PV industry in China and three Southeast Asia countries: A systematic literature review using PRISMA

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Abstract. One form of renewable energy utilization that has been recognized as environmentally friendly and helps maintain world carbon emissions is Photovoltaic (PV), where global energy companies are starting to move towards PV investment. This study highlights the PV industry condition in China as a giant country in producing PV and three South-East Asia states. Systematic literature review with Preferred Reporting Items for Systematic Review and Meta-analyses (PRISMA) is used as the methodology for collecting data. PICOS (Population, Intervention, Comparator Group, Outcome or Endpoint, Study Design) is used as an approach method for forming questions in searching for data sources. PRISMA diagrams are formulated in a hierarchical form to select potential sources of literature. Finally, this study uses 71 literatures from China, 5 literatures from Indonesia, 9 literatures from Malaysia, and 4 literatures from Vietnam. This finding indicates that with abundant literature discusses China's PV industry, their PV industry is more advanced compared to three South-East Asia countries, which they are still lack understanding and knowledge of PV especially its industry and their aim for PV industry is still unclear.

1. Introduction
As the world society grows faster and bigger, energy consumption is also increasing. A lot of countries move for the transition of energy, from conventional energy use to renewable and green energy. One of the potential renewable energy sources is solar energy with using solar cell photovoltaic (PV) as a device to “capture” light and “convert” it into usable energy [1]. The most dominant solar cell type in the market is silicon solar cell, which covers 95% of total solar cell PV world production [3].

China is the world's number one PV manufacturer, which has a 76% and 71% share of the total production of solar cells and PV modules, respectively [2]. On other hand, PV also makes its place as a very potential usable renewable energy in South-East Asia (SEA) countries. Solar
PV experienced the largest reduction in investment costs (45% decrease) compared to other renewable energy sources [4]. After China, Malaysia got the second place as the solar cell manufacturer and third place as a PV module manufacturer [2]. Vietnam is among the five biggest countries with a PV market which have a 66% share of total new PV installation globally in 2020 [5]. With Indonesia as the country with the most energy consumption in SEA and PV as its biggest potential energy source [6], those three SEA countries and China are ideal territories to be observed and compared for the PV industry in each region. The focus of this study is to understand the difference in the PV industry situation of each country based on their technology, policy, and market PV and what factors drive those countries to develop their PV industry.

2. Methodology

This study uses systematic literature review and meta-analysis as research methodology, which both are important as the methodology for collecting evidence accurately, precisely, and reliably [3]. The meta-analysis which is used is PRISMA (Preferred Reporting Items for Systematic Review and Meta-analyses). This study uses the University of Indonesia (UI) online library as the source of literature. The following subsection is referred to [3].

2.1 Research Protocol and Eligibility

PICOS (Population, Intervention, Comparator Group, Outcome or Endpoint, Study Design) is used as an approach method for forming questions in searching for data sources, wherein this research the PICOS elements formed are: (a) Population: PV Industry of each country, (b) Intervention: Factors affecting the PV industry (Technology, Market and Policy), (c) Comparator: PV Industry of each country (Population also as Comparator), (d) Outcome: The condition of the factors that affect the PV industry in each country of observation, (e) Study Design: Not limited in this study.

Source criteria that are included in this study are: (a) Literature published from 2000 to 2021, (b) Literature using English, (c) Literature that is accessed from the UI library (https://remotelib.ui.ac.id/menu) and is fully accessible literature (full text), (d) Literature that can answer research questions regarding the PV industry in Indonesia and the countries of observation. Then, the source criteria that are excluded in this study are: (a) Literature published before 2000, (b) Literature that does not use English, (c) Literature that cannot be accessed completely through the UI library, (d) Literature sourced from review journals, articles or review papers which doesn’t have any clear analysis framework, opinion articles, articles from newspapers, and data from unofficial institutions, (e) Literature that is not related to the PV industry and does not answer research questions regarding the PV industry in Indonesia and the countries of observation.

