manage different construction types. This is customized BIPV building material development technology. It will be a new industry in the future and a model accepted by the construction industry

Table 8: Matrix of R&D strategy.

Degree of protection	Patent R&D capability	Benefit creation	R&D strategy	Description
H	H	H	Leader	The patent with high-strength and high-product benefits usually adopt a cross-licensing model and other competitors to obtain the balance of terror
H	H	L	Attacker	Actively to the goal of Sheep to obtain royalty patent portfolio through intensive construction
H	L	H	Stalker	Through the acquisition of key patents, in addition to protection products and the other can sue the other party infringement strategy
H	L	L	Patent Troll	As a means through to obtain and hold patents and patent infringement litigation as a threat to force payment of royalties
L	H	H	The target	Revenue up to the scale of the degree will become the main subject matter of the patent litigation with the attacks to pay high royalties
L	H	L	Problem	Uncertainty region
L	L	H	Responder	Technologies and strategies for competitive advantage, and only passively follow the changes in the environment
L	L	L	Give up	

low-energy buildings. With technological development of a new generation of low-energy buildings, researchers also can evade patents in the patent radar district and also can compare the similarities and differences through analysis and interpretation of the patent information for reverse engineering in order to find a niche cut into the conducting dig technology policy. In addition, vertical walls of BIPV technology for space technology to divide policies are found in the lower reaches of this technology on the chain of a key, and that node is full of patent as long as the technology vendor in this field must go through this technology node (Table 7) and must pay patent royalties for different strategies.

Technology research and development policy is often associated with the market environment and technical ability having a close relationship. Technical developments, in particular in the early development of BIPV, through a technology growth curve that still has a long development time, and BIPV technology are the future of new generations of low buildings. Annual energy output of high technology and reduced costs to obtain construction and low construction investment for technology development and market factors continue. Therefore, enterprise technology products developed simultaneously must consider technology research and development capabilities, patent protection, and creating patent interest to locate the future development strategy of the three factors.

However, enterprises in competitive markets must improve manpower, time, and resources to maintain the technological lead. Technological backwardness of a company or country must be to narrow the distance with the technology leader in technology R&D and innovation. If companies want to enhance overall competitiveness, they must first assess their own abilities (including R&D personnel, capital, and the ability to create benefits and protect patents) and then, according to the size of the business and its abilities, select suitable R&D strategies. This study provides a three-dimensional matrix (Table 8) of degree of protection, R&D capability, and benefit creation to select R&D strategies. The first assessment indicator is the intensity of innovative R&D and the degree of patent protection. The second assessment indicator is the R&D capability of an enterprise with R&D manpower and resources. The third assessment indicator is the ability of an enterprise to create benefits using technology. This assessment method proposes eight strategies to assist an enterprise in locating their future R&D strategy when conducting BIPV technology R&D.

The results (Figures 13, 14, and 15) show that BIPV development moves gradually from roofs to outside walls or glass curtain walls. If companies want to produce a BIPV technology patent portfolio, they can use the three-dimensional matrix to assess and select a suitable R&D strategy according to individual enterprise circumstances. They can also use the patent map from this study to understand key high-intensity factor technologies for strategic actions to build important technology paths and patent intensity to increase profitability.

6. The Future Work of BIPV Industry

The results show that the BIPV industry is experiencing rapid growth and technology R&D. However, the BIPV manufacturing industry faces global competitive pressures, and the following characteristics can assist future development of the BIPV industry.

(1) Low installation costs: because of different factors such as global economic conditions, the built environment, and landscape, balancing the regional economic environment and technology is important for the BIPV industry;

(2) diversification of building materials: materials must be lightweight and fit building exteriors. PV modules must meet the requirements of different buildings, high

security and reliability, unique color, and pattern change while maintaining high photoelectric conversion efficiency. This enhances market appeal;

(3) amorphous silicon solar-cell efficiency: amorphous silicon thin-film solar-cell modules can be bent and absorb diffuse light to produce electrical energy characteristics. These advantages are not matched by silicon solar-cell modules. Amorphous silicon thin-film solar-cell module use in the BIPV industry is small. However, power generation efficiency of amorphous silicon thin-film solar-cell modules is less than that of silicon solar-cell modules. In the future solar-cell market, silicon solar-cell modules will remain the main market, but amorphous silicon thin-film solar-cell modules will continue to grow. Therefore, enhancing the photoelectric conversion efficiency of amorphous silicon thin-film solar-cell modules should be a BIPV industry priority;

(4) strategic integration of industry groups: to continually improve BIPV market attractiveness and reduce manufacturing costs, the BIPV industry must integrate the PV, construction, and electromechanical industries to form an industrial group. Active industrial and technical cooperation can promote and enhance the BIPV industry for future development;

(5) import green building materials: as government subsidy policies gradually decrease, subsidies will no longer affect BIPV market development. Future BIPV technology development must be combined with the concept of green buildings and comply with building material specifications. Making BIPV products a part of green building materials is necessary for the future.

7. Conclusions and Recommendations

Due to the issue of global warming, the renewable energy technologies become more essential nowadays. The solar energy technology is concerned in the worldwide. Therefore, the interdisciplinary integration is an important trend. The building-integrated photovoltaic (BIPV) is an emerging technology integrating the photovoltaic and building fields. We are interested in the BIPV's development and aim to explore its evolution. From the perspective of patent analysis, this study hopes to offer some useful recommendations for BIPV's technology development. To explore life cycle of BIPV technology, we use logistic model analyzing patent numbers from the database of United States Patent and Trademark Office (USPTO).

We propose a hybrid approach in exploring the life cycle of BIPV technology and develop the R&D strategies of related industry. The proposed approach comprises the following submodules. First, patent analysis is employed to transform patent documents into structured data. Second, the logistic growth model is used to explore the life cycle of BIPV technology. Third, patent matrix map analysis is used to develop the R&D strategies of BIPV industry. Through the analysis by logistic model, the BIPV technology is expected a long-term life cycle from the emerging stage to the growth stage. The logistic results show the development of BIPV technology is growing fast since 2000 and still have development potential up to 2057.

The other important result is discovered in the three-dimensional matrix for R&D strategies in this paper. The three dimensions are R&D capability, degree of protection, and benefit creation of patent. There are eight patent-portfolio strategies for BIPV industry. We

think that the proposed model is useful for forecasting the trend of technology, especially in the field of BIPV. In the future, we hope it will also be applied in other technologies and industries.

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