博　士　論　文

The advantages of systems integration as a technical and business strategy
- the case of the Photovoltaics industry-

（技術的経営戦略としてのシステムインテグレーションの有効性
－太陽光発電産業の事例－）

Masahiro Nomura

野　村　昌　弘

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Peer-reviewed Papers

1. Nomura, Masahiro (2014). The advantage of systems integration business strategy: A case study in the photovoltaic industry. Commercial Science Studies, 8(issue), 11-33. Japan Commercial Science Academy ISSN1880-5353

2. Nomura, Masahiro (2015). Characteristics of systems integration and its applicability: The case of the photovoltaics industry. Commercial Science Studies, 9(issue), 19-39. Japan Commercial Science Academy ISSN1880-5353

Conference Presentations

1. Nomura, Masahiro (2013, March 13). The importance and strategic advantages of global systems integrators in the photovoltaic industry. Presented at the 2013 Spring Convention of the Society of Project Management, Toyo University.

2. Nomura, Masahiro (2013, August 6). The supply chain and patterns of integration/specialization in the photovoltaic industry. Presented at the 22nd Academic Convention of the Japan Institute of Energy, Kougakuin University.

3. Nomura, Masahiro (2014, July 5). The advantage of systems integration business strategy: A case study of the photovoltaic industry. Presented at the 10th Annual Academic Convention of the Japan Commercial Science Academy, Reitaku University.

4. Nomura, Masahiro (2015, July 4). Characteristics of systems integration and its applicability: The case of the photovoltaics industry. Presented at the 11th Annual Academic Convention of the Japan Commercial Science Academy, Tamagawa University.

Abbreviation of key words/phrases

Figure 1 shows the abbreviations of key words and phrases used in this dissertation.

List of abbreviations/phrases

The following abbreviations of word and phrase are used in this dissertation.

・Photovoltaics	PV
・Systems integration	SI
・Systems integrator	SIer
・Systems integrator in PV industry	PVSIer
・PVSIer performing globally	GPVSIer
・PV panel	(PV)module
・Necessary components required in order to install PV system other than module (inverter, mounting system, cable etc.)	BOS (Balance of systems)
・Engineering, Procurement, Construction	EPC
・Complex Products and Systems	CoPS
・Large Technical Systems	LTS
・Kilowatt peak(size of PV installation)	kwp
・Operation & Maintenance	O&M

・To simplify, exchange rates used are : Euro 100 yen, USD 100 yen, Norway Krone 16 yen, Taiwan dollar 3 yen , RMB (Chinese currency) 16 yen.

Figure 1 Abbreviation of key words and phrases

1. Introduction

1.1 Background

In recent years, we have seen the business function called systems integration and the role of systems integrator firms playing important roles in industries that require complicated systems, such as the aerospace, defense, IT and communication network industries. For example, Ericsson and Cable & Wireless (C&W) in the telephone and telegraph industry are systems integrator firms that procure telecommunication components internally or externally and provide the entire system as a turnkey service provider, including operation and maintenance (O&M) services (Davies and Brandy, 2000).

In the past, systems integration operations have been conceptualized and analyzed as confined to a technical, operational task which is part of a wider area of systems engineering. (Hobday, Prencipe and Davies, 2011) Recently, however, systems integration has become regarded as a key factor in the operations, strategy, and competitive advantage of major corporations in a wide variety of sectors such as computing, telecommunication, military systems, and aerospace. Systems integration now goes beyond just the engineering level and has become a strategic task central to the business strategies and competitive advantages related to senior management decision-making of many of the world's leading corporations including General Electric, Dell, IBM, Siemens, Nokia, Rolls-Royce, and Boeing. However, academic research into the implications of systems integrations as a core industrial activity is still in an early stage (Hobday, Prencipe and Davies, 2011).

Within the IT industry, the business category known as "IT service" involves firms procuring components from hardware manufacturers and application software from software manufacturers to provide the best system for the customers. Such companies provide services as a package, including their customers' business analysis, system design, programming, system development, user education, system testing, system transfer and operation and maintenance, and are called systems integrator firms.

As will be described more fully in the next chapter, systems integration in general involves "building the best system for each customer by procuring various components and services and designing a substantial, customized system to integrate them." In previous literature, this systems integration business category is said to be needed in certain industries that involve large-scale, complicated capital goods, called "complex products and systems" (CoPS) (Hobday, Prencipe and Davies, 2011; Brusoni, Prencipe and Pavitt, 2001; Hobday, 1998).

The global photovoltaics (PV hereinafter) industry has developed markedly in the last few years. It created a job demand of 170,000 in the world in 2008, which is estimated to grow to 670,000 in 2025. The accumulated installation capacity was 40 GW in 2010 and grew to 102 GW by just 2012. It took 40 years to reach 40 GW, but after that, it took only two years to reach 100 GW. According to a projection by the EPIA (European Photovoltaics Industry Association), we will have a new installation demand of 30-50 GW every year in the coming several years, mainly in China, Japan and the USA, to arrive at 230 GW in high scenario in 2022 in total accumulated installed PV capacity (Figure 2: Global Market Outlook for Solar Power 2018-2022). In figure 2, the orange bar shows low scenario, the yellow bar shows high scenario and the line shows medium scenario.

As this dissertation will show, we can observe systems integration playing an important role in this fast-growing industry. Systems integration in PV industry means the activity of design, engineering, procurement of components and actual construction work to build PV power generation facilities.

Table 1 lists many of the firms in the PV industry that have entered the systems integration business.

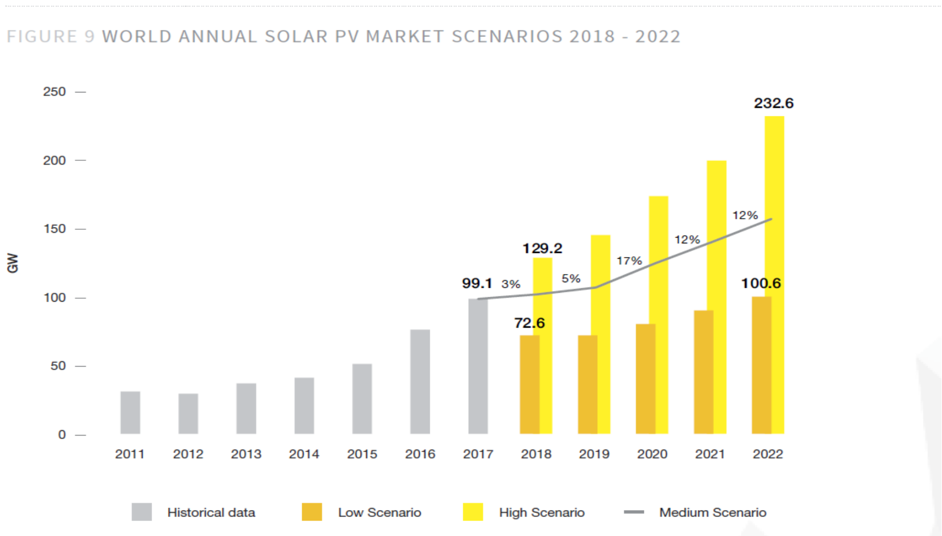


Figure 2 Global Market Outlook for Solar Power 2018-2022

Source: Solar Power Europe by the new EPIA

Company name	nationality	year	Business activity
Solar Frontier	Japan	2012	Expanded system integration business in Germany by establishing joint venture company with German PV systems integrator, Belectric.
REC	Norway	2008	Invested 20% (approximately 40 million USD) in American PV system integrator, Mainstream Energy.
Suntech	China	2008	Bought American PV systems integrator, EL Solutions, who focuses utility scale PV systems in the US.
Q-Cells	Germany	2010	Expanded systems integration business by establishing Q-Cells International after spinning off module production business.
MEMC	USA	2009	Used to be a crystalline material manufacturer, but entered down-stream business by merging American major PV systems integrator, Sun Edison. They skipped medium stream : cell, module production process business.
Chiyoda Kako	Japan	2014	Entered PV systems integration business dealing with only thin-film type modules.
AUO	Taiwan	2014	Currently active in systems integration business only in Taiwan, but planning to expand it up to 25% of total business worldwide.

Table 1 Examples of entrants into systems integration business in PV industry

Source: Field interview and firm records

A lot of PV module manufacturers often call themselves “total service providers” that can provide entire PV services to their clients, as opposed to simple module manufacturers, claiming that they can provide a package of integrated service that runs from procuring modules to final handover of an energy generating system, which they call “one-stop service.” For example, First Solar (USA) was originally a module manufacturer, but recently it considers itself “a vertically integrated utility-scale PV power solution provider.” This is a typical example that shows how some PV module manufacturers are entering the PV systems integration market. In fact, IMS Research of HIS (a USA research firm) ranked First Solar as one of the globally active dominant photovoltaics systems integrators (PV systems integrator firms) in 2012 and 2013 (IMS Research. Quarterly PV System Integrator Report 2011, 2012, 2013) .

This introduction summarizes themes that will be discussed in more detail in the remainder of this dissertation.

1.2 Literature review

1.2.1 Previous definitions of systems integration

Now let us look at how the term of systems integration has been used in various industries. In the information technology service industry in Japan, "The summary of registration rule of systems integration" was released in 2009 by the Ministry of Economics, Trade and Industry. This rule was to give end-users in Japan information about the firms that have sufficient technical capability and financial reliability to be registered as systems integrators, so end-users can invest aggressively and effectively in installing information technology systems. The systems integration service was defined as a service which handles basic design, programming, preparation of operational work, maintenance as a total solution by incorporating all the users' requirements in building a system, which is distinguished from separate service by independent system developers. According to these rules, IT systems integrators play a similar role to that played by general construction companies in the construction industry ("The summary of registration rule of systems integration," 2009, Ministry of Economy, Trade and Industry).

There are several studies concerning systems integration in IT industry in Japan. Ishikawa and Sekikawa analyzed the role of systems integration firms in the IT industry in Japan and defined the systems integration business as "combining information technology of both hardware and software in order to build a system that clients want to make" (Ishikawa and Sekikawa,2012). They say that there are various software/ hardware parts and components in the market which constitute information systems. It would be difficult for end-users who do not have experience or knowledge on how to evaluate, select and combine these products for their own systems. It also difficult to utilize the systems in order to achieve their corporate objects and solve the tasks they face by themselves. Here system integrators can play an important role.

The term systems integration has been used in many different ways in the past. According to Paoli (2011), systems integration is a meta-super-cognitive-negotiable-dynamic process among individuals distributed throughout the contexts of several firms made up of specific physical attributes, combined with the knowledge of the agents themselves, their linguistic myths, and cultures. He argues that using new concepts of personal and social knowledge, firms must retain and dominate in-house contexts of knowledge in order to control systems integration. Brusoni, Prencipe and Pavitt say that systems integration is the technological and organizational capabilities to integrate changes and improvements in internally and externally designed and produced inputs within an existing product architecture. By analyzing aircraft engine control systems, they show that multi-technology firms can coordinate loosely coupled networks of suppliers of components with a capability of systems integration to benefit from the advantages of both integration and specialization (Brusoni, Prencipe and Pavitt, 2001).

According to Hobday, Prencipe and Davies, systems integration has two facets. The first facet refers to the internal activities of firms as the firms integrate the inputs needed to produce new products. The second facet, which has assumed much greater importance in recent years, refers to the external activities of firms as the firms integrate components, skills, and knowledge from other firms—including suppliers, users, and partners—to deliver ever more complex products and systems, going beyond the engineering level. This second facet has become central to the business strategies and competitive advantages of many of the world's leading corporations including General Electric, Cable & Wireless, Siemens, Rolls-Royce and Boeing. The drivers of business of systems integration include the increasing complexity of product and systems, the rapid pace of technological change, and the increasing breadth of knowledge required to manufacture and deliver products. (Hobday, Prencipe and Davies 2011).

Systems integration has long been used in the aerospace and defense industries. One U.K. defense and aerospace panel defined systems integration as "The ability to understand and model the overall requirements for a major system and the interaction and performance of its many interrelated parts in an unambiguous way, accommodating the various subsystems technologies; then to design the complete systems together with its manufacturing processes and production facilities" (Prencipe, 2011). Prencipe, based on empirical evidence from a 4-year field study in the aircraft engine industry, identifies two analytical categories of systems integration, namely synchronic and diachronic. Synchronic systems integration refers to the capabilities required by firms to sustain competitive advantage in the short term. It refers to the capabilities to set the product design and coordinate the network of suppliers within a given architecture. This is based on static view. Diachronic systems integration refers to the capabilities that firms require to compete in the long term, enabling them to keep pace with technological developments, enhancing the firms' capabilities for innovation and flexibility, and knowledge creation. This is based on dynamic point view.

Johnson (2011) defines systems integration as separate from systems engineering to describe how it historically evolved. According to Johnson, systems integration is an element of systems engineering, which historically developed from the 1940s through the 1960s as a means to coordinate and control the development of complex aerospace and computing systems. When system engineers usually refer to systems integration, they typically refer only to component integration. However, from a managerial and strategic perspective, systems integration recently has been regarded as a much wider concept than systems engineering. Johnson further pointed out that most technical failures ultimately result from human error and miscommunication and solutions to these problems are social in nature. He says a critical element of systems integration is to uncover interactions among humans and technologies in the system.

1.2.2 Literature review of systems integration generally

Systems integration is related to various academic fields, such as theory of the firm, the history of technology, industrial organization, regional analysis, strategic management, and innovation studies (Hobday, Prencipe and Davies, 2011; Brusoni, Prencipe and Pavitt, 2001). Systems integrator firms need a variety of capabilities. Those technological capabilities have two measures: breadth and depth. Outsourcing without certain strategies as to which areas companies should source internally versus outsource externally to specialized suppliers could result in loss of future growth opportunities. Systems integrator firms should maintain a broad and deep range of capabilities in-house to retain the systems integration capabilities over time to manage unexpected technological innovation and uncertainty in the industry (Prencipe, 2000).

Nightingale (2000) analyzed the capability of systems integrators in a case study of the aero engine project and pointed out that linkage of knowledge, technology, and organization is important to handle design uncertainty and redesign feedback loops that affect the schedule, the cost, and the quality of the projects.

McKelvey (2011) analyzes the systems integration phenomenon in pharmaceutical and open software industries to argue that the boundaries of the system shift over time, as does the role of systems integrator firms. This means new firms may join and old firms may exit, or new types of firms may become important for the innovation processes. She describes the developments of Linux, which is an open-source software operating system where users, developers, and system integrators have fuzzy boundaries.

In the information age, products are less valuable than services (Moore, 2000). One of the unique characteristics of systems integrator firms is that they provide not only a system but various services that come with a system.

Gann and Salter mentioned services like planning, technical support, environmental analysis, design and engineering, systems integration consultancy, economic assessments, procurement advice, and legal services. The role of service is a "bundle" of both products (systems) and services and is an important factor that shows a competitive advantage. Gann and Salter examined a ventilation equipment company in a case study to show how the firm moved from manufacturing and manufacturing plus services to being project-based and a service-enhanced integrated systems solutions provider. This history is similar to that described in my case study in chapter 6 where I examined how First Solar transformed from a module manufacturer to a total solutions provider. Ericsson and Cable & Wireless provide clients who attempt to enter the telecommunications business with various services, such as financial assistance, technical support, and consulting services (Gann and Salter, 2000). As will be shown in subsequent chapters, in the PV industry, many PV systems integrator firms are competing to differentiate themselves from their competitors by providing various services, such as financial assistance, consulting, legal negotiation, customer support, and operational support.

Best says an example of systems integration as a principle of business and industrial organization is captured by the comparison of the minicomputer and personal computer (PC) industries. The minicomputer industry was dominated by vertically integrated firms while the PC industry has "open systems" by networked groups of firms, and firms focus on a core capability and network for complementary capabilities. Best describes how systems integration relates to the dynamic of regional clusters and regional innovation patterns by comparing the minicomputer industry—where vertically integrated business models are popular along Route 128 in Boston—and the PC industry—where decentralized, open-system production prevails in Silicon Valley.
His underlying concept in systems integration is mainly based on strategy, in other words, whether manufacturing products by vertical integration or by specialization in a regional network with the latter more typically embodying more systems integration (Best, 2011).

The role of systems integration is an important concept when we discuss innovation, because innovative products and processes in complex systems are recognized as an innovation for users only when the innovation is incorporated into a certain system and operated practically and effectively. Systems integration is an example of the "new combination", as Schumpeter refers to, of the process of manufacturing complex products and systems. Schumpeter (1934) suggests innovation occurs not only when new products are created, new manufacturing method is created and new market is developed, but also it occurs during "the new source/supply of materials" and "the carrying out of the new organization".

Utterback and Abernathy categorized the concept of innovation in two types: product innovation which creates new products by new technology and process innovation which enhance product innovation by improving various processes. They showed that product innovation has stages of performance-maximizing, sales maximizing and cost minimizing, while process innovation has stages of uncoordinated, segmental and systematic process. They insisted that process innovation follows after product innovation so that new products can have better price, better quality and are well distributed. Systems integration is an example of "process innovation," which brings better complex products to customers (Utterback and Abernathy, 1975).

Teece (1986) explained why innovating firms often fail to obtain economic returns from an innovation. He suggested that, from the perspective of the regimes of appropriability, when the innovation needs certain complementary asset the innovating firm is required to integrate other complementary assets to benefit from an innovation. This is an example of integration with other complementary assets to enhance appropriability.

Kash and Rycoft (2000) show that, in six case studies covering GE's jet engines, SONY's audio compact disc, floppy disc, and Intel's microprocessor of the evolution technology, the innovations in network and technology in complex technology systems can be analyzed. Kash and Rycroft present a framework that offers insight into three patterns of innovation. They call the predictable, incremental improvements by established trajectory as the normal pattern, the less predictable movement to a new trajectory as the transition pattern, and the highly uncertain launching of a new trajectory as the transformation pattern. Kash and Rycroft insist that systems integration capability is required in the transition pattern period where a new subsystem must be integrated into an existing technology by systems integration. One illustration is the transition from propeller to jet aircraft. Generally, this model of innovation is applicable mainly to manufacturing industry sectors, and accords with Schumpeter's analysis mentioned earlier. However, in the case of large scale, complex, and customized products and systems, architectural innovation that combines innovative products and related products and processes is needed, in addition to regular innovation, niche creation, and revolutionary innovation. Without it, specific products and systems that customers need cannot be provided (Henderson and Clark, 1990; Abernathy and Clark, 1985).

Henderson and Clark (1990) proposed the concept of product architecture. Henderson and Clark distinguished between products as whole (systems) and products by their parts (components) and pointed out we should look at innovation in product architecture (which they call architectural innovation) rather than innovation in each product that comprises a system. They examined such innovations closely and distinguished between the components of a product and the ways they are integrated into the system. Henderson and Clark examine cases where firms that manufactured the stepper machines used to make semiconductors (e.g., Kasper Instruments) were not aware of this type of innovation, which caused serious problems. In complex products and systems industry, systems integrator firms have to be aware of this type of innovation because how to integrate components is their key expertise and differentiation.

Ulrich (1995) analyzed the product architecture of a manufacturing firm in terms of product change, product variety, component standardization, product performance, and product development and management, and suggested four patterns of modularity architecture: slot, bus, sectional, and integral.

A good example of modularity is containerized sea transportation, which is the modularization of a transportation system. Inland transportation and sea transportation used to be different areas, and how to allocate and load cargoes transported inland into sea transportation system more effectively has been the know-how of transportation companies for a long time. Once the standardized size of "box" was fixed, items could be transported both inland and by sea, and since then, much of the accumulated know-how of transportation firms has become obsolete. Inland transportation and sea transportation are different areas, but the simple idea of standardizing boxes for cargo packages has changed the transportation industry drastically, and firms were able to integrate vertically (Takeichi and Takanashi, 2001). This is an example of process innovation in the entire complex transportation system in both inland and sea, which integrated existing different areas of systems. This is one example of innovations in how to integrate different systems into one single system.

By the 1980s, all components were interchangeable within and across firms in the bicycle drivetrain components industry, which is said to be similar to personal computer components. In the 1990s, however, the industry structure changed drastically. Some firms started offering integrated components sets rather than offering individual components. Shimano, one of the major components manufacturers, dominated the industry by offering unique and integrated sets of components to provide better bicycling experience (Fixson and Park, 2008). This is an example of new type of integration in components in a single product.

Chesbrough and Kusuonki (2001) examined the hard disc drive industry to show how a product's architecture dynamically shifts over time through technological innovation, going from an integral phase to a modular phase and from a modular phase back to an integral phase. Chesbrough and Kusuonki pointed out that firms that have organizations fitting with modular technology sometimes fail to handle the shift to an integral phase, because those industries are lacking in the experience and the knowledge required for technological interdependency; therefore, such industries cannot respond well to innovation. Chesbrough and Kusuonki called it the modularity trap. This phenomenon occurs in modular products, such as hard disc drives. Systems integration firms, in contrast to the manufacturers of each component, are required to be always aware of these technological changes and innovation, and adopt such changes to those industries' fields to offer the latest and best technology to their customers. In complex products and systems, the systems integrators' role is, on behalf of components manufacturers, not to make this trap occur in the entire system.

Only recently has systems integration been discussed in academic literature as a new model of industry organization (Hobday, Prencipe and Davies, 2011).

The concept of systems integration raises important issues with respect to the boundaries of firms and the operational structures of firms, because firms have final options to choose the organization (internal), the market (external), and the intermediate organization (a combination of the two) (Aoki and Itami, 1985).

Penrose (1995) pointed out that the boundaries of firms are becoming unclear and emphasized the importance of formal contracts and cooperation between firms.
The concept of "network" has been used widely, according to Penrose, and she mentioned that "network" or "business network" now technically refers to formal contractual arrangements or alliances among a limited number of firms bound together in an interrelated managerial framework and sometimes even referred to as "quasi firms" or "virtual corporations" as a different means of firms' growth from mergers and acquisitions.

Examples of intermediate organization types are Keiretsu (Imai, Itami, and Koike, 1982) and "hybrid organization" (Williamson, 1991). These organizations are characterized by a combination of integration and specialization. They often maintain the disadvantages and advantages of these types of industry organizations. For example, Keiretsu, a vertical intermediate organization, can maintain a stable cooperative relationship in product development and supply for a long period of time, but it keeps a competitive environment where suppliers compete with each other. A "long-term supply contract" ensures long-term transactions provide stable revenue for suppliers and stable procurement at a fixed price for buyers, thus being a benefit for both of them. Long-term supply contracts are frequently employed by intermediate organizations. Systems integrators firms sometimes also use long-term supply contracts to secure particular components or materials in order for them to get advantage in competitiveness in price over competitors.

Asanuma (1995) examined the Japanese automobile industry to point out how the main manufacturing firms do not cover all the manufacturing processes nor sell their products directly to the final users, but most products are produced and marketed by a network by multiple firms. Asanuma calls the firm that establishes the network a "core firm". Systems integrator firm also is a core firm in the systems integration process that establishes network to build a system and perform as a key firm.

Robertson and Langlois (1995) say that the government's role in industrial policy must be performed, assuming there are not only two types of organizational forms—large vertically integrated firms and the network of small specialized producers—but various network types. Robertson and Langlois use two dimensions along which to analyze organizational forms to classify six network types in terms of the degree of ownership, integration and the degree of coordination integration. These are, for example, holding company with high degree of ownership integration and no coordination integration mechanism, "Marshallian industrial district" with high degree of vertical and horizontal specialization (no ownership integration) and very heavy reliance on market mechanism (no coordination integration), "Japanese kaisha network" where degrees of ownership integration and coordination integration are loose, "Third Italian district" in his term, with higher degree of coordination and low degree of ownership integration, where firms are generally small and independent, with high degree of specialization.

Systems integration offers a similar type of coordination network that fits with Robertson and Langlois' category of core industry networks.

Lawrence and Lorsch (1967) studied the chemical processing industry and analyzed its six internal organizations and their subsystems—sales, applied research, fundamental research, and production—to show how the degree of differentiation and of integration affect the performance of the firms. Lawrence and Lorsch defined integration as a process of achieving effort unity among the various subsystems in the accomplishment of the organization's task. This is the approach of internal firms' organization theory based on the concept of subsystems, which constitute each firm. Systems integration, on the other hand, is the activity of combining products and services performed by independent firms.

Systems integration is a new role that differs from the intermediate organization or a firm's internal organization, but provides the benefits of integration to the customers while maintaining the independence of the various firms involved in the project. In other words, system integrator firms procure the components manufactured by horizontal specialization based on customers' specifications, combine them, and build the optimal systems (Aoki and Itami, 1985). It enables firms to benefit from the advantages of integration and specialization (Brusoni, Prencipe and Pavitt, 2001.)

Systems integration can relate to the area of integration and specialization of firm organization. According to Arrow (1974), active entities are individuals in traditional economic theory, but in the real economic system, the active entity is in fact an organization and a system. He also pointed out that no matter the kind of organization, it takes cost to get the information on quantity and price in the market (Arrow, 1974). It is necessary to know the information on price and so on when we have economic activities. Coase (2012) defined transaction cost as a cost of getting information in the market and defined a firm as an organization that can work for this purpose, because a firm can offset various market transactions with other firms' internal decision- making processes, thus reducing their transaction cost. Aaker (1986) proposed vertical integration as a strategy of a firm's growth and discussed its advantages and disadvantages. He also suggested vertical coordination between firms as an alternative to integration and as a strategy to be considered before commitments to integration are pursued. Furthermore, he describes long-term contracts, exclusive dealing agreements, strategic alliances, and technology licensing and franchising, illustrating the relationship between a winery and vineyards. Williamson (1975) argues, focusing on technological interdependency, that vertical integration economizes transactions by harmonizing interests and permitting a wider variety of sensitive incentive and control processes to be activated, thus minimizing transaction costs. He analyses organizations in firms and their relationships with markets, but did not go into inter-firm relationships, such as systems integration. Systems integration is a function where a firm can get integration benefits by remaining an independent firm.

Moore pointed out that in the age of the Internet, value is changing from assets to information and from products to services. He then suggested that we see the move from vertical integration to virtual integration and that basic principles would be to divide core tasks and context tasks; then, if outsourcing is possible, outsource the context, insource the core, and if not possible spin out the context, not the core (Moore, 2000).

Systems integration can be viewed as the other side of the outsourcing. The concept of systems integration from the perspective of vertical integration and horizontal specialization can be explained in Figure 3 below. As shown in the left figure, firms competing in the same market or firms that attempt to diversify to downstream or upstream can be vertically integrated to scale up the size of business. On the other hand, systems integrator firms provide a whole solution to users by procuring components from each independent manufacturer and constructing systems or goods.

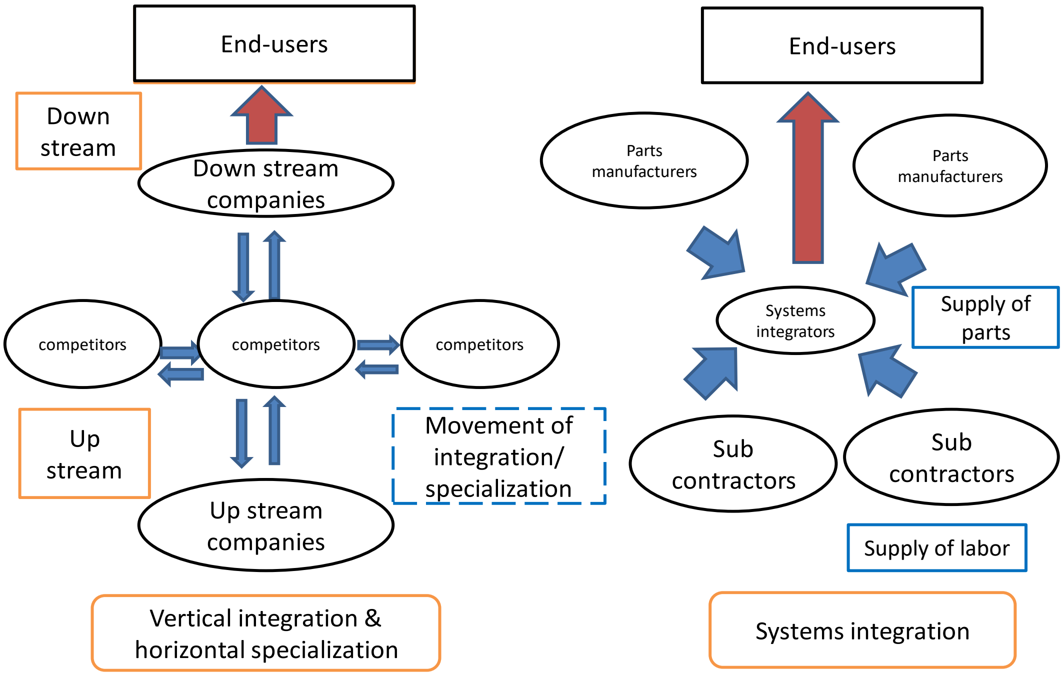


Figure 3 The difference between vertical integration/horizontal specialization and systems integration
Source: By author

1.3 CoPS and systems integration, including relevant literature

In the past decade or so, large-scale and complex capital goods have been studied.[1] This is called complex products and systems (CoPS). CoPS is defined as high cost goods made up of many interconnected, often customized parts, designed for specific customers and that requires a broad range of skills and techniques products, systems, networks, and constructs to complete (Hobday, 2000).[2] CoPS are normally produced by one-time project-based organizations through multiple firms. Preceding literatures show that systems integration and systems integrator firms are often seen in CoPS.

Systems integration is one of the business activities or business models that plays an important role in CoPS industries. Figure 4 shows the conceptual relationship between CoPS and systems integration. In industries characterized by mass production, such as home electronics, mass production capability could be a critical capability, just as systems integration capability is in CoPS industries. Geographical networks could be also an important competence in the retails sales industry such as discount stores.

Industry groups	**Industry examples**	**A critical capability in each industry**
CoPS	Railway network Plant construction	*Systems integration*
Consumer commodity goods	Apparel Home electronics	Mass production capability
Retail sales	Department stores Discount stores	Geographical network

Figure 4 CoPS and systems integration
Source: By author

The examples of CoPS include communication networks, high-speed train operation systems, intelligent buildings, and electricity control systems as shown in Table 2.

Aircraft carriers
Banking automation systems
Chemical plant
Electricity network control systems
High speed trains
Intelligent buildings
Mainframe computers
Nuclear power plant
Offshore oil production platforms
Oil refining equipment
Passenger aircraft
Space stations
Supercomputers
Telecommunication network management systems
Water supply systems

Table 2 Examples of CoPS industries
Source: Adopted from Hobday (1998)

In CoPS, mass production does not take place and suppliers' chief task is one of the project management, design, development and systems integration (Hobday, 1998). Many project-based firms engaged in large projects are positioning themselves to provide systems integration services, which they view as a key source of competitive advantage (Gann and Salter, 2000).

Davies and Brandy describes CoPS industry characteristics where strong capabilities in systems integration are required (Davies and Brandy, 2000). Prencipe shows that systems integration capabilities must be retained in-house in the CoPS firms to maintain breadth and depth of technological capabilities (Prencipe, 2000). Geyer and Davies suggest that in CoPS industry such as railway projects, dynamic systems integration is required (Geyer and Davies, 2000).

Orton and Weick (1990) discussed the concept of a "loosely coupled system", which is widely used in various industrial organization theories, by summarizing it from five perspectives: causation, typology, effects, compensations, and outcomes. They pointed out that, without either responsiveness or distinctiveness (he describes here distinctiveness as the degree of uniqueness, customization), a system is not truly a system, but it can be defined as a non-coupled system. If there is responsiveness without distinctiveness, the system is tightly coupled. If there is distinctiveness without responsiveness, the system is decoupled. If there is both distinctiveness and responsiveness, the system is loosely coupled. Brusoni, Prencipe and Pavitt further explained clearly when the system is tightly coupled, the system requires coordination via vertical integration; when the system is decoupled, the system requires coordination via market mechanisms, often the case with modular type products; when the system has both distinctiveness and responsiveness, the system is loosely coupled and requires coordination via systems integration (Brusoni, Prencipe and Pavitt, 2001).

Steinmueller identifies three fundamental aspects of systems integration in CoPS, namely coordination, negotiation, and memory. He particularly highlights that "technical compatibility standards" provide means for solving transaction issues between systems integrators and other external suppliers. Technical compatibility standards are useful in achieving inter-organizational coordination necessary for creating CoPS such as interface between components and subsystems. These standards also help both systems integrators and components suppliers to avoid unnecessary negotiations. He also describes how capabilities are constructed and retained over time by citing the issue of organizational memory with the examples of Intel and Microsoft (Steinmueller, 2011).

Hobday (2000) suggested when a large-scale project—such as CoPS—is performed in a firm, several organizational structures are available: he proposed five types:

1. a functional matrix organization where various functional departments of the organization (e.g., marketing, finance, human resources, engineering, R&D, and manufacturing) mainly perform their functions with weak project coordination,
2. balanced matrix organization,
3. project matrix organization,
4. project-led organizations
5. project-based organization.

Hobday proposed—through the study of the strengths and weaknesses of each organization—that a project-based organization is most suitable for large projects like CoPS.

Construction projects are often project-based, as they are mainly produced by temporary coalitions of firms using one-off or small-batch processes. The cooperating firms generally have different technical and organizational specializations, as well as varying knowledge and skill. However, as they are one-off processes and have little continuity, it would be difficult to maintain adequate inter-organizational co-operation.

Barlow (2000), through a case study of an offshore oilfield construction project, which is considered as a typical CoPS project by British Petroleum, explained that partnering is a useful tool for effective inter-firm alliances through enhancing inter-organizational collaboration. Offshore oil and gas projects are composed of highly technological, complicated systems and each oilfield has its own unique specifications, such as location and seafloor depth, and each project has to be highly customized. Also, for the expected project lifetime—normally 25 years—continuous innovation in technology and organization is required to be operated effectively (Bower and Young, 1995).

With this background, systems integrator firms appear. For example, in the electrical communication industry, the companies, Ericsson, Cable and Wireless (C&W), the U.K. international telecom operator, are systems integrators that procure various electrical components internally or externally and provide whole systems with operation and maintenance services as turnkey solution providers (Davies and Brandy, 2000). Davies and Brandy show two case studies of CoPS suppliers in telecommunications equipment and services that have moved from standard product lines to new types of products and services. According to Davies and Brandy, Ericsson, the Swedish telecommunications equipment company with strong capabilities in systems integration, has moved from a mobile communications manufacturer to a provider of turnkey solutions offering planning, construction, project management, technology upgrades, and after-sales support. Also, C&W is a systems integrator and service provider with the capability to integrate, manage, and operate networks using external sources for equipment supply. The case study is similar to the case study shown in chapter 6, where First Solar, one of the major PV-related firms, has moved from a module manufacturer to a total solution service provider.

Davis also shows five case studies to illustrate how some of the world's leading companies are changing the strategic focus to compete by selling whole solutions, rather than individual products or service lines. He describes this type of supplier firm as "the integrated solutions provider". He studied the cases of a railway signaling systems firm, mobile phone networks firms, a flight simulation firm, an infrastructure and built environment firm, and a corporate telecom network firm, and described how the firms were combining products and systems with services to specify, deliver, finance, maintain, support, and operate a system throughout its life cycle (Davis, 2011). Many PV-related firms illustrated in chapter 4 also call themselves "the integrated solutions provider" to differentiate themselves from competitors.

Systems integration is often seen in CoPS, but sometimes CoPS is one of the subsystems that consist of large technical systems (LTS). For example, railway projects are operated as a subsystem of a larger operational railway network. Therefore, systems integrator firms are expected to perform well to provide a system where more efficient operations can be performed. Systems integrator firms are also expected to provide continuous solutions contributing to the evolution of larger technical systems by way of coordination with LTS.

Geyer and Davies show case studies of large-scale railway projects in Germany and the U.K. of dynamic systems integration and effective coordination capabilities between CoPS and LTS. The systems integrator—or prime contractor—has to deal with a broad range of organizations, including components suppliers, manufacturers, financial institutions, government authorities, and diversified clients (Geyer and Davies, 2000).

Tell (2011) discusses the role of systems integration in LTS and electrical power systems as an example to show that capability needs differ depending on the life cycle of complex technology networks and LTS: the newly established electrical utilities perform systems integration on their own in the first epoch, perform "visible hand" in the second epoch, and are "loosely coupled" federations of businesses in the third epoch. LTS can be seen in the areas of public transportation, electric utilities, and national defense where government is involved and LTS cannot be developed unless social commitment—such as legal and political policies—allow it (Walker, 2000). Infrastructure services like road, transportation, and water supply are often performed as a public–private partnership (PPP), and sometimes the government outsources the construction and operation of the systems to private sectors, and the private sector parties transfer the ownership to government after a certain period of time. This is called build–operate–transfer (BOT). This is a CoPS project where multiple parties are involved over a long period of time, which is a part of LTS performed by systems integrator firms expected to coordinate all of the parties involved.

In the case of many public sector projects, the roles of systems integrator firms are even more important than in private sector CoPS projects (Motohashi, 2013). Particularly, in the area of infrastructure, government is a major regulator of complex systems and is sometimes the final customer for the CoPS. Due to the political and regulatory process, however, entrapment occurs, such as the delay regarding making decisions about new technology utilization, where systems integration firms can avoid these problems by coordinating systems, government agencies, and private supplier firms (Walker, 2000). Particularly, the PV industry needs government subsidies in most cases, due to the cost of power generation compared to fossil energy. As we see in these examples, systems integration is needed in the capital goods industries where large-scale, complex customized systems that consist of numerous technologies have operated for a long period of time with a rapid pace of technological change

1.4 Industry examples of systems integration, including Non-CoPS

Several other industries are examined in this chapter where systems integration is seen (except for the PV industry, which will be examined in a later chapter). The key factor is whether the term "systems integration" is currently used in each industry.

(Information technology (IT) service industry)

The IT service industry, which does not mean the entire IT industry or the personal computer industry, is similar to the PV systems integration industry. IT service firms procure optimal components from various parts manufacturers, propose the best solutions to clients based on client specifications, and undertake building a total system by using subcontractors (Figure 5).

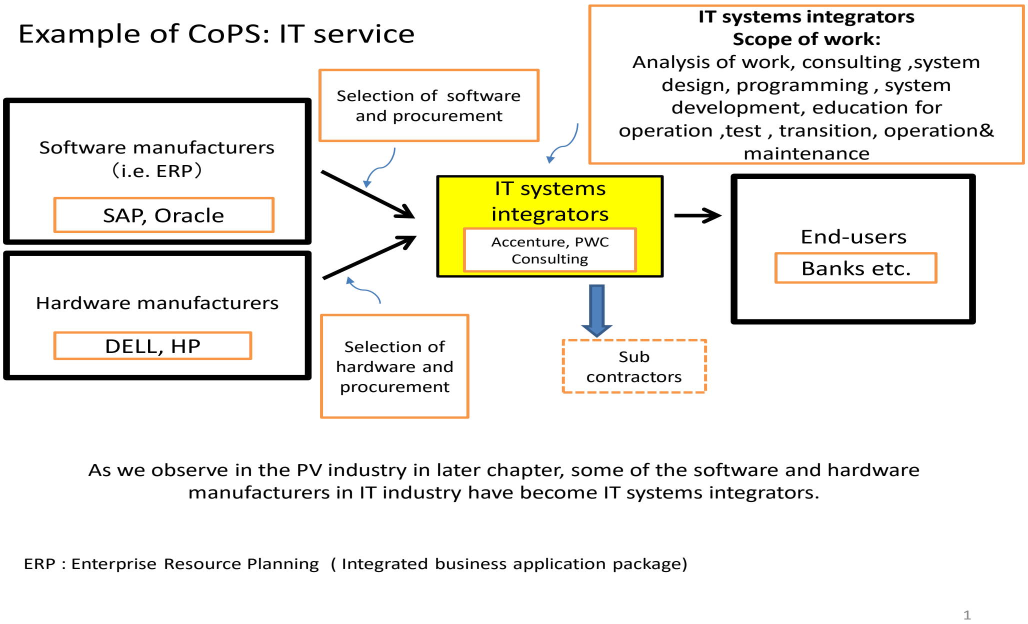


Figure 5 The roles of systems integrators in IT service industry
Source: By author

Through observing the Japanese IT industry, as figure 6 shows, various types of Japanese firms have been attempting to enter IT service industry such as consulting firms, hardware manufacturers, software manufacturers and even end-users. These firms are successful as systems integrators in Japan, but have not been active globally.

In the global IT service industry, IBM—which has already withdrawn from the personal computer manufacturing and focuses now on commercial and service segments—Accenture, and Computer Science Corp. (all of three are U.S. firms) are dominant globally. IBM is particularly dominant and provides commercial components to total services as a typical systems integrator that performs one-stop services.

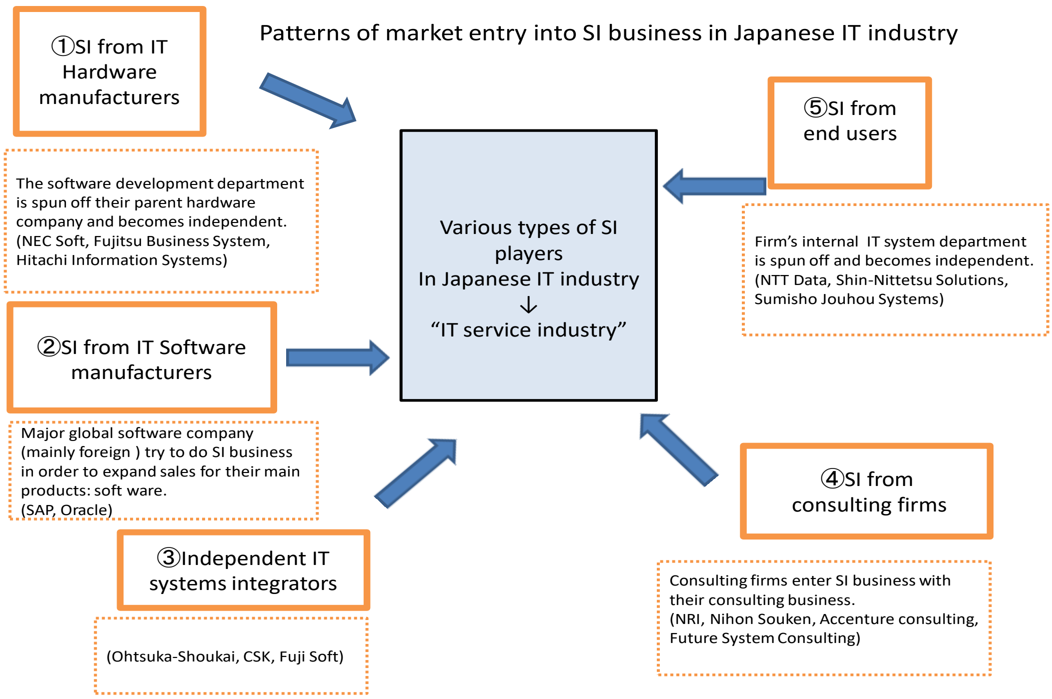


Figure 6 Market entries into IT service segment in IT industry in Japan
Source: Ishikawa and Sekikawa 2012 , and author's elaboration
on interview data and industry records

(Defense/Military industry)

In Western countries, R&D, production and systems operation in defense and military industries are largely classified, and several firms that are referred to as systems integrators are active. Examples include Lockheed Martin (U.S.), Boeing (U.S.), BAE Systems (U.K.), Northrop Grumman (U.S.), and Cassidian System (France), which is a division of EADS (Airbus group). Mitsubishi Heavy Industry Ltd., Mitsubishi Electric Corporation, and Kawasaki Heavy Industry Ltd. are components providers in the same segment, but they are just supplying components and not systems integrators, at least as far as their interactions with Western military systems integrators are concerned.

These systems integrator firms not only manufacture and provide mechanical components but establish networks that enable the whole defense and military system to be operated effectively. Employees of such companies consider the possibility of future expansion of the system, understand the nation's strategic long-term direction of defense, and design, select, procure, build and integrate optimal components. These companies often handle the cost and management of the systems and sometimes send company staff to clients for the operation of systems, except participation in combat. These companies' customers are usually government entities, and consequently, larger firms have industry advantages, and new industry entry is limited. Mergers and acquisitions have occurred in pursuit of the merit of scale; in 1994, Northrop bought Grumman, and in 1997, Boeing bought McDonnell Douglas.

Gholz analyzes the U.S. defense industry to show there are three levels of systems integration: component systems integration, platform systems integration, and architecture systems integration. According to Gholz, the lowest level of systems integration is to tie various components, often supplied by subcontractors, into a single product (e.g. a surface-to-air missile or a fire control radar). This is often done by subcontractors like Northrop Grumman. Second, platform integration combines various types of equipment (weapons, sensors, communications, etc.) into a mission capable form like a fighter aircraft. This task is done by usually prime contractors such as Lockheed Martin Aeronautics. The real emphasis in the level of systems integration in the industry is architecture systems integration. It connects different types platforms to facilitate cooperative military operations. This task has been accomplished by organizations within the military services (e.g. laboratories and research center such as the Naval Surface Warfare Center and other U.S. Government funded research and development centers.) A number of different kinds of organizations have specific skills and expertise: government, private non-profit organizations, and private for-profit organizations. Each organization is required to have various types of systems integration capabilities and techniques (Gholz, 2011).

(Plant engineering construction industry)

(This subsection is based on the interview with a Nikki executive.)

Plant engineering construction is considered as a typical CoPS where systems integration plays important roles. Let us look at Nikki (JGC Corporation) which is the largest Engineering construction firm in Japan. Nikki was established in 1928 as Nihon Kihatsuyu Co. Ltd. It has 7,500 employees (as of March 2016), a consolidated revenue of 8,800 million USD, and consolidated net profit of 430 million USD (as of March 2016). It started an oil refinery plant construction business in the 1950s and an overseas business in the 1960s. It even entered the areas where Japanese automobile firms or electronics firms had not yet entered. The company has performed more than 20,000 projects in 70 countries worldwide. Nikki call themselves "a group of borderless technical engineers". Their main business is EPC, engineering, procurement, and construction. Nikki is called one of the "Big Four" in LNG (Liquefied Natural Gas) world plant business along with KBR, Bechtel Corporation and Chiyoda Corporation. As for engineering construction in Japan, it is called one of the "Big Three" along with Chiyoda and Toyo Engineering Corporation. Nikki sent 100 Japanese employees (including 20 new college graduates) to British Petroleum's LNG project in Indonesia in 2009, which was a 3,000 million USD project over 5 years.

Based on an interview with a director of Nikki, the firm's systems integration capability is described as EPC mentioned above. The firm basically controls and manages engineering, design and procurement at the headquarters in Japan. Particularly, procurement is handled and controlled efficiently, and the company unifies all of the information worldwide to achieve effective procurement. At the same time, construction, which consists of 40% of total project cost, is the key factor for the project's success. Finding good local partner subcontractors is particularly vital. Currently, Nikki has a strategy of implementing its engineering and procurement tasks in the Philippines office as the company's Asian business headquarters (in view of the Asian business expansion) to achieve cost-effective performance with 1,000 local employees under the control of Japan Headquarters.

According to the Nikki respondent, the main difference between general construction and plant engineering construction is the degree of customization. In plant engineering construction, almost all designs—such as piping and the flow of materials—have to be customized, whereas in general construction, materials and designs are standardized. Consequently, these two segments do not compete directly with each other, but are active in their individual areas. In the case of large projects with many standardized constructions, engineering firms often subcontract their work to general construction firms with which they collaborate by performing only customized portions of projects.

1.5 Introducing an example of a non-CoPS industry where SI is important

There are several differences between plant engineering construction and photovoltaic (PV) systems integration (same concept as PV plant construction), which will be analyzed later as an example of non-CoPS systems integration. First, plant engineering construction is far larger in terms of project size than PV plant construction. PV projects are around 50 million USD even in a super, megawatt-scale project around 50 Mega Watt. But plant engineering construction is, in the case of the LNG plant, a 1,000-3,000 million USD project requiring 3–5 years of construction. Therefore, normally only large firms can undertake this type of engineering construction project. On the other hand, in PV plant construction, it is rather easy to enter this market, and the market is said to be fragmented (many medium–small firms are active). Second, plant engineering construction requires fully order-made specifications with each plant. In PV plant construction, companies build the best solutions with a variety of components, but each component is usually standardized. In plant engineering construction, companies generally build from scratch, but PV companies generally integrate standardized components. Third, in plant engineering construction, the relationship with the final user ends after the commission, and the company does not usually perform daily operations or maintenance after services, but, in contrast, these are the critical services provided by PV systems integrator firms.

1.6 Purposes and structure

1.6.1 Purposes

The purpose of this dissertation is to show the advantage of systems integration business and suggest how the same sort of systems integration capabilities and processes that are useful in CoPS (Complex products and systems) industries where the outputs are complex, high-cost capital goods products, are also seen in other industries.
Critical systems integration capabilities are also discussed and new aspect of capabilities are proposed. Systems integration has been regarded as a key factor for success and an essential capability in CoPS projects.

By examining systems integration roles and capabilities in the photovoltaic (PV) industry, it shows how systems integration is becoming an increasingly important capability in a modern, science-based, but, nevertheless, non-CoPS industry. The analysis suggests that systems integration is also important in other emerging non-CoPS industries. Implications for Japanese firms are also discussed.

The PV industry has diffused very rapidly all over the world, along with other renewable energy industries. Systems integrator firms play a significant role in this development. However, the PV industry is a relatively new industry and has been little studied academically. This dissertation has already shown how systems integration plays an important role in CoPS industries. In the following chapters, it shows how many of the same systems integration processes and capabilities in CoPS can be seen in the PV industry. In doing so it analyzes the differences in systems integration roles between CoPS and the PV industries. The implications for government policies, firms' strategies, industry organization as well as academic development will be discussed in the final chapters.

1.6. 2 Structure

Chapter 1 introduces the concept of systems integration and complex products and systems (CoPS). Industry examples of systems integration including non-CoPS industries are shown. This chapter also explores in greater depth the difference between systems integration in CoPS and the PV industry. Starting from Hobday's framework to differentiate industries in which systems integration is an important competence from industries in which it is not, it expands the range of such industries beyond CoPS industries. It does so on the basis of the dissertations prior analysis of the PV industry and also other emerging industries, such as smart city projects, where various complex technologies are needed. It shows that one feature of such non-CoPS complex technology industries where systems integration is a vital competence is that such industries do utilize mass-produced, platform-like components (for example, the PV modules, themselves) -- in contrast to a typical CoPS project in which nearly all key components are custom made. Thus, a new aspect and an expanded concept of systems integration is introduced. This has implications for the business strategies of Japanese companies engaged in such non-CoPS, complex-technology projects.

Chapter 2 summarizes in greater depth previous definitions of systems integration as well as how the concept of systems integration relates to other research areas. The methodology in this research is also shown.

In chapter 3 by contrasting PV plant construction with CoPS plant engineering construction, and general building/road construction, systems integration roles and capabilities are analyzed to show that these industries have the same characteristics in some aspects but difference in other aspects.

Chapter 4 focuses on the PV industry. Firstly, the unique characteristics of PV energy are discussed, and the value chain and entire market of the PV industry are described. Then, based on interviews with major global PV firms, the roles of PV systems integrator firms and their capabilities are discussed. Also, the chapter explores how major global

PV systems integrator firms were established and how their business strategies developed and highlights their actual strategies.

Chapter 5 focuses on Japanese PV firms in the context of the global competitive situation. The global PV systems integrator firms are mainly from Europe and the USA, and there are almost no Japanese firms, in contrast with the PV manufacturing sector in this industry, in which many Japanese firms were dominant until a few years ago. The implications of this phenomenon are discussed.

Chapter 6 explores in more depth evidence that systems integration can be a successful business survival strategy in the PV industry as well as practical challenges in implementing strategies where systems integration is a core component of PV operations. Data are presented on PV firms entering the systems integration market. A Spearman rank-order analysis of the PV firms for which financial information is available provides a rough suggestion that adopting systems integration as a core business strategy helps PV firms to realize a stable gross profit rate, an indicator of firms' added value. However, because the PV industry is still immature and therefore there are few firms for which financial information is available, a detailed case study of a German PV systems integrator and a US PV module manufacturer is presented to complement the Spearman analysis. This indicates these firms have been trying to increase their systems integration businesses and their repositioning in the market to stabilize performance.

Chapter 7 describes critical systems integration capabilities mainly in PV industry based on field interviews and other industries in preceding literatures. It attempts to suggest what specific capabilities are particularly important in order to differentiate from competitors and eventually be successful as systems integration firms in PV industry.

2. Definition of systems integration and methodology

2.1 Definition of systems integration in this dissertation

In this disseration, I define systems integration as "an activity or business model which develops systems, networks and constructs that can be found in large scale, high cost, complex, customized, small batch production, engineering–intensive industries" such as CoPS. Systems integration is a new type of industrial organization whereby firms/groups of firms join together different types of knowledge, skills, and activities, as well as hardware, software, and human resources to produce new products for the marketplace. The business of systems integration has both engineering design and organization/management aspects.

Some high cost, mature products such as roadworks and simple building construction are not considered to involve systems integration, as they involve a narrow range of knowledge and skills and utilize mostly standard components and materials. Consumer electronic products and passenger cars are made up of many complex parts and components, but these are highly standardized, enabling the final product to be mass-produced at low per-unit cost; therefore, this would not be considered as systems integration (Hobday, 1998). Banking information technology systems, for example, are considered systems integration. However, consulting businesses and Sogo Shosha (Japanese trading houses) do not require engineering expertise and therefore are generally not considered to involve systems integration. Also, personal computers, medicines, and steel are mass-produced complex goods and are not considered systems integration. On the other hand, many building projects—such as airport terminals—incorporate highly sophisticated IT systems and new materials where systems integration is required. Of course, the key attributes of a systems integrator all exist on a continuum, thus classifying individual companies according to whether they are systems integrators and entire industries as to whether they are often characterized by systems integration, inevitably involves judgements about where they fall along the multiple continua that constitute the key elements of systems integration (Hobday, 1998).

Let us look at international oil majors. The process of oil refining is a complex segment of the industry. The industry has discovery, extraction, refinement, storage, transport, wholesale, and retail processes. The barrier to entry is high and the market is an oligopoly. It seems similar to the plant engineering construction industry, but the oil industry's final product, namely oil, is a typical commodity with no product customization. Consequently, production and distribution of this industry's final product is not considered systems integration. Refined oil is generally not a highly differentiated product. Similarly, other petroleum products are traded in the business practice of a barter transaction, where oil products are often bartered between oil companies.

Such practices are not seen in customized product industries. Let us look at the apparel industry (Taniguchi, 2006). In this industry, there are many kinds of production roles and the distribution network is complicated. The products vary in terms of color, size, shape, and brand, and the products are substantially differentiated. A few decades ago, the supply chain in the apparel industry consisted of small, medium, and large companies that specialized in manufacture, wholesale, and retail. We recently observed firms controlling a total supply chain of products, which is called specialty store retailer of private label apparel (SPA). Examples are Gap (USA), Unique Clothing (Japan), Zara (Spain) and H&M (Sweden). These firms handle the overall supply chain network, including merchandising and developing the product, distributing the product, controlling stock, and managing sales in wholesale and retail. This type of operation is similar to systems integration, but differentiation comes from suppliers rather than customers, and the products are not high-cost, capital goods. Therefore, apparel goods and the manufacturing processes of such goods are also not considered to be systems integration industries – industries where systems integration, as defined above, is a core business competence. A similar stream of integration in the apparel industry can be seen in other industries where products are personal preference non-commodity goods, and the speed of trends change fast. We can observe the similar characteristics in shoes, eye glasses, and furniture.

2.2 Methodology

In order to proceed with this research, I interviewed about 40 people multiple times in the management levels of major global PV module manufacturers and PV systems integrator firms from 2010 until 2016. I attended Inter Solar, the world’s largest PV-related industry exhibition, held in Munich in June 2012; a PV exhibition held in Taipei in Oct. 2012; a PV exhibition held in Bangkok in Sept. 2012; a PV exhibition held in Manila in June 2011 and several PV exhibitions held in Tokyo over the past few years and collected much company specific information. Table 9 is the summary of the information and analysis of 29 firms. I visited the factories of AU Optronics Corp. (AUO) in Taiwan in Oct. 2012, Renewable Energy Corporation (REC) in Singapore in March 2011, First Philec Solar Corporation in Manila in June 2011, Conergy in Frankfurt in June 2012 and Solar Frontier in Miyazaki in Feb. 2009. In addition, I examined annual reports over the last 5 years of the 11 PV firms worldwide that issued public reports, case studies of failures and successes over several years of these firms gleaned from published reports and my own interviews, and statistics of the PV industry collected mainly from industry journal such as PV News, Solarbuzz, PV Eyes.

As a basic method of approach, I adopted a case study method, which normally is used for research studies based on qualitative information in social science (Denscombe, 2010). I selected two industries comparable to PV to include in a three-industry comparative analysis, because this method is more reliable than single case studies to assess similarities and differences between industries (Yin, 2009). As for the specific means, I adopted an interview method because it allows collection of more direct, specific and detailed information than methods such as observation or administration of questionnaires. Since this research required specific information about strategies, purposes and results of each firm, and I used open-ended, semi-structured and in-depth interview methods in one-on-one interviews (Denscombe, 2010; Yin, 2009).

As for the analytical perspective, I asked questions point by point based on predetermined issues related to each firm. I often used comparative analysis, which is considered to be effective for social science analysis (Corbin and Strauss, 2008). I adapted the constant comparison method based on predetermined items. The people interviewed were at management level—directors or those at the same level or above—because the target items for the interview were basically related to corporate strategies.

The firms that I interviewed and factories I visited are the following (individual interview schedules are included as an attachment to this dissertation). The reasons these firms were selected are described in section 3 in chapter 4.

<u>Fifteen PV companies interviewed</u>

- Sun Power (Philippines entity)
- Trina Solar (Japanese entity)
- JA Solar (Japanese representative)
- Solar World (JV with Shizen Dengen , a sole Japanese partner)
- Phoenix Solar (managing director , Asia head office)
- REC (Singapore office, Japanese entity)
- Q-Cells (office in Tokyo)
- Conergy (head office in Germany, Singapore office)
- Solar Frontier (head office, Miyazaki plant)
- Sharp (former managing director)
- Kyocera (former managing director)

- AUO (CEO, PV division global)
- Moser Baer (Japanese representative)
- Enfinity (President , Asia)
- EDF (Japan office)

Five PV module factories visited

- SunPower Philippines
- REC Singapore
- Conergy Frankfurt Oder, Germany
- Solar Frontier Miyazaki, Japan
- AUO Taiwan

The remainder of this dissertation clarifies the concept of systems integration, summarizes previous research in this area and explores in more depth the issues introduced above.

3. Systems integration roles and capabilities as seen in PV plant construction and plant engineering construction (a CoPS industry), contrasted with general construction

3.1 Background

As reviewed in chapter 1, systems integration business is observed in CoPS industries. I proposed the definition of systems integration in this dissertation in chapter 2. This chapter analyzes the characteristics of industries where SI is a core competency, taking plant engineering construction as an example of a CoPS industry and PV plant construction as an example of a non-CoPS industry. The characteristics of general construction (a non-CoPS industry) are analyzed for comparison.

3.2 Purposes

The purpose of this chapter is to compare the role of systems integration in the PV industry and non-PV industries, specifically in industries that can be classified as CoPS (or CoPS-similar) industries. For reasons described below, I selected plant engineering construction and general construction as the comparator industries.

3.3 Methodology

The reasons I selected plant engineering construction and general construction to compare with systems integration in the PV industry are as follows. Preceding literature on systems integration and CoPS list many industries as examples of CoPS industries (Hobday, 1998) including public utilities, water supply and electrical communication network industries, which are all strictly regulated by laws. The national defense industry handles classified and national confidential defense information and only a few large firms can enter the market. Also, the nuclear power industry requires firms in this market to be large enough to follow strict regulations in the industry set by the government, which affects the companies' strategies. Smart city industries are expected to grow in the future, but currently these industries have not matured sufficiently to have stable market structures. Narrowing down based on these considerations, I selected the plant engineering construction among CoPS industries, as it shares common characteristics with PV projects in the sense of "building relatively large facilities" that have few public characteristics and thus are not tightly regulated.

In the plant engineering industry, the firms are called “EPC companies” (engineering, procurement and construction) by tradition just as they are called in the PV industry. General construction is selected as the comparator industry since it is also similar to PV projects in the sense of building facilities, and, in reality, general construction and PV companies often collaborate with each other on actual projects. General construction is generally not classified as a CoPS (Hobday,1998).

Table 3 summarizes interviews conducted over the past three years comparing the roles of systems integration in these three industries. Some of the valuation factors in table 3 are based on Hobday(1998): degree of customization, source of competency, regulations, easiness of entry and others are added by author in order to highlight the difference among each industry: level of gross profit rate, existence of additional service, as well as the typical items that can be compared each other such as company size, scope of work. Figure 7 shows the relationship of the main business segments within each industry. Within each industry, some companies have systems integration roles while others do not. In PV plant construction, the former includes PV systems integration firms and the latter module manufacturers, power conditioner manufacturers, BOS manufacturers, and subcontractor construction companies. The latter companies provide components and labor work to PV systems integrator firms and PV systems integrator firms deliver the PV systems to the end users (normally power producers). The dotted line shows the systems integration role. General construction firms are not normally considered to be systems integrator firms as described in chapter 1.

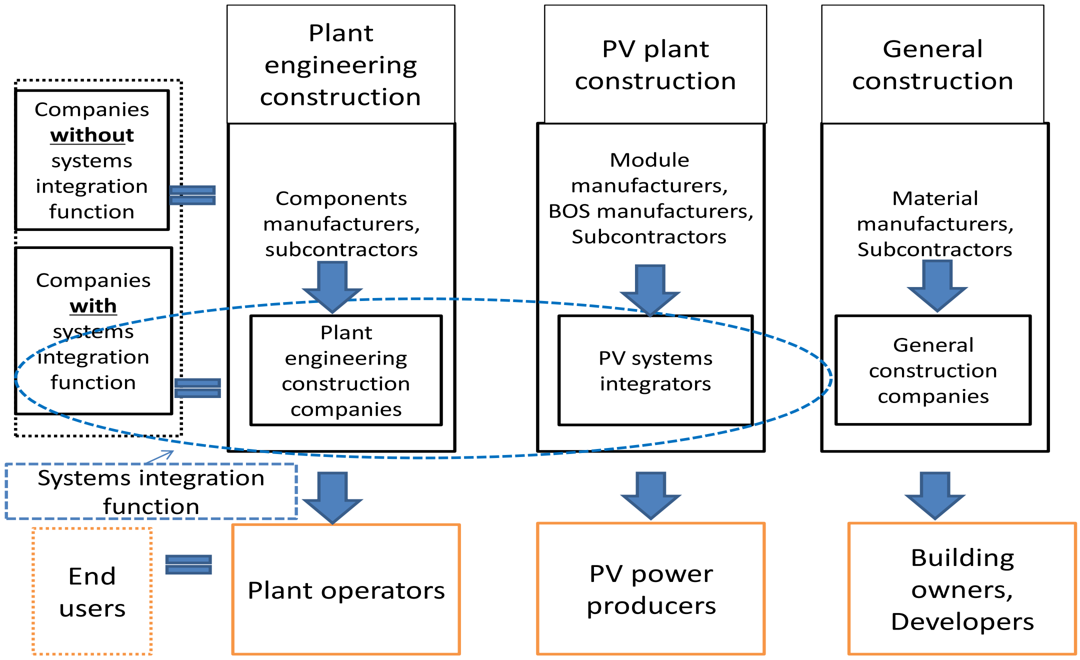


Figure 7 Similar roles of systems integration in three industries
Source: By author

3.4 Result

Table 3 summaries the interviews with representative companies in each of the three industries concerning systems integration roles (or roles considered to be similar to systems integration) in terms of scope of work, average size of project, size of firms in each industry, degree of competitiveness, ease of entry, degree of project customization, follow-up system after delivery, possibility of follow-on business, source of competitiveness, level of gross profit rate which shows the added value rate, whether firms are called systems integrators, and the existence of governmental rules and regulations.

Comparison in systems integration roles (and similar roles) among Plant engineering construction, PV systems integration, General construction

	Plant engineering construction	PV systems integration	General construction
Companies interviewed	**Nikki**	**Conergy**	**Taisei Construction**
Company overview	Largest Japanese plant engineering construction company. Started oil refinary plant construction in 1950's and expanded into overseas market in 1960's. Has business in 70 countries, more than 20,000 projects.	Established in 1998. One of the major German PVSIers. They had bought several other businesses than PV,but later they focused in PV. Expanded their module production capacity to 250 kwp in 2008, which lead to "PV system manufacturer". Restructured some of their production businesses (wafer, cell, mounting systems, inverters) in 2011 and changed themselves to "PV solution & service provider".	One of the 5 super general construction companies. They are good at civil work such as dam , high-rise building, bridge, tunnel, subway.
Basic scope of work	Design of plant, procurement of components, construction. Often called as EPC (Engineering, procurement and construction company).	Design of PV plant, procurement of components, construction. Often called EPC. Usually perform work with operation and maintenance.	Categorized as civil work (tunnel, bridge, dam,road etc.) and architectual work (construction of building). Major general construction companies have 30% civil work and 70% architectual work.
Size of project	Very large (oil refinery, LNG plant are 1billion USD – 5 billion USD)	Small (even very large PV plant such as 50MW, total investment is around 100 million USD)	Small – large (1 million USD – 5 billion USD).They have long-term customers and would accept any size of project.
Size of firm	Very large firm only. Nikke (English name of the company is Japan Gasolin Company:JGC): annual sales 6.9 billion USD. Net profit 470 million USD (March 2013), Number of employees: 6,700. *Japanese big three plant engieering companies are Nikki, Chiyoda Kakou Kensetsu,Toyo Engineering. *World big four : Nikki, Chiyoda Kakou, Bechtel (USA), KBR (USA)	Small – medium (even largest firm , its annual sales is around 1 billion USD).	Small – large. Local small constructor – super general construction. There are 5 super general construction companies in Japan. Medium-size general construction companies which belong to "Japan Federation of Construction Contractors" are around 140. Annual sales is , in case of big companies,1 billion USD to 10 billion USD. Taisei Kensetsu has consolidated annual sales is 15 billion USD, ordinary income is 567 million USD, Net profit is 320 million USD.(March 2013) Total employees : 13,500
number of firms in each industry	Few	Many	So many. 400,000 firms in the industry in Japan.
Easiness of new entry	Very difficult.	Comparatively easy.	Very easy. Having contractor license, anyone can start business today, even one employee.
Degree of customization	All work are customized from the beginning. All work processess such as material, pipe fitting are order-made. *According tothe interview, engineering construction and general construction do not compete each other because of the difference in customization. However, in the engineering construction projects where there are many standardized work, engineering companies sometimes perform as a sub-contractor under general constructor to handle customized works only.	Components used are standardized, but the specifications required are different depending on each project and must be selected carefully from the product lines in order to be fitted so that the selection would be best. Necessary to integrate standardized components into their best combination for each project by system integration.	Specifications for each project are different depending on its size, but they perform basically standardized work.

work of scope after handover	Usually service provider (engineering constructor) do not follow up after handover. Clients does follow-up work.	Normally they contract with customers for after-service work such as O&M (Operation and Maintenance).	Usually do not after-service work.
Additional service function other than construction	No	Usually additional work are performed such as application for regulation, financing arrangement , insurance, O&M, monitoring systems .	Sometimes contractors help some additional service such as financing, but rarely. Such kind of need from client side are few. Having these services in-house would not be effective for contractors.
Source of competency	①cost competitiveness ②shorten construction period③ management of environment(i.e. desert area). Basically Headquarter(HQ) in Japan handles E(engineering) & P(procurement). Especially they control in Japan all the information from worldwide concerning P and procure the best components from worldwide.	①cost competitiveness ②designing capability for generating maximum solar power production ③procurement capability for the best components fitted to each project	①cost competitiveness ②shorten construction period ③quality ④capability of proposal
Source of differenciation	Construction (40% of total work) is the most critical work among Engineering, procurement and construction. Success depends on whether the best local subcontractor can be found. Since Asian market is expanding rapidly, Nikki has control center for E and P in the Philippines where they have one thousand local staffs. By doing this Nikki achieves very competitive price in E & P rather than doing this in Japan. The common critical factor as well as PVSIer is to manage local workers.	They try to differenciate from competitors by combining long-term warranty in performance by components manufacturers, special insurance policy that covers unexpected troubles, monitoring service.	Contractors have their own special expertises. (i.e. building medicine plant needs special knowhow.) Hospitals, hotels, shopping centers require specialists in contractors and they try to accumulate these expertise internally. Also they differenciate by original proposal in technology of demolishing method, laminating method.
Level of gross profit rate which shows added-value	10-13%	12-15%. Sometimes 10% in the very competitive, large projects, but in the immatured market like Japan, it is around 20%.	Relatively low. 5-7%.
Are they called as "System integrator" in their industry?	They do not have be called as system integrators because there is small number of firms and relatively not so competitive. They do not have to be called as SIer in order to be distinguished from other companies in the industry.	They are called as system integrators.	No.
Existence of strict regulation in the industry	Usually there are certain regulations and safety standards by government and clients, but no administrative guidance.	Since PV installation is related with energy policies in each country, they have various strict rules and regulations. For large projects, license/approval with govenmental agencies are required. We have to confirm the capacity of electricity transmission which vary with utilities companies. The components must have local certification.	Usually there are regulations and certain safety standards by government and clients, but no administrative guidance.

Table 3 Comparison among plant engineering construction, PV plant construction and general construction

Source: Author's elaboration on interview data

3.5 Conclusion/discussion

When we compare these three companies, several differences in the specifications of systems integration roles become apparent. In the plant engineering construction industry, the size of each project is huge and therefore only big firms can perform them. Inevitably, the number of firms in the industry is few. In contrast, it would be relatively easy to enter the general construction market. As long as you can have a license to do this business, a company can be established with just a single person. The number of general construction companies in Japan is approximately around 400,000. Degree of customization of each project is one of the main factors distinguishing these two industries. In the general construction industry, work is basically standardized, although it depends on the location and scale of each project. But in plant engineering, many activities, such as single pipework and material flow, are entirely different in each project, and therefore work is generally unstandardized. In PV system integration, the components used are relatively standardized, but because the required specifications of the components differ depending on the scale, location, design policy, and environmental conditions, systems integration to select and configure the best system requested by each client is essential. Also, PV systems integrator firms normally provide various services, such as financial assistance, project development, and a unique insurance policy, in addition to the normal EPC works done by plant engineering construction companies. PV systems integrator firms also usually provide after-services, such as operation and maintenance, but general construction companies normally do not offer these kinds of after-services.

This analysis demonstrates that PV systems integration shares different characteristics with plant engineering construction and general construction. For example, jobs are customized in plant engineering, while they tend to be standardized in general (e.g, building) construction. In PV systems integration there are standardized components, but customization is necessary when considering which components should be used depending on the sunlight exposure, the shape of the property, and the project owner's specific needs.

Now let us look at how the firms in these three industries compare with each other. We know there is a difference in project size as shown in Table 3, where Nikki started entering into a particular PV systems integration market while adhering to its normal project size. The company has already performed the design, construction, and operation of one of the largest (30-40MW) PV power facilities in Japan, but they started a construction business overseas of super large PV facilities. They integrate all the works, such as planning, construction, and operation to achieve much lower costs. Thereby they aim for a 5-year investment payback period, which would normally be 8-10 years for mega-scale PV facilities. The locations will be in the Middle East, Asia and Africa where they have experience in their core business of plant engineering construction.

The company just announced that it was awarded the 50 MW (approximately 50 M USD in price) PV project in Vietnam in March 2018. This is the first overseas PV project for Nikki. The company also presented its plan to explore the same type of PV project in the Philippines, Malaysia and Indonesia to utilize its expertise in performing LNG engineering projects: engineering, procurement and construction. It started this strategy by making a new overseas infrastructure department in 2017 to aim at achieving the company not being influenced by resource prices such as oil and natural gas. (Nikkei News Paper, March 5 2018). This marketing strategy utilizes Nikki's existing expertise for its new PV business. At the same time, it shows the basic difference of typical project size between plant engineering construction and PV systems integration.

On the other hand, based on the interview with major Japanese general construction company, Taisei, the PV market is not considered to be an attraction for general construction companies because they see more risks in PV projects than general construction. The company is often requested to perform PV installation by their existing good customers, but PV projects are relatively smaller in size than general construction, and they have to offer a long-term warranty for normally 20-25 years for PV power generation performance. The customers of a PV business are often independent energy investment funds which often demand new credit evaluations by general construction companies. Sometimes the overseas PV modules manufacturers do not have sufficient financial creditability. These risks are beyond the normal scope and expertise of general construction companies.

Figure 8 shows the significant characteristics, degree and difference of scale of company, size of project, and degree of customization in these three industries.

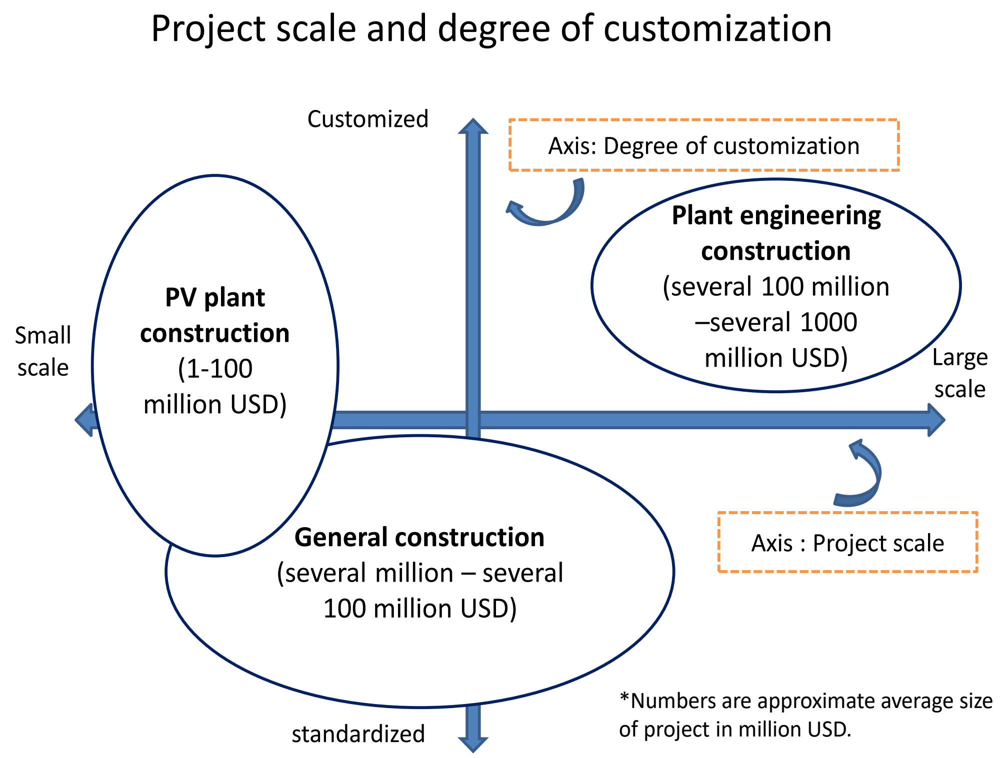


Figure 8 Characteristics of three illustrative industries according to the degree of customization and project scale
Source: By author

This comparison among these three industries raises the issue of skills versus incentives. As described in following chapters, systems integrator firms must have certain capabilities. As described later, some of the major PV module manufacturing companies have attempted to enter PV systems integration because of their falling profit margins in module manufacturing business, but they have not been so successful due to lack of systems integration skills. On the other hand, plant engineering companies such as Nikki have skills of systems integration, but they are adept in entering PV systems integration except for very large projects because they only know how to exercise their capabilities in the setting of much larger projects overseas.

4. PV and PV systems integration

4.1 Background

4.1.1 Characteristics of PV energy and energy source attributes

In this section, I review the recent renewable energy policies in Japan and examine the energy source attributes proposed by the preceding literature, and attempt to propose new perspectives.

The Japanese government has been trying to expand renewable energy with various incentive policies. Since 1997 it has implemented a subsidy scheme and introduced:

--RPS (Renewable Portfolio Standard: a regulation that requires electricity supply companies to produce a specified fraction of their electricity from renewable energy sources),

--Net Metering scheme (a billing mechanism that credits renewable energy system owners for the electricity they add to the grid) (2009)

-- Feed In Tariff (FIT) scheme (2012) to provide a base price for all renewable energy suppliers.

The current share of renewable energy in total energy produced in Japan is 12% (but only 3% if large hydropower generation is excluded) which the Japanese government targets to reach at 22-24% in 2030. The purposes of this policy are (1) increasing energy self-sufficiency rate (the rate was 58% in 1960, but only 6% in 2013) (2) achieve a low carbon society (3) creating new related industries. (Shinji Watanabe, head of renewable energy department of the Ministry of Economy, Trade and Industry, at PV Expo, March 4 2016).

The energy pictures vary in each country, but the trend for renewable energy is expected to be growing globally in view of global warming perspective, and PV industry is considered to be a growth industry up to around 2050. PV industry, different from typical high-tech or complex products, is closely related to national energy policies and at the same time its cost of installation is still relatively high in many areas, and depends on the national subsidy policies. It also has environmental implications. The diffusion of PV power generation therefore depends on not only technical innovation but also local conditions, societal perceptions and culture (Rogers, 2010).

PV energy has several unique characteristics compared with other conventional energies and renewable energies. In addition, it is a new energy and has only 50 years of history, but has rapidly developed in last 15 years. Thus, several technical issues are still unresolved. Among these are: How long commercial PV panels produce energy (a typical manufacturers' warranty for production is 25 years)? What is the expected deterioration in terms of energy production efficiency for the period of use?

Peter Tertzakian classifies various energy sources according to nine attributes (Tertzakian, 2009).

(Versatility)

Tertzakian emphasizes the advantage of oil which is currently popular for a wide range of uses. He also suggests that PV and wind power could have potential wide versatility if they can be plugged into energy from other sources. However, this would require improvements in batteries and other means of energy storage.

(Scalability)

He points out that the biggest challenge of renewable energy is scalability and it is difficult to scale up many types of renewable energy facilities compared with oil, coal and natural gas. But in the case of PV, we already have 100-megawatt-size PV installations and the size of installations is increasing rapidly. Also, PV installations are fairly flexible in terms of size if we consider "scale down" rather than "scale up". Most fossil fuel plants require a substantial size for efficiency and pollution control, but we can decide freely the size of PV installations. PV energy sources range from those on portable calculators, to light in the streets, roof top installation, and megawatt size power plants (Kuwano, 2011). When we discuss scalability, usually it would mean only expandability, but we have to also consider the aspect of "flexibility of scale".

(Storability and Transportability)

Tertzakian also points out the advantage of oil as PV can only be transferred by grid and cannot be stored without batteries. On the other hand, unlike fossil fuels which are found in only certain geographic regions and usually need to be transported to refineries and power plants, PV can generate power anywhere the sun shines. It can even generate power in space. PV energy does face a delivery challenge, but "local production and consumption" is often possible.

(Continuity of supply)

PV can generate power only daytime and therefore, without batteries or some other energy storage mechanism, PV energy is disadvantaged compared with other energies.

(Energy Density)

Tertzakian indicates that oil is quite advantageous in term of unit energy produced.

(Power Density)

Tertzakian correctly notes that PV needs much wider space compared with other energies in order to produce the same amount of energy and therefore it's power density per unit space is low.

(Constancy)

PV output is also affected more by weather conditions compared with fossil fuel energy.

(Environmental Sensitivity)

PV generates zero carbon emission, also no waste, vibration, sound, heat.

(Energy security)

Tertzakian claims that this is the most important among the aforementioned eight attributes from a geopolitical perspective. As mentioned above, PV can generate power almost anywhere in the world as long as there is irradiation of the sun. Also, the lifetime of the sun is said to be around ten billion years, compared with 50 years of oil supplies, 60 years of natural gas, 100 years of uranium and 120 years of coal. Silicon, which is the main raw material of PV module, is inexhaustible on earth. We must recognize as one of the important attributes "inexhaustibility of raw materials". Tertzakian adds, as a tenth attribute, sustainability when we think the best and healthiest energy mix. This attribute indicates the best combination for the use of available sources of energy without destroying the environment. Therefore it integrates the above nine attributes.

However, Tertzakian does not consider the cost of power generation (the cost of generating power per kwh). PV do not need much cost for operation and maintenance. It needs no human power or daily operation. It rarely has mechanical problems during operation compared with fossil power generation. Thus, we should add "manageability of daily operation" as a new attribute. PV industry is still a new industry, but PV modules have already become commodities. The current specifications of PV modules in the industry are more or less the same in terms of technology and performance, and they cannot be differentiated sufficiently and therefore are likely to face price competition. But many firms are going to enter this market looking at the future demand growth for PV power in the world. The majority of firms adopt the silicon-based technology for module manufacturing, which is already a "dominant product design" (Utterback,1996;

David,1985).

Normally the first-mover has the advantage in the market with the newly introduced products or processes, but sometimes the follower firm may have advantages. (Lieberman and Montgomery, 1988). The first mover or innovator could take a lead in technology, resources, market share, but on the other hand the followers have advantages in learning from the experiences of the pioneer, employing the latest technology at cheaper price, having more market certainty, and being able to use the most appropriate business structure to respond to new market dynamics. Major global PV module manufacturers were established around the late 1990's to 2000's, but we can observe many large companies trying to enter the PV market even in the 2010's. This is because, anticipating even more growth in the industry, they can utilize the antecessors' technologies, with less uncertainty, and can start this business easily with the ideal organization structure from the beginning.

4.1.2 Value chain and market segmentation of PV industry

Figure 9 describes market segments in terms of size of systems, how to be sold/consumed and types of grid connection. PV markets are normally categorized into 3 types of market in terms of size of systems: residentials (up to 10 kwp), commercials (10 kwp to 1 MW) and utility scale (more than 1 MW). Almost all utility scale projects are based on Feed-In- Tariff (FIT) scheme to be connected to existing grid connection. Commercials usually depend on private power purchase agreement (PPA) between power generation company and commercial users such as factories, warehouses and office buildings. However other commercial customers consume PV electricity for self-consumption instead of selling it to the grid at FIT rate. Residential house owners often sell electricity based on FIT rate, which is a different rate from utility scale or commercials, but also consume for self-consumption. In remote areas or islands where there is no grid connection and therefore diesel generators are used, residentials or small-scale power systems use PV power as off grid systems, i.e. independently, without any connection with the grid.

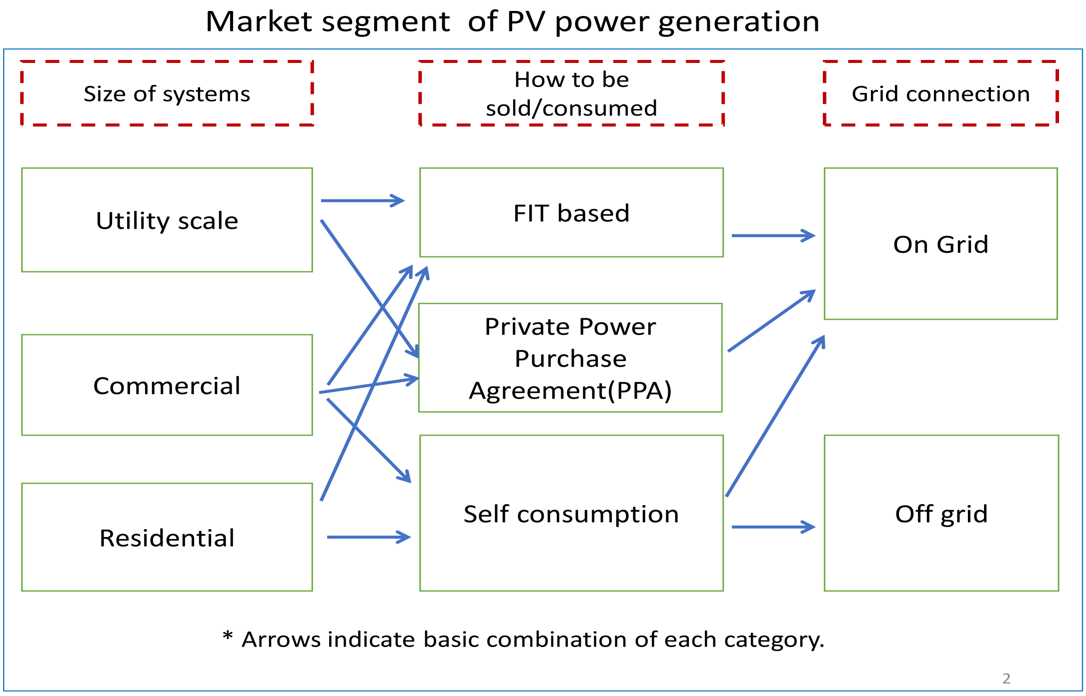


Figure 9 Market segmentation in PV power generation
Source: Elaborated by author

Figure 10 shows the value chain of PV power generation. The upstream value chain consists of manufacturing of components of modules, power conditioners, mounting systems and balance of systems. Middle stream consists of systems integration where systems integrators perform significant roles such as planning, engineering, procurement of components, construction of systems and additional services. Systems integrators sell systems to power generation companies which sell electricity to their customers. If power generation companies consume PV electricity by themselves, it is as commercial type customers who own PV systems to consume PV energy for themselves. The main focus of this paper is the core of PV value chain, systems integration.

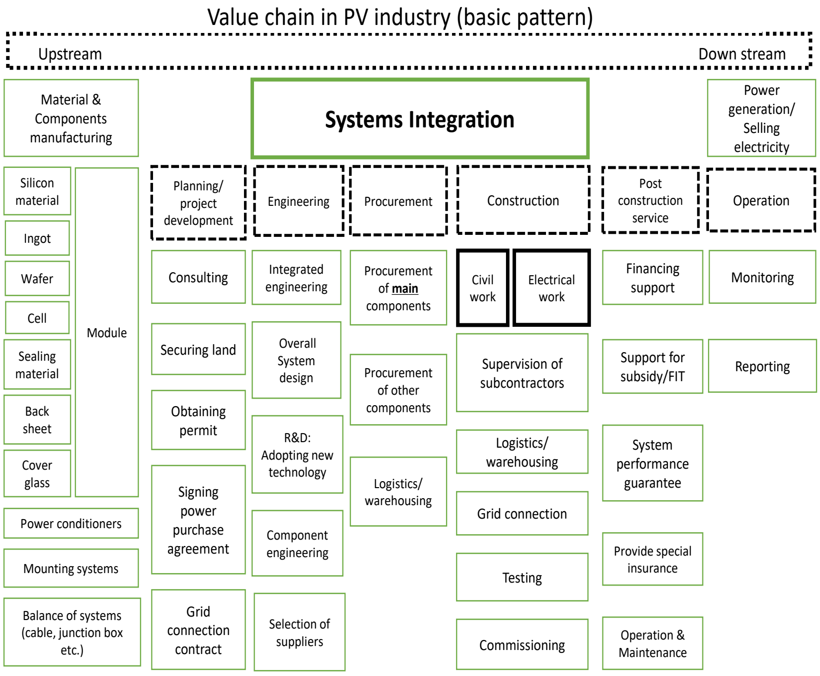


Figure 10 Value chain of PV industry
Source: By author

4.1.3 Definition of PV systems integration

In chapter 2, the general concept of systems integration was discussed. In this chapter, systems integration in the PV industry is discussed. As an example of the definition of PV systems integration, I introduce the definition by Phoenix Solar AG, one of the major German PV systems integrator firms. According to Christopher Inglin, managing director of Phoenix Solar AG Asia, a functional definition of PV systems integration is as follows:

The efficiency of a photovoltaic system depends to a great extent on the ideal interaction of all the individual components. The more technologies and products offered for selection in the market, the greater the optimization potential through consistent systems integration. The tasks of systems integration include the selection and checking *of the individual components, as well as the reconciliation of all the details in the system, taking account of local conditions on the respective sites.*

In Japan, PV systems integration has not yet been defined in a way that represents a consensus within the industry, probably because there are few independent specialized PV systems integrator firms - even firms whose main revenue is not from PV systems integration but that nevertheless perform many PV systems integration functions. The Solar System Industry Strategy Committee, organized in 2008 by the Ministry of Economy, Trade and Industry and Agency for Natural Resources and Energy in Japan, issued an annual report in March 2009, where the current analysis of the PV industry in Japan, forecast, and industry strategy were reported. This report notes:

> Industry participants should not propose PV system only to consumers, but they should examine what solution is sought for an effective PV system and propose to provide the entire system that could be the best solution for the consumers. In order to achieve this, systems integration, which can handle design, engineering, construction and operation/maintenance of the system, is required (The report on strategies of Solar System Industry; The Solar System industry research committee, The ministry of Economics and Trade in Japan, The Agency for Natural Resource and Energy. March 2009).

Toshiba, one of the major PV module manufacturers, considers construction of a complete facility (system), that takes into account local climate conditions and the interests of investors, to be systems integration, using the term *PV systems integration*. The company says it is developing a basic foundation of systems integration to achieve an efficient PV systems integration framework in PV engineering. It proposes a method to systemize the workflow of PV systems integration activities. This is the proposal for system technology ("Systems integration framework for Global MW-class Photovoltaic Power Generation Solution" Takeshi Ishi, Mikito Iwamasa, Yoshiro Hasegawa, Toshiba Review, Vol. 67, No. 1, 2012).

Next, I examine the specific functions of PV systems integration.

4.1.4 Functions of PV systems integration

(Relationship chart in PV systems integration)

Figure 11 illustrates the range of PV systems integration roles. PV systems integrator firms, based on the requests of the project owners, design systems (engineering), select and procure suitable components, such as modules, balance of systems (BOS), and mounting systems (procurement), and construct the facility by supervising subcontractors, such as civil work companies and electrical work companies (construction). We often call these firms EPC companies.

In the design process, they must carefully select the best components to fit for the local specific conditions (sun exposure, inclination of land, orientation of the roof, average temperature, quantity of rainfall, wind speed, distance from the ocean, distance from the nearest grid connection point, access from the major road, etc.). [3]

The main components are PV modules, power conditioners (PC) and mounting systems. For example, if the location is a high-temperature area, PV systems integrator firms select the specific modules that do not lose their performance/efficiency capability even in high-temperature areas. If their locations are close to the ocean, they would select the modules that can withstand salt corrosion, while if their locations are areas where wind speed is strong or areas that have many typhoons, they would change the method of the installation of mounting systems.

In the process of procurement, based on their own designs, they can procure the most appropriate parts and components in terms of price and functionality after they examine and compare the products among suppliers worldwide. In parallel, they seek to find the best local partners, particularly reliable and reasonably priced civil and electrical construction firms. PV systems integrator firms often help project owners to finance the projects by introducing banks. This is useful, because banks that finance the projects sometimes judge the validity for financing by reviewing the components used (normally the main component, PV module, which accounts for 30% of the total investment). We often call modules "bankable components" as financing arrangement decisions depend on the reliability of the modules, their performance warranties, and the financial corporate credibility of module manufacturers.

If the project owners are the investors who sell PV power based on FIT scheme, PV systems integrator firms often apply for the approval of FIT or subsidies on behalf of project owners. In addition, PV systems integrator firms that have contracted to provide entire systems normally perform operation and maintenance (O&M) after commissioning according to service contracts, because they know their systems well.

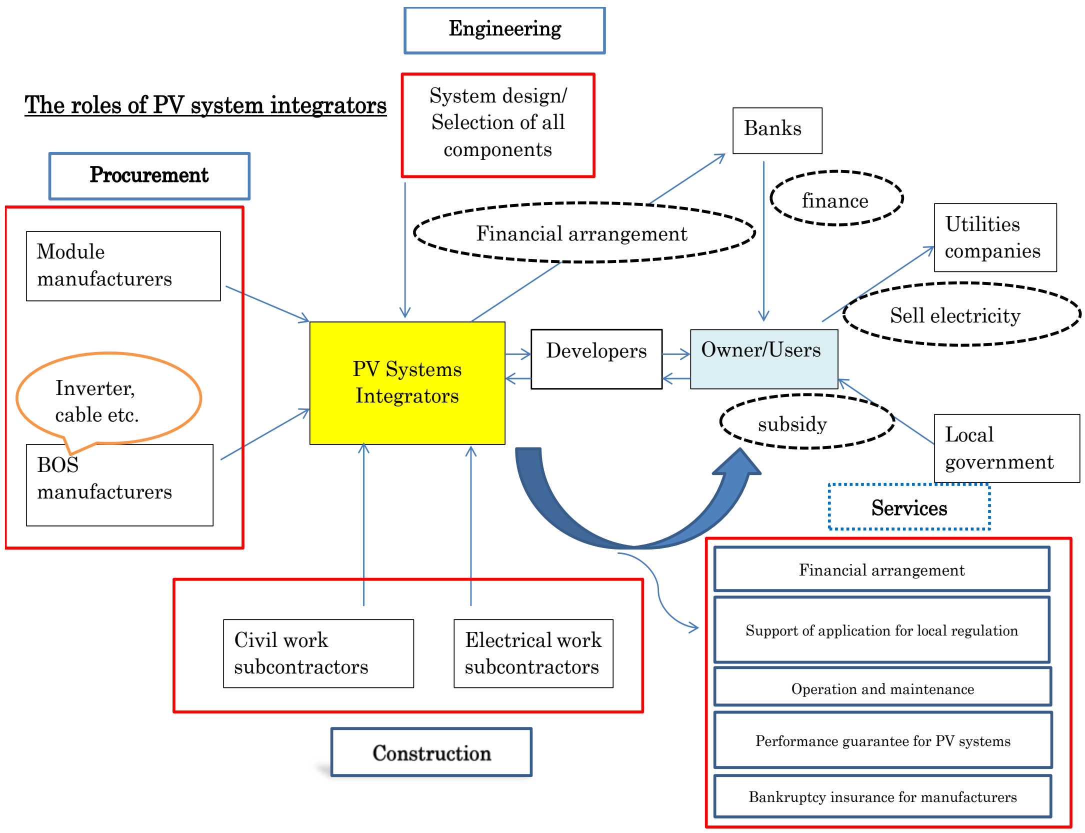


Figure 11 Relationships between PV systems integrator firms and other players
Source: By author

(The roles of PV systems integration over project and operation lifetime)

Figure 12 describes the roles of PV systems integrator firms in terms of three phases. In the planning phase, PV systems integrator firms focus on onsite investigation, designing systems, and securing assistance for financing. In the actual construction phase, they procure components, perform construction, and connect to the grids of utility companies. After they deliver the facilities, PV systems integrator firms monitor the power generation systems, report regularly, and handle troubleshooting. Normally they work 24/7 based on real-time information on power generation.

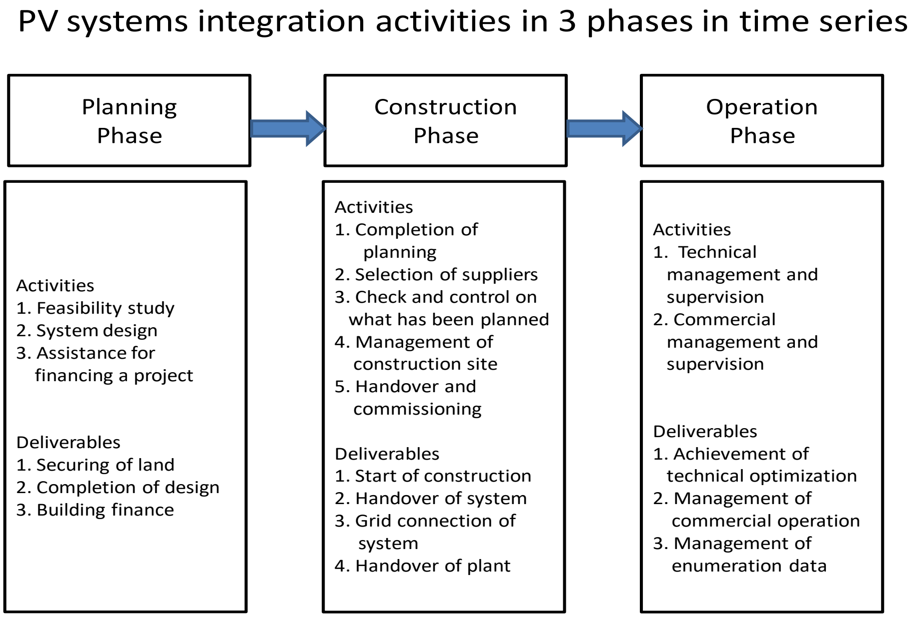


Figure 12 Three phases of roles of PV systems integrator firms in terms of time series
Source: Internal firm record by Conergy

(The service roles of PV systems integration)

The roles of PV systems integrator firms described so far are similar to those of EPC (engineering, procurement and construction) firms in other industries, such as plant engineering construction, but PV systems integrator firms usually provide various additional services (Figure 13). For example, they often help project owners to obtain financing from banks or introduce investors to the project owners; obtain land for the project and necessary use permits; negotiate with other landowner and power companies regarding ways to connect to the main grid; help project owners to apply for subsidies or approval from utility companies and local governments; handle operation and maintenance services after delivery; offer various warranties and guarantees for the efficiency of modules and product performance usually for 20–25 years; offer insurance for business interruption, which would cover the loss of revenue if accidents occur due to the breakdown of components; and sometimes offer particular insurance that covers all of the warranties that module manufacturing firms guarantee in case module manufacturers go bankrupt. These services provide investors/users with long-term schemes that would benefit them. Normally, in the case of large, complicated project-based construction projects, the ability not only to supply actual products but also to offer these particular services is required (Gann and Salter, 2000). Recently, particular services often have high value for customers (Moore, 2000). Particularly in the PV industry, systems integrator firms very often compete for differentiation from one another in the areas of assistance with financing, general consulting, helping with negotiation with local government agencies, customer support in operation, and education for operation. These total systems integration services are, in fact, important aspects to offer in a "bundle" of products and services to maintain competitiveness as PV systems integrator firms. This is similar to how telecommunications systems integrators, such as Ericsson and C&W, provide various services for firms that attempt to enter the telecommunication industry, such as financial assistance, technical support, and consulting in various areas.

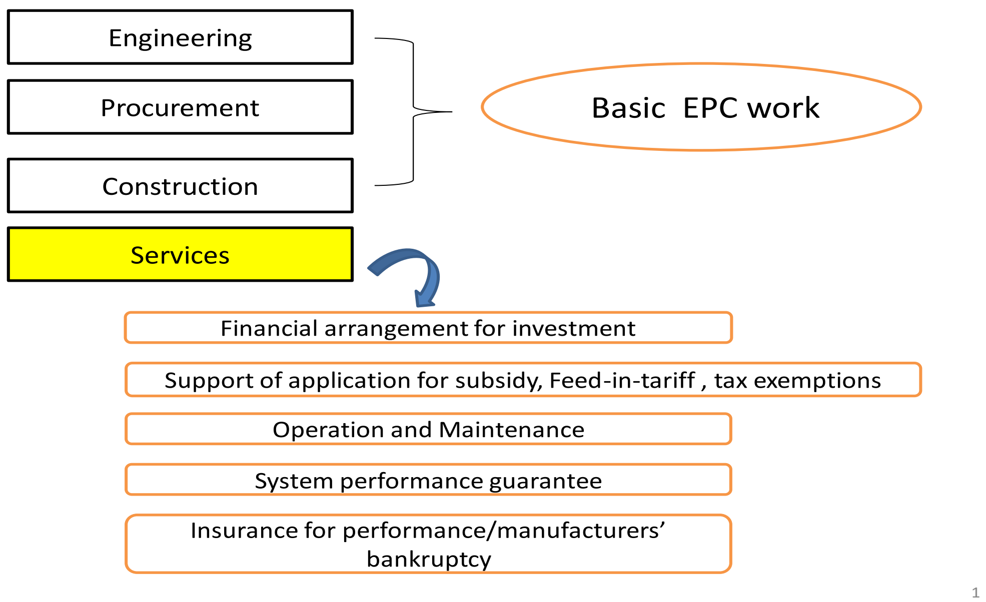


Figure 13 Four roles of systems integrators in the PV industry
Source: By author

It is held that the efficiency and performance of PV systems substantially depend on the combination of the various components which has various specifications. The more options that customers have to select the best components and technology, the more consumers can seek better solutions from PV systems integrator firms. The task of PV systems integrator firms is to build the system that best fits the particular customer's needs by combining all of the factors related to products and services. Particularly, engineering and designing the system are crucial, as the future performance of the PV system is almost fixed at the beginning of installation (Sakakibara and Matsumoto, 2006). Sometimes architectural innovations have occurred in the PV industry. The technology of PV modules has recently developed substantially resulting in rapid improvements in efficiency. One such recent development is that the inverter is already retrofitted on the back side of each module, which could make inverters unnecessary for procurement. PV systems integrator firms can follow these innovations (Henderson and Clark, 1990).

4.1.5 A new aspect of systems integration: Non-CoPS systems integration

4.1.5.1 Non-CoPS industries

In the previous sections industry examples of systems integration were discussed and the concept of non-CoPS systems industry where SI is important were introduced.

This dissertation began with a review of previous academic studies on systems integration, noting in particular Hobday's suggestion that, as an essential core business competence, systems integration is limited to CoPS industries (Hobday 1998). Hobday also set forth a framework to distinguish CoPS from non-CoPS industries where one of the distinguishing features of CoPS industries is their focus on custom-designed solutions and components. This section returns to this question of where systems integration can be observed and where systems integration fits within the framework of core competencies required for innovation. Building upon the case studies and other analysis in the following chapters showing the important role of systems integration in a non-CoPS industry (PV), this section suggests a framework for broadening Hobday's analysis in order to accommodate systems integration as a core competence in certain non-CoPS industries. This section describes the general characteristics of such non-CoPS industries where systems integration is important.

As we reviewed in the previous sections, preceding literature says systems integration can be often seen in CoPS industries and plays important roles. However we can also observe systems integration in other industries than CoPS. What kind of industry they are and what kind of characteristics they have are discussed in this section.

4.1.5.2 CoPS, PV plant construction and mass production industries

Hobday discussed the characteristics of CoPS, by comparing CoPS and mass-produced commodity goods such as automobiles, TVs, and personal computers according to the criteria in his classification system and recapitulated in Table 4 (Hobday, 1998). In this section, extending Hobday's framework, I classify PV systems integration both as CoPS and as mass-produced commodity goods.

To resolve this apparent discrepancy I sub-classify Hobday's characteristic dimensions defining CoPS industries into two main sub categories: "supply/product side" and "demand/market side" as shown in Table 4. This table shows that PVSI has common characteristics with CoPS in the supply/product side, but also has commonalities with mass-produced commodity goods industries in the demand/market side.

Comparison : CoPS, PV plant construction, Mass production

categorization in supply chain	Dimension	CoPS	PV plant construction	Mass production
	Product interface	Complex component interfaces	Medium complex interfaces	Simple interfaces
Supply side/ Product side	Unit cost	High	Medium-medium high (residential: 1 million Yen - utility scale: 10 billion Yen)	Low
	Product life cycle	more than 20 years	more than 20 years	Relatively short
	skill/knowledge required	Many skills & knowledge required	Many skills & knowledge required	Mass production
	Customization/ standardization	Customized	Customized design/Standardized components	Standardized
	Market positioning in supply chain	Upstream	Utility scale : upstream commercial, residential: downstream	Downstream
	Product characteristics	capital goods	capital goods	consumer goods
	Production style	By project/small batch	By project/small batch	Mass production/large batch
	Product design	Systems integration	Systems integration	Design for manufacturing
	Innovation Process	User-driven	Supplier -driven	Supplier-driven
	Knowledge resources	People-embodied knowledge	People-embodied knowledge	Machinery embodied knowledge
	Competencies	Systems integration competencies	Systems integration competencies	Volume production competencies
	Industrial organization	Project-based multi firm alliances	Project-based multi firm alliances	Single firm as a mass producer
	Market dominance, number of producers/buyers	Duopolistic	Many buyers and sellers	Many buyers and sellers
Demand side/ Market side	Market segment, characteristics of producers/buyers	B to B	B to B and B to C	B to C
	Customer knowledge	High knowledge	Little knowledge	Little knowledge
	Market mechanism	Adminitered market	Regular market	Regular market
	Market Politics	Institutionalized/Politicized market	Free traded market	Free traded market
	Market regulation	Heavily regulated	Minimal regulation except for large systems	Minimal regulation
	Market pricing	Negotiated prices	Market prices	Market prices
	Market competitiveness	Partially contested	Highly competitive	Highly competitive
Industry examples		Railway systems, Electric communication, Aerospace, Air traffic control systems	PV plant construction	Automotive, TV, Personal computers

Table 4 Comparison among CoPS, PV plant construction and mass production Source: Author's elaboration on interview data and adapted from Hobday (1998)

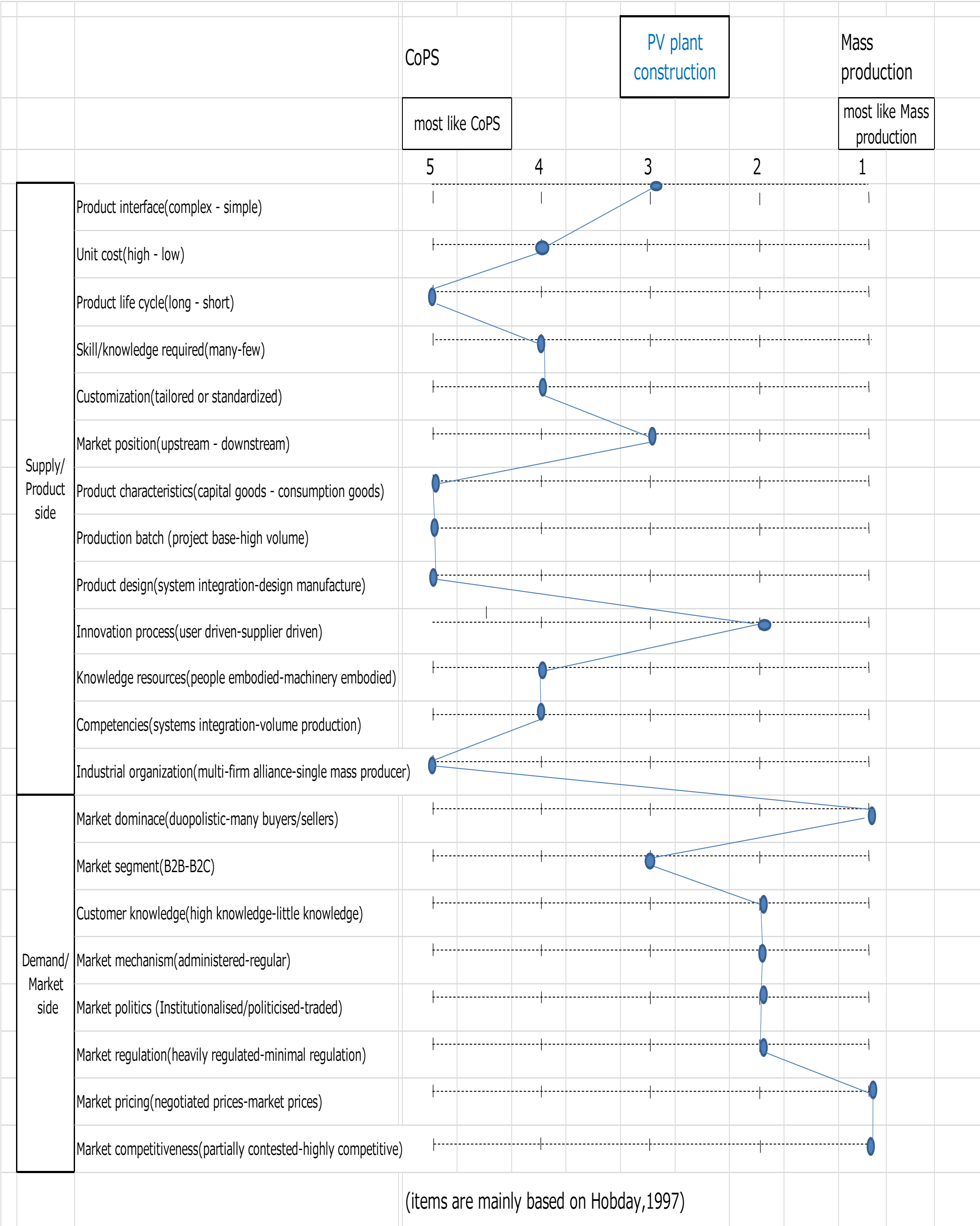


Figure 14 Characteristics of PV plant construction in comparison with CoPS and mass production

Source: Author's elaboration and adapted from Hobday (1998)

In order to quantify this comparison as best as possible, based on Hobday's conceptual five-level categorization method (Hobday, 1998), I classify each of the dimensions in Table 4 on a 1 to 5 scale (Figure 14) according to whether the characteristics of the PV industry for that dimension are closer to a CoPS industry (5) or a mass-production industry (1).[4]

For example, PV plant construction is a capital goods and is implemented on a project basis or in small batches by multiple firms, similar to CoPS industries and as we will see in the example of the Thailand project in Chapter 4. So it is plotted as 5 along this axis. In contrast, in mass-produced commodity goods, a single company normally provides goods into the market, although it procures components from external suppliers. In the PV plant construction, user-oriented specifications are prioritized in design as they are in CoPS industries. Each project has its own characteristics in geographical features, customers' preferences, distance from grid, climate and irradiation. Manufacturers do not decide the product's specifications as in commodity goods manufacturing. So it is plotted as 5 in this axis. A product's lifecycle in the PV system construction projects is long, normally 20-25 years (the normal period of FIT schemes and warranty periods by PV modules manufacturers), which is similar to CoPS but unlike most commodity goods. Thus, it is plotted as 5 in product cycle. Also in PV plant construction, the components such as PV modules, power conditioners, cables used are relatively standardized, but similar to CoPS in a sense that overall design and the selection and procurement of components are totally customized. So I plotted it as 4 in customization.

However, there are other aspects in PV plant construction that are similar to mass-produced commodity goods. PV construction markets have wide and various markets: huge mega-scale power generation plants to small residential facilities as described in chapter 3. Customers (power producers, commercial firms and residential owners) are also various and large in number. When we examine the degree of monopoly (market dominance by large corporations), most CoPS industries have an oligopolistic structure (dominance by a few firms) as described by Hobday (1998). But many companies participate in the PV plant construction. In this sense it is plotted as 1 in the axis of market dominance. Consequently, the PV systems integration market is very competitive and contestable, and the business is controlled by market mechanisms, which is similar to mass-produced commodity goods. Market pricing is highly competitive. So it is plotted as 1 in market pricing. In the LNG plant construction market, which is a typical CoPS industry, it is considered to be oligopolistic, as Nikki, Chiyoda Corporation, KBR (USA), and Bechtel (USA) are the "Four giants in the world" as we discussed in chapter 1. On the other hand, the IMS studies about PV systems integrator firms worldwide (described in chapter 4) show that the top 30 firms accounted for only 22% of worldwide installed capacity in 2010, 25% in 2011, and 24% in 2012, and the market is considered to be "very fragmented." Particularly when we compare PV systems integration markets with PV module manufacturing markets, the PV systems integration segment is much more fragmented (Figure 15; IMS Research Report, 2011, 2012, 2013).

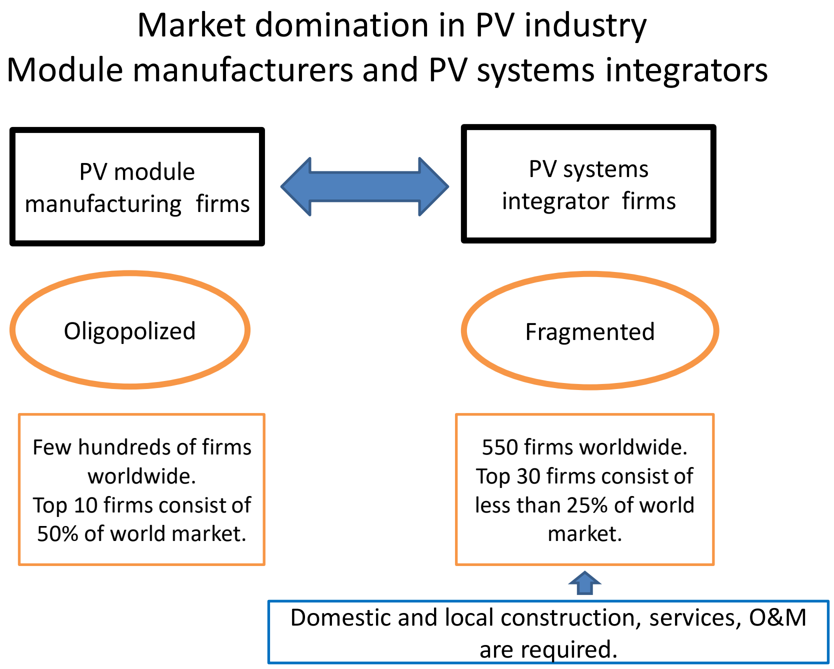


Figure 15 Market dominance: PV module manufacturers and PV systems integrator firms
Source: IMS Research Report 2011,2012,2013

Also, in the PV system construction market, there are few strict regulations and institutional constraints by local or central government except for the need to negotiate with local government and utility companies for grid connection, whereas there are many governmental regulations concerning environmental regulation and safety management that affect most CoPS industries. In this sense PV plant construction is plotted as 2 along this axis of market regulation.

Therefore, PV plant construction has contrasting characteristics of both CoPS and non-CoPS industries. This suggests that the systems integration business model is advantageous not only in CoPS industries as suggested by previous literature, but also in other industries, such as PV plant construction, that have market/demand-side characteristics similar to those facing mass-produced commodity goods industries.

4.1.5.3 Non-CoPS systems integration

To summarize the discussion and to add PV plant construction to the analysis of CoPS industries pioneered by Hobday, and also to expand his framework, figure 16 shows the industry characteristics of Hobday's model, with an added dimension that depends on supply side vs demand side market factors. The upper right domain is that of CoPS industries, where systems integration firms have been considered to play a significant role according to previous literature. But it is also suggested that systems integration is needed also in the upper left domain where PV system integration is positioned.

PV plant construction has various markets in terms of size and specifications. The number of users is many, and users in general are people/firms who do not have detailed technological knowledge, thus they are obliged to rely on systems integration firms' expertise. That kind of need on the demand/market side requires systems integration competence in the industry. The example of PV plant construction which has characteristics of both CoPS and mass-production industries described above suggests that a new category of industries may be emerging that has similar characteristics as PV plant construction with respect to systems integration roles and the extent to which these roles represent important capabilities for the companies in these industries. [5]

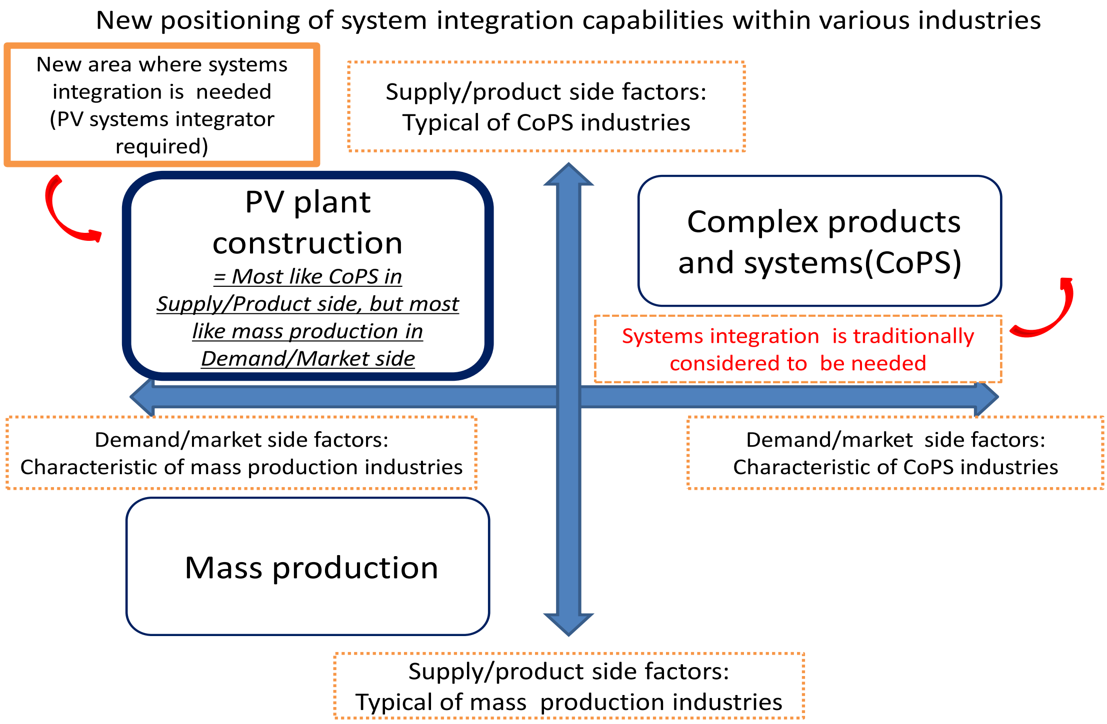


Figure 16 New positioning of PV plant construction
Source: Elaborated by author

I propose that this kind of systems integration be called as "Non-CoPS type" systems integration. Figure 17 summarizes our discussion in this section.

CoPS type SI and Non-CoPS type SI

		CoPS type SI	Non-CoPS type SI
Different features	Market dominance Market segment Customer knowledge Market pricing Market competitiveness Project size SI company size Customization Way of co-work	Duopolistic B2B High Negotiated prices Partially contested Very large Big Fully customized One company takes care of an entire project	Many buyers/sellers B2C Little Market prices Highly competitive Small to large Small to medium Partially customized/reproduciable A systems integrator controls/manages the alliance team who allocate each work
Industry examples		Defense Plant engineering construction	PV plant construction
Candidate industries			Robot systems Smart City

Figure 17 CoPS type systems integration and Non-CoPS type systems integration
Source: By author

4.2 Purpose

The purpose of this chapter is through case study method to attempt to clarify how PV firms (and PV systems integrator firms) are performing their roles in terms of their strategies and capabilities.

4.3 Methodology

4.3.1 An example of PV systems integration project

First a PV systems integration project in Thailand is described as an example of PV systems integration to show how an actual PV plant construction project is executed. Next, 29 major global PV firms are selected and based on in-depth interviews their main business strategies such as marketing, overseas sales and specialization are described. Finally, major global PV systems integrator firms are examined through case study method regarding how they were established and developed.

In the previous section, I discussed the general functions of PV systems integrator firms. In this section, I introduce a specific example of PV systems integration by observing a mega scale project in Thailand implemented by Conergy, a German listed

PV systems integrator firm, (hereafter company C), in 2011.[6] This example illustrates in some detail the actual work of a systems integrator in a real-life context.

(Overview of the project)

This is a 2.4-megawatt solar power generation plant located 150 km from Bangkok (Table 5). The owner of the project is an investment capital fund. Company C proposed this facility as a package of its own modules, inverters, and mounting systems.

Project Highlights	
Completed Date	April 2011 (8 months construction period)
Location	Lop Buri, Thailand(155km north of Bangkok)
Output	2.37MWp
Produced MW/h annually	3,500 MW/h annually (equivalent to 1,200 households supply)
Modules	10,800 Conergy Power Plus modules
Inverters	135 Conergy IPG 15T inverters
Mounting System	1,080 Conergy Solar Linea
Size of Plant	44,500 square meters
CO2 emissions saved	1,860 tons/year
Project Owner	Indorama Ventures Public Company Limited
Local partner	Annex Power Limited, Ensys

Table 5 The overview of the project by company C in Thailand
Source: Internal firm record by Conergy

(Project organization)

Figure 18 describes the work allocation in systems integration roles in terms of specific names and functions and Figure 20 shows the division of work in our standard format. Figure 19 shows that which segment of PV market the Thailand project works by yellow color.

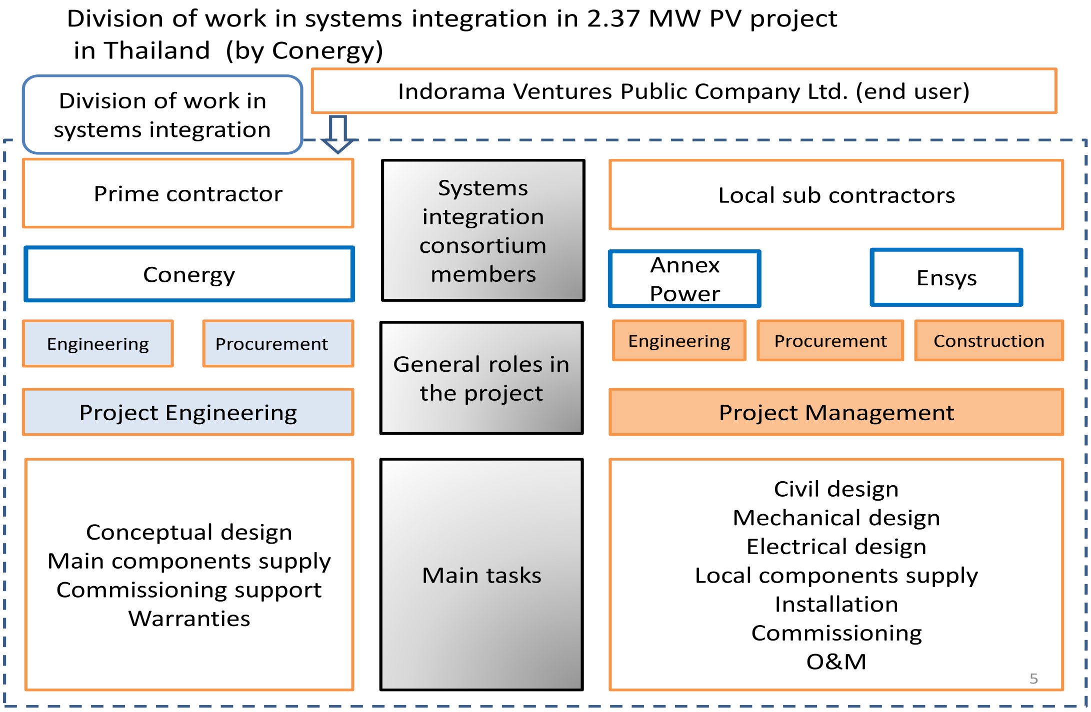


Figure 18 Collaboration in systems integration consortium in the Thailand project by Conergy

Source: Author's elaboration on interview data

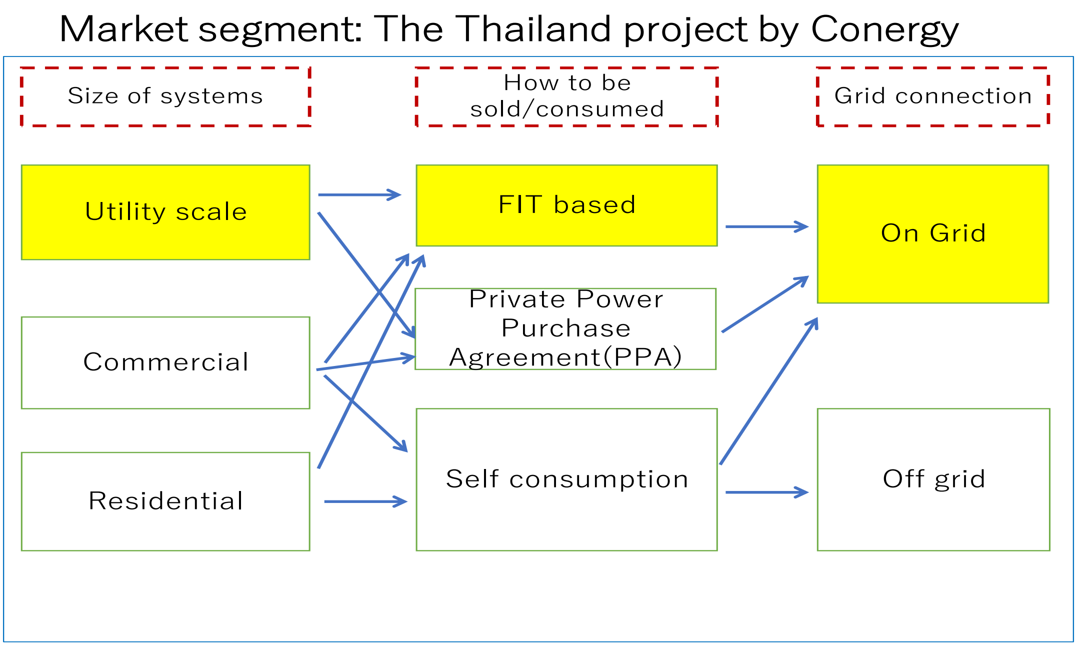


Figure 19 Market segment of Thailand project by Conergy

Source: By author

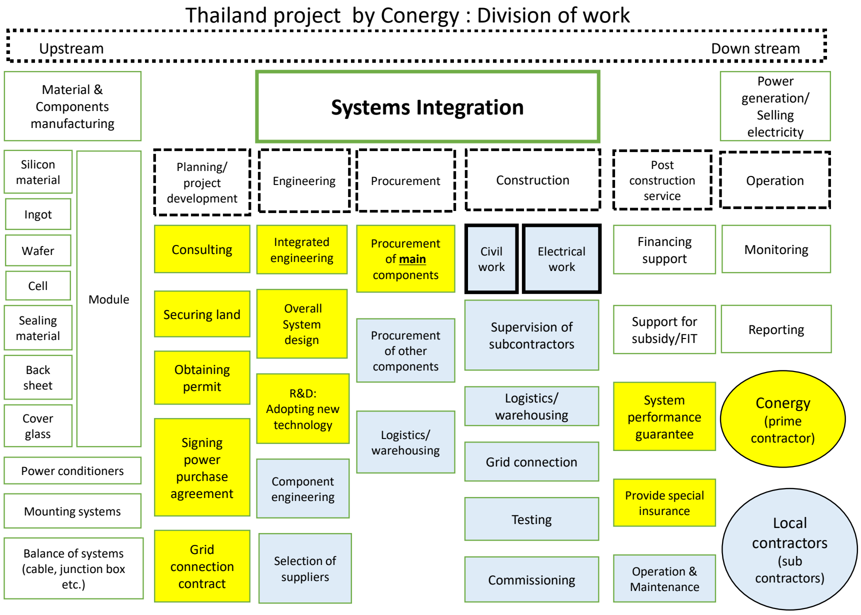


Figure 20 The division of systems integration roles in the Thailand project by Conergy
Source: By author

Normally PV systems integrator firms that are active in the global PV market have alliances with local partners, because PV systems integrator firms should handle specific local regulations and also procure local labor forces through local partners for construction work. In this example, company C has an alliance with Annex Power, which is one of the major EPC companies in Thailand. It is active not only in PV but also in other types of renewable energy, such as wind power and biomass power generation in East Asia. Also, company C has an alliance with Ensys, which is one of the major electric construction firms in Thailand, to subcontract electrical construction parts (Figure 18). Here, company C is the prime contractor, and Annex and Ensys are the cooperating, subcontractor companies.

The diagram indicates that company C handles the entire design of the facility, the procurement of major components, and the warranty of components. The two cooperating companies are in charge of designing of smaller parts of the facility; procurement of minor components, such as cables, which would be better in terms of cost to procure locally; and also actual civil infrastructure works, electricity works, and operations and management after commissioning. The key to success for company C is whether it can develop an effective alliance with local teams that are reliable and capable. In CoPS projects, usually the project organization is project-based rather than being based on a normal corporate organization (Hobday, 2000), and therefore, continuity can be maintained and alliances can be kept for a long time.

It would be critical to enhance organizational collaboration among partners, even just temporarily for the duration of a project, to achieve full efficiency (Barlow, 2000).

On the other hand, the speed of technological change in the PV industry is fast and maintaining the level of expertise of the systems integration function in depth and breadth is also critical. It is important to secure internally the key parts of the function with which they can control the entire process rather than outsourcing all functions (Prencipe, 2000).

(The task details of the project)

The project has the following phases described in figure 21.

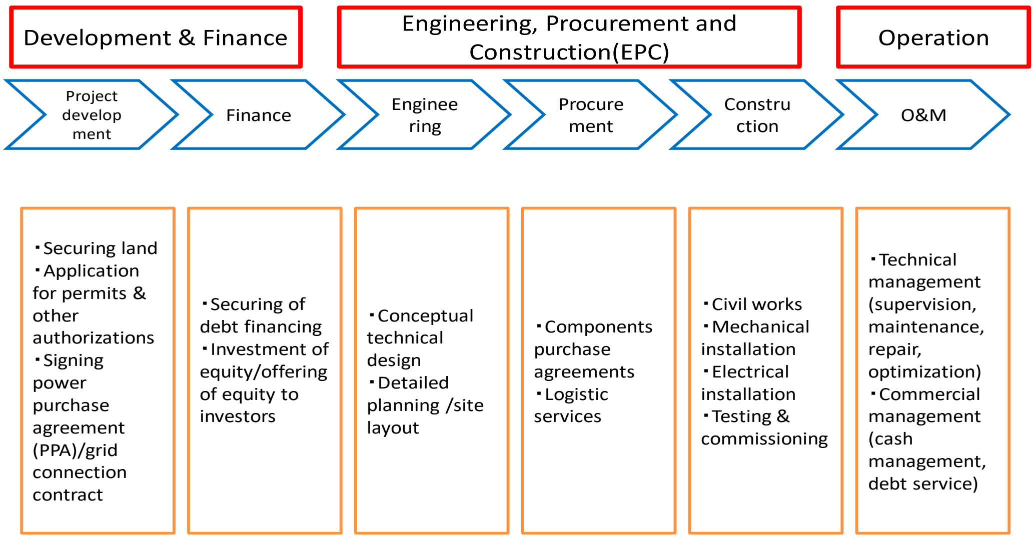


Figure 21 The tasks of PV systems integrator firms in the Thailand project by Conergy
Source: Internal firm record

In the project development phase, Indorama handles, together with company C, the selection of land; issues such as the connection distance to the grid and environmental issues; confirmation of the availability of necessary components; the securing of the construction permits; and the securing of the grid connection permits.

Company C has a branch office in Thailand, where two staff are working on sales and technical matters, but they also have an Asian headquarter office in Singapore, and the staff there often visit Thailand to help the local staff with sales and technological matters. In the finance phase, Indorama has already secured funds, and therefore, assistance from company C is not required. In Thailand, the PV market has already matured, and major financial institutions have track records for financing PV projects. Sometimes larger projects are easier to get financed than smaller projects because large projects are already popular in Thailand and paperwork required are the same regardless of the size of projects.

Thailand has substantially higher solar radiation than other parts of the world. This enhances stability of the grid connection and the allocation of electricity, and therefore, bankability (the ease of obtaining financing) is high. [7] In the engineering phase, company C handles the fundamental design of the system and subcontracts the minor design to local cooperating companies. Designing a fundamental system is one of the most critical parts, as it affects the schedule, cost, quality, and efficiency of the project (Nightingale, 2000). In the procurement phase, key components are modules, inverters, and mounting systems. There are a variety of modules in the market, and power efficiency, weight, and prices vary. Here, company C, which has a high capability of procurement, buys key components, and other components are procured by local cooperating companies. The key factor is how to procure the components at better prices including logistic costs. In the construction phase, two local firms work under the management of company C.

4.3.2 Methodology of this chapter

To obtain a broader perspective on the strategies of firms that become PV system integrators, as well as firms in the PV industry that do not become system integrators, I collected information on the large PV module manufacturers and the large PV systems integrators globally. Among all the business segments of the PV industry shown in Fig. 22, I selected system integrators, because this is the focus of my study, and I also selected module manufacturers, because, as noted in Chapter 1 and described more fully below, some module manufacturers have become successful systems integrators. However, no company from any other segment of the PV industry, for example, cell manufacturers has become a successful PV systems integrator. Therefore, for the purpose of comparing

PV systems integrators with other companies in the PV industry that may have the option to become systems integrators, it makes sense to focus on PV systems integrators and PV module manufacturers. Such a focus will provide the clearest contrast between the capabilities necessary for a company in the PV industry to be a successful systems integrator, and also the clearest insight into strategies to become a systems integrator.

With this rationale for the overall analytical approach in mind, from the set of module manufacturers and systems integrators I had identified, I selected companies that met any of the following criteria:

1. PV module manufacturers who either focus on module production or entered PV systems integration segments, and that were ranked as top-10 PV module manufacturers globally (2005-2015) in terms of production volume (Table 6)
2. Globally active PV systems integrator firms who were ranked in "Global PV systems integrators ranking" (2010-2013) by IMS research company (Table 7)
3. In addition to the above firms, I added Solar Frontier, which has a unique and significant presence in the market; AUO and Moser Baer, which were originally non-PV-related firms but have expanded their PV business in the world market; Conergy, which was established in Germany, the origin country of the recent PV industry; and REC (Norway), which was established in a country other than Germany or the United States of America (USA) where the PV industry is already mature. [8]

Thus the set for analysis consisted of the following 29 firms.
(USA) First Solar, Sunpower, SunEdison/MEMC
(China) Trina Solar, JA Solar, Suntech, Yingli, Jinko Solar, China Power Investment, TBEA Sunoasis, Jiangsu Zhenfa Technology, GD Solar
(Germany) Solar World, Phoenix Solar, Q-Cells, Conergy, Juwi, Belectric
(Norway) REC
(Canada) Canadian Solar
(Taiwan) AUO, Jintech, Motech
(India) Moser Baer
(Belgium) Enfinity
(France) EDF
(Japan) Solar Frontier, Sharp, Kyocera

Table 8 tabulates information on these 29 major PV-related firms, in particular, (1)the share of systems integration as part of the entire PV business (2) the share of the PV business in the entire business if they have non-related PV business (3) the share of overseas business (4) their target market (i.e. residential, commercial, and utility scale) and (5) vertical integration or horizontal specialization in manufacturing, if they are PV module manufacturers.

I picked up these 1-5 factors because they show the extent to which diversified companies (such as Kyocera) focus on the PV industry, and the extent to which PV operations focus on systems integration business. Also these factors give insights into overseas business strategies, target markets and manufacturing strategies in the case of module manufacturers. These perspectives are significant in view of their long-term business strategies.

Several Chinese firms, except for large module manufacturers which are listed, there is no detailed public information available (firm number 24-27 in Table 8). However, we can assume from market information and statistics that they are active only in China, focusing on big projects in PV industry. Also large consolidated firms such as Sharp, Kyocera, AUO deal in numerous other businesses and there is little precise segmental information available. Nevertheless, comparing them with large PV firms where precise and detailed information are available, gives us significant clues concerning their strategies.

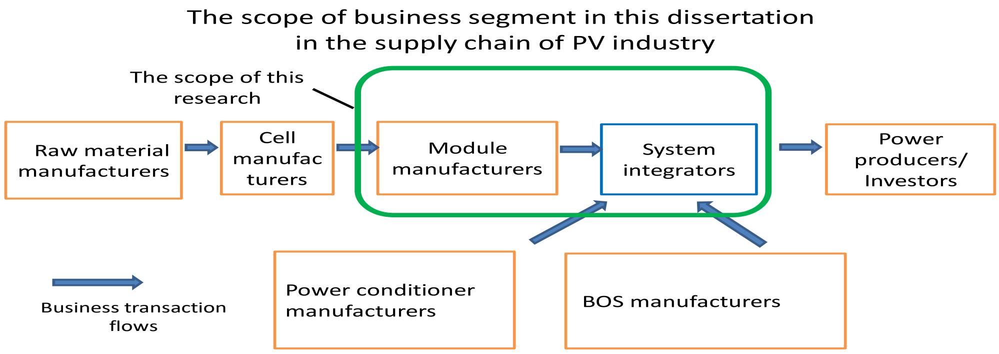


Figure 22 The main scope of this dissertation
Source: By author

Figure 22 shows the scope of this chapter's analysis of the PV industry supply chain. Module manufacturers and systems integrators are the focus of this analysis because PV systems integration is usually performed by companies active in these two segments.

4.4 Result

4.4.1 Industry analysis and business strategies of 29 major global PV firms

To continue this analysis, table 6 shows how the rankings of the top ten firms in terms of production volume (in MW) have changed over the 11-year period from 2005 to 2015.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1	Sharp	Sharp	Q-Cells	Q-Cells	First Solar	Suntech	Suntech	Yingli	Yingli	Trina	Trina
2	Q-Cells	Q-Cells	Suntech	First Solar	Suntech	JA Solar	First Solar	First Solar	Trina	Yingli	Canadian Solar
3	Kyocera	Kyocera	Sharp	Suntech	Sharp	First Solar	JA Solar	Trina	Sharp	Canadia nsolar	Jinko Solar
4	Sanyo	Suntech	First Solar	Sharp	Q-Cells	Sharp	Yingli	Suntech	Canadian solar	Jinko	JA Solar
5	Mitsubishi	Sanyo	Kyocera	Kyocera	Yingli	Yingli	Trina Solar	Canadian solar	Jinko	JA Solar	Hanwha Q.Cells
6	Schott Solar	Mitsubishi	Motech	Yingli	JA Solar	Trina Solar	Canadian Solar	Sharp	Rene Sola	Hanwha Q.Cells	First Solar
7	BP Solar	Motech	Sanyo	JA Solar	Kyocera	Q-Cells	Sharp	JA Solar	First Solar	Rene Sola	Yingli
8	Suntech	Solar World	Sun Power	Motech	Trina Solar	Motech	Motech	Jinko	Hanwha Q.Cells	First Solar	SFCE
9	Isofoton	Sun Power	Yingli	Sun Power	Sun Power	Jintech	Sun Power	Sun Power	Kyocera	Sun Power	Rene Sola
10	Motech	First Solar	JA Solar	Solar World	Jintech	Canadian Solar	Jintech	Hareon solar	JA Solar	Kyocera	Sun Power

Table 6 Top 10 rankings in PV module production
Source: Author's elaboration from NPT Solarbuzz, Jan. 2014, Module Tracker Quarterly Report, PV News, PV Eyes Magazine

(Yellow: Japan, Green: Germany, Blue: USA, White: Taiwan, Orange: China, Brown: Korea)

From these time series rankings, we can observe the following: (1) There were four Japanese firms that were ranked within the top 10 in 2005, but there is no Japanese firm in 2015. (2) Instead there was only one Chinese firm that were ranked within the top 10 in 2005, but there are seven firms within the top 10 in 2015. (3) The rankings of Sharp and Kyocera declined from 2006, but then temporarily recovered in 2011–2013. This period coincided with the period of implementation of a FIT in Japan starting in July 2012. Sharp and Kyocera declined again in 2014–2015, when the Japanese PV market stopped expansion, likely due to the decrease of the FIT rate in Japan that began in 2012. Chinese module manufacturers have dominated the PV market since 2013. Q-Cells, which was ranked first in 2007 and 2008, went bankrupt in 2012 and was bought by Hanwha, a Korean company. Suntec, which was ranked first in 2010 and 2011, also went bankrupt in 2013 and was bought by SFCE, a Chinese company.

	2010	2011	2012	2013
1	(G) Belectric	(G) Belecric	(U) First Solar	(U) First Solar
2	(G) Juwi	(C) China Power Investment	(U) SunEdison	(C) TBEA Sun Oasis
3	(U) Sunpower	(U) First Solar	(G) Belectric	(C) GD Solar
4	(F) EDF	(U) SunEdison	(C) China Power investment	(C) Shanghai Solar Energy
5	(U) SunEdison	(U) Sunpower	(G) Juwi	(U) SunEdison
6	(G) Q-Cells	(G) Juwi	(G) Enerparc	(C) Zhongli Talesun solar
7	(U) First Solar	(G) Solar Hybrid	(F) EDF	(C) Astronergy
8	(B) Enfinity	(G) Q-Cells	(C) TBEA Sun Oasis	(U) Sunpower
9	(G) Phoenix Solar	(C) Huanghe Hydro Power Development	(C) GD Solar	(C) Jiangsu Linyang Solar
10	(G) Gehrlicher Solar	(C) CGN Solar Energy Development	(C) Jiangsu Zhenfa New Energy	(S) Abengoa Solar

1

Table 7 Global PV systems integrators rankings
Source: Adapted from the data by IMS Research

Country names: G Germany, U USA, F France, B Belgium, S Spain, C China,
Yellow: Germany, Red: China

Table 7 shows global PV systems integrator firms ranking in terms of installation MW (Megawatt) volume in the world's non-residential PV market (more than 10 KW in size), the data and classification as PV systems integrators being based upon IMS 2010,2011, 2012 and 2013. There are no comparative statistics about global PV systems integrator firms that have an international presence except for these studies by IMS Research.

As noted previously and as shown in Table 8, few firms are pure systems integrator firms and many earn a majority of their revenue from non- system integration activities. One limitation of these data is that the ranking is based on the actual installation volume. Therefore, they do not necessarily mean that top-ranking firms are dominant in all of the PV market segments, because a firm that installed a very large number of panels in a small number of projects tends to be ranked high here.

We can see several trends from Table 7. Five German (seven European) firms were within the top ten PV systems integrator firms in 2010. Meanwhile, there were only three German (four European) firms in 2012 and no German firms (one European firm) in the top ten in 2013. According to this report there were 13 German PV system integrators among the top 30 firms and there were 19 German PV system integrators among top 20 firms for the German market.

In contrast, while no Chinese firm was ranked within the top ten in 2010, there were four firms in 2012 and six firms in the top ten in 2013. These Chinese firms do not disclose their operational /financial information, but the IMS report which investigated the world's 550 PV system integrators says that their areas are basically the huge domestic Chinese markets. It is contrasting when we remember the fact that Chinese module manufacturers are dominant in the global PV market. There were three American firms within the top ten PV systems integrator firms in 2010. Then, the first and second in 2012 were American firms, and there were also three firms in the top ten in 2013. These three U.S.A. firms are also expanding in focusing their activities on the large domestic market according to the IHS report

First Solar, which was originally a module manufacturer, can have a full range of system integration tasks, including designing, procuring materials and construction. Some firms like First Solar build projects and developed in-house, generating revenue from the sale of completed PV power plants. Others focus on EPC for third-party developers, sometimes in combination with in-house development. First Solar's strategy is to cultivate a pipeline of PV projects, in which it takes on major undertakings, sells them to other firms and then uses the proceeds to buy other large-scale projects. For example, First Solar announced in May 2013 the sale of the Campo Verde Solar Project, which is under construction in Southern California. Campo Verde will have a capacity of 139 MW when it was completed at the end of 2013. With the money it made from the sale, First Solar expanded its pipeline with the acquisition of three other projects under development with a total capacity of 260 MW scheduled to be completed by the end of 2015. With the company's solar module business suffering because of drastic falling prices, this is going to be a strategic approach for the company.

"First Solar's successful strategy of acquiring, installing and divesting projects will keep the company among the world's leading PV systems integrator over the next years," said Josefin Berg, senior analyst for downstream solar research at IHS. "This approach not only offers sales outlets for its modules, but more importantly also generates project-sales revenue that cushion the company when seeking new growth markets." (IMS Research, EPC and Integrator Market Shares and Projects Tracker, 2013)

We can say that the major PV market is moving from Europe to China and the USA.

According the IMS PV systems integrators report, the total amount of installation in 2013 is 30GW, with the top 30 firms accounting for 9 GW, 30% of world's non-residential market.

First Solar installed 1.1 GW in 2013, 50% up from 516 MW in 2012 and TBEA Sun Oasis did 1.0 GW in 2013 which is 10% of China market, up from 250 MW in 2012. GD Solar did 715 MW in 2013, up from 220 MW in 2012. Sun Edison in the USA did 505 MW in 2013, up from 389 in 2012.

The report shows that the active market for PV systems integration has moved depending on the attractiveness of local FIT schemes, if both global PV systems integrator rankings and annual installation records in major countries are examined. For example, Phoenix Solar, one of the global PV systems integrators, shifted to international sales from domestic German sales. Its international sales were 26% in 2010 of total sales and 57% in 2011, but its overall sales revenue was 635 Million Euro in 2010 contrasted with 393 Million Euro in 2011 -- a substantial decrease over just one year (Phoenix Solar AG, internal firm records, conference call, Financial results in 2011 and 2012; annual report 2010 and 2011, May 15,2012).

Figure 23 shows the annual PV installation capacities in MW in major countries and global total capacity. The bar chart shows annual worldwide installation capacity. The line and dot line show annual PV installation capacity of each country: red line Japan, yellow line China, Green line Germany, blue line USA, navy dot line Italy and red dot line Spain.

While global PV market has expanded every year steadily, the listed countries each year has been changing. There were substantial decreases in Spain in 2009, Italy in 2012, Germany 2013 due to the changes in FIT schemes, FIT rates, revision in subsidy schemes and tax incentives. Also there were jumps in China and USA in 2015 and 2016 due to attractive incentives by the governments. This means local markets depend still on the changes in local rules and subsidy schemes, although the trend worldwide PV installation is growing steadily to reach 75 GW annually in 2016. The left axis is annual installation capacity of each country and right axis is annual installation worldwide.

Figure 24 shows the accumulated installation in MW up to 2016 and annual installation in 2016 by each country. The bar chart shows, from the left the countries in top 10 in terms of accumulated capacity as of 2016, China, Japan, Germany, USA, Italy, UK, India, France, Australia, Spain. The blue portion shows the accumulated capacities and yellow portion shows the annual installation in 2016. The circle graph shows the proportion of each country in accumulated installation as of 2016

China became the largest PV installation country in the world in 2016, while Japan and USA have already surpassed Germany in annual installation in 2016. This highlighted a huge increase in China in 2016.

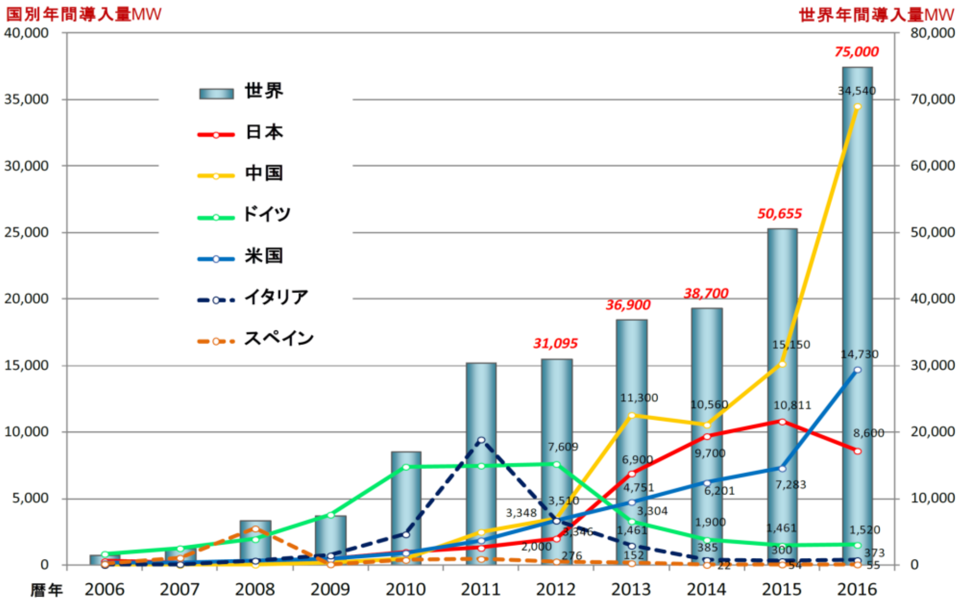


図 2-3　世界の太陽電池設置量の推移（2006-2016）

Figure 23 Annual PV installation capacity in major countries and worldwide 2006-2016
Source: JPEA PV Outlook2050, Japan Photovoltaics Energy Association

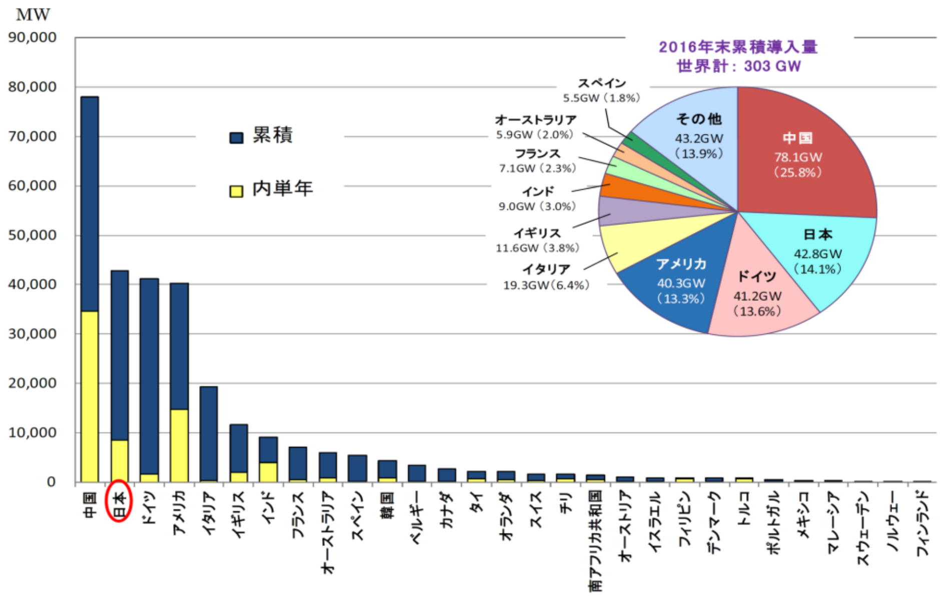


図 2-4　主要国別 2016 単年・累積設置量

Figure 24 Cumulative and 2016 PV installation capacity in major countries
Source: JPEA PV Outlook 2050, Japan Photovoltaic Energy Association

The report also points out that the development and installation of PV remains "incredibly fragmented" as the share of top 30 firms in the non-residential market were 22% in 2010,24% in 2011,25% in 2012 and 30% in 2013, while the size of projects are becoming larger especially in China and the USA.

It is remarkable that while Japanese module manufacturers have been dominant in the global PV market for a long time, there is no Japanese firm in the PV systems integration rankings. The report forecasts that Japan is to be the second-largest (next to China/USA) market in 2013, but the installations will be a wider range of sizes rather than large-scale ground-mounted installation, resulting in a more fragmented competitive landscape.

There are a variety of global PV systems integrator firms in this ranking. For example, EDF is a large power producer, and First Solar, Sun Power, and Q-Cells began as PV module manufacturers and still obtain most of their revenue from this source. Table 8, which summarizes data on both major PV module manufacturers and major PV system integrators, allows further exploration of the origins of PV systems integrator firms and the strategies that enable companies to become successful systems integrators.

The list of PV firms researched

○annual report (for 3 Japanese firms, segmental information only) available △ interviewed □ factory visited

Notes: As for the companies who have other businesses than PV, overseas business % indicates the % of total overseas business.

				company names	nationality	establis hed/ent ry	module category	①SI business % in PV business	%	②PV business % in total company	%	③ overseas business % in PV business	%	④target markets in PVSI business	⑤vertical integration/hor izontan specialization of PV modules makers	comments
				categorization			(T)thin film	(S) pure SI & wholesaler		(P) PV only		(D) domestic 50%-		(A) All 3 segments (residential,commercial,power plant)	(V) vertical integration	
							(S)silicon	(E) module Mfer expanding to "solution business"		(O) less than 20% of parent company or group		(G) global overseas 50%-		(B) big projects only	(H) horizontal specialization	
							(A)all types	(M) pure manufacturer								
								(P) power generation								
○			1	First Solar	USA	1999	T	E	23	P	100	D	45	B	V	originally cell, module manufacturing → cell,module manufacturing + EPC + IPP. 3 years (2010-2012) average overseas sales = 45%, 9% in 2012 → "domestic"
○	△	□	2	Sunpower	USA	1985	S	E	47	P	100	G	50	B	V	originally cell manufacturing only → + module manufacturing → + SI. EU 70% in 2010 → USA 70% in 2012
○	△		3	Trina Solar	China	1997	S	M	0	P	100	G	92		V	focusing module manufacturing. 3 years overseas sales average : 92%, 87% % in 2012
○	△		4	JA Solar	China	2005	S	M	2	P	100	D	51		H	focusing module production (not vertical integration) and sales (not SI), 50% sales in China
○	△		5	Solar World	Germany	1997	S	E	7.5	P	100	D	50	B	V	focusing "large scale solar power plant project" . 50% sales in Germany
○	△		6	Phoenix Solar	Germany	1999	A	S	44	P	100	G	70	A		Independent PV only system integrator.
○	△	□	7	REC	Norway	1996	S	M	0	P	100	G	100		V	focusing manufacturing module ,has alliance with Phoenix Solar in SI. 80% sales in Europe (55% Germany, 19% Italy)
○			8	Suntech	China	2001	S	M	0	P	100	G	93		V	originally only cell, module manufacturing and bought Chinese wafer company in 2011 to be vertically integrated company. No SI business.
○			9	Yingli	China	1998	S	M	0.5	P	100	G	77		V	42% Germany, USA 14%, China 23% (2012)
○			10	Canadian Solar	Canada	2001	S	E	2.3	P	100	G	75	B	V	system solution 13% (2012). Europe 48%, USA 25%, others 27%
○	△		11	Q-Cells	Germany	1999	S	E	37	P	100	D	44	B	H	originally focusing cell manufacturing only. system solutions 37% (2011). outside of Germany sales : overall 44%, Cell 59%, module 47%.
○	△	□	12	Conergy	Germany	1998	A	S	90	P	100	G	73	A		originally PV and other renewable energies, later focused in PV. Then expanded module manufacturing, mounting system, inverter manufacturing. Then sold inverter business to Bosh.
○	△	□	13	Solar Frontier	Japan	1978	T	E	0	O	3	D	10	B	V	spinned off from Showa Shell Oil Co. Sales percentage is 3% of total sales of SS group.

○	△		14	Sharp	Japan	1959	S	E	0	O	9	D	N/A	B	V	9.1% PV sales of total Sharp.
○	△		15	Kyocera	Japan	1975	S	E	0	O	16	D	N/A	B	V	16.5% PV sales of total Kyocera.
	△	□	16	AUO	Taiwan	1996	S	M	0	O	2	G	N/A		V	One of the world larget liquid crystal panel manufacturers.
			17	Jintech	Taiwan	2007	S	M	0	P	100	G	N/A		V	established in 2005. manufacturing cell and modules.
			18	Motech	Taiwan	1999	S	M	0	P	N/A	G	N/A		H	originally focusing only cell manufacturing then later + module, power conditioners
			19	Juwi	Germany	1996	A	S	100	other renewable energies	50	G	70	B		other renewable energies such as wind, bio,hydro and geothermal. 1800 employees, revenue 1.1 billiion Euro in 2012
	△		20	Belectric	Germany	2001	T	S	100	P	100	G	N/A	B		active globally,but mainly Europe. 18 offices in 5 continents. only handles thin film modules(First Solar, Solar Frontier, Sharp) 2000 employees. focusing on construction of large solar plants.
○			21	SunEdison /MEMC	USA	1959	S	E	61	more than 60%	64	G	71	B	V	MEMC bought SunEdison in 2009. Focusing construction of mega solar plants including SI investment in PV power plants.
			22	Jinko Solar	China	2006	S	M	N/A	P	100	G	N/A		V	fully vertically integrated (Ingot, Wafer, Cell, Module) . 10,000 employess. originally ingot, wafer manufacturing → by M&A, began cell & module manufacturing.
	△		23	Moser Baer	India	1983	S	E	N/A	O	N/A	D	40	B	H	6 continents, 35 countries, cell & module manufacturing, coal/hydro power generation. second largest in the world in CD,DVD record media devices. 300MW in India 200MW outside of India in 2012 (overseas 40%)
○			24	China Power Investment (CPI)	China	2002	A	P	N/A	O	1	D	0	B		aluminium, coal production, power generation (thermal, hydro,wind and PV)
			25	TBEA Sunoasis	China		S	E	N/A	P	100	D	0	B	V	silicon, wafer, module and SI business
			26	Jiangsu Zhenfa technology	China	2004	S	E	N/A	P	100	D	0	B		large projects only in China. PV only.
			27	GD Solar	China	2009	S	E	N/A	P	100	D	0	B	V	ingot,wafer,cell,module and SI, only PV, fully integrated
	△		28	Enfinity	Belgium	2005	A	S	51	P	100	G	55	A		sales 375 million Euro in 2011. 105 MW in EPC . among 207MW in total (51% in SI.) Belgium 45%, others 55%
	△		29	EDF	France	2006	A	P	0	O	12	G	84	B		PV is 0.5% out of total business. PV is also 12% of renewable energy business. Government share is 85%. Total sales is 65 billion USD. world wide 4,206MW and France is 690MW (overseas 84%)

Table 8 Summary of research of PV firms

Source: Author's elaboration on interview data and internal firm records

4.4.2 PV systems integrator firms' business strategies

Here, I explore the actual PV systems integration strategies by selecting four major German PV systems integrator firms out of the 29 firms investigated. I interviewed these four firms to compare their PV systems integration strategies.

I picked up these four German firms in order to examine PV systems integrators' strategies because all of these firms were established around 1995-2001 in Germany, where PV industry arose initially in the world PV market. All of them came into the market with their entrepreneurship rather than diversification of large existing firms. They grew up to several hundreds of million US dollars annual sales revenue. There are few firms which can be compared with these firms in terms of size, focus on PV, and availability of information.

The evaluation factors here are consistent with the analysis in table 8 except for the inclusion of strategies for the Japanese market.

Conergy is the one of the large global PV systems integrators firms. According to the interview with Mr. Marc Lohoff, one of the directors, the company was founded by the former chairman, Hans-Martin Ruter, in 1998 in Hamburg, Germany. It had 1 billion Euros sales in 2005. But the company tried to diversify by merger and acquisition (M&A) into the different renewable energy fields, which caused cash flow problem in 2007, and as described in later chapter it restructured itself to focus on its original core-competence business, PV. However, the company had to manage the long-term procurement contract with MEMC, a silicon manufacturer, which was unfavorable to Conergy. Finally, Kawa Capital Management, USA, bought the company without manufacturing businesses in 2013. The company opened its first office in Japan in 2014.

Phoenix Solar AG has an unique history. The Phoenix Solar Initiative was set up in 1994 by the German Association of Energy Consumers. The objective of this consumer initiative launched throughout Germany is to provide high-quality, cost-effective photovoltaic plants, thereby promoting the development of the German photovoltaic market. Dr. Andreas Hanel, former CEO of Phoenix Solar AG, had sold more than 10,000 Phoenix Solar Initiative systems by 1999. The initiative was the basis on which Phoenix Sonnenstrom AG was founded on 1999. All photovoltaic competencies from the initiative were concentrated under Phoenix Sonnenstrom AG. In 2007 the name of Phoenix Sonnenstrom AG was changed to Phoenix Solar AG. According to Mr. Christophe Inglin, former managing director of Phoenix Solar Asia, it has announced explicitly that it would not expand to solar module manufacturing. It identifies itself "internationally active independent PV systems integrator". Independent implies that it would not have any connection with specific module manufacturers, which other PV systems integrators usually do, in order to be flexible to provide the best solutions to their customers.

A Physicist Matthias Willenbacher and an agricultural economist Fred Jung decided to work together and founded Jung and Willenbacher Windenergie GmbH, later re-named as Juwi GmbH, in 1997. They built their first wind power plant in 1997 and connected to the grid. In 1999 Juwi entered the solar business to install its first large PV plant. Although the company expanded its business with more than 1,000 employees in 2010's, but after German solar market collapsed in 2012, it restructured the businesses and decided to concentrate on the development and systems integration of wind and solar farms and their operation and maintenance. In 2014, MVV Energie AG bought a 50.1 % share of the Juwi group.

Belectrtic was founded in 2001 by six shareholders. They are unique in that in their projects they only use thin-film type modules which have been only 5-10% market share of world PV module market. Belectric formed a joint venture with First Solar and EPC alliance with Solar Frontier in 2013, both of which manufacture thin-film type modules. The company was ranked as largest European solar O&M service provider in 2016 by Bloomberg. Although it has not entered module manufacturing business, Belectric manufactures most of the BOS (Balance of systems) components such as cabling, energy distribution and monitoring systems and inverters, which enable them to reduce the costs and reliable systems. According to the interview from management of Solar Frontier, though they tried to utilize Belectric's expertise for Japanese market, they have not been able to be successful yet.

Based on the interview and internal company information, their scopes of work are described in Figure 25. Although Belectric categorizes its work in more detail, basically these four firms do not have much difference in their scopes of work, and they cover all of the areas described in the previous chapter.

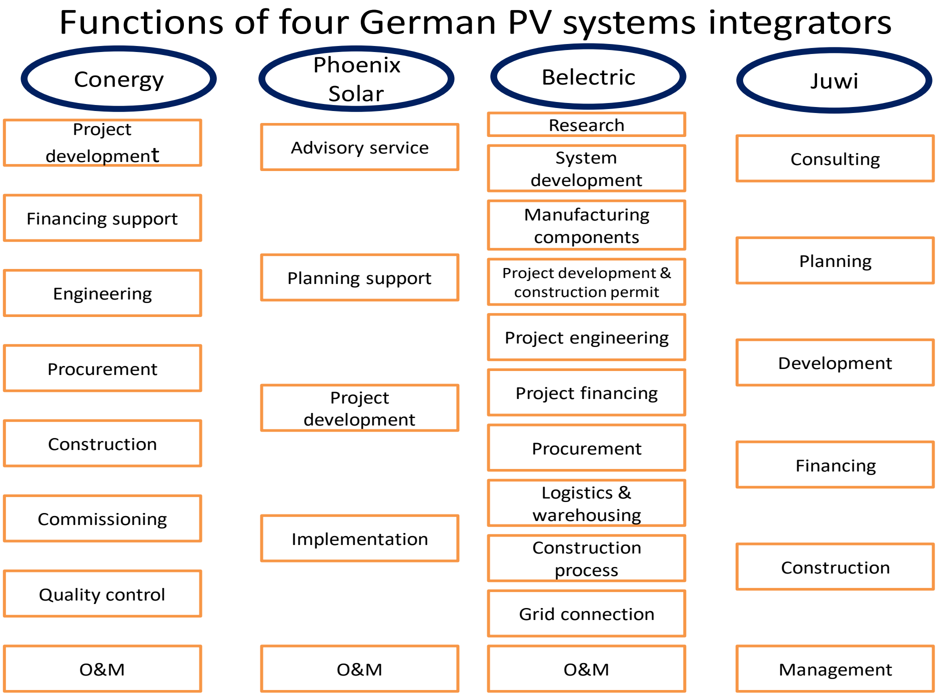


Figure 25 The roles of four German PV systems integrator firms

Source: Internal firm records

Figure 26 shows in what market segments of the PV industry these four PV systems integrator firms are active. Each firm has its own target market strategies.

If we summarize the systems integration roles and put them into our standard form of value chain chart, refer to the following figure 27.

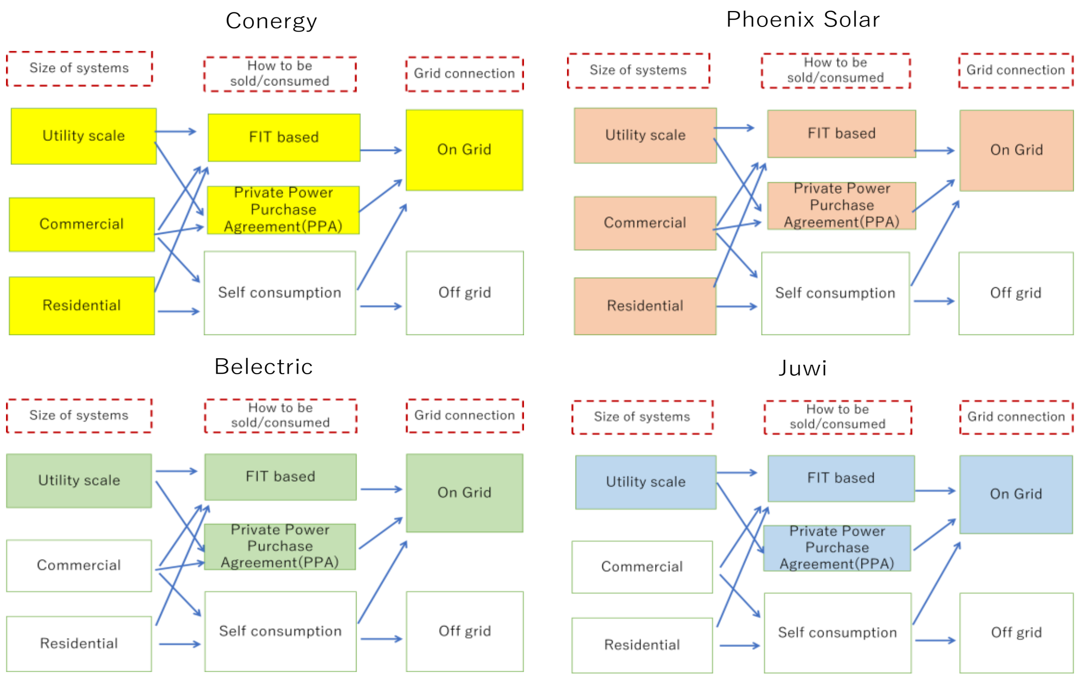


Figure 26 Target market segments of four German PV systems integration firms

Source: By author

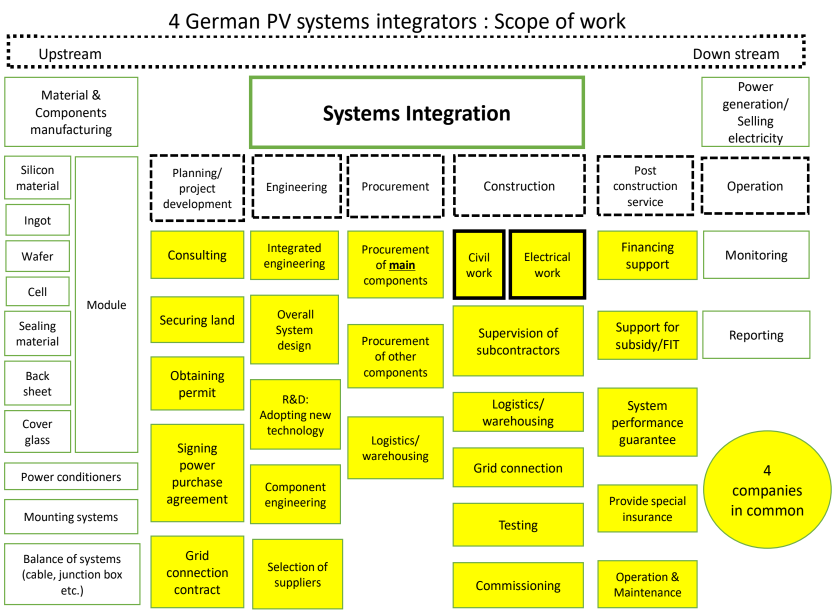


Figure 27 Four German PV systems integrators: systems integration roles

Table 9 shows the details of their scopes of work and differences in the business strategies among them. Colored items are common factors for comparison as the analysis of Japanese PV systems integrator firms discussed in later chapter. The additional items in the table show how these firms are trying to approach to Japanese market.

Comparison of four major German PVSIer firms			Exchange rate : 1 Euro @140 Yen	
	Conergy	Pheonix Solar	Belectric	Juwi
Listed market	Frankfurt	Frankfurt	not listed	not listed
Established year	1998	1999	2001	1996
Number of employee as of 2012	1,700	262	2,000	1,800
Annual sales (2012)	473 Million Euro	155 Million Euro	570 Million Euro	1,100 Million Euro
Accumulated capacity track record	400MW	1,000MW	1,000MW	2,900MW
PVSIer ranking by IMS research (by installed capacity)	out of ranking	9th in 2010, but out of ranking in 2011, 2012	first in 2011, 3rd in 2012	6th in 2011, 5th in 2012
modules used	Established module plant in 2007 to produce crystalline modules, but then spinned off it and sold it to another company.Currently still uses the modules from that plant, but also uses other crystalline modules as well as thin film modules depending on requests from customers.	Uses both crystalline and thin film module.	Uses only thin film type modules. The reason is that thin film is not affected by temperature and generates more electricity than crystalline modules. Also they see much more potentials of improving technology in thin film in the future.	Uses both crystalline and thin film modules.
Main brands of components	module: Conergy mounting system: Mounting System power conditioners: SMA	module: has alliance with REC module in Norway They consider themselves as an independent SIer as they can source any module.	module: First Solar, Solar Frontier, Sharp only(all are thin film) power conditioners: SMA	module: has alliance with First Solar mounting system: Scheletter power conditioners: SMA
Degree of PV business	Dealt with other renewable energy business than PV until 2005. Expanded by M&A acquiring 48 firms. After building several plants of wafer,cell and module in 2007, concentrated on PV. Then sold other renewable business, ceased production of wafer and cell, they focused module, mounting system, and SI business. Splitted into several companies after financial problem in July 2013, currently engaged in only PVSI business.	PV 100%	PV 100%	Deals in 50% in PV and 50% in wind power. (installed capacity : PV 1.4GW, Wind 1.5GW) Was able to keep away from excessive competition due to global PV market decline by diversification.
Degree of SI business	90% was their SI business in 2008, but later sold their power conditioner manufacturing subsidiary and module manufacturing subsidiary, was 100% SI company in 2012. Manufacturer + PVSIer ⇒shifted to 100% PVSIer	Originally has not had production segment and SI only. Half of sales is wholesale business of components and other half is PVSI business.	Originally 100% SI.	Dealing in IPP business in a different affiliated company, but basically only SI business of development, EPC, O&M. No production business. 100% SI business.

Targeted markets in PV business	Depends on the areas, but basically deals in all of three markets (residential, commercial, utility scale)	Deals in all three markets because they believe this creates synergy.	utility scale business only.	utility scale business only.
Degree of overseas business	Has offices in 5 continents, 15 countries, 44 locations worldwide. Has business 27% in Germany and rest are other European countries, USA, Asia. Degree of overseas business is 73% (2011).	Has offices in Munich (head office), USA, Singapore, France, Greece, Italy, Spain, Malaysia. Overseas business is 70%, domestic 30% in 2012.	Has office in 20 countries in 5 continents, but their business is maily in Germany. Also other European countries such as France, Italy, Poland, Spain, Turqy, England, Greek. Also USA, India, Australia, UAE.	Business in Germany is 1GW out of 1.4 GW in PV. Maily Europian countries such as Italy, France, England, Spain. Other than Europe, North America, India, South America. Overseas is 30%, 70% in Germany. Announced that they are going to USA, Japan due to the demand decrease in Europe.
Strategy towards Japanese PV market	Established a Japanese subsidiary in 2013(Conergy Japan Inc.). Appointed a Japanese, the former president of the subsidiary of Sojitz(Japanese major trading company), who used to work in Germany.	They have thought that there is vertical integration by major PV module manufacurers, need to speak Japanese language or hire Japanese people , and business customs are normally bureaucratic and therefore no chance to enter this market for foreign PVSIers. However after attractive FIT scheme is implemented, they are trying to enter Japanese market.	They established PVSI company as JV in Europe with Solar Frontier(Japanese module manufacurer) in 2012. Then they had an alliance agreement in 2013 with Shoseki Engineering (a group company of Solar Frontier) to enter Japanese mega scale PV market.	They established a JV with Shizen Denryoku (Japanese PV company) in 2013 with 50%-50% equity to enter Japanese PV market. They have not had any JV in the world except Japan and usually enter the local market by themselves. They also say that they will enter wind power business in Japan.
Current status in Japan	Other than this Japanese person, they have Australian sales manager who used to work in energy industry at Japanese trading company, Japanese engineer, a female assistant, in total 4 people.Their target is 100MW in installation in 2014. Currently focus on large scale PV plant project,but will start also residential business.	They are currently doing research for Japanese market and seek for a partner in Japan.	They entered Japanese market in the beginning of 2014 with this alliance. But they do not have regular German staff in Japan.	They already have seven foreign staffs in Japan. Three of them are working in Tokyo office and four of them are usually going around Japan dealing with several projects. Currently they have many projects particulary in Kyusyu.
Details and Differentiation of PVSI roles	8 phases : Project development, Financing Support, Engineering, Procurement, Construction, Commissioning, Quality control, O&M	5 phases : Advisory service, Planning support, Project development, Implementation, O&M	11 phases : Research, System development, Manufacturing components, Project Development & construction permit, Project engineering, Project Financing, Procurement,Logistics & warehousing, Construction process, Grid Connection, O & M Especially keep their competitiveness in price by handling projects with their own team rather than oursourcing .	6 phases : Consulting, Plannning, Development, Financing, Construction, Management

Table 9 Comparison among four German PV systems integrator firms
Source: Author's elaboration on interview data and internal firm records

Germany has been a pioneer in the development of the PV industry. All four firms were established around the 1990s to 2000s, earlier than PV systems integrator firms in other countries. These German PV systems integrator firms were dominant in the global PV systems integration market in the 2000s up to around 2010 until Chinese and American PV systems integrator firms emerged to become dominant recently. These four firms have different business strategies. Juwi not only has PV business but also other renewable energies, such as wind power, thereby dispersing the business risk. Juwi commented that they were able to avoid the turbulence of the PV market, the drastic price decrease, and the oversupply of PV modules via this strategy. Juwi is called the "Google in energy industry," where its corporate vision is clear, the employee's work-life balance is maintained well, and its contribution to the local economy is always considered. Conergy tried to differentiate from its competitors by owning manufacturing segments for modules, inverters, and mounting systems, but due to having owned manufacturing segments, it was affected significantly by the drastic price decrease of PV modules and the price volatility of module materials, which resulted in its insolvency in 2013, and the company was divided into several companies. The other three firms except for Conergy have focused on systems integration and have avoided the plunge in revenue that undermined Conergy. The PV market is normally divided into three submarkets in terms of the sizes of projects: residential market, commercial market, and utility-scale market. Conergy and Phoenix are active in systems integration in all three markets hoping to achieve synergies among these markets. On the other hand, Belectric and Juwi are focusing only on the utility-scale market to achieve the large economies of scale that are easier to achieve in this market. However, all of these firms are seeking the most attractive markets, and therefore, they often have changed the target markets depending on the growth expectations for each market. What is interesting is that the major pure and independent PV systems integrator firms that are currently dominant are all German companies. It is true that Chinese and American module manufacturers are trying to enter the PV systems integration segment, but that is only an extension of their module sales business strategies. Moreover, the German firms have made the greatest progress in expanding their systems integration services outside their home markets, including increasingly outside the EU. To the extent that Chinese PV firms do systems integration, it is almost entirely domestic. First Solar is expanding its operations, including systems integration, outside the U.S., but overseas systems integration services still account for just a small proportion of total revenue. Figure 28 shows the comparison axis in business strategies among these four German firms.

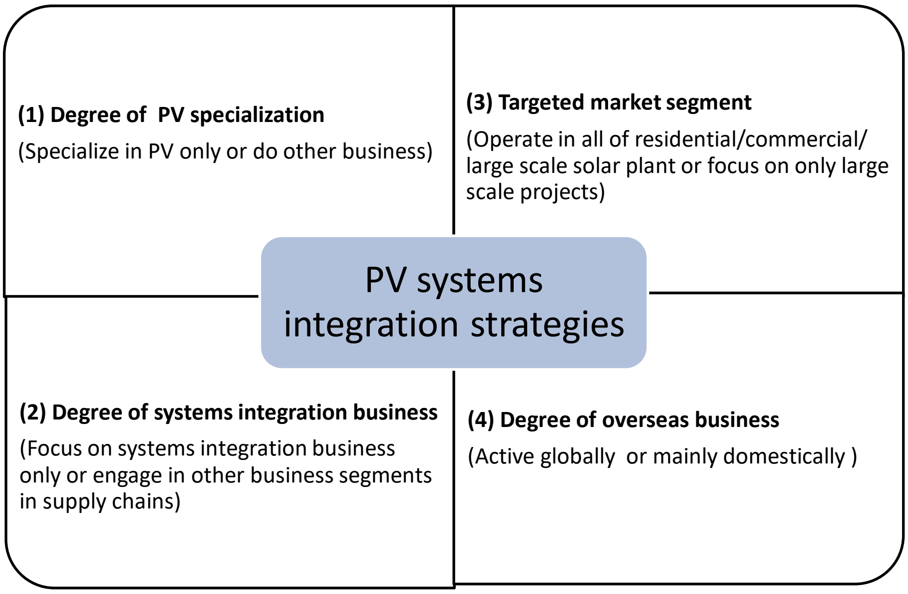


Figure 28 Strategic dimensions of PV systems integration strategies
Source: By author

There are several market categorizations in the PV industry,[9] but in this dissertation, I follow the following normal categorizations in three segments: residential market (under 50kwp), commercial market (50kwp-1MWp), and utility-scale market (more than 1 MWp).[10]

Figure 29 shows the differences in the PV systems integration strategies in these four firms.

The differences of four German PV systems integrators in business strategies

PV system integrators	Conergy	Phoenix Solar	Belectric	Juwi
①Degree of PV business	Concurrent business ⇒PV only	PV only	PV only	50% PV 50% wind
②Degree of SI business	Manufacturer +SI ⇒ SI only	wholesale of components & SI	SI only	SI only
③Target markets in PV business	All three markets (large scale, commercial, residential)	All three markets	Large scale only	Large scale only
④Degree of overseas business	Worldwide	Worldwide	Mainly Europe	Mainly Europe

Figure 29 Summary of the differences of PV systems integration strategies: Four German PV systems integrator firms
Source: By author based on interview and firm records

4.5 Conclusion/discussion

The case study in the actual PV plant construction project in Thailand by Conergy, one of the major PV systems integrators, clarified how prime contractors (normally systems integrator firms) and sub-contractors allocate each other their tasks.

The statistics of PV module manufacturing firms and global PV systems integrator firms shows the significant transition of manufacturing and systems integration segments worldwide indicating drastic fall of Japanese PV manufacturing firms and rise of Chinese PV manufacturing firms as well as systems integration firms.

We can see from Table 8 several implications. Almost all PV specialized companies were established around late 1990's to 2000. They have only 10-15 years company history. The exceptions are Japanese companies such as Sharp, Kyocera, Solar Frontier which began their technical research development around thirty years ago. The industry itself is very young and has only short history and therefore little research has been done academically.

There are two directions among PV modules manufacturers: focusing only production PV modules (Trina, JA Solar, Yingli) and expanding their scope to systems integrations, as they call "solutions business" (First Solar, Sun Power). As Mr. Yeon, sales manager overseas, solar business division of Toshiba says, although some of the manufacturers have tried to expand their business to systems integration, they gave up in doing so after they found out that it was better option for them to focus on manufacturing and leave systems integration work to specialized PV system integrator firms.

There are several existing large companies which entered PV module manufacturing business in addition to Japanese companies mentioned here. AUO, one of the largest Taiwanese plasma display manufacturers, has a division of solar business as well as Moser Bauer (India), one of the largest optical storage media manufacturers.

We can see from Table 8 that the major technology in PV modules market is crystalline silicon. Major manufacturers that use other technologies are First Solar (USA) and Solar Frontier (Japan) only. Their technology is thin film modules, whose market share in term of category of module in the world is less than 10%. This point does not relate to systems integration directly, but the world's largest system integrator in 2012, 2013 in terms of volume of installation is First Solar. The company has been successful in systems integration partly by using and promoting its own unique technology.

We can also point out that almost all module manufacturers are seeking vertical integration rather than horizontal specialization in the manufacturing process. Some companies make cell or module only, others make modules (final product) from silicon materials, ingot, wafer, cell and modules. That is based on the companies' internal records, published promotion kits, and web sites. They explicitly commented that they would seek either specialization or vertical integration. This trend seems to be a little different from the trends of other manufacturing industries, where they either tend to focus on their core competence and outsource other parts and processes or integrate all the processes in-house. According to interviews with major manufacturers, PV module manufacturers believe that, by vertical integration, they can achieve a high level of quality control, create more room for cost reduction, and save logistic costs that would be needed in specialization (Interview with the management of Trina Solar and AUO). Particularly since they have to compete with competitors in terms of price, they tend to build module factories near their consumer markets, seeking "local production for local consumption". However, it should be noted that this particular company, Trina Solar based in Changzhou, China, does not do systems integration and obtains almost all its revenue from sales of its modules.

Almost all global PV-related firms were independent firms established originally to do PV business, except for the Japanese firms (Sharp, Kyocera, Solar Frontier, Mitsubishi, Toshiba, Panasonic and Kaneka) which started their businesses originally as departments of a large corporation. The scope of these Japanese companies is mainly manufacturing and selling PV modules while some of them, like Sharp, are trying to provide HEMS (Home Energy Management System) with PV modules to their residential customers as a package of their product line. (Mr. Inada, general manager of energy solution business, Sharp: PV Eye, May 2017). These Japanese PV divisions of large companies still have the same business structures except for Solar Frontier, which was spun off from Showa Shell Sekiyu, a major oil refinery company. [11] As mentioned above, there is insufficient data to indicate that any of the major Japanese PV firms is substantially engaged in systems integration activities.

The case study of four PV systems integrator firms' business strategies shows how these entrepreneurial German firms were established and have grown. As contrasted in this chapter they have various strategies. In contrast to major PV module manufacturers which all have similar business strategies: reducing costs, improving power-generation efficiency, and improving the vertical integration manufacturing process, these four PV systems integration firms, although they were established in Germany in the same period, have a variety of strategies. This suggests that there currently are a wider range of promising growth models or options in the PV systems integration business compared with PV module manufacturing. Nevertheless, systems integration seems easy in a firm's domestic market. Empirical data so far suggests it is more challenging to conduct systems integration in foreign markets. This may be because of the needs to rely upon and interact with many local companies, as illustrated by the case study of Conergy in Thailand.

4.6 Limitation

The analysis in this chapter is based mainly on case study method through in-depth interview with several firms and has a limitation. 29 PV firms are examined in terms of pre-determined factors, but information on Chinese firms were not available. Also the analysis of PV systems integrator firms' business strategies are explored with four major global PV firms which were incidentally all Germany firms and therefore they may have specific characteristics due to their common origin.

5. Japanese PV systems integrator firms

5.1 Background

In this chapter, I discuss Japanese PV systems integrator firms. According to the report by the New Energy Industry Research Conference in the Ministry of Economy, Trade and Industry dated Sept. 2012, "The global size of new energy industries will be 2.8 times larger in 10 years and will be 86 trillion USD in 2020. In the PV industry, the profit margin of upstream segments, such as module manufacturing and materials, is going to decrease due to new market entries by many firms. However, the profit margin in the downstream segments, such as systems integrators who handle turn-key service, actual operation and operation & maintenance and power producers, is going to increase. The systems integration business will definitely be an opportunity to grow for Japanese firms." In this chapter how Japanese PV systems integrator firms are performing is discussed.

5.1.1 Categorization of Japanese PV systems integrator firms

52 firms are registered in the category of "sales and construction (including general construction, housing, systems integrators)," which is the main role of PV systems integrator firms, along with other categories such as "cell/module manufacturers", "balance of systems, material, components manufacturers" and "power producers", among 134 member firms in the Japan Photovoltaics Energy Association (JPEA). This organization is the largest PV-related industry association in Japan. There are different kinds of firms in terms of their core business, size and origin in the 52 firms. I attempted to categorize these 52 firms into 5 different groups.

<u>Group (1) Japanese subsidiary firms of foreign-affiliated big PV systems integrator firms</u>

Conergy Japan (a Japanese subsidiary of Conergy) and Shizen Denryoku Group (which has a joint venture in Japan with Juwi, discussed in chapter 4) are included in this type.

<u>Group (2) Electrical construction companies, engineering companies</u>

TOENEC, Fuji-Furukawa E&C, JFE Engineering, Toko Electrical Construction and IHI Plant Construction are included here. They specialize in electrical construction needed for PV installation, and they can use their know-how and experience for PV installation construction. However, they consider the PV-related construction business as one of the extended businesses from their core electrical construction rather than their new core business.

Group (3) Pure Japanese PV systems integrator firms

Nitten, Xsol, and West Holdings are included here. These firms are not large, compared with the 4 global German PV systems integrator firms, which I discussed in the earlier case study, but they clearly focus on PV-related sales and construction. These firms are still young, with only 15 years or so since their establishment.

Group (4) Housing construction companies, housing facility companies

Misawa Homes and LIXIL are included here. These firms mainly handle the residential PV installation market as an extension of their core business of residential construction/residential facilities.

Group (5) Others

ORIX and NTT Facilities are included here.

See table 10 for this categorization which shows 52 PV systems integrator firms.

52 JPEA members of PV systems integrator firms					
category	(1) Subsidiary firms of foreign PV systems integrator firms	(2)Electrical construction/ engineering construction companies	(3)Pure Japanese PV systems integrator firms	(4)Housing construction/ housing facility companies	(5)Others (leasing companies/ large facility companies and others)
	Krannich Solar Japan	IHI plant construction	West Holdings	Attaka Mori No Kunikara	NTT Facilities
	Conergy Japan	Enetec	EL.E	ESM Daikin	Orix
	Shizen Denryoku	Ooshima Electrical construction	Xsol	Orvis	Coretech
	Europe Solar Innovation	Kokko Facility	Ecosmile	Gantan Beauty Construction	Toshiba
		JFE Engineering	Energy Products	Sanix	Hitachi
		JFE Plant Engineering	K&M	Sanko	Yanegiken
		Smart Tech	Solar Partners	Sanwa House	
		Seibu Electric	Nitten	JM	
		Toko Electric	Japan Eco System	Sekisui	
		Toenec	Japan Eco Life	Takashima	
		Nippon Lietec	Next Energy	NAC	
		Fujisaki Electric	Meisei Shokai	Noritz	
		Fuji Furukawa E&C	Rising Corporation	Makitec	
		Mitsui Bussan Plant Systems		Misawa Homes	
				Lixil	

9

Table 10 JPEA members of PV systems integrator firms

Source: JPEA

5.2 Purpose

We observe many European/American PV systems integrator firms being active in the global PV market, but there are almost no Japanese PV systems integrator firms being active outside of Japan, while many Japanese PV module manufacturers used to be dominant in global PV market a decade ago. The purpose of this chapter is to explore how Japanese PV systems integrator firms are doing in PV industry overseas as well as in Japan and attempt to present implications for Japanese PV firms.

5.3 Methodology

In these 5 groups above I picked one firm, each, from groups (1) and (2), and two firms from group (3) that have different characteristics in each group and then made a comparative analysis based on interviews with each firm about how it is performing and what the differences are in terms of PV systems integrator firm activities. I selected these firms because they have the typical standard characteristics of each group (1), (2) and (3). I did not select a firm from category (4) and (5) because firms in category (4) are typical housing construction companies who handle residential PV installation only and firms in category (5) are very large companies in other areas or very small firms.

The evaluation factors are consistent with those in table 8 so that we can easily compare with firms in Germany and other countries.

In addition case studies on Japanese PV firms show both how they are doing domestically and globally.

5.4 Result

5.4.1 Characteristics of Japanese PV systems integrator firms

Table11 summarizes the result of interviews with 4 Japanese systems integration firms. The activities in PV projects are similar to what German firms as we observed in the previous chapter. However the size of firm are small and scope of work in systems integration are narrow compared with German firms. The colored items in the table are common factors as German PV systems integrator firms.

	Shizen Denryoku Group	Toenec	Xsol	Nitten
Listed market	Not listed	Nagoya	Not listed	Not listed
Established year	Shizen Denryoku was established in June,2011. The Joint Venture with Juwi(Germany),Juwi Shizen Denryoku, was established in 2013.(Juwi is a major PV/wind power Systems integrator established in 1996.)	Oct. 1944	Jan. 2001	Apr. 2001
Number of employee	approximately 100	4,772 as of March 2015	464 as of Jan. 2016	40 as of Aug. 2015
Annual sales	N/A	1,907 million USD (March 2015)	468 million USD (May 2014)	N/A
Main businesses	Development, design, procurement, O&M of renewable energies such as PV, wind, hydro, geothermal.	Planning, design, construciton, maintenance of electrical , communication network, air conditioning, power generation.	Planning, construction, sales, operation, O&M of PV power system and retail of electricity	Construction, sales of PV system, reforming of residence, sales of all electricity system
Degree of PV	PV only up to 2015, but will enter wind, hydro, geothermal power in 2016. Currently PV 100%.	They do not disclose the share of PV business,but approximately 10%.	100% Their original main business was sales and trading of products of related products.	100% They are trying to develop other renewable energy business, but not achieved yet.
Degree of SI	Mainly systems integrator business in renewable energy, but sometimes they own facilties by themselves. Their SI trackrecord is around 500MW and they own 22 MW, therefore estimated that 5% is no SI business, which is power generation business.	They are basically general electrical facility construction company. They have PV- related business in one of the segment, solutions business department. Not disclosed in details. They have other 5 departments: Electrical facility construction, communication network facility, air conditioning facility residential related construction.	They have some other PV related business than PV systems integrator (PV power generation, sales, O&M), but estimated that 80% is PV systems integrator business.	100% They are ranked as NO. 1 residential sales dealer for Solar Frontier module in 2015.

Targeted market in PV	Large scale projects only.	Mainly public and commercial projects.	They were once No. 1 of sales dealer for Mitsubishi and Canadian Solar modules for residential market. But now concentrate on commercial - large scale projects.	90% is residential business.
Degree of overseas business	No overseas business. Has an alliance with Juwi (German PVSIer) in Japan.	They have overseas subsidiaries in Taiwan, China, Indonesia, Thailand, Philippines, mainly Asian countries. They do not have their own PV plant business oveaseas except that they are subcontracted from bigger general construction compan.(see the case study in the Philippines in chapter 5.)	They have offices and their own PV power plants in Shanghai and Korea.	No overseas business.
Other notes	Since they are focusing on large scale PV projects, they specifically appeal their capability of developing projects and financial assistance.	Cyubu Denryoku (major utilitys company in Cyubu area) has 50% share of this company.	They used be originally a sales dealer for Mitsubishi PV modules. Now selling not only Mitsubishi, but Canadian Solar, Toshiba, Sunpower, Ingli, First Solar. They appeal their one-stop service in PV solution including EPC and O&M.	Established as a retail division of Solar Frontier, but re-established as Nitten in 2009 by MBO. Since the establishment for this 9 years they have built 2,000 residential PV installation. Their 95% of business is Solar Frontier modules.
Interviewed person	Interview with founder and current CEO, Mr. Ken Isono.	Interview with Mr. Yoshida of TOENEC PH.	Interview with Mr. Shinichi Suzuki, President.	Interview with Mr. Hiderou Gouma, sales manager of corporate business.

Table 11 Summary of comparison of four Japanese PV systems integrator firms
Source: Author's elaboration on interview data and internal firm records

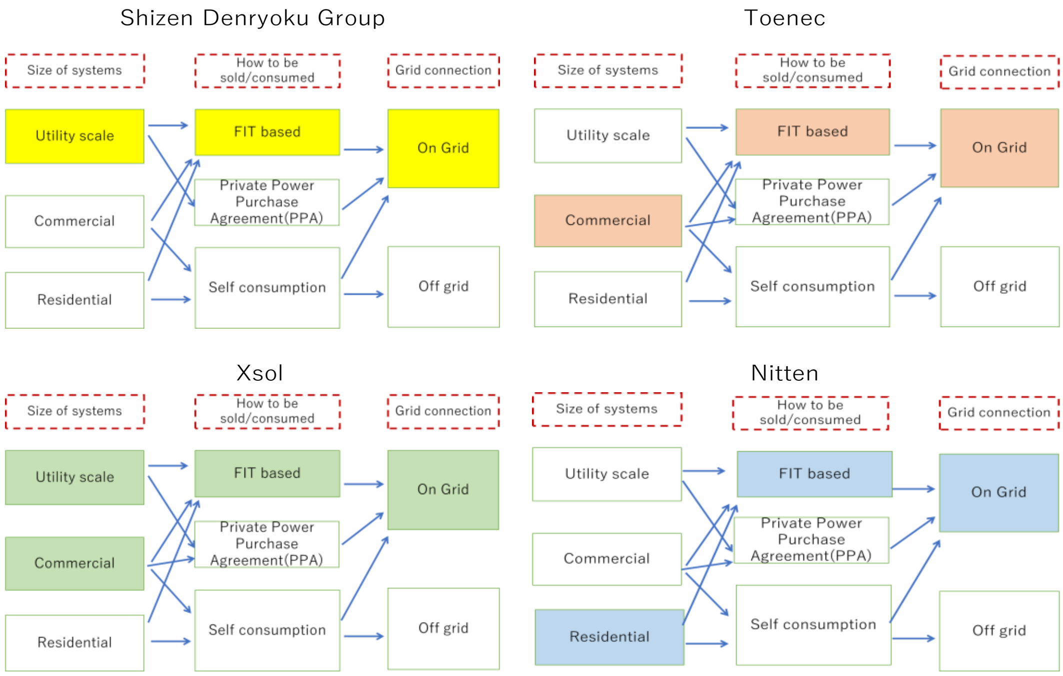


Figure 30 Target market strategies of four Japanese PV systems integrator firms
Source: By author

Figure 30 shows in which segment of PV market these four Japanese firms are working. The following chart figure 31 shows their scope of systems integration roles.

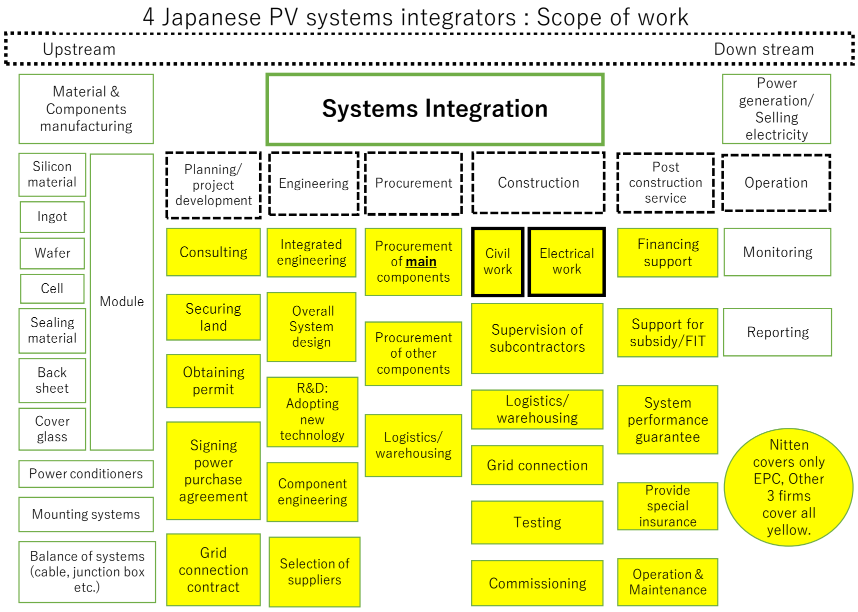


Figure 31 Four Japanese systems integrators: systems integration roles

5.4.2 Case studies on Japanese PV systems integrator firms

(A case study of company U)

I use an example of a company I identify as U, which is a middle-size Japanese PV systems integrator firm to examine how Japanese PV systems integrator firms are doing in Japan. (The names of the companies are indicated in alphabet as U to protect confidentiality.)

This firm has been active in the renewable energy business as a department of a large firm group whose core business is logistics. In 2009, it entered the PV-related market and moved forward with full-scale implementation of projects in this area. It established a joint venture in the PV business with a local big firm in the Philippines (described in the next case study). Then the parent company spun it off from the renewable energy department as a business subsidiary in 2012. This subsidiary firm is now handling PV construction, from commercial rooftops of factories/warehouses to utility-scale projects, as a PV systems integrator firm. It is categorized in group (3). The following is a case study of an actual utility-scale project that this firm undertook. Since firm U is also a power producer, this type of activity is known as a "self-development project." Table 12 shows the overview of this project.

Business plan

Project name　：　Gotemba PV project

Overview of the project

Owner of project：Power producer SPC of Company U

Site：Roof top of parking lot at Company R in Komamon, Gotemba, Shizuoka

7,985.82㎡　(Owner of property ：Company R)

Selling PV power to ：Tokyo Electric Power Co.　(Feed-In-Tariff @36 yen)

Prime contractor : Company U

Sub contractor ：Company K

Construction period: Jan. 2016-May,2016

System specifications

System capacity ： 967kW

Module used ： Solar Frontier 165-S × 5,860 pcs

Power conditioner ： 500kW × 2

Annual electricity production ： 1,062kWh

Table 12 Business plan of the Gotemba project

Source: Internal firm records

Gotemba project: total business structure

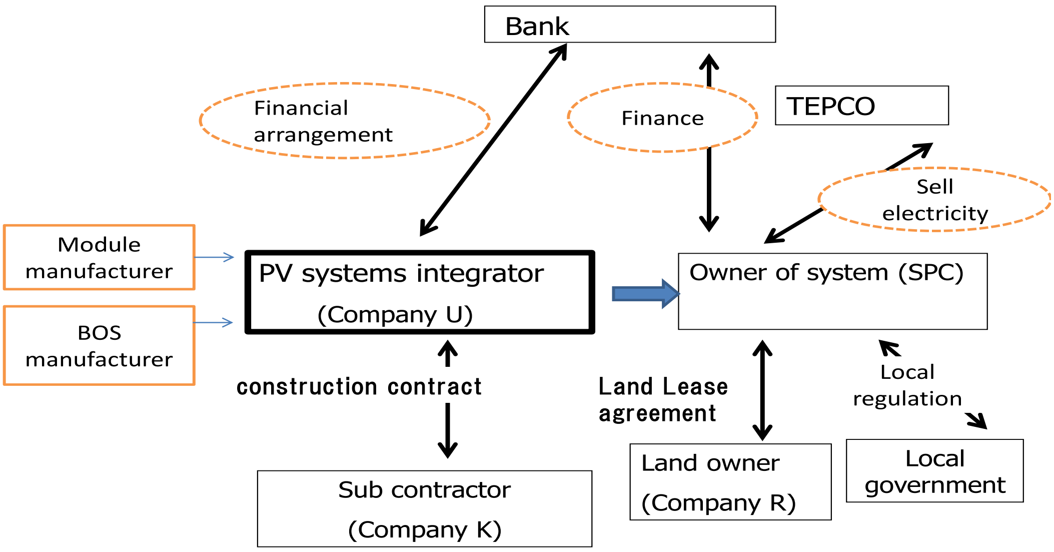


Figure 32 The business scheme of the Gotemba project
Source: Internal firm records

Firm R planned to be a power producer itself on its property, but it finally decided to lease its roof to a third party (firm U), which would provide systems integration services, and firm U became a developer and power producer. Under the current arrangement, firm U will set up a special purpose company (SPC) that will generate power under a feed-in-tariff scheme as well as perform as a systems integrator firm.

In this project, systems integration tasks are allocated between firm U, which made an equity investment in the SPC, and firm K. Integrated engineering is performed by firm U. Almost all electrical parts and components except for main components are procured by firm K. Actual construction is performed by firm K. Project development work, such as negotiation and coordination with Tokyo Electric Power Company (TEPCO), is done by firm U, but firm K also joins firm U on negotiations with TEPCO, giving advice. Firm U selects and procures particular PV-related components such as PV modules, power conditioners and balance of systems because of its specialized knowledge. Firm U also supervises and manages the construction by firm K. Some of the most important roles of firm U as a systems integrator are coordination with the local government administrative office, applications for development permits, and negotiation of the grid connection with TEPCO to finalize the entire contract. This length of time required by these activities varies depending on projects and sometimes takes a few months per negotiation. Firm U has to visit local offices often to get and exchange new information (Figure 32).

Figure 33 shows the market segment where Gotemba project is implemented.

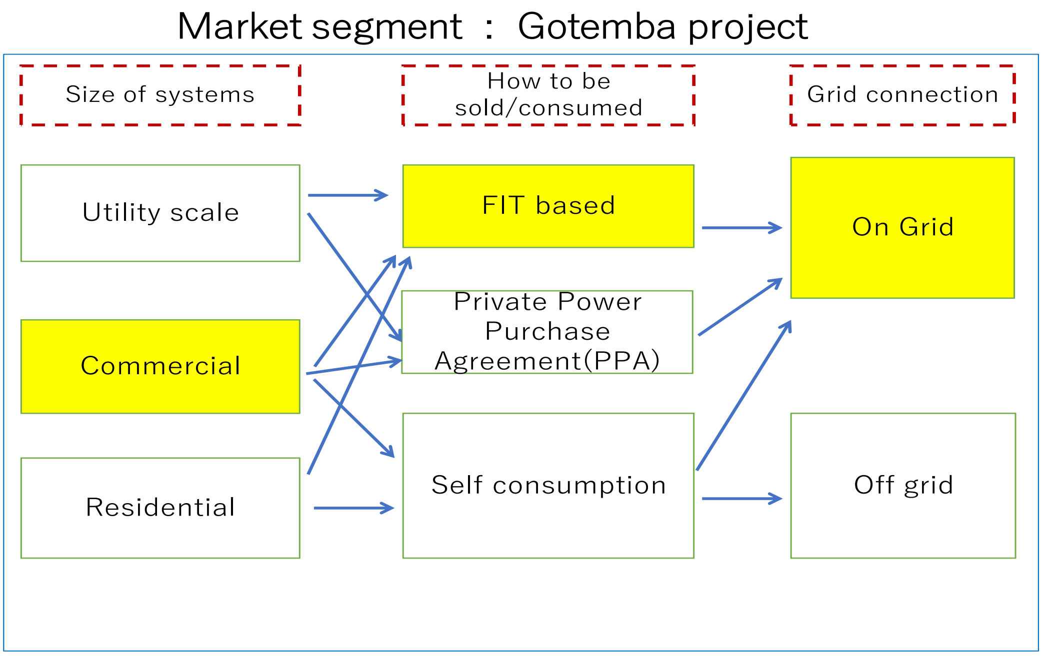


Figure 33 Market segment of Gotemba project

Source: By author

The following figure 34 shows how company U and company K divide their roles in systems integration.

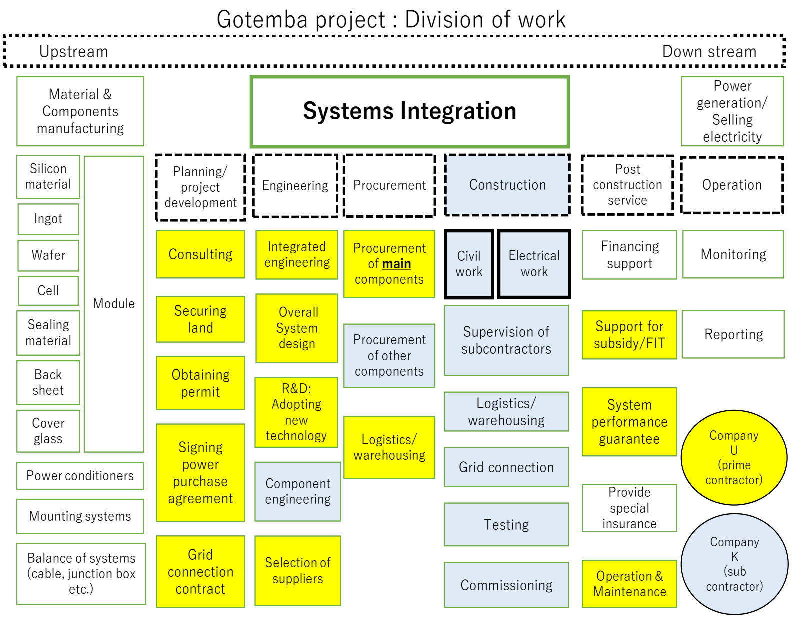


Figure 34 Gotemba project: systems integration roles

Source: By author

Table 13 below is the summary of the business plan of this project.
The total investment is 305 million Yen, and the payback period is 14 years. The IRR for 20 years is 3.1%. Normally, systems integrator firms make this type of investment plan simulation for their clients.

Summary of plan in investment and profit	
□Total investment cost	
Design and construction	216 Million Yen
Components cost	76 Million Yen
Other costs	13Million Yen
Total investment cost	305 Million Yen
□Power generation profit projection (20 years average)	
Revenue	36 Million Yen
Rent of land, O&M, admin.	12 Million Yen
Depreciation	15 Million Yen
Ordinary income	9 Million Yen
ROI	1.7%
IRR	3.1%
Payback period	14 Years

Table 13 Summary of business plan for the Gotemba project
Source: Internal firm records

(A case study of company TU,Philippines : the overseas PV business subsidiary of company U, Japan)

Now we examine the PV systems integrator firm business performed by firm TU as a joint venture between firm U and a local firm T in the Philippines, as an example of global market entry by a Japanese PV systems integrator firm. Very few Japanese PV systems integrator firms have overseas business. Firm U started its overseas PV systems integrator firm business by establishing a JV (firm TU) in 2011 in the Philippines.[1] [2]

A major Japanese printing machine manufacturer (company E) plans to install a 3MW PV facility on the rooftop of its new factory. This will be the largest PV installation among Japanese firms in the Philippines, and many module manufacturers and local construction companies have been competing to get this business. The manufacturer was in the final phase of narrowing down its "formation" (modules, other components and their procurement and selection of construction companies). I will examine how specific schemes have been performed in terms of systems integration tasks. Figure 35 shows the allocation of systems integration tasks between the firms.

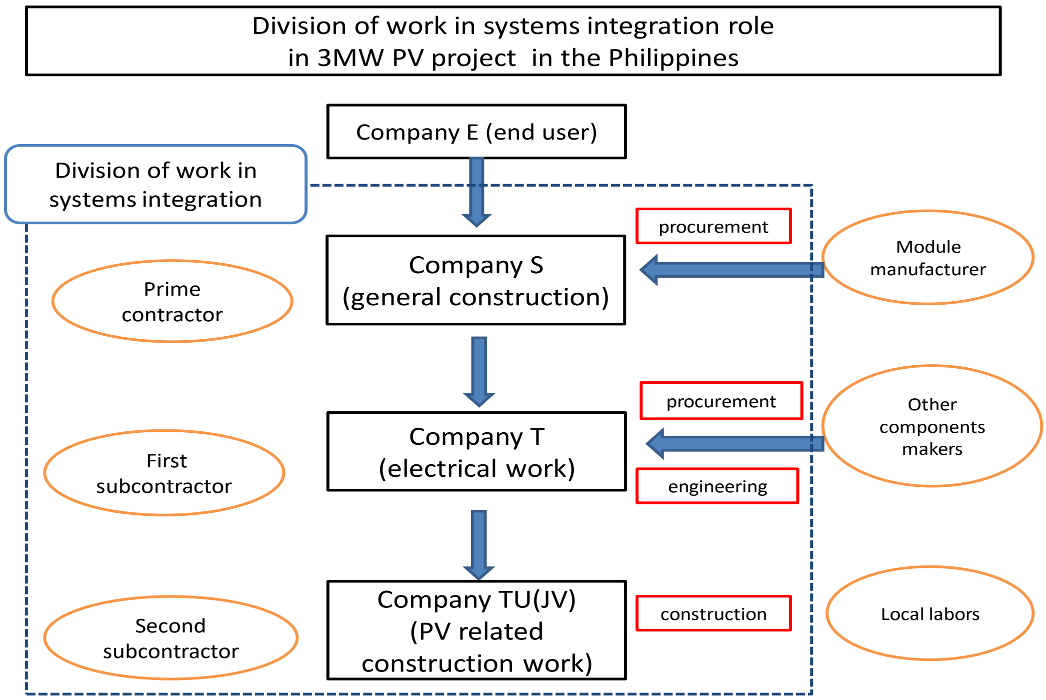


Figure 35 Three Mega Watt PV project by a Japanese printer manufacturer in the Philippines
Source: Author's elaboration on interview data

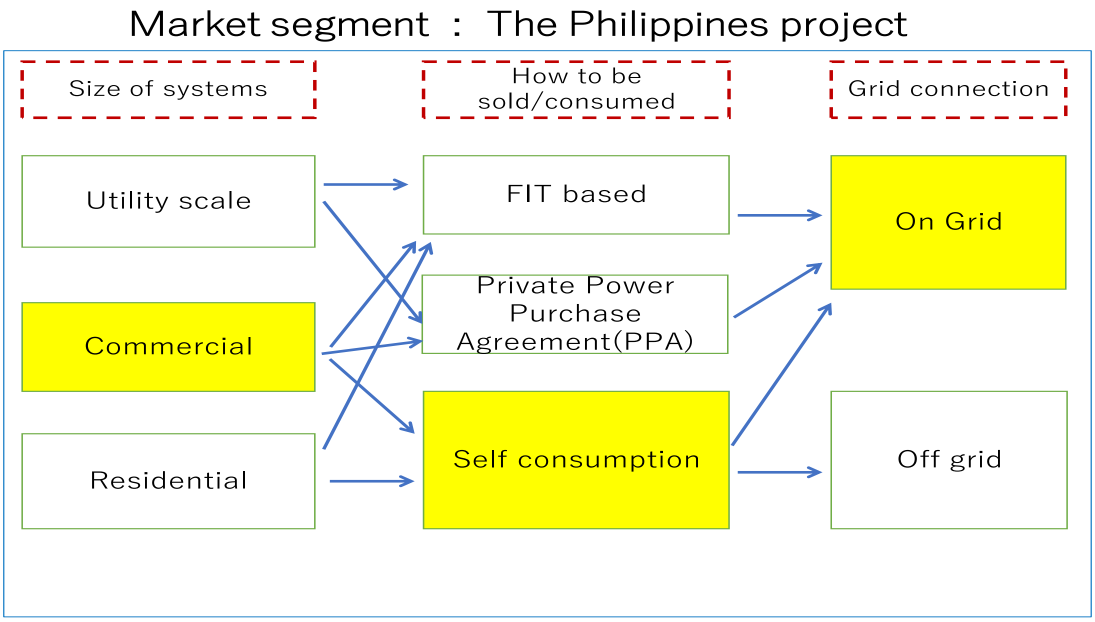


Figure 36 Market segment of the Philippine project

Source: By author

Figure 36 shows the segment of PV market where this project is performed.

The following figure 37 shows the multi-layer division of work in systems integration in our standard form of systems integration role.

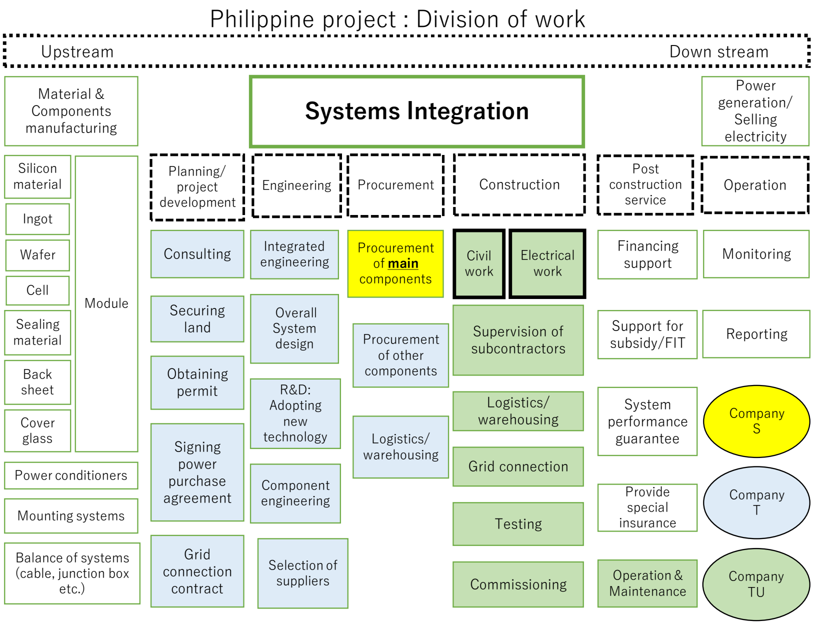


Figure 37 The Philippines projects: systems integration roles

The owner of this project is firm E. In other words, the investor is firm E, which will benefit from this project. What is particularly interesting is that multiple-layer subcontractors are performing systems integration tasks, as is done in typical general construction projects in Japan. Firm E appointed Japanese super general construction firm S as the prime contractor that will handle the entire project, including building Company E's new factory. Firm S is responsible for the entire new factory expansion project, valued at 120 million USD, and has subcontracted its electricity work to firm T. Firm T has a contract for PV installation valued at 5 million USD along with contracts for other electricity work for the new factory. Firm T also subcontracted its tasks partially to the local PV systems integrator firm (in this case, company TU) as a secondary subcontractor.

In the Philippines, these kinds of multiple-layer contracts are very rare. This is an example where the typical Japanese practice of a "multilayer contract" has also been seen in overseas projects run by Japanese companies.

Among the main functions of EPC (engineering, procurement, construction), engineering, such as designing, is done by firm T. Firm S selects and directly procures modules, which are one of the major components. Major balance of systems, such as power conditioners, are selected and procured by firm T by using its advantage of its core business of electrical construction. The second subcontractor, a local PV systems integrator firm TU only performs work related to PV installation.

This allocation of tasks also differs from typical PV systems integration activities. According to the interview from Mr. Sento, former director of Taisei Corporation, a Japanese super-large general contractor, this practice of splitting up tasks to several companies in a project is popular only mainly in Japan, probably because Japanese clients prefer contracting with large construction firms, who prefer to subcontract some tasks to subcontractors which have more specialized expertise in certain areas. In the example of above project in the Philippines, firm TU may have preferred to be responsible for additional tasks (such as procurement of components etc.), however as long as it can perform a specialized role in PV installation, including giving advice to its prime contractors, it would end up performing specialized PV systems integration roles that nobody else in the project performs. That would give firm TU a certain revenue and profit.

If Japanese firms like firm T in this project had not subcontracted systems integration roles to firm TU and had performed it by themselves, they would have been able to build up PV systems integration expertise.

5.5 Conclusion/discussion

5.5.1 Implications for Japanese PV firms

In this chapter, I have categorized Japanese PV systems integrator firms into five types and examined the actual practice of their activities by interviewing specific firms among three of the most types. Also, I looked into the activities of a medium-size Japanese PV systems integrator firm and examples of its Japanese and overseas projects. The analysis leads to observations on the following themes.

(The unique background of Japanese PV systems integrator firms)

Among the 48 non-foreign affiliate Japanese PV firms in table 10, almost all were already large firms in other industries that entered the PV industry (in the case of Sharp, Kyocera, Mitsubishi and other electronic majors, as module manufacturers) and then subsequently began to assume systems integration roles in this industry. In other words, not only are they new to systems integration activities, they are also relatively new to the PV industry as a whole, and their core business activities still are outside the PV industry. The notable exceptions are the group (3) companies, but the largest of these has total annual revenue of only 460 million USD (West Holdings in 2015, which included not only systems integration business but also PV power generation and components businesses.) Other group (3) firms have 50-100 million USD annual sales revenue, and the median year of formation was around 2000. This completely differs from the situation in Germany, where major pure and independent PV systems integrator firms dominate in the market. This may be due to the tendency for human and financial resources to be concentrated in large companies in Japan and also to barriers to the formation and growth of new companies in technical fields in Japan.

As we observed in chapter 4, most major global PV systems integrator firms were newly established mostly around 1995-2005 and dedicated from the beginning to the PV business.

Among the Germany firms Conergy was founded by Hans-Martin Ruter in Hamburg in 1998. Phoenix Solar AG was originated from The Phoenix Solar Initiative by the German Association of Energy Consumers to provide high-quality, cost effective PV plants in Germany market in also 1999. Juwi was established by a physicist Matthias Willenbacher and an agricultural economist Fred Jung to build their first wind power plant which connected to the grid in 1999. Belectric was founded by six shareholders in

2001. Thus, except in Japan, entrepreneurship played an essential role in the formation of most PV businesses, especially those that have focused on systems integration.

Nikki (the English company name is JGC) is one of the big three engineering construction companies in the world. Mr. Yoshihiro Shigehisa (former chairman and group representative) established Nikki's overseas business. He described his efforts to develop its overseas business at the very initial stage in his personal history, *Watashi no Rirekisho* in the Nikkei Newspaper in Feb. 2015:

"In any organization, if you try to start a new business, somebody who wants to deny it or prevent it appears. 'Why don't you do the same thing you have done so far?' In the 1960s, there were many new oil refineries and chemical plant projects developed domestically in Japan and all my colleagues sent me cold looks at what we were doing in the overseas department. But I reacted sharply against them to try to develop overseas projects. I tried to contact the manager of Mobil Oil in Japan, who introduced me to his Hong Kong colleague. I took a flight to Hong Kong, which was my first time getting on an airplane and stayed in a hotel there. The hotel was very good one for a young employee with only a 2-year history with Nikki—Nikki did not have a company rule for overseas business trips since it had never sent an employee overseas before. I presented Nikki's experiences in the oil refinery plant business to them in English. In fact, I had never had an English presentation before. They asked me, 'Can Nikki make LPG tanks?' How could this young employee know whether Nikki had ever built an LPG tank before? But I replied immediately, 'Why not?' When I came back to our head office in Tokyo, the management of Nikki was upset and got angry with me because Nikki had no experience with LPG tanks before. But I appealed anxiously and requested our design department and cooperating companies to support us; then we made a proposal that took six months, which was accepted by Mobil. I stayed in Hong Kong with cooperating companies to complete this project. This was in fact Nikki's very first overseas project.

"When I was a general manager of the overseas department in the 1970s, we had almost no business after the first Oil Crisis in 1973. But I believed that the Middle East was an important market in the long-term and built offices in Bahrain, Saudi Arabia, and Kuwait. When I visited Saudi Aramco, the representative told me he was going to drive me to my hotel. I thought he probably appreciated my efforts to come to Saudi Arabia after 9,000 km flight. On the way to my hotel, he stopped his car and told me to get out of it to look at something. As he suggested, I looked at the building in front of me. The building was 30-storied, built and owned by Fluor Corp, which was the rival US company to Nikki. He told me, 'If you wish to develop business in Saudi Arabia seriously, you would have to do something like this.’ This comment instantly made me decide to make Nikki the first Japanese contractor for Saudi Aramco.”

This difference between plant engineering industry and PV plant construction industry in terms of presence of Japanese firms implies that Japanese firms have learned to perform systems integration overseas in the context of CoPS type systems integration such as plant engineering construction, but not yet in Non-CoPS type industries, such as PV plant construction, that usually involve operation, not only in a new environment, but also in an environment where the Japanese systems integrator firms must interact with many local organizations - sometimes not as the dominant contractor.

(Further perspectives on overseas business by Japanese PV systems integrator firms)

In contrast to the four major German PV systems integrator firms, Japanese PV systems integrator firms operate almost exclusively in Japan. Firm U, which established a joint venture company locally, is an exception. As far as my knowledge and experience in the field, there is very little overseas PV systems integration activities among JPEA member systems integration companies. Mr. Yeon, a specialist of overseas PV systems department of Toshiba, commented that Toshiba had tried to enter overseas PV systems integration market hoping to combine it with their module sales business in places such as Thailand, Indonesia, Malaysia, but they gave up the strategy. In view of challenges they faced that they must obtain local licenses for construction, they need to invite a partner to satisfy regulations requiring domestic equity ownership and they indeed had to hire local workers to implement actual constructions, they concluded that they had better focus in selling modules with an alliance with local reliable EPC companies. (Interview on March ,2017)

In part, they have not had to do so because of the rapidly expanding PV market in their own country, based on its very attractive feed-in-tariff (FIT) scheme. In contrast, German PV systems integrator firms first worked within the domestic market and expanded the market but went out into the global market after Germany’s PV market shrank. FIT schemes are arranged in each country based on each country’s situation. The purpose of FIT is to help renewable energy develop in the countries by subsidizing it until the cost of electricity in renewable energies goes down sufficiently for companies to develop it by themselves. Once PV becomes diffused throughout each country, the FIT schemes have to be phased out and the expansion of PV market will normally slow down. PV systems integrator firms, as well as module and balance of systems manufacturers, will then have greater incentives to enter attractive overseas markets. Therefore, PV systems integrator firms ought to become "global" (Global PV systems integrator firms) to survive in the market. This is why major German PV systems integrator firms have already left their domestic market and are trying to enter attractive overseas markets such as the US, Southeast Asia and the Middle East. It is worth seeing how Japanese PV systems integrator firms will perform their overseas strategy.

An interview with the German managing director of Phoenix Solar Asia, one the largest German PV systems integrator firms, provided helpful insights related to these issues. These are summarized under the following three subthemes:

① Presence of an effective FIT scheme for utility-scale PV facilities in Japan

Previous energy policies were reexamined in Japan after the Fukushima nuclear accident. As a result, special measures for renewable energy were enacted in Aug. 2011, and a feed-in tariff scheme was executed in July 2012. Before then, there was no incentive for private-sector construction of mega-scale solar facilities like the attractive FIT scheme in Germany. Therefore, PV systems integration functions had not been needed in the Japanese market until 2012. There certainly was a residential PV installation market before the FIT scheme was implemented in 2012, but the size of each facility in the Japanese residential market is relatively small (3-4 kilo watt peak on average). Thus, there was no demand for large PV systems integration, while the small scale residential facilities could be installed and managed by local small-size construction firms (often called "installers"). This fact implies that, in order for large PV systems integration firms to consider the market attractive, there must be an attractive FIT scheme for investors in the initial industry development stage. An effective FIT scheme is necessary to let specialized PV systems integrator firms think that the market has potential, with a degree of incentives from a government that really seeks the development of solar energy.

② The uniqueness of the Japanese supply chain

Highly integrated Japanese module manufacturers such as Sharp and Kyocera were dominant in the Japanese supply chain until 2011, and there was no specialization in the initial stage of industry development. This is a unique phenomenon if one looks at the history of world PV industry. The silicon type module, which is a major technology in the current PV industry, has several manufacturing processes: manufacturing (1) silicon material (2)ingot/wafer (3)cell (4)module. In Germany, Q-Cells which was established in 1999, started cell manufacturing and expanded into module manufacturing later to become No. 1 module producer in the world in 2007 and 2008.

Deutsche Solar started their business as a wafer manufacturer and was bought by Solar World, a German module manufacturer. An American company, MEMC (Monsanto Electronic Materials Company) was manufacturing silicon wafer since 1959 and started manufacturing wafer for PV cells in 2006. MEMC merged with Sun Edison, an American power producer, in 2009.

It was quite difficult in Japan for newly established firms or even global major PV systems integrator firms to make a market entry as systems integrator firms into the supply chain in an already highly-vertically-integrated PV market dominated by large domestic vertically-integrated companies. Although the domestic PV market has expanded significantly after the rapidly implemented FIT scheme, start-up companies did not emerge in the systems integration market because the PV industry was completely new and certain departments of existing large firms were able to rapidly acquire dominant PV-related market shares. [13]

③ The necessity of global operations

Since the FIT rate in Japan has been high, both Japanese and foreign investors entered the power generation market in Japan. As a result, the domestic PV market expanded rapidly and extensively, Japanese firms did not have to go into the foreign market and take various risks. German PV systems integrator firms, on the other hand, tried to enter foreign markets just after they realized that the German market was shrinking as described in preceding subsection.

Japanese PV firms, regardless of their size, are now trying to enter foreign markets, after the drastic decrease in demand in Japan in 2014-2015, especially since the FIT rates have been reduced annually, from 40 yen per kwh in 2012 to 36 yen in 2013, then to 32 yen in 2014, 29 yen in 2015 and 24 yen in 2016. The firm described above—firm TU, which is a joint venture PV subsidiary in the Philippines—has been approached by many large firms that want to enter foreign markets. However, Japanese firms that try to enter foreign markets have numerous problems to overcome in order to be successful. They have to handle issues of language (especially in Asian countries where English is not widely spoken), equity regulations (in particular, power generation business is required to follow a foreign investment regulation on the part of the host nation), warranty issues for long periods beyond Japan's borders, and the need to offer operation and maintenance services. German PV systems integrator firms are overcoming these challenges. One of the options to overcome these issues would be to establish a joint venture with reliable local partners to operate as a local company. [14]

5.6 Limitation

The result of this case study on Japanese PV systems integrator firms are based on only the PV firms in Japan Photovoltaics Energy Association. Also the result and conclusion have limitation due to case study method.

6. Advantages of PV systems integration

We can observe many companies entering systems integration business in PV industry as well as other industries. In the PV module manufacturing industry, companies who suffered from problems in profitability have attempted to enter systems integration business. In order to explore why they do so, I undertook a Spearman rank order analysis examining the relation between the volatility of the gross profit rate and share of systems integration in the entire business of the companies. Volatility in the gross profit rate is often an indicator both of business health in the face of market volatility and of the contribution of a particular activity to stable profits. This statistical analysis is followed by a case study for two major PV big firms who changed their business structures by entering the systems integration business.

Figure 38 shows the analysis framework for this chapter.

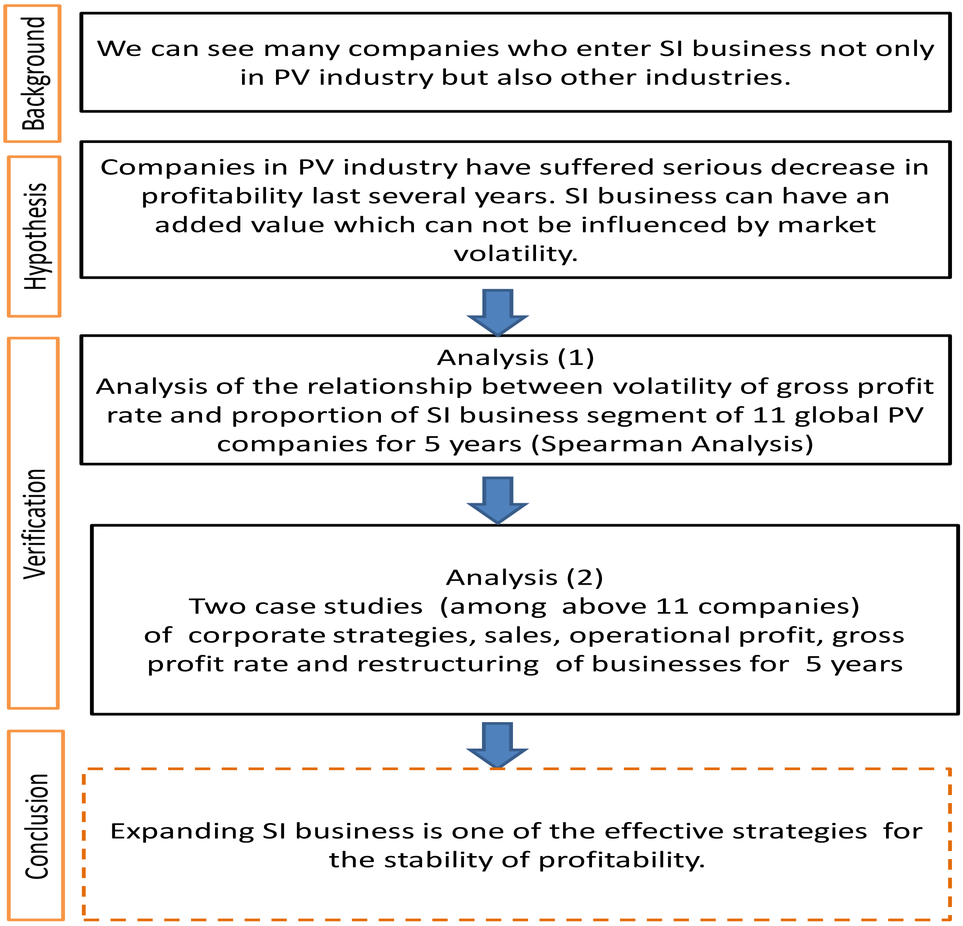


Figure 38 The framework of this chapter

Source: By author

6.1 Background

As discussed in the previous chapters, we can see many examples of entry into the PV systems integration business segment. For example, when we examine firms registered as "systems integrators" in the Japan Photovoltaics Energy Association (JPEA), many are module manufacturers (i.e. Toshiba), major heavy equipment manufacturers (i.e. Hitachi), major engineering construction firms (i.e. JFE Engineering), independent power producers (i.e. West Holdings), and big firms in other industries (i.e. Orix). They are already active in PV module manufacturing or other industries, but are now trying to enter the PV systems integration segment.

Takashi Yoshikawa, chairman of West Holdings, Ltd., says that they established a systems integration firm subsidiary (West Energy Solution Ltd.) in 2011 to enter commercial roof top systems integration business because they believe they need to offer an "one stop solution in PV business" to be competitive (PV eyes, April,2012).

Figure 39 shows several patterns of entry into PV systems integration business segment.

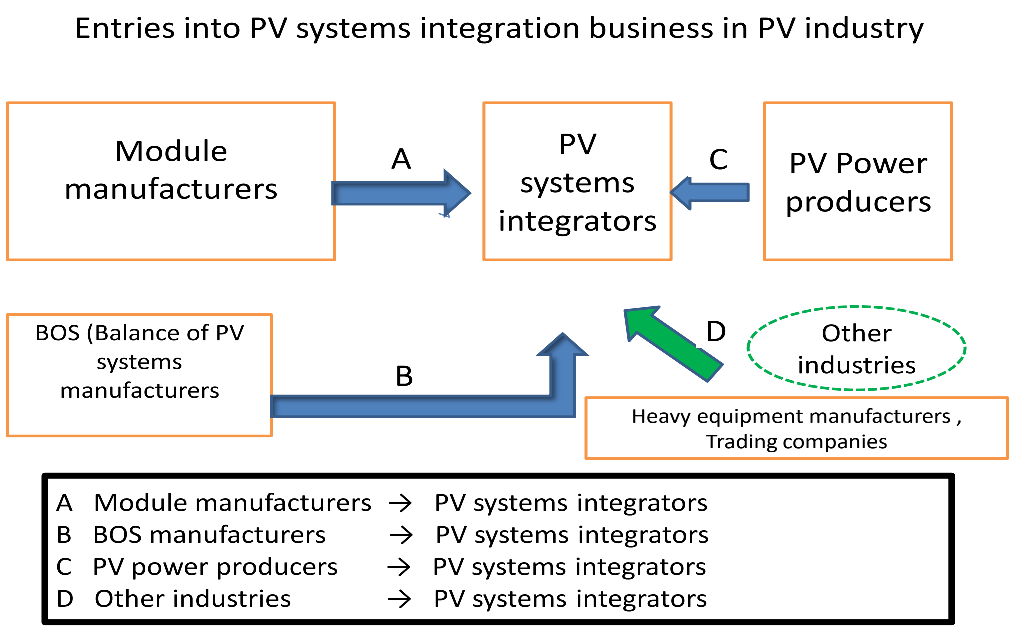


Figure 39 The patterns of market entries into PV systems integration

Source: Author's elaboration in interview data

We can also see many module manufacturers that are trying to enter the PV systems integration segment under the name of “solution business.” Based on interviews with these module manufacturers, their reasons are:

(1) The security of obtaining profit from systems integration based on the inevitable demand for these services. PV systems integrator firms play roles in uniting customers with all the necessary parts and services. Whatever a decrease occurs in module price, there must be a value in uniting the two parties. Module sales are just “sales of a product,” but PV systems integration is a business process wherein actual construction is required, with actual labor work, therefore, the margin must be the labor cost plus the PV systems integrator firm's margin. PV systems integrator firms would not have to be involved in severe price competition by selling their products below actual cost. Figure 40 shows the transition of worldwide PV system prices in the past and its forecast. While the system price was 3.42 USD per watt in 2010, it dropped to1.39 USD by 2015, a decrease of 60%, and is projected to decrease further. However, when we look at the breakdown of prices within the PV system, there are significant differences. The price of modules decreased from 1.95 USD in 2010 to 61 cents in 2015, a 70% decrease, but the systems integration segment (often called EPC: Engineering, Procurement and Construction) has decreased only a small percentage. This is probably due to the fact that this function requires a variety of labor that cannot be automated, as well as a variety of services.

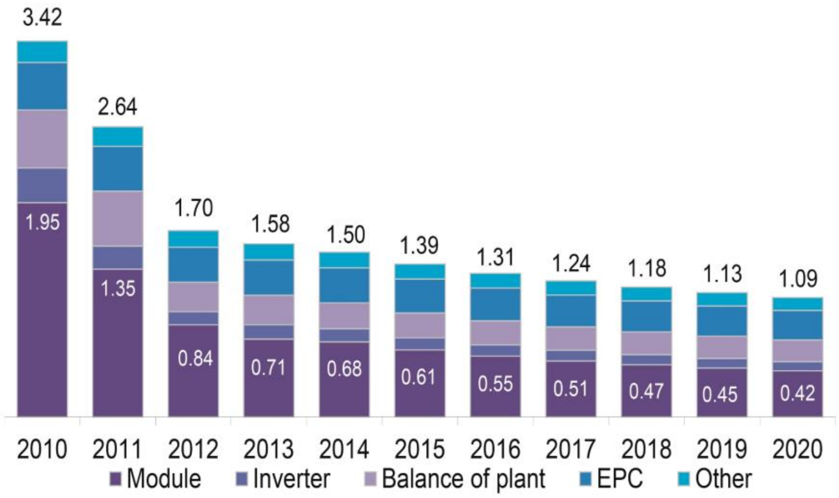


Figure 40 Global PV system prices for utility scale installations (USD/Wp)
Source: Bloomberg New Energy Finance, June 2015

(2) By working as PV systems integrator firms, module manufacturers can control entire projects, thereby gaining many opportunities for additional business, which can provide additional sources of profit. PV systems integrator firms collect all the necessary information, such as the quality and price of the module/BOS, all the local regulations, and incentives. What "brand" (the manufacturer of the product) to be used primarily depends on the PV systems integration firm's decision. That puts PV systems integrator firms in a position to control entire projects. That brings opportunities for obtaining more profit from those projects.

6.2. Purpose

The purpose of this chapter is to attempt to explore empirically why these PV firms are trying to enter systems integration business. As we discussed in previous chapters, many firms are entering the PV systems integration segment. I will examine how this strategy affects a firm's performance in this section.

6.3 Spearman Rank-order Correlation Analysis

6.3.1 Methodology

Almost all major PV firms have experienced a substantial profit decrease or deficit in the last several years. When we examine the historical gross profit rates of major PV firms, we can see a substantial decrease in gross profit rates (Figure 41) in the most recent five years. The gross profit rate usually indicates the added value the company receives. It is obtained by dividing gross profit by sales revenue. Gross profit is calculated by deducting costs of goods sold (including transport charges, etc.) from sales revenue. Gross profit rate is normally considered as a factor which indicates how much value is added in business accounting principle.

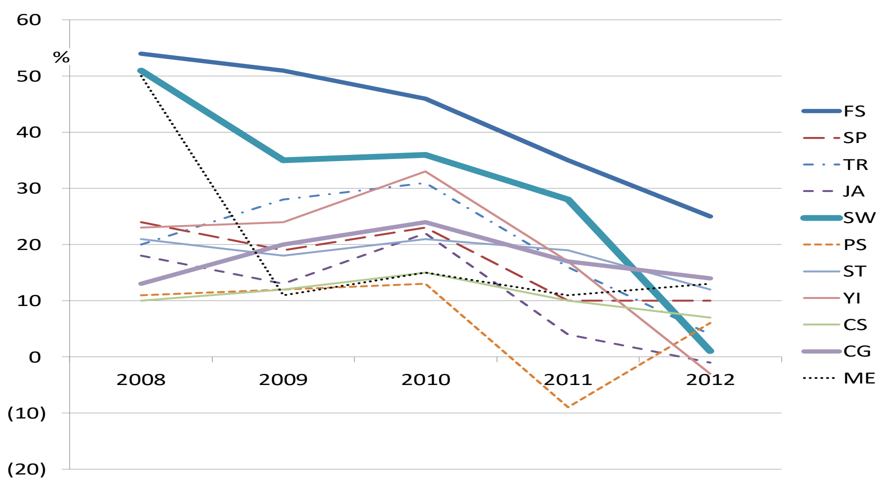


Figure 41 Gross profit rates of 11 major PV firms
Source: Author's elaboration from internal records

First Solar	FS
Sunpower	SP
Trina Solar	TR
JA Solar	JA
Solar World	SW
Phoenix Solar	PS
Suntech	ST
Yingli	YI
Canadian Solar	CS
Conergy	CG
MEMC SunEdison	ME

Table 14 Abbreviation of company names

PV modules are considered to have become "a commodity," and many module manufacturers are struggling with the rapid decrease in price. But since there are several inevitable added values in PV systems integrator firms' activities, such as design, procurement, construction and services, the security of obtaining profit from these activities should not be affected as other components in the supply - demand price volatility.

I here can hypothesize that the greater a firm's degree of systems integration business (the percentage of the firm's entire business revenue accounted for by systems integration), the more stable gross profit rate (added value) they have, and this fact motivates companies to enter the PV systems integration segment. I examined the co-relationship between the systems integration business degree and gross profit rates of the 11 major PV-related firms shown in table 15. These are firms whose financial information was available in annual reports for the past five years and which include a breakdown in revenues attributable to systems integration. Table14 shows the abbreviation of the firm names. The number of samples is small, but it includes Chinese, American, German major firms and therefore at least has a degree of global representation.

As for which segment in a certain supply chain has the highest added value, Stan Shih Chen-Jung of Acer Laboratories proposed the "smiling curve" theory (Stan Shih Chen-

Jung, 1998). This holds that the added values in both the (upstream) parts production segment and the (downstream) sales of personal computers of the personal computer industry are large, but they are small in the assembly segment (middle stream). It is well known by persons in the PV industry that the same phenomenon where the added values are high in both the silicon material (upstream) segment and the systems integration (downstream) segment, but they are low in the module manufacturing (middle stream) segment.

6.3.2 Result

I calculated the gross profit rate fluctuation ranges (the difference between the maximum and minimum values of gross profit rate) of the 11 firms over the five years 2008 through 2012, and then divided these ranges by the average gross profit rate values over the same five years. I named this variable, factor A, which shows the volatility of the gross profit rates. I then calculated the five-year average percentage of systems integration business among these firms' entire PV business and named it, variable factor B. Then I estimated the relationship between these two variables using the Spearman rank-order correlation coefficient analysis. In other words, I calculated the correlation between the ascending ranking order of variable A (low to high volatility) and the descending ranking order of variable B (high to low systems integration degree) to reach the result described in the table 15. The value was 0.27, which suggested that a relationship exists, although it is not very strong. This result is based on standard interpretations of the rank-order correlation, as seen in table 16.

Correlation of 5 years average of gross profit rates (variable factors) and SI degree

	gross profit rate		2008	2009	2010	2011	2012	5 years average	(largest-smallest) /5 years average	variable factor			variable factor ranking	SI degree ranking		SI degree (%)	SI degree ranking
1	First Solar	FS	54%	51%	46%	35%	25%	42%	(54-25)/42	0.69	0.33	MEMC SunEdison	1	2	Conergy	90	1
2	Sunpower	SP	24%	19%	23%	10%	10%	17%	(24-10)/17	0.82	0.5	Suntech	2	10	MEMC SunEdison	61	2
3	Trina	TR	20%	28%	31%	16%	4%	20%	(31-4)/20	1.35	0.61	Conergy	3	1	Sunpower	47	3
4	JA solar	JA	18%	13%	22%	4%	-1%	11%	(22+1)/11	2.09	0.69	First Solar	4	5	Phoenix Solar	44	4
5	Solar world	SW	51%	35%	36%	28%	1%	30%	(51-1)/30	1.66	0.72	Canadian solar	5	7	First Solar	23	5
6	Phoenix solar	PS	11%	12%	13%	-9%	6%	7%	(13+9)/7	3.1	0.82	Sunpower	6	3	Solar World	7.5	6
7	Suntech	ST	21%	18%	21%	19%	12%	18%	(21-12)/18	0.5	1.35	Trina	7	10	Canadian Solar	2.3	7
8	Yingli	YI	23%	24%	33%	17%	-3%	19%	(33+3)/19	1.89	1.66	Solar world	8	6	JA Solar	2	8
9	Canadian solar	CS	10%	12%	15%	10%	7%	11%	(15-7)/11	0.72	1.89	Yingli	9	9	Yingli	0.5	9
10	Conergy	CG	13%	20%	24%	17%	14%	18%	(24-13)/18	0.61	2.09	JA solar	10	8	Trina	0	10
11	MEMC SunEdison	ME	50%	11%	15%	11%	13%	12%	(15-11)/12	0.33	3.1	Phoenix solar	11	4	Suntech	0	10

The result of Spearman correlation analysis : n=11,rs=0.27, 「Low relation found」

「The more SI degree they have(more SI business % they have), the less fluctuation of gross profit rate they have.」

Table 15 Spearman analysis for eleven firms: The relationship between stability of the gross profit rate and the degree of systems integration
Source: Author's elaboration on internal firm records

Spearman Rank-order Correlation Co-efficiency evaluation

r	meaning	Expression
0	No relation	“no relationship found”
0<[r]<0.2	Very Little relation	“very little relation found”
0.2<[r]<0.4	Low relation	“Low relation (plus or minus) found”
0.4<[r]<0.7	Relation exist	“relation(plus or minus) exist”
0.7<[r]<1.0	High relation	“high relation(plus or minus) found”
1.0 or -1.0	Complete relation	“complete relation found”

Table 16 Categories on Spearman rank-order

6.3.3 Conclusion

This analysis suggests that the more PV firms' revenue depends upon systems integration, the less volatile are their gross profit rates although this relationship is not strong.

6.3.4 Limitation

This analysis targeted major PV-related firms for which we could obtain official financial information. But the group of 11 firms is a small sample in terms of statistical validity. (As for MEMC, it experienced a large-scale merger and acquisition in 2008, changing its business structure, so the financial numbers before 2008 were not used in this analysis.)

6.4 A case study of two PV firms

6.4.1 Methodology

I then selected an American module manufacturer and a German PV systems integration firm to examine, using the case study method, how PV-related firms try to improve gross profit rates by focusing on PV systems integration. First Solar

(USA) was the second largest PV module manufacturer in 2012 that also had a systems integration business. Conergy (Germany) is one of the oldest German PV systems integration firms and is very active worldwide. Table 17 provides an overview of the two firms.

Other factors that lead me to select these firms include: they are firms from two of the world's largest PV markets that are dominant market. Also my research indicates that they are representative of firms that have been able to shift their business structures successfully from manufacturing to systems integration business. Evaluation factors in table 17 are consistent with evaluation criteria used throughout this dissertation, as first illustrated for the 29 PV firms in table 8. The colored factors are common items with our previous case studies.

	First Solar	Conergy
Nationality	USA	Germany
Listed market	Nasdaq	Frankfurt
Established	1999	1998
Sale revenue(2012)	3,368 million USD	473 million Euro
Module Production capacity (2012)	2.7 GW	280 MW
Factory sites	USA , Malaysia 2 sites	Germany 1site
Main business	PV module production and sales	PV system integration
Main product	Thin film module	Crystalline module
Number of employee	4,700 (2010)	1,600 (2011)
Overseas branches	USA, Mexico, Brazil, Belgium, Turkey, Germany, Dubai, Morocco, Australia, Japan, Thailand, India	5 continents, 15 countries, 44 locations
①degree of systems integration	4%(2008)→65%(2012)	90%(2008)→100%(2012)
②degree of PV business	100%	100%
③degree of globalization	87%(2010)→20%(2012)	73%(2012)
④active market as system integrator	Focusing utility scale projects	All 3 markets (utility scale , commercial , residential)
⑤integration/specialization as manufacturer	Fully integrated production	Production of wafer, cell, module →module production only

Table 17 Company overview: First Solar and Conergy
Source: Author's elaboration on interview data and internal firm records

6.4.2 Result

<u>First Solar</u>

(Company overview)

FS was established as a PV module manufacturer in 1999 in the United States. It uses cadmium telluride (CdTe) to achieve highly competitive prices and solar conversion efficiency, unlike other major manufacturers who use silicon crystal-type PV cells. Table 6 shows that FS rankings in terms of PV module production have been fairly stable from 2007 to 2012, with only one year (2006) when it was absent from the top four. Japanese firms such as Sharp, Kyocera, Mitsubishi, and Sanyo, which were ranked high up until around 2006, have been ranked lower since 2010, except for Sharp, which still remains within the top ten. On the other hand, Chinese manufacturers have been expanding since 2007, and seven Chinese firms were within the top ten in 2012 (see table 6 in chapter 4). FS is an unusual company that has been successful in keeping its dominance high for a long period in this fast-moving and expanding industry. Figure 42 shows its sales revenue and operational profit for the five years 2008-2012.

FS has two business segments. Its traditional business, called the components segment, covers sales of PV modules which FS designs and manufactures. Its customers are project developers, systems integrators, and the operation entities of projects. Another segment is called the system segment, which provides the fully integrated and complete PV systems. This is called also its "turn-key solution" business. This business consists of ①project development ②engineering, procurement, construction (EPC) ③ operation and maintenance (O&M) ④ financial arrangement assistance, etc. and involves the sales of total PV systems wherein its modules are used. Its customers are investors who own power generation facilities, independent power producers, and general firms. In other words, the system segment business directs FS's services more downstream in the supply chain of the PV industry to provide systems and related services to final users.

(Restructuring of business)

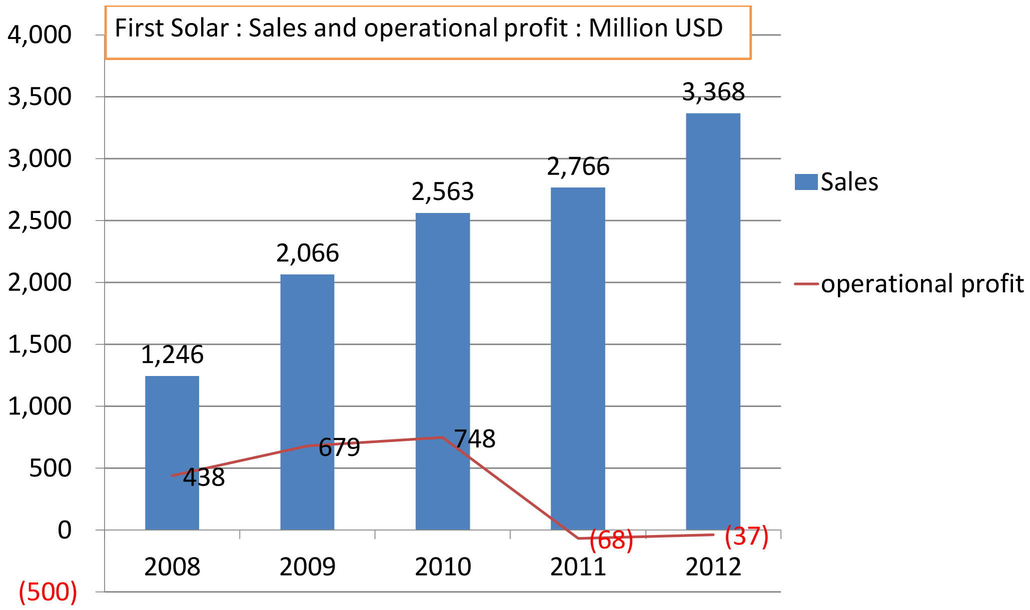


Figure 42 First Solar: Sales and operational profits

Source: Author's elaboration on internal firm records

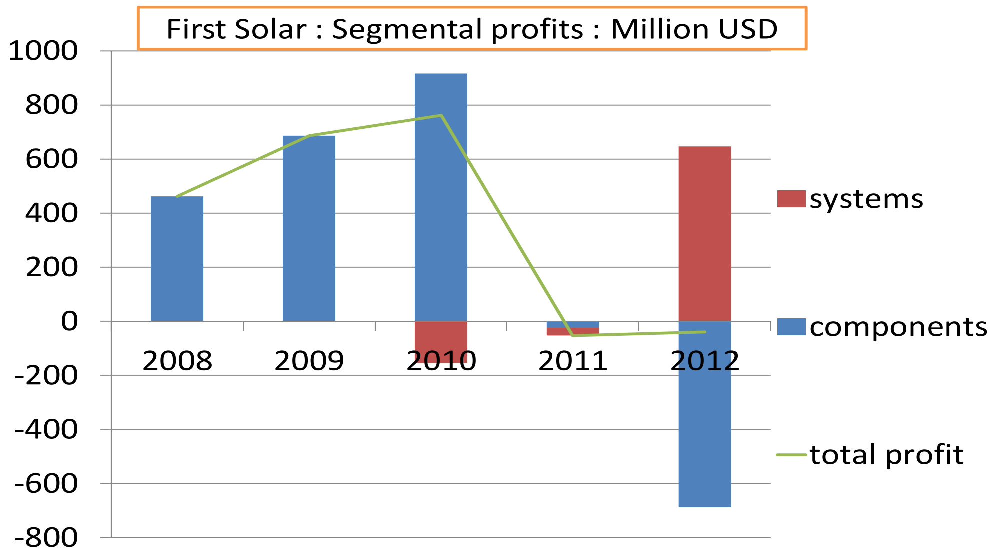


Figure 43 First Solar: Segmental profits

Source: Author's elaboration on internal firm records

When we observe FS's performance for 5 years (2008–2012), it increased sales revenue successfully. However, it had deficit years in 2011 and 2012 due to a substantial decrease in module price resulting from an oversupply of Chinese products. It started the system solution business—its systems integration business—in 2008, but 2010 was still a trial period, during which time the system solution business was called "others." It has categorized this segment separately as the "system solution" segment since 2010.

While First Solar was successful in expanding its sales revenue, as shown figure 42 and figure 43, the profit from system business did not cover the deficit from components business.

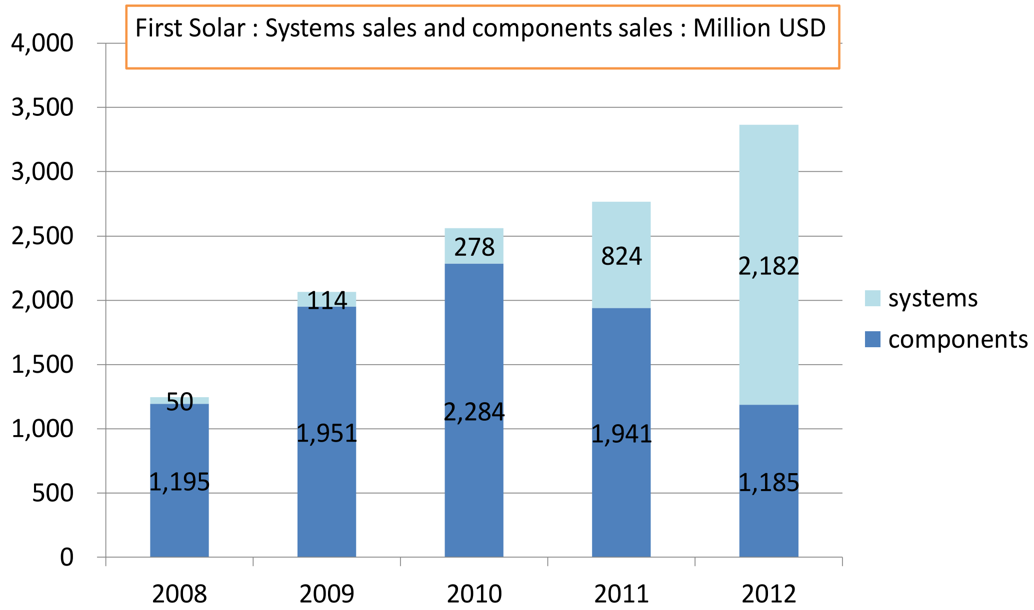


Figure 44 First Solar: Segmental sales revenues
Source: Author's elaboration on internal firm records

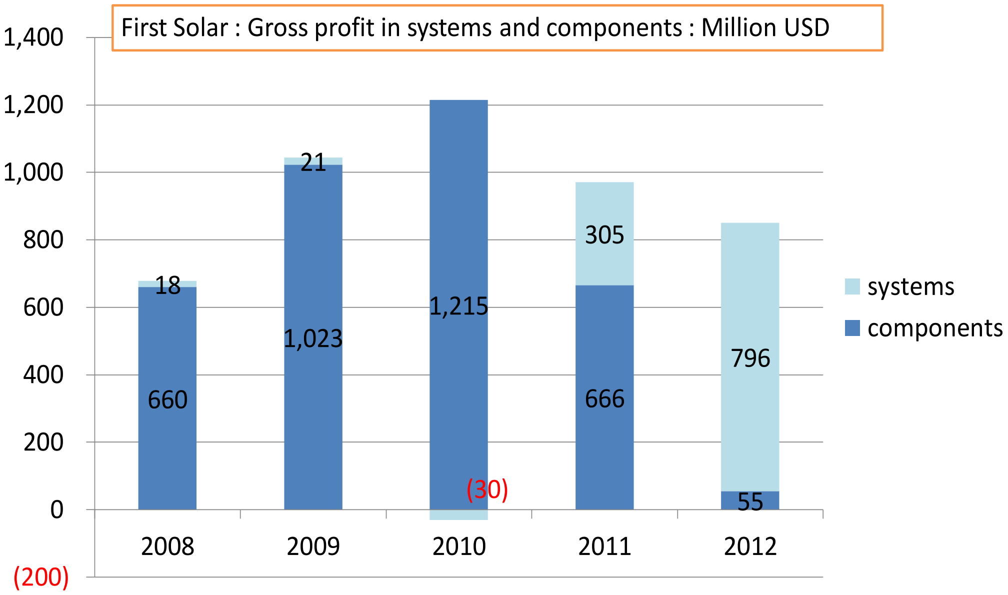


Figure 45 First Solar: Segmental gross profits
Source: Author's elaboration on internal firm records

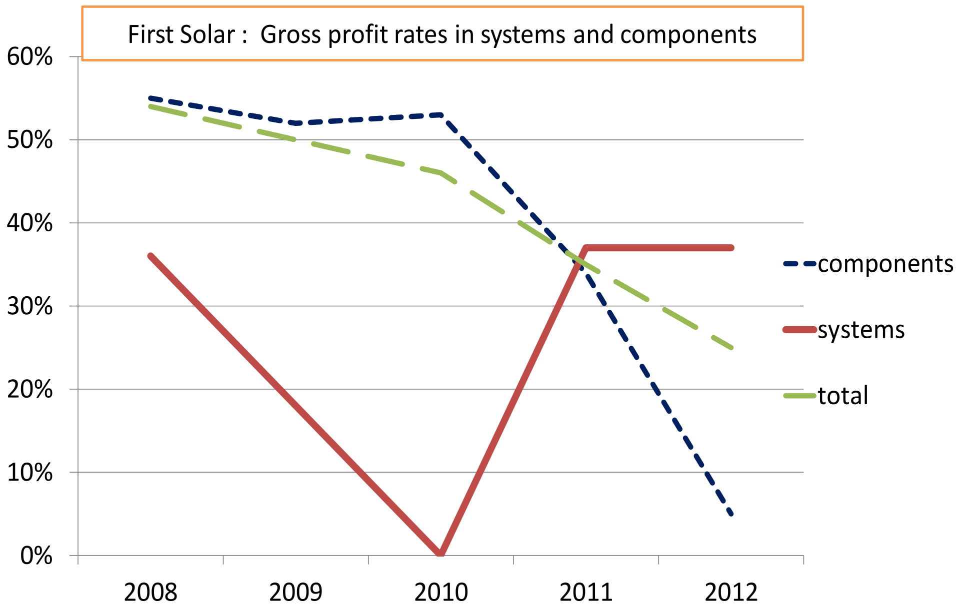


Figure 46 First Solar: Segmental gross profit rates
Source: Author's elaboration on internal firm records

First Solar has expanded the solution business rapidly since 2011. The segment already occupied 30% of both sales and gross profit in 2011, and it accounted for 65% of sales and 93% of gross profit in 2012 (Figure 44 and Figure 45). Looking at the transition of its gross profit rate, the gross profit rate of the components segment decreased 55% in 2008, down to 4.6% by 2012, while the gross profit rate of the system segment has been maintained around 30% since 2008 (except for the years of global recession 2009 and 2010), even when global price competition was fierce in 2011 and 2012 (Figure 46).

We can surmise that First Solar was able to establish its current advantageous position because it began re-structuring the business to move toward systems business before the competition in the market became tough around 2008. The systems segment contributed more than 90% of total gross profit in 2012. The gross profit rate, which shows the added value rate in the market, does not vary as much in the systems segment, where companies provide not only product sales but also various services and construction works, whereas the components segment is influenced by price competition and the balance between supply and demand for a few largely-interchangeable products.

Conergy

(company overview)

Established in Germany in 1998, Conergy (CG) is one of the dominant PV systems integrator firms. It was active in renewable energy other than PV until around 2005, when it bought 48 firms by merger and acquisition. But after it built the factory that makes wafers, cells, and PV modules, it focused on its PV business, selling off its non-PV-related firms. It increased its capital by 399 million Euros in 2008–2009 and expanded its capacity for module production up to 250 MW, which cemented its position as a "PV system manufacturer." Figure 47 shows the company's revenue for these five years, along with its negative operational profits. Figure 48 shows that the proportion of sales of goods and service revenue were 60% and 40%, respectively. But according to the interview with the company's executive, Mr. Alex Lenz, managing director of Conergy Asia, pure sales of goods without systems integration activity were only around 10% of the total revenue in these years, and almost all of module sales were handled within the company's systems integration business. Thus its systems integration business (including provision of modules through this business) actually accounted for around 90% of revenue. The gross profit rates in these years were relatively stable, in the 13%–24% range, as shown in Figure 49, due to the high percentage of revenue from the PV systems integration business. While they had positive gross profits for these years, they also had substantially decreased total sales revenue and gross profit rates for 2010-2012, which caused deficits in the years.

Another reason for these deficits is that they had to buy silicon material for their modules in their manufacturing sector at a certain fixed level of price in a long-term supply contract with an American supplier (interview with Mr. Lenz).

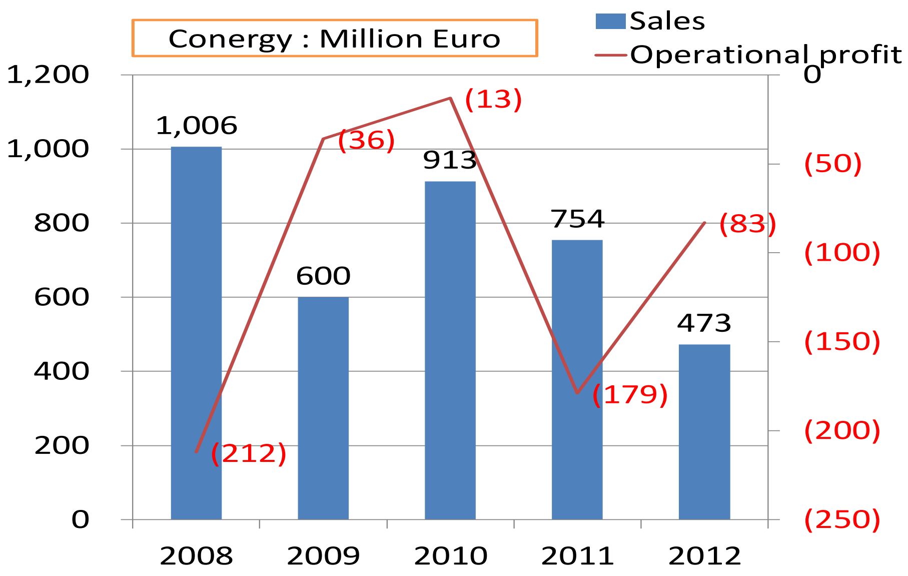
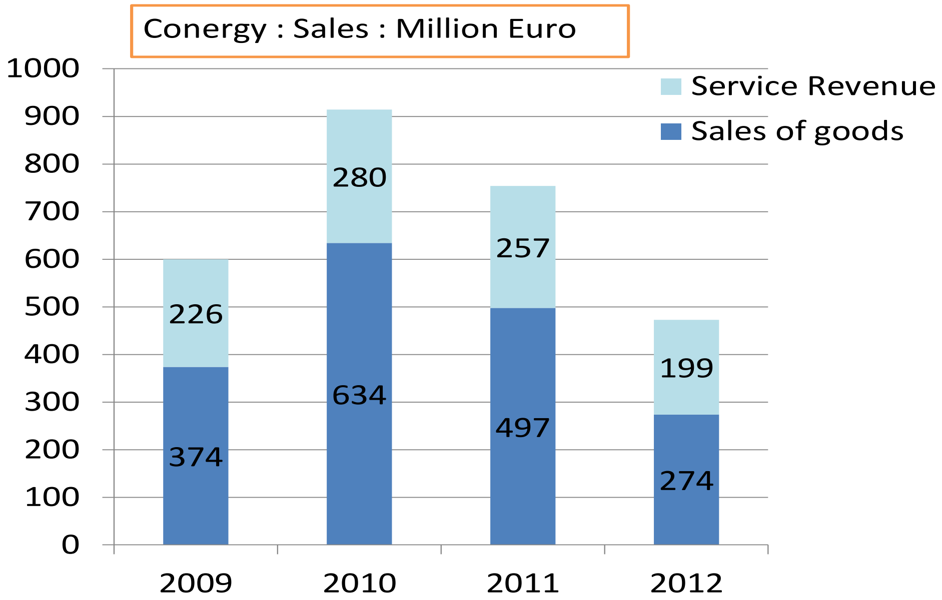


Figure 47 Conergy: Sales and operational profits
Source: Author's elaboration on internal firm records



(same category is not available in 2008)

Figure 48 Conergy: Segmental sales revenue

Source: Author's elaboration on internal firm records

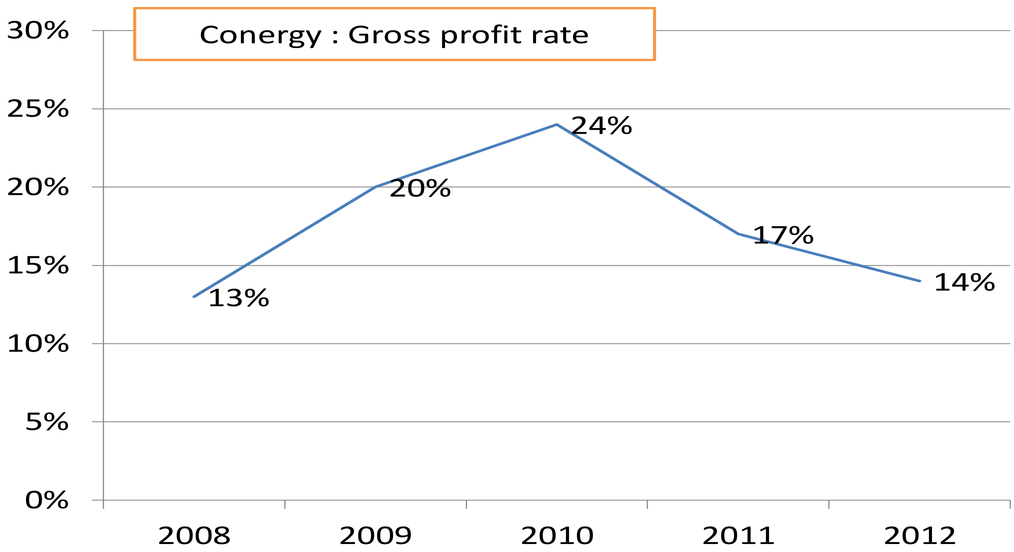


Figure 49 Conergy: Gross profit rates

Source: Author's elaboration on internal firm records

(restructuring of business)

Conergy started restructuring its upstream segment (production) in 2011.

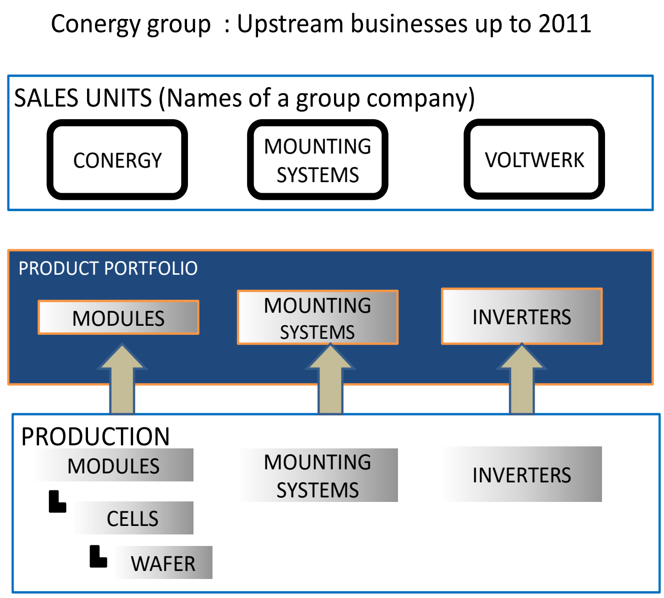


Figure 50 Conergy: Restructuring of business segments
Source: Author's elaboration on interview and internal firm records

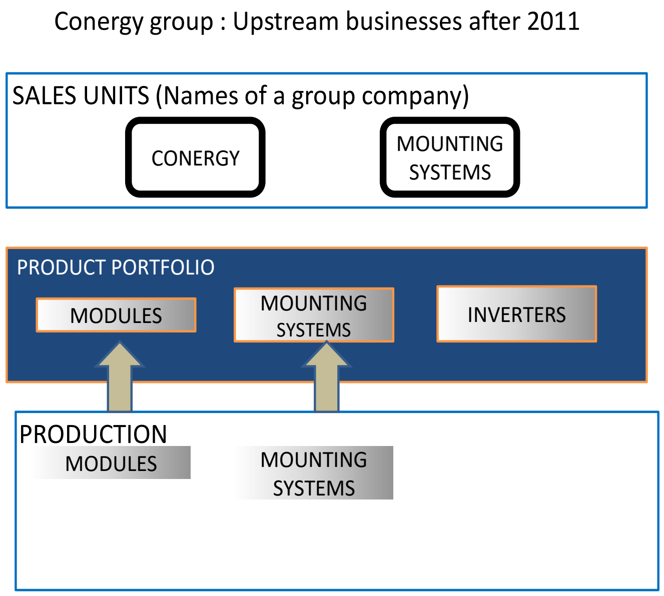


Figure 51 Conergy: Re-structuring on business segments
Source: Author's elaboration on interview and internal firm records

Conergy was manufacturing all the main PV components—such as wafers, cells, modules, mounting systems, and power conditioners—internally within its group companies up until 2011, but it ceased production of wafers and cells and sold its subsidiary company making power conditioners in 2011. By doing this, it made its cost structure more flexible by saving on capital investment. This major structural reform made it possible to begin concentrating on its systems integration business (Figure 50 and Figure 51).

6.4.3 Conclusion

The following is a summary of this case study: FS restructured its business from a "100% PV module manufacturer" to a "total PV system solution provider using its modules," while CG did the same by switching from "a manufacturer that makes major PV components such as modules, mounting systems, and power conditioners" to a "PV solution and service provider" (Figure 58). By doing this, both companies have achieved gross operational profits, demonstrating profitability and added value, and their business operations have become more stable.

The following charts (Figure 52,53,54 and 55) show how both firms have changed their business structures by moving to more systems integration focused: before and after their reconstruction.

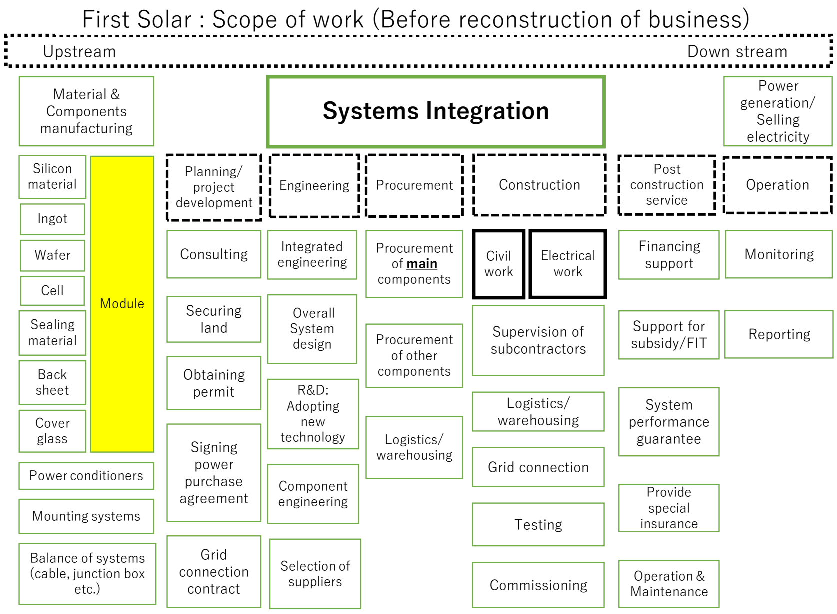


Figure 52 First Solar: Before reconstruction of business

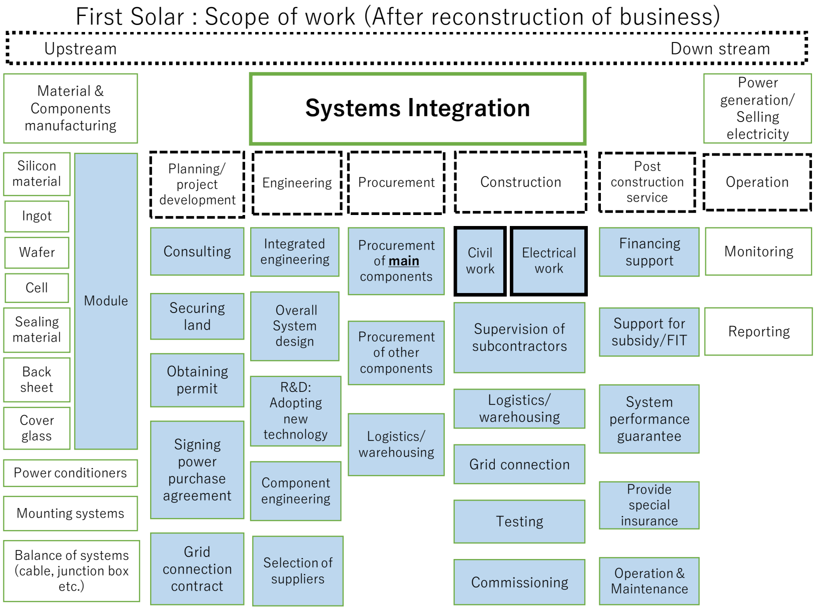


Figure 53 First Solar: After reconstruction of business

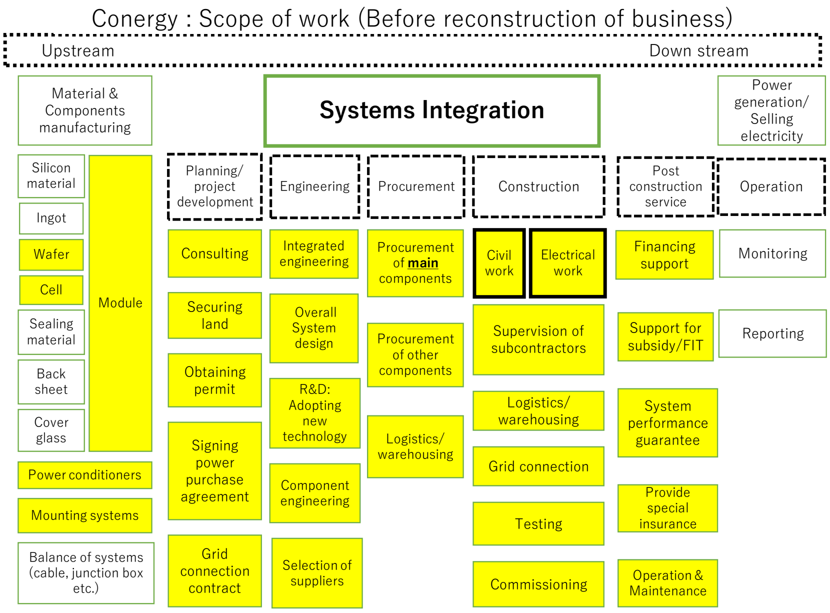


Figure 54 Conergy: Before reconstruction of business

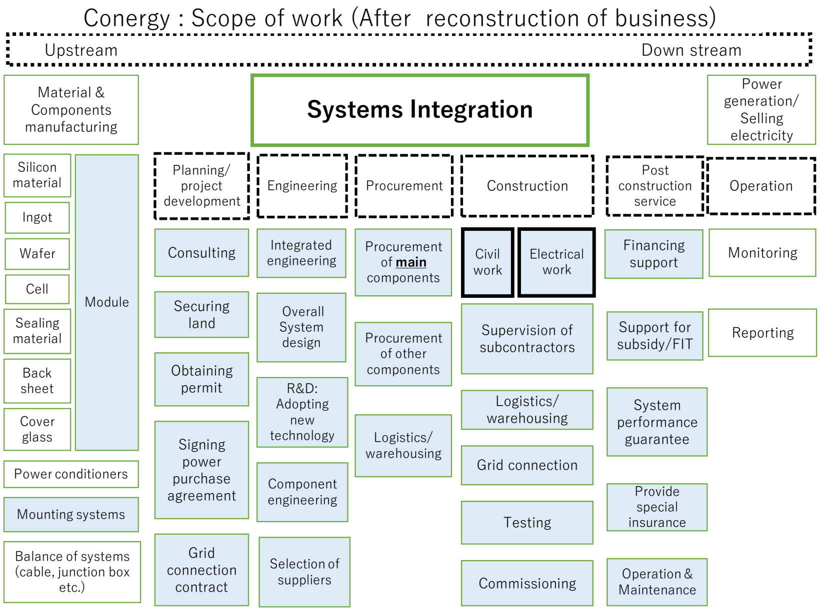


Figure 55 Conergy: After reconstruction of business

The following figures 56 and 57 show which market segment of PV systems integration each firm are working after reconstruction. First Solar used to be a module manufacturer, it focuses on utility scale market due to its large scale business, while Conergy which was mainly a systems integrator firm focuses on all markets.

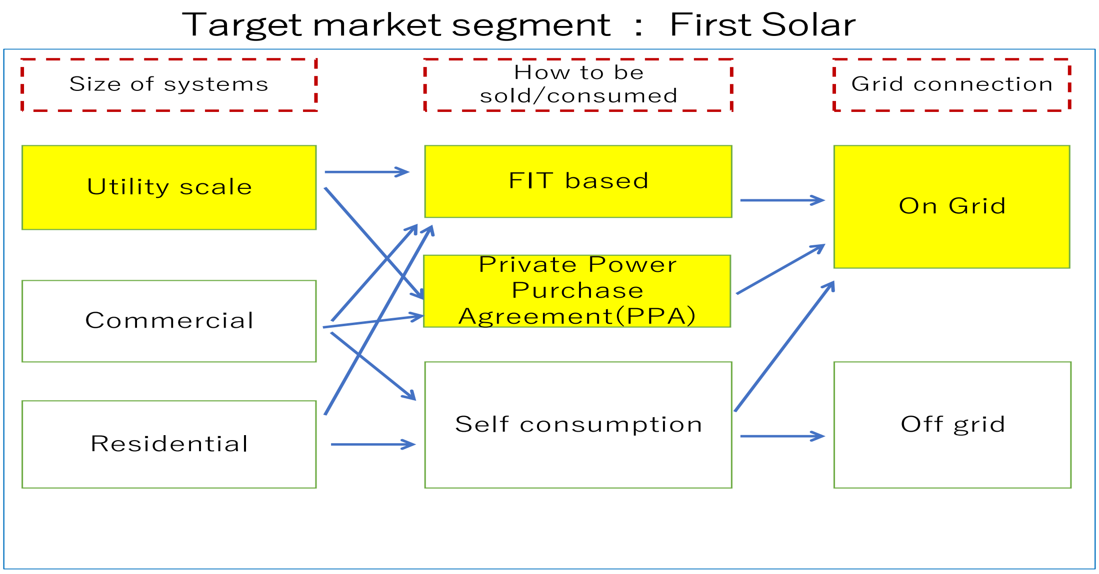


Figure 56 Target market segment by First Solar

Source: By author

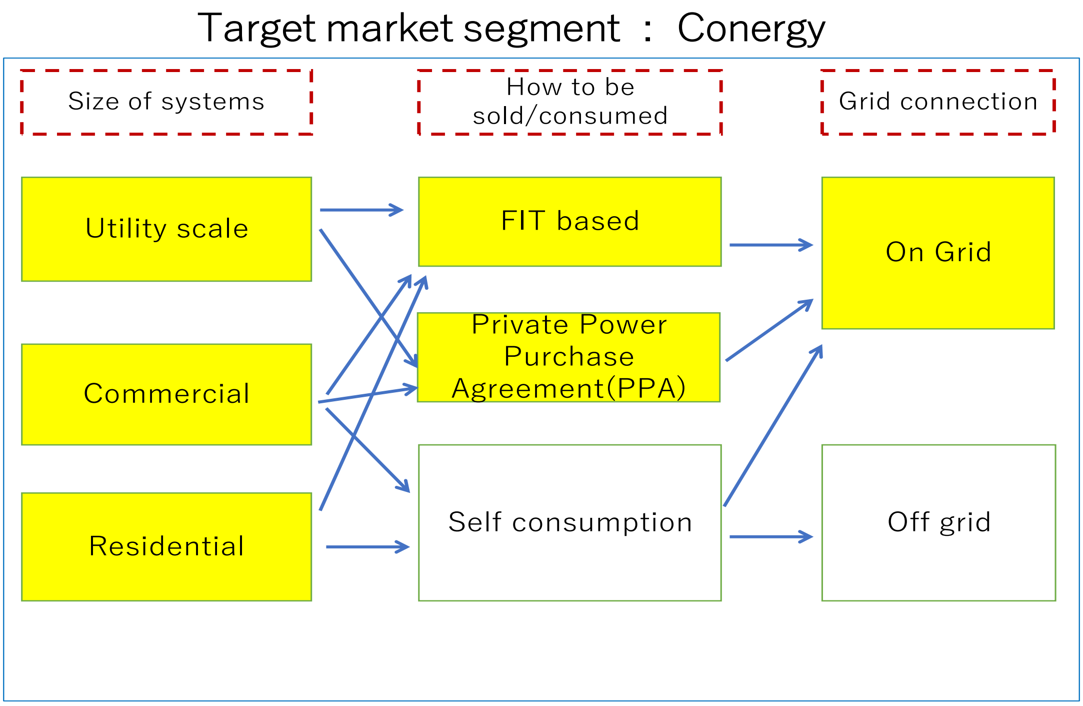


Figure 57 Target market segment by Conergy

Source: By author

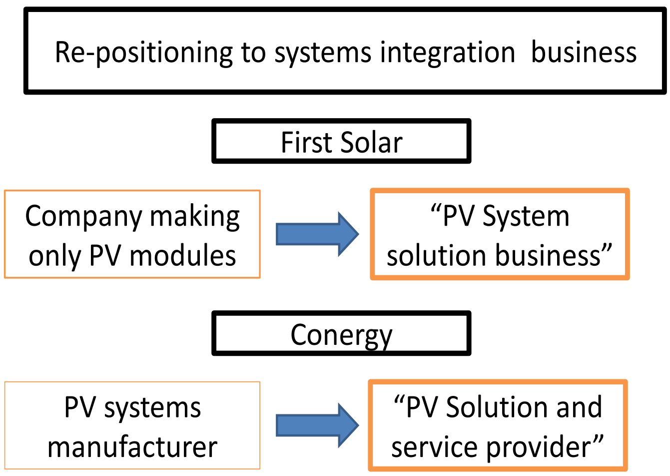


Figure 58 Re-positioning strategy to systems integration business by First Solar and Conergy

Source: By author

6.4.4 Limitation

This analysis is a case study focusing on two major firms in the PV industry and has a limitation of case study.

6.5 Integrated conclusion

Although the two analysis in the chapter have limitation they show insights into our hypothesis that firms attempted to systems integration business to seek for stable profitability.

7. Systems integration capabilities

Chapter 6 describes the advantage of systems integration business strategy by case study in the PV industry. This chapter summarizes systems integration capabilities drawing upon previous studies and the above analysis of systems integration in the PV industry. It also examines how systems integrator firms are trying to differentiate from competitors and what factors are critical in systems integration activity. This examination focuses on PV systems integration, but it also suggests that these factors are similar in other technology-based, non-CoPS industries, examples of which are given in the previous chapter.

7.1 Definition and scope of systems integration capabilities

Sapolsky refers to the prime contractors of large engineering projects and their capabilities in aerospace and defense industry (Sapolsky, 2011). He further introduces a definition of systems integration by the UK Technology Foresight Defense and Aerospace Panel, "the ability to understand and model the overall requirements for a major system and the interaction and performance of its many interrelated parts in an unambiguous way, accommodating the various subsystems technologies; then to design the complete systems together with its manufacturing processes and production facilities" (Office of Science and Technology 1990). He defines systems integration as an ability of business activities.

Prencipe identifies two analytical categories of systems integration, namely synchronic and diachronic. Synchronic systems integration refers to the capabilities to sustain competitive advantage in the short term: It is a static view of systems integration including product concept design, involving mainly coordination of the network of suppliers to meet customer requirements (Prencipe 2011). Diachronic systems integration refers to the capabilities that firms require to compete in the long term, enabling them to keep pace with technological developments, enhancing the firms' capabilities for innovation and flexibility and knowledge creation. This is a dynamic point of view of systems integration (Table 18). In the PV industry PV systems integrator firms perform the synchronic systems integration, that is called as EPC (engineering, procurement and construction), but also PV systems integrator firms have to address the rapid change in technology such as significant improvement of module efficiency, rapid decrease in prices of components. As described previously they attempt to keep certain expertise in-house so that they can differentiate themselves from competitors in the long run.

Analytical categories of systems integration and its capabilities

Systems integration Dimension	Competitive advantage on		Examples of required capabilities
Synchronic	Short run	Static	Access external resources Product design Coordinate network of suppliers Match the work of suppliers to meet customer requirement
Diachronic	Long run	Dynamic	Keep pace with technological developments enhancing firms' capability Knowledge creation New product

A case study of aircraft engine industry
By Prencipe, 2011

Table 18 Analytical categories of systems integration and its capabilities
Source: Prencipe 2011

Davies and Brandy had a case study of Ericson and Cable & Wireless to show that they successfully became to be a total solution provider instead of a manufacturer. They break down systems integration capabilities into three capabilities in CoPS industries (strategic, project and functional capabilities) as shown in figure 59 (Davis and Brandy, 2000). Project capabilities include integrating functions, purchasing resources inside and outside of the firm, work on a team basis. Project capabilities and economies of repetition in systems integration are particularly critical in CoPS projects because they are one-off and small batch production, customized product, non-routine tasks.

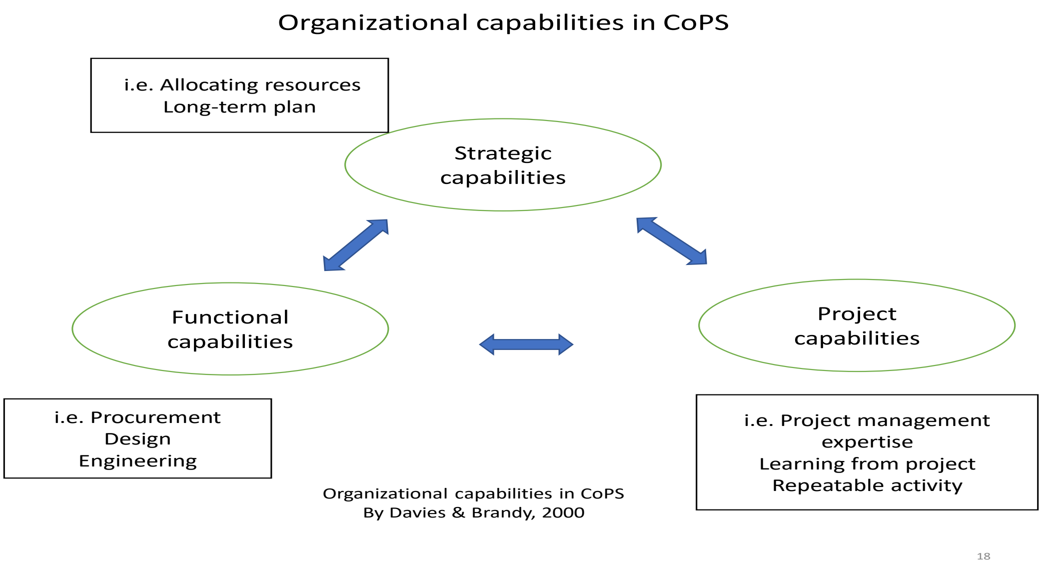


Figure 59 Organization capabilities in CoPS
Source: Davies and Brandy 2000

Prencipe shows those technological capabilities have two measures: breadth and depth by a case study of engine manufacturers. Outsourcing without certain strategies as to which areas companies should source internally versus outsource externally to specialized suppliers could result in loss of future growth opportunities. Systems integrator firms should maintain a broad and deep range of capabilities in-house to retain the systems integration capabilities over time to manage unexpected technological innovation and uncertainty in the industry (Prencipe, 2000). As described previous chapters, PV systems integrators often outsource some of their work of scope, but perform other work in-house. Usually some of procurement and construction are often outsourced to external sub-contractors.

McKelvey suggests the boundaries of activity by systems integrator firms shit over time (McKelvey, 2011). This idea has implications for how, why, and who can influence the systems integration of all the components into a system. At certain points, certain firms can act as systems integrators, but other points the activities of all the various actors need to be coordinated through more distributed coordination mechanism: such as market transactions which provide price signals to influence many distributed individuals, community of developers and informal relationship. She points out that the firm as systems integrator may be replaced by distributed coordination mechanism or vice versa. The development of Linux, which is open source software operation system, where users, developers and systems integrators have fuzzy boundaries between them.

In this chapter, systems integration capabilities are defined as capabilities related to systems integration defined in chapter 2, "an activity or business model which develop systems, networks and constructs that can be found in large scale, high cost, complex, customized, small batch production, engineering-intensive industries".

7.2. PV systems integration capabilities and its evaluation

I interviewed several PV systems integrator firms' engineers, sales persons and management as well as final users who own PV systems to categorize the systems integration skills (table 19). In particular, customers look at firms' track record of previous work which shows their level of reliability, cost competitiveness which indicates economic benefits such as internal rate of return (IRR) and payback period of investment, and finally various additional services (including consulting and monitoring services and financial arrangements with investors) which differentiate them from their competitors.

Engineers in systems integrator firms state that design phase is most critical because designing a fundamental system is one of the most critical parts, as it affects the schedule, cost, quality, and efficiency of the project. Nightingale discussed how systems integrator firms in CoPS improve their development processes and suggests costly redesign feedback loops in CoPS depends on reducing uncertainty and is done by firstly making sure that the design matches its specification, and secondly, making sure that the design specifications are correct (Nightingale,2000).

PV Systems Integrators' evaluation by clients					
		Systems Integrators' roles			
Scope of work	Plannning/ Project development	Engineering	Procurement	Construction	Service
Key factor for success (KFS) (evaluation factors by clients)	Understanding customers' needs and priority	Swiftness of making proposal	Cost competitiveness in price for total system integration	Capability of completing constcution in a shorter period of time	Variety of additional services provided
	credibility and integrity at initial level of discussion	Level of technical knowledge	Specific optimal combination of components	Quality level of construction work	
↓					
Capability for success (CFS) (capability to achive KFS)	ability of understand the particular customers' needs	Experience and track record	Having variety of source of procurement globally to source the optimal components	Having network of contractors in order to select the best subcontractors for specific projects	Offering special types of insurance
		Having best technical staffs	Having procurement power to buy at the lowest prices	Management/supervising skill with subcontractors	Assistance/consultanin g in obtaining finance
					Offering power generation performance guarantee

Table 19 Systems integration capabilities in PV industry
Source: by interview

As described in previous chapter, German PV systems integrator firms have their own scope of systems integration work (Figure 60). Their scopes are basically similar and sub-categorized as five phases: development (research, consulting) phase, engineering (design) phase, procurement (logistics) phase, construction phase and service (quality control, operation & maintenance) phase. As we observed in case studies in PV projects in Thailand and the Philippines, they often outsource some of engineering, some of procurement and construction work, but keep in-house consulting, project development and planning which are more critical capabilities in systems integration.

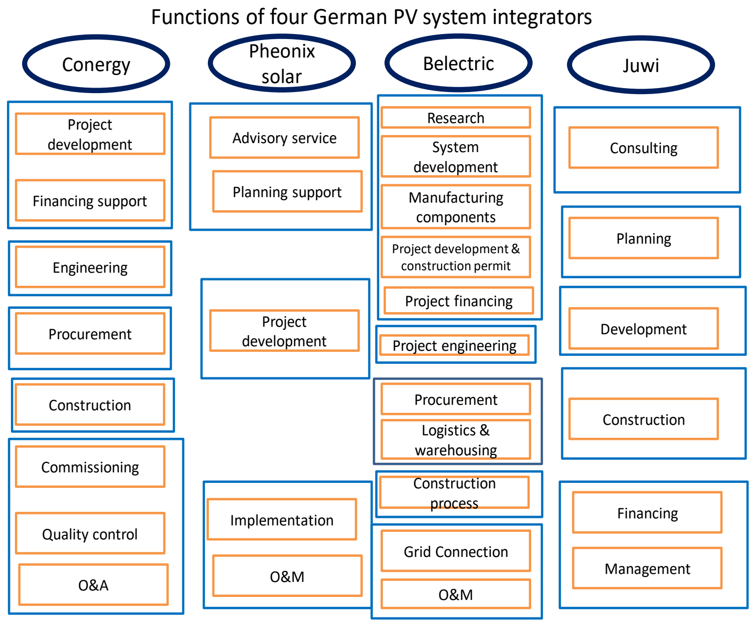


Figure 60 Functions of four German PV systems integrators

Source: Internal firm record

Based on interviews with twenty company engineers, Prencipe identified and ranked five systems integration skills (table 20). The highest ranked was the understanding of the underlying bodies of knowledge and systems behavior rather than the activities of design and assembly. In fact systems integration capability to assemble component interfaces ranks the lowest. These five skills seem a little general, but these results show that integration of the engine product is primarily seen as the integration of technological knowledge rather than the mere assembly of components.

Highest rank	Understanding of underlying technological disciplines and therefore ability to integrate them	
	Technological understanding of the entire system behavior in terms of relevant parameters	
	Ability to design the entire system	
	Ability to design most key components of the system	
Lowest rank	Ability to assemble components interface	

Table 20 Systems integration underlying skills
Source: Adapted from Prencipe (2011)

(A) Critical systems integration capabilities
(the capabilities that must be kept in-house to be a successful systems integrator firms)

One of the considerations is whether a systems integrator firm which has manufacturing capability would be more competitive or not than others. As far as PV systems integrator firms are concerned it is not a critical capability as we observed in the case study of major German PV systems integrator firms. PV systems integrator firms without manufacturing function can choose any PV module in the market depending on their customers' needs. Having manufacturing function could be even a disadvantage because they often have to be in a position where they must use their own panels due to production perspective. Conery has even split its manufacturing functions of panels, mounting systems and inverters. Japanese PV manufacturers such as Toshiba, Solar Frontier, is still struggling to expand their systems integration business due to the difficulties of being a manufacturer which usually take time to make quick decisions. Only exception is First Solar, which we observed in a case study in chapter 6.

Other perspective is that which capabilities are being outsourced by PV systems integrator firms. They often outsource construction and procurement of local components, but never outsource key integrated engineering, overall system design and procurement of main components.

In the case study of the Thailand project by Conergy in chapter 4, Conergy had an alliance with local partners, but Conergy performed integrated engineering, entire system design and procurement of main components such as panels and inverters. In the case study of Gotemba project, company U also performed integrated engineering, entire systems design and procurement of main components. They can achieve their cost competitiveness through their network worldwide with the best procurement. Systems integrator firms would have to be large enough in terms of size of the company because they have to procure main components. As Prencipe pointed out, the dynamic aspect of systems integration is also important because the speed of technological development is rapid in the PV industry. PV systems integrator firms usually have specific department which tracks technology advancement in the industry since maintaining technology level is critical for systems integrator firms as described later in this section.

In summary, integrated engineering, entire system design, adopting new technology and main components procurement are the most important capabilities for PV systems integration to be a first-tier PV systems integrator firm. They do not outsource these functions and always keep them in-house.

(B) Differentiating capabilities related to essential services

Based on our case studies and interviews, planning/project development and post-construction services are also important capabilities that can differentiate from competitors although they are not critically important for PV systems integrator firms. Some firms provide these services and others do not. Firms which provide these services sometimes offer many services, but other firms provide only limited services. Firms which provide more services could be more advantageous than firms which do not. Figure 61 shows the summary of this discussion. Yellow boxes show the critical capabilities for system integration and green boxes show the capabilities that differentiate them from competitors.

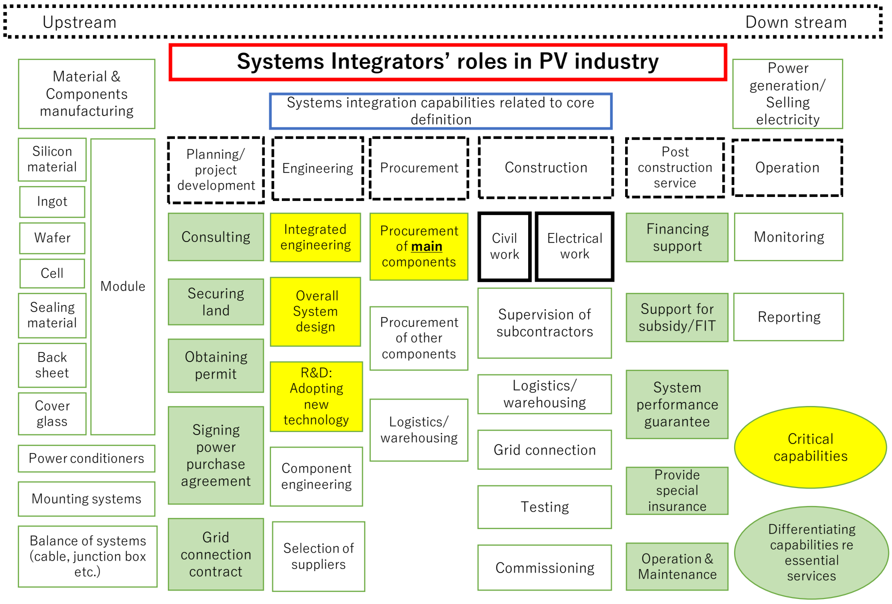
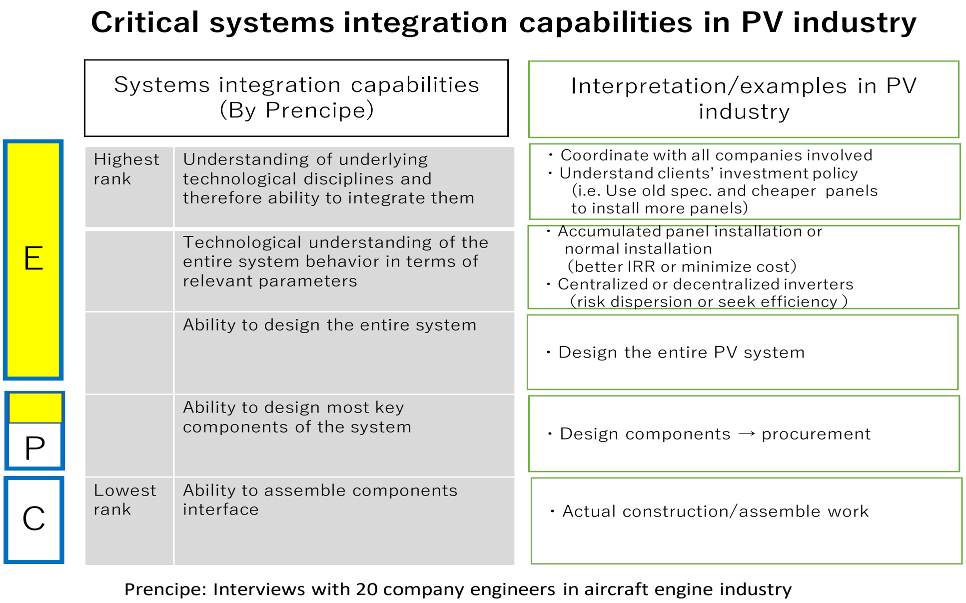


Figure 61 Critical PV systems integration capabilities
Source: By author

We can interpret Prencipe's five ability rankings into our systems integration capability categorization above as: "ability to assemble components interface" is construction, "ability to design most key components of the system" is procurement, "ability to design the entire system" is engineering. Two higher ranking abilities in table 20 are included in engineering capability because high level of understanding is required in order to design the optimal entire system. Figure 62 shows the interpretations/examples of each capability in the PV industry. Yellow color shows critical systems integration capabilities drawn from our discussion.



E: Engineering, P: Procurement, C: Construction

Figure 62 Critical systems integration capabilities
Source: By author

Planning/project development and post-construction services in our categorization in table 19 are not included in Prencipe's categorization. In PV systems integration planning/project development and post-construction services could include the items in figure 63. High and low are indicated by basic criteria based on the interview whether these services can be done internally by clients or not. As we have observed previous case studies in PV systems integration, providing these services could be a competitive advantage.

Phase : Planning/project development

High

(project development)

- Environmental analysis
- Economic assessments
- Searching projects

Low

(external assistance)

- Legal service
- Negotiation with local governmental agency
- Financing assistance

Phase ：Service

High

(Offer guarantee/ insurance)

- Providing special insurance to keep sustainability of the system
  (i.e. business interruption risk insurance, bankruptcy insurance)
- Guarantee for power production of the system

Low

(provide actual services)

- Technical support
- Teaching and training
- Facility management
- Operation and maintenance

Figure 63 Differentiating systems integration capabilities

Source: By author

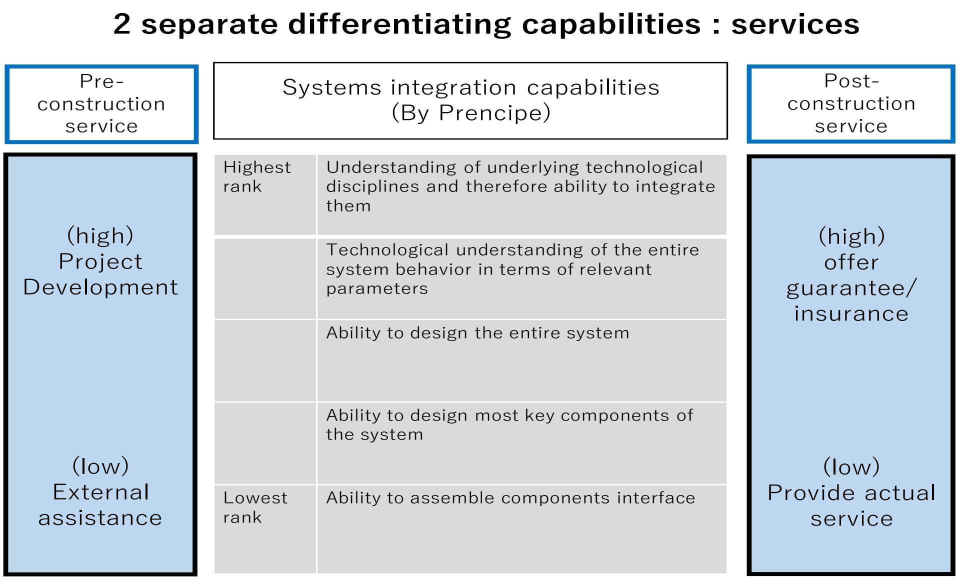


Figure 64 Differentiating systems integration capabilities

Source: By author

Gann and Salter suggested that the "bundle" of both products and services are competitive advantage, but I attempted to analyze in detail to categorize it into 2 parts in the PV industry before and after conventional capabilities. Figure 64 also shows high and low importance to clients.

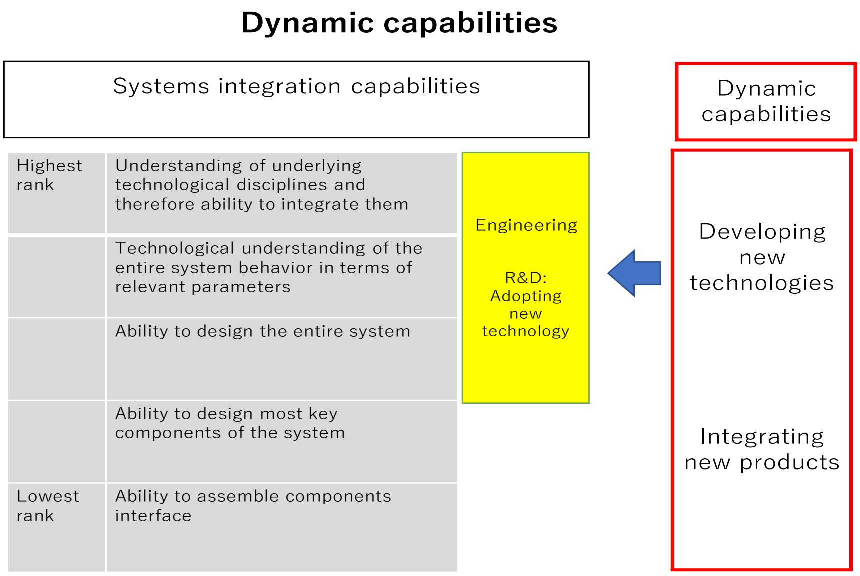


Figure 65 Dynamic systems integration capabilities
Source: By author

As Prencipe shows, dynamic aspect of systems integration capabilities is also significantly important indicated in figure 65. Dynamics in PV systems integration would include:

<u>Integrating new products</u>

Bendable panels

Panel with micro inverter

Adapting speed of increasing efficiency in panel technology

<u>Developing new technologies</u>

Floating solar system

Hybrid with wind/hydro power generation

Battery combined system

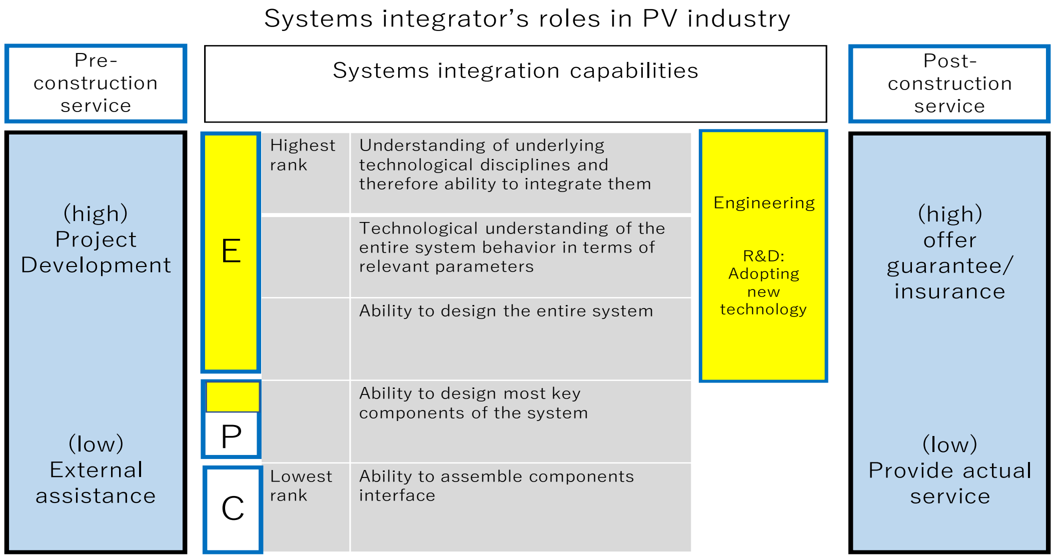


Figure 66 Expanded systems integration capabilities in the PV industry
Source: By author

Figure 66 summarizes our discussion of PV systems integrators' roles in PV industry based on Prencipe's discussion to show the critical systems integration capabilities and differentiating capabilities in the PV industry.

8. Conclusion

8.1 Integrated conclusion

In this dissertation I carried forward the analysis based on the research framework shown in chapter 1. First, I explored the functions of systems integration in the PV industry with several case studies and examined the business operations of the dominant 29 firms in the PV industry. As my first objective, to confirm the advantages of a systems integration business strategy in the PV industry, I analyzed the relation between the share of systems integration business in PV firms and the gross profit rate, using a Spearman rank-order analysis and several case studies to show that stable profits in PV firms is correlated with expanding their systems integration business.

In the PV industry many upstream sector firms are attempting to enter systems integration business located in downstream. In normal manufacturing industries, expanding to downstream sectors does not always lead to improved profitability (Gemba and Kodama, 2001). However, it seems that in an emerging industry, such as the PV industry, or in downstream sectors where a total solution is required, systems integration involving downstream sectors could be one of the effective strategic options. The Monsanto Electronic Materials Company (MEMC), which is a major silicon wafer manufacturing US firm, bought Sun Edison in 2009, which was a major PV systems integration firm, to acquire a systems integration capability. This is a typical example of expanding from upstream to downstream.

This dissertation proposes that the systems integration business has an advantage in achieving stable profitability compared to other sectors in the PV industry supply chain, which have substantial volatility in demand and price. Even if the profitability in overall PV industry decreases over the long-term due to maturation of the industry or to decreasing prices of components, the profitability of the systems integration segment probably will not change significantly, at least in the short run, compared to other segments such as the module manufacturing business, because systems integration is a critical function requiring labor of various skills that cannot be easily replaced with automation.

Following up this discussion of advantage of systems integration business the dissertation also suggests that certain capabilities are critical among many other capabilities for system integrator firms to be sustainable and successful: the skill set of integrated engineering, overall systems design, adopting new technology and procurement of main components. The firms also usually try to provide essential services before and after the construction which could differentiate from competitors.

With regard to the second topic in this paper, the prevalence and importance of systems integration in various industries, I showed that PV-industry-like systems integration can indeed be found in a CoPS industry, such as plant engineering construction. This analysis likewise showed that systems integration is not confined to CoPS industries, but probably can be important in industries that face the same sorts of demand-side market forces as mass production industries, while facing the sorts of supply side market environments that CoPS industries typically face.

As we see figure 23 and 24, Germany and Japan are the largest and forth largest cumulative PV installation countries next to China and the US. In manufacturing sector, Japanese companies used to show their presence along with German companies, but in the PV systems integration sector, they have not shown their presence in the global market. There are no large-size specialized PV systems integration firms in Japan compared with German PV systems integrator firms as we observe in chapter 4 and 5. These German PV systems integrator firms are still active in the global PV market although Chinese systems integration firms are dominant in China.

As shown in this study, systems integrator firms are vital for end-users such as power companies who want to use feed in tariff schemes to buy renewable energy for a long period of time. Such schemes are common in many countries, although some are being phased out. However, we recently have observed a situation in which PV energy can be effectively used without a feed in tariff scheme (e.g., rural electrification, meaning PV power generation is independent, often called as "off-grid" in unelectrified areas). Systems integration is also important for this off- grid power generation and utilization activity.

8.2 Implications and significance

8.2.1 Implications

Previous research has shown indications of systems integration moving beyond the technical field, where it traditionally has been embedded within the field of systems engineering, to the strategic business domain. Systems integration has been considered as one element of systems engineering, but now it is not just integration of components, but also a strategic task, which pervades business management not only at the engineering level but also in senior management decision- making. The business of systems integration is vital to the strategy of many of today's modern corporations (Hobday, Prencipe and Davies, 2011).

Firms in the PV industry, particularly modules manufacturers, should explore the advantages of expanding a systems integration business strategy as shown in this study. At the same time, this study suggests that the path to becoming a global systems integrator often begins by building up systems integration capabilities in one's own market, and then expanding to foreign markets as the companies gain expertise in dealing with local organizations in these foreign markets. Systems integrator firms in CoPS industries generally do not have as complex an array of local organizations with which they need to interact as systems integrator firms in the PV industry and perhaps other non-CoPS industries. Interviews with Japanese PV manufacturers indicate that these requirements of local networking and local adaptability are particularly challenging for Japanese companies. But just as companies such as Nikki overcame challenges in the case of overseas CoPS projects such as building LNG facilities, Japanese companies should be able to overcome the somewhat more complex challenges in non-CoPS industries.

8.2.2 Significance

The significance and contributions of this dissertation are as follows.

(academic)

The increase in importance of the systems integration business category and the importance of the role of systems integrator firms has been pointed out, but to date there has been little published research, which provides the theoretical, analytical, and empirical underpinnings needed to understand and explain systems integration (Hobday, Prencipe, and Davies, 2011). This dissertation tries to show the analytical and empirical studies concerning systems integration.

(companies)

By exploring these underpinnings, we can give companies that are already active in their industries and that plan to enter the systems integration market some important suggestions about their business strategies.

Furthermore, although systems integration plays an important role in the PV industry, only German and American PV systems integrator firms are strong outside their home markets. Almost no Japanese PV systems integrator firms are active in the global PV systems integration market, although Japanese PV module manufacturers were dominant globally, Analyzing the strategies of global PV systems integrator firms could provide suggestions to Japanese PV firms. Also the lessons from the experience of German, US and Japanese companies that have undertaken systems integration outside their home markets, indicate competencies that Japanese companies will have to develop to become global systems integration players.

(industry)

Although the systems integration business category is said to be present in all CoPS industries, the systems integration business category cannot be seen in all large-scale industries but rather only in certain industries that have particular characteristics. Thus, this dissertation also aims to clarify the characteristics of the industries where systems integration is an important competency, in other words, the characteristics of industries in which a systems integration business model is likely to be effective. It might also aid certain Japanese industries to decide whether they are industries where developing systems integration competency is likely to be a good business strategy.

(government)

PV is a key technology for harnessing one of the most important renewable energies for mankind, and thus the PV industry is a key industry in humanity's quest to secure needed energy but to combat global warming. But this industry is relatively new, having developed only in the last 20 years, and therefore, few academic studies have been performed yet. By analyzing the importance of systems integration in the PV industry, this study will also contribute to understanding how increased progress can be made in this vital industry.

(society)

CoPS industries that include systems integration provide a considerable share of gross national products worldwide, and it is said that the speed of evolution in those industries has been accelerated and complexity has been increased (Hobday, 1998). Our society now faces numerous energy issues. We need to develop a new solution in energy, which could be a new industry later. This study can contribute to emerging industries such as smart cities, which seem to need systems integration functions.

8.3 Limitation

This study is based on the interviews, field research, and case studies mainly in the PV industry. There is a need to extend this work of systems integration to industrial and service sectors other than PV and CoPS industries in order to test this paper’s analysis and compare the importance of systems integration with other key drivers of industrial competitiveness.

APPENDIX

The following industries would be candidate examples of Non-CoPS type systems integration.

(Robot systems)

Robot systems integration is the process of programming and outfitting industrial robots so they can perform automated manufacturing tasks according to the needs of various industrial customers. System integrators in the robotics industry are companies that will analyze your robotic system needs, provide a plan for automation, and put the automation into production.

In the global robot industry, Kuka of Germany, and ABB of Switzerland are the two big manufacturers followed by several Japanese firms such as Fanuc, Yasukawa Electric, Kawasaki Heavy Industry. There are many robot systems integrators in the US.

In the robot industry in Japan we observe robot systems integrator firms are now emerging to help manufacturers to make their manufacturing process more efficient and competitive. They propose the design of robotic systems, engineering of such systems, and implementing their operations. They work between robot-related component manufacturers and end-users to provide customized and optimized solution ("Reference book of robot systems integrator's skills", Ministry of Economy, Trade and Industry, and Japan Robot Association, June 2017). Mr. Kubota, president of Sanmei Kikou Co., the president of FA and Robot Systems Integrator Association, which has 123 members firms and 21 cooperating firms, points out that the robot systems integrator firms in Japan are relatively small to medium in size. His company is rather small and engages in manufacturing of factory systems and robot related components and has 25 million USD annual sales and 100 company employees. He explained in his presentation ("Aiming for Robot revolution, the current situation of Japanese robot systems integrator firms ", Sept. 3, 2015.) the issues of Japanese robot systems integration.

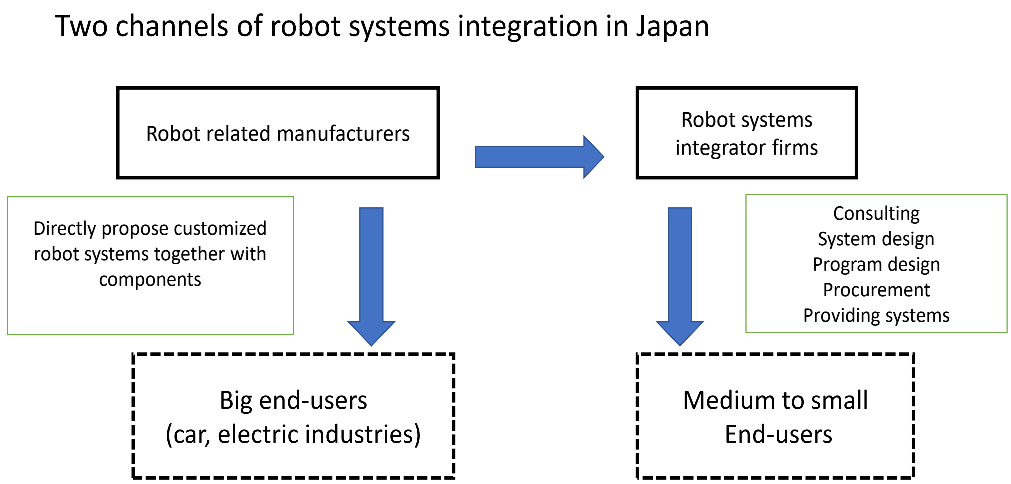


Figure 67 Two channels of robot systems integration in Japan
Source: Aiming for robot revolution - the current situation of Japanese robot systems integrator firms Sept. 2015

He indicates that there are two channels for providing robot systems in Japan: directly from large robot manufacturers to big end-users, and through systems integrators to medium to small size end-users (figure 67). Also Japanese systems integrator firms are normally small companies which are manufacturing robot components rather than independent systems integrators which specialize in systems integration (figure 68). This phenomenon illustrates the similarity to PV systems integrator firms. As the Ministry of Economy, Trade and Industry suggests more Japanese robot systems integrator firms are needed ("The survey of Japanese robot systems integrator firms, January 2018").

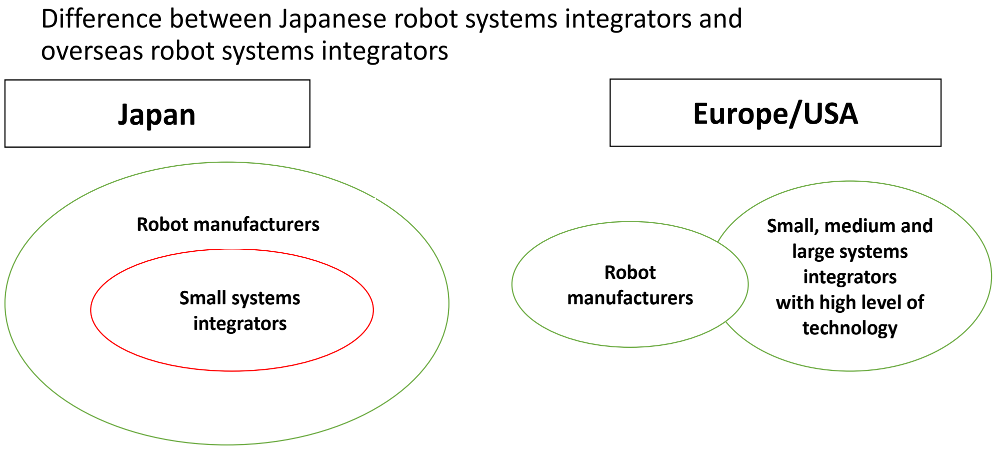


Figure 68 Difference between Japanese and overseas robot systems integrators
Source: Aiming for robot revolution- the current situation of Japanese robot systems integrator firms Sept. 2015

(Smart city)

The systems integration function plays an important role in new industries such as smart housing, smart grid and smart cities which are given attention to recently. The concept of smart housing aims for the optimization of a house hold energy usage by HEMS (home energy management systems) by controlling using information technology at the micro household level. The concept of smart grid targets also the optimization of variety of functions of electrical power: power generation, transmission, distribution, storage of power. It controls demand and supply of electricity by information technology maximizing usage of renewable energies such as wind power and solar power which are not stable enough yet. Further smart grid is a new concept that integrates both smart house in micro perspective and smart grid in macro perspective to achieve the optimization of usage of renewable energies as well as conventional energy sources at the macro level. One of the major attributes of the smart grid is to integrate renewable and storage energy resources at the consumption level (A.R. Al-Ali, Ayman El-Hag et al., 2011).

Smart city is a broader system that attempts the optimization of an energy supply by combining both micro and macro level optimization systems. In smart cities systems integration takes place at physical, network and application levels (Suzuki, L. 2017).

Vahid, Hanifa et al. proposes the need of Business Process Change (BPC) for systems integration in smart city development (Vahid, Hanifa et. al.2014). BPC is defined as analysis, redesign, and improvement of existing business processes to achieve a competitive advantage in performance. They discuss that systems integration is a common term in private enterprises, but city as a system of systems is also considered as a large-scale enterprise, which includes all of its elements (Vahid, Hanifa et. al. 2015) (figure 69).

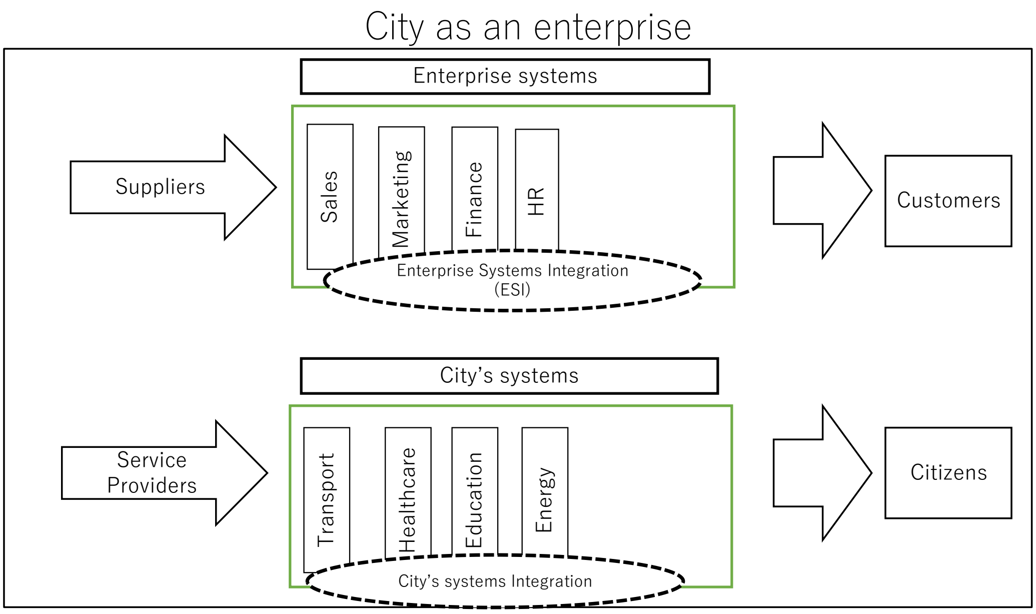


Figure 69 City as an enterprise
Source: Vahid, Hanifa et. al. 2015

CITIES in the Technical University of Denmark is the largest Smart Cities and ESI (energy systems integration) research project in Denmark established in January 2014. According to them, "A wide range of research activities have arisen to support the Danish target of a 100% renewable energy system by 2050. Projects focused on individual aspects of the energy system, such as zero emissions buildings or intelligent power systems provide valuable insights, which facilitates flexibility throughout the energy system. CITIES will address this deficiency by establishing an integrated research center covering all aspects of the energy system, including gas, power, district heating/cooling and biomass." (Intelligent Energy systems Integration in Smart Cities, CITIES, The Technical University of Denmark; Smart City Dialog, Singapore, October 2015). The center proposes intelligent energy systems integration in smart cities and the concept of Energy Systems Integration (ESI), the process of optimizing energy systems across multiple pathways and scales (figure 70).

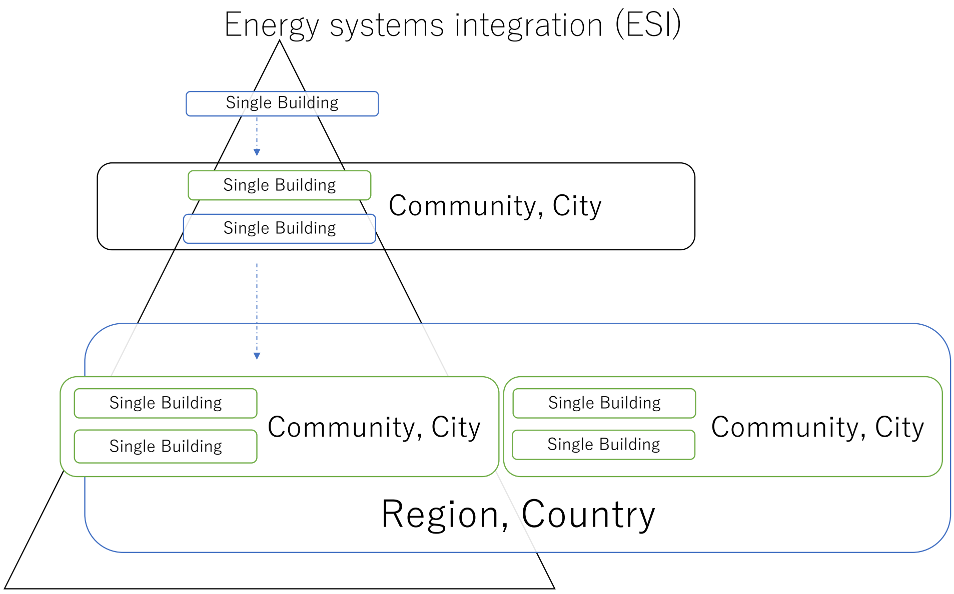


Figure 70 Energy systems integration
Source: CITIES, DTU, Intelligent Energy Systems Integration in Smart Cities, Smart City Dialog, Singapore Oct. 2015

In order to implement smart city projects effectively, coordination is needed between top-down, project owner leadership, usually by local government, and bottom-up systems integration by individuals (figure 71). People have already owned IoT based smart products at home. We need to combine, coordinate both government-driven systems integration and household/business level systems integration. I propose this as "Across-industry systems integration".

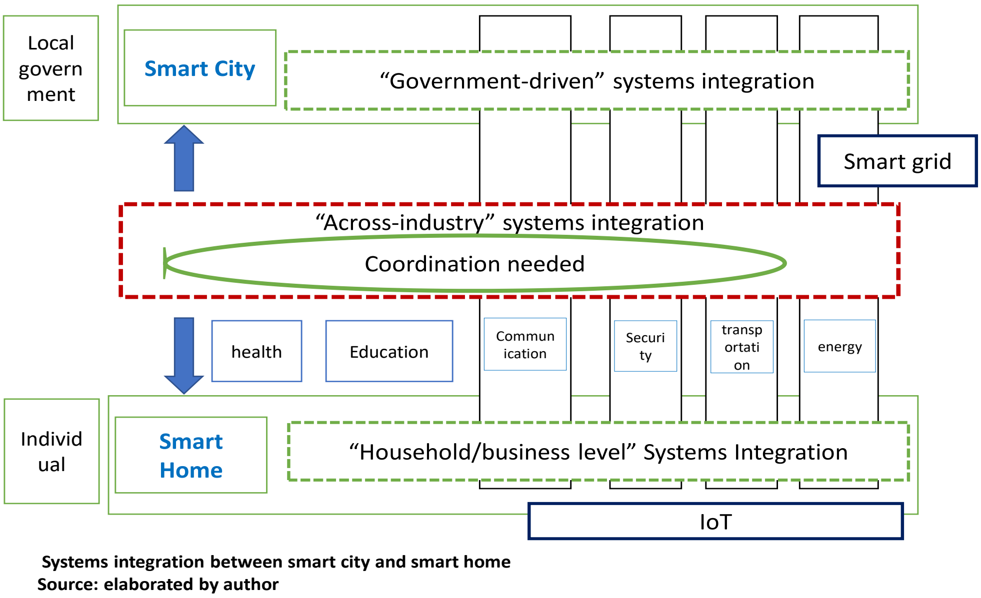


Figure 71 Systems integration between smart city and smart home
Source: elaborated by author

Interview records

(dates, companies, persons to be interviewed, locations)

<u>**Exhibition, trade show, conference attendance**</u>

June 2, 2011 Attendance with The Renewable Energy Conference in Manila, Philippines
December 7, 2011 PV Japan Exhibition in Makuhari, Tokyo, Japan
June 13-14, 2012 Intersolar Exhibition in Munich, Germany
September 12, 2012 The Renewable Energy Conference in Bangkok, Thailand
October 3, 2012 PV Exhibition in Taipei, Taiwan
December 6, 2012 PV Japan Exhibition in Tokyo
March 1, 2013 PV Expo in Tokyo
July 25, 2013 PV Japan in Tokyo
February 26, 2014 PV Expo in Tokyo
August 1, 2014 PV Japan in Tokyo
July 29, 2015 PV Japan in Tokyo
January 20-21, 2016 Japan Photovoltaics Energy Association Philippines visit
March 4, 2016 PV Expo in Tokyo

<u>**Factory visits and observations**</u>

January 20, 2009 Miyazaki Plant One of Solar Frontier, Mr. Yoshida, factory manager
February 19, 2009 Miyazaki Plant Two of Solar Frontier, Mr. Yoshida
March 24, 2011 Factory observation of REC, Singapore
June 3, 2011 Factory observation of First Philec (Joint venture company with Sun Power), Manila, Philippines
June 18, 2012 Factory observation of Conergy, Frankfurt, Germany
June 18, 2012 Factory observation of Mounting Systems Inc., Frankfurt
October 2, 2012 Factory observation of AUO, Taichung Taiwan

<u>**Company interviews**</u>

<u>**・Solar Frontier Company Ltd.**</u>

March 17, 2009 11:45 Mr. Kuroda, head of corporate planning
March 27, 2009 10:00 General shareholders' meeting of Showa Shell Sekiyu Company, Ltd. (Solar Frontier is the subsidiary of Showa Shell Sekiyu.)
April 3, 2009 10:00 Interview with Mr. Kameda, president
June 26, 200913:00 Interview with Mr. Kameda, president

August 25, 2009 10:00 Interview with Mr. Kameda, president
October 7, 2009 9:30 Interview with Mr. Kameda, president
October 21, 2009 13:00 Interview with Mr. Hirano, executive in overseas business
October 22, 2009 10:00 Interview with Mr. Kuroda, head of corporate planning
November 18, 2009 9:30 Interview with Mr. Kameda, president
March 30, 2010 10:00 General shareholders' meeting of Showa Shell
March 30, 2011 10:00 General shareholders' meeting of Showa Shell
January 10, 2012 10:00 Interview with Mr. Kuroda, head of corporate planning
March 29, 2012 10:00 General shareholders' meeting of Showa Shell
April 16, 2012 15:00 Interview with Mr. Hirano, director
March 28, 2013 10:00 General shareholders' meeting of Showa Shell
April 17, 2013 16:30 Interview with Mr. Tamai, president
June 11, 2013 9:30 Interview with Mr. Kato, chairman of Showa Shell
July 23, 2013 15:00 Dealers' meeting of Solar Frontier
November 15, 2013 15:00 Interview with Mr. Kato, chairman of Showa Shell
March 27, 2014 10:00 General shareholders' meeting of Showa Shell
September 30, 2014 10:00 Interview with Mr. Hirano, director
February 23, 2015 14:00 Interview with Mr. Kuroda, head of corporate planning
July 2, 2015 13:30 Mr. Abe, manager of overseas business
July 13, 2015 13:30 Mr. Abe, manager of overseas business
July 17, 2015 10:00 Mr. Abe, manager of overseas business
August 17, 2015 13:30 Mr. Abe, manager of overseas business
December 15, 2015 14:00 Mr. Ueno, manager of overseas business
February 9, 2016 10:00 Mr. Ueno, manager of overseas business
February 15, 2016 PM Dealers' meeting of Solar Frontier
March 15, 2016 10:00 Mr. Ueno, manager of overseas business

・Exsol

May 17-18, 2016 Mr. Suzuki, Vice president and other executives in Manila
July 14, 2016 Overseas sales team in Manila

・Solar Silicon Technology (SST) Company, Ltd.

July 2, 2009 11:00 Interview with Mr. Tezuka, president (former managing director of PV department of Kyocera)
April 7, 2011 13:30 Mr. Tezuka, president

・Smart Solar Company Ltd.

July 30, 2010 18:00 Interview with Mr. Tomita, president (former managing director of PV department of Sharp)

October 5, 2010 18:00 Interview with Mr. Tomita

・Phoenix Solar Company Ltd.

June 3, 2011 18:00 Interview with Mr. Inglin Christophe, managing director

October 12, 2011 13:30 Interview with Mr. Inglin Christophe, managing director

February 1, 2012 15:00 Interview with Mr. Inglin Christophe, managing director

June 15, 2012 9:15 Interview with Mr. Inglin Christophe, managing director

July 26, 2012 13:00 Interview with Mr. Inglin Christophe, managing director

October 3, 2013 14:00 Interview with Mr. Inglin Christophe, managing director

・Conergy Asia Company Ltd.

July 20, 2011 16:30 Interview in Singapore with Mr. Lenz , managing director Asia

September 28, 2011 10:00 Interview in Manila with Mr. Lenz

October 11, 2011 10:00 Interview in Singapore with Mr. Lenz

February 2, 2012 9:30 Interview in Singapore with Mr. Lenz

March 6, 2012 10:00 Interview in Tokyo with Mr. Lenz

April 10, 2012 10:00 Interview in Tokyo with Mr. Lenz

May 30, 2012 full day Technical meeting with Conergy team in Tokyo

June 14, 2012 15:00 Meeting in Germany with Mr. Comberg, president of Conergy Headquarter

July 26, 2012 full day Meeting in Tokyo with Conergy team

September 18, 2012 10:00 Interview in Singapore with Mr. Lenz

October 9, 2012 10:00 Interview in Tokyo with Mr. Lenz

November 20, 2012 9:30 Interview in Singapore with Mr. Lenz

February 20, 2013 18:30 Interview in Tokyo with Mr. Lenz

July 11, 2013 14:00 Interview with Mr. Ohtaka, Conergy Japan

August 8, 2013 9:30 Interview with Mr. Ohtaka, Conergy Japan

October 18, 2013 9:30 Interview with Mr. Ohtaka, Conergy Japan

December 19, 2013 16:00 Interview with Mr. Ohtaka, Conergy Japan

January 28, 2014 18:30 Interview in Tokyo with Mr. Lenz

May 20, 2014 13:00 Interview in Tokyo with Mr. Lenz

August 1, 2014 12:30 Interview in Tokyo with Mr. Lenz

September 10, 2014 14:00 Interview in Tokyo with Mr. Lenz
October 7, 2014 9:30 Interview in Tokyo with Mr. Lenz
August 4, 2015 10:00 Interview with Mr. Ohtaka, Conergy Japan

・SMA

February 20, 2013 15:00 Interview in Manila, Philippines
December 4, 2014 10:30 Meeting with SMA Japan
December 15, 2014 11:00 Meeting with SMA Japan

・Trina Solar

November 12, 2013 15:00 Meeting with Trina Solar,
Ms. Helena Li, Managing Director, Mr. Imazu, president of Trina Solar Japan, Mr. Kondo, sales manager, Mr. Funakoshi sales supervisor
February 26, 2014 10:00 Trina Solar in Tokyo
July 2, 2014 13:30 Trina Solar in Tokyo

・Shizen Denryoku

March 20, 2014 18:00 Interview with Mr. Isono, president and founder
May 2, 2014 16:00 Interview with Mr. Isono

・Sharp

August 19, 2014 10:00 Ms. Fukushi, Solution department of Sharp
September 18, 2014 14:00 Interview with Peter, sales manager of Sharp Philippines

・First Solar

April 7, 2014 16:00 Interview with Mr. Soga, manager of First Solar Japan

・Omron

September 2, 2014 14:00 Meeting with Omron Field Engineering

・EDF (French Electric Public Utility)

April 12, 2013 12:00 Interview with the Tokyo representative of EDF in Tokyo

・Infinity

January 7, 2013 14:40 Interview with Danny, president of Infinity Philippines

・Showa Shell Engineering Company(SEC)

November 11, 2013 16:00 Meeting with SEC team
December 25, 2013 14:30 Meeting with SEC team

・Q-Cells Japan

March 15, 2011 13:30 meeting with Q-Cells Japan

・Epson Philippines project

March 3, 2015 11:00 Epson Philippines (PH)
March 18, 2015 13:30 meeting with Mr. Nishimura of Epson Tokyo HQ(Nagano)
March 31, 2015 13:30 Epson Philippines (PH)
April 28, 201510:30 meeting with Mr. Nishimura of Epson Tokyo HQ(Nagano)
June 4, 2015 15:00 Interview with Mr. Ikezu, Shimizu Construction PH
July 8, 2015 14:00 Interview with Mr. Ikezu, Shimizu Construction PH
September 17, 2015 10:00 Mr. Yoshida of TOENEC PH
December 7, 2015 15:30 Mr. Yoshida of TOENEC PH

・Moser Baur Company Ltd.

June 27, 2012 16:00 Meeting with a Japan representative, Moser Baur

・Taisei Construction Company Ltd.

May 15, 2014 12:00 Mr. Sento, former director in sales.

・Nikki（JGC）

November 6, 2012 16:30 Interview with Mr. Wada, general manager of the Solution Department
August 5, 2013 17:00 Interview with Mr. Wada

・AUO

April 16, 2012 13:30 Interview with Helen Lou, Tokyo representative
January 22, 2013 14:00 Interview with Helen
July 11, 2013 10:00 Interview with Helen
September 3, 2013 14:00 Interview with Helen
March 7, 2014 10:00 Interview with Jerry Sam of Taiwan HQ
May 19, 2014 16:00 Interview with Jerry Sam of Taiwan HQ
July 1, 2014 16:00 Interview with Jerry Sam of Taiwan HQ

・Nitten

March 17, 2016 17:30 Interview with Mr. Gouma, sales manager

Footnotes

[1] CoPS and its related areas are being researched in the Science and Technology Policy Research (SPRU) of the Complex Product Systems Research Center, University of Sussex, UK. There is also the Complex Product Systems Innovation Center Unit, Center for Research in Innovation Management (CENTRIUM), University of Brighton, UK.

[2] Wang and Tunzelmann (2000) analyzed the concept of "complexity" in terms of two dimensions: depth and breadth. They pointed out that we have to be aware of new complexity in the market, production process, and administration and management, in addition to the complexity of the technology and product.

[3] Sakakibara and Matsumoto (2006) say that "appropriability of innovations" (the innovator's ability of getting returns from innovations) varies between different industries, product categories, and firm strategies. The authors described an example where cartridge technology used in the laser beam printer business was used again when Canon Corporation developed the ink jet printer. Getting profits from new products not only involves marketing and sales issues but engineering and design issues. In the PV industry, the roles of engineering and design in systems integration substantially affect the total performance of the whole PV system.

[4] Hobday commented that measurements of the scales of high to low were not provided here. The scales are somewhat arbitrary, and some rely on subjective judgement. They help illustrate the range of factors involved and show the different characteristics of each industry (Hobday, 1998).

[5] Shum and Watanabe proposed the concept of "platform-based small customization projects" as a sort of combination of CoPS and mass-produced products. Particularly in a case study of a US grid-tied small PV system, they suggested that independent, third-party system integrators who perform roles between component suppliers and end users must learn a broad range of technology, particularly in the cost of non-module portion (Shum and Watanabe, 2008).

[6] I had more than 20 times interviews with Conergy between 2011 and 2015.

[7] Thailand has about 1,800 kWh/m2/year irradiation on average. It is one of the highest irradiation areas in the world. Germany, which is the first mover of PV power generation, has around 1,100 kWh/m2/year.

[8] Incumbent oil and gas firms have entered the PV business as a key challenge for a sustainable energy future. British Petronium, Royal Dutch/Shell and Total entered the PV business. However, they had difficulties with integrating solar PV technology in their supply chain and therefore established independent business units. Shell and BP withdrew from the PV business later (Pinkse and Buuse, 2012).

[9] Hoffmann (2006) tried to classify the PV market into four segments in terms of method of utilization: consumer applications (residential), remote industrial electrification (such as a hybrid PV diesel system that is backed up by battery), developing countries (very little or no electricity areas), and grid-connected systems.

[10] In Japan, installations below 50kwp are often categorized into two segments: 10-50kwp installation for the FIT scheme and below 10kwp residential installation for the net metering scheme.

[11] The spinoff has been an instrument to achieve corporate growth objectives for Japanese firms. The spinoff is a widely used flexible organization arrangement that is suitable to survival and offers an alternative method of diversification. It notes that large U.S. firms tend to be more diversified compared with comparable Japanese firms, but U.S. firms do not generally spin off their highly promising businesses (Ito, 1995). Ito and Rose analyzed parent-subsidiary relationships in Japanese firms and listed the conditions for spinoffs and subsidiaries such as parent size, subsidiary size, parent profitability, and subsidiary profitability (Ito and Rose 1994). The share of Sharp's PV business was substantial, but they did not spin off it. Kneller categorized and analyzed the types of Japanese innovation firms. Sharp would be an "established newcomer," and Solar Frontier would be a "tethered spinoff" (Kneller, 2007).

[12] The irradiation is high in South East Asian countries and therefore, they are suitable for PV power generation. These countries have already been trying to introduce PV with various schemes such as FIT. The Philippines is also trying to use the FIT scheme, but the rate of FIT is not so attractive that PV has not yet prevailed with exceptions of very

large-sized utility scale installations. However, due to the significant increase of electricity rate in the past decades and the persistent shortage of supply of electricity, the commercial self-consumption market is expanding.

13 Shum and Watanabe analyzed the difference in diffusion of PV installation between Japan and the United States of America. They showed that PV was developed originally for the residential market in Japan, led by highly vertically integrated module manufacturers, which they called "manufactured technology," whereas PV was developed by user-oriented and customized installations, "information technology," in the USA. This shows the uniqueness of the Japanese supply chain in the market (Shum and Watanabe, 2007 and 2009).

14 Ghemawat, by describing Google's difficulties in Russia and China, shows his framework by introducing four factors for the study in a firm's globalization. Administrative distance and economic distance are particularly critical for PV-related firms to be successful because the keys for success in the PV industry are local FIT regulations and local electricity prices (Ghemawat, 2007).

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