2.2 Data Source and Searching Strategy, and PRISMA diagram

Sources of scientific articles which were obtained from the UI library are sourced from official international databases, namely ScienceDirect, ProQuest, SpringerLink, Taylor & Francis, IEEE explore, Royal Society of Chemistry, and Sage Journals. The keywords are designed following the PICOS and were input in Scopus search engine with category “Article title, Abstract, and Keywords”. Therefore, the keywords with its algorithmic logic are:

(Industry) AND (Photovoltaic) AND (Development) AND (Factor OR Technology OR Policy OR Market) AND (Indonesia OR China OR Malaysia OR Vietnam).

The PRISMA diagram as a guide for selecting literature is depicted in Figure 1.
3. Result and discussion

3.1 Literature Search Results

Table 1. depict the number of literatures which was appearing after the keywords were input in the Scopus search engine. Because the keyword with Vietnam as a country didn’t produce any appearance, the keyword was changed to (Industry) AND (Photovoltaic) AND (Vietnam), therefore, 5 literatures appeared in the Scopus. Because of the limited appearance of literature based on SEA case study, this study doesn’t use PRISMA method to filter them and straightly using 5 case study-based literatures in Indonesia, 9 case study-based literatures in Malaysia, and 4 case study-based literatures in Vietnam. After the first screening, the screening of the title and abstract, the accessible literature which is passed have the number of 115 case study-based literatures in China. After screening of problem, method and result, and the full text review, this study uses 71 case study-based literatures in China.

|          | China       | Indonesia | Malaysia | Vietnam |
|----------|-------------|-----------|----------|---------|
| Factor   | 68          | 2         | 2        | 0       |
| Technology | 172        | 7         | 7        | 0       |
| Policy   | 190         | 5         | 3        | 0       |
| Market   | 134         | 3         | 7        | 0       |
3.2 Discussion

3.2.1 China

The number of literatures discussing the PV Industry in China are greatly exceeding rather than the SEA countries, indicating there is more research and development in PV Industry in China. In China, the PV industry and market growth with a remarkable development, which make China become the most producer of PV and one of the biggest PV market in the world. In this research, the PV industry and market development is divided into three eras; before 2000, in range of 2000 until 2010, and after 2010. Furthermore, there are three topics which will be discussed, namely (A1) Technological development of production, research and development status, subsidies, and policies related of PV industry, (A2) PV market and producent, installment, and trade dispute growth, and (A3) Incentives, fund, installment and industrial development policies and government domestic-international relation. Figure 2. describes the total share of China-based literature with each corresponding topic. The A1 topic uses 38 literatures, the A2 topic uses 42 literatures, and the A3 topic uses 34 literatures. There are 9 literatures shared by A1 and A2, 6 literatures shared by A1 and A3, 14 literatures shared by A2 and A3, and 7 literatures shared by all three topics.

Figure 3. depicts the distribution of the literature based on their journal rank and article type. Literatures from Q1 ranking journal are the most from all with 46 literatures, follows by proceeding/conference article with 20 literatures, and then there are Q2 and Q3 ranking journal with only 4 literatures and 1 literature, respectively. Therefore, Figure 4. shows the share of articles from Q1 ranking journal in regards of their journal. The “Renewable and Sustainable Energy Reviews” is the journal where this study gets the most sources. The others journal which the journals that in this study only one source was taken are “Energy research and social science”, “IEEE Transactions on Sustainable Energy”, “Energy and Environmental Science”, “Journal of Contemporary China, Solar Energy”, “Journal of Environmental Management”, and “IEEE Transaction on Engineering Management”.

Figure 2. The share of the topic of China-based literature
Figure 3. The distribution of the literature based on their journal rank and article type

Figure 4. The share of articles from Q1 ranking journal in regards of their journal title

3.2.1.1 Technological development of production, research and development status, subsidies, and policies related of PV industry. Currently, in China, the government bodies which manage research and development investment: Ministry of Science and Technology (MOST), the Ministry of Finance (MOF), the National Development and Reform Commission (NDRC) and regional support agencies. Research and development policy in China is more focus to production push and create a gap between annual PV production and installation [7].
Table 2. Data extraction from A1 topic articles

| Period of time | Status and Innovation | Source of Literature |
|---------------|-----------------------|----------------------|
| **Before 2000** (1970s) | PV as a research topic on satellite technologies | [8-10] |
| | The central government funded several PV research and development (R&D) projects for research institutes and universities to develop polysilicon silicon solar cells and Gallium Arsenide (GaAs) solar cells | [11] |
| | China optics and electronics technology center was set up to start the study of polysilicon silicon solar cells and the application of PV systems, and the Cadmium Telluride (CdTe) solar cell was developed in China | |
| **Before 2000** (1990s) | the global PV market leader, Yingly Solar, was founded, and the company combines local and foreign organizational arrangements. | [12] |
| | the “9th Five-Year Program” in 1995 was implemented which focused on establishing a modern enterprise system, supporting scientific research, and launching national projects | [13] |
| **2000-2010** | In the earliest of this stage, China’s poly-silicon purification technology was still low level, energy-consumed and with no cost advantage | [14] |
| | The refining technique of high-purity silicon is basically in the hands of foreign manufacturers | [15, 16] |
| | China's had remarkable achievements in patenting activities in relation to renewable energy, which have surpassed technologically advanced Western countries since 2000. However, In the 2000s, there was no R&D dedicated renewable energy generation technology to track and study international advanced technologies and conduct research on these technologies | [17, 18] |
| **2004** | China's first 12 pairs of rod polysilicon energy-efficient reduction furnace tests were successful, and the technical indicators reached the international advanced level. | [11] |
| | The main players in terms of patent applications were mostly located in China and mostly focus on cells and panels. Chinese companies lead among the top patent applicants. | [7, 19] |
| **2009–2013** | Then China came to the accelerated period, as China has recently begun to focus more on R&D to advance PV-related technologies, such as silicon production, to catch up with major producing countries | [20] |
| | Domestic polysilicon was in short supply in China until the stateowned Emei Semiconductor Research Institute achieved a successful R&D of polysilicon technology and transferred it to polysilicon manufacturers in China | [21] |
| **Pre-2007** | China still lags behind developed countries such as the United States and Japan in terms of cell and component efficiency, production equipment technology, and testing technology | [22] |
| | In 2007, the Shanghai Institute of Technical Physics of the Chinese Academy of Sciences discovered and developed a physical purification method whose silicon purity of solar cells can reach 99.9999% | [9] |
| **Pre-2010** | Compare to other developed nation (US, Japan and Germany), PV module price in China was still higher | [7] |
| | PV rooftop was very costly, so more research and development on PV technology was required | [23] |
In this time, the maximum power point tracking and battery charge control were two main research topic in PV power generation system. First-tier manufacturers, such as Trina and Yingli, also collaborate with foreign research institutions, notably the School of Photovoltaic and Renewable Energy Engineering at the University of New South Wales (UNSW) in Australia. The cumulative expenditure for PV research and development is about 5.02 million yen. Exemption of import tax and VAT for R&D institutions by the Ministry of Finance when foreign R&D institutions import equipment and instruments, companies can benefit from exemption from import taxes and related VAT; when foreign or domestic research and development institutions purchase domestic equipment, they get a full VAT refund.

**After 2010**

Chinese inventors were starting to be involved in about 3% of the total number of transnational patent applications in the PV field. Although the PV electronics group has experienced rapid growth in patent activity since 2010, it still lags behind the first two groups with a share of the total number of patent fractions of around 9%. On the other hand, energy monitoring and storage technologies have the lowest patent shares at 4% and 2%, respectively. Inventions with combined properties account for 7% of the total patents.

The MOF support by gives money via import tax and value added (VAT) exemption for research and development purchasing domestic equipment or importing foreign equipment and instrument.

China research on PV is emerging in CdTe. Dye-sensitized solar cell and PERC single crystal solar cell. Also, in the future after 2020, high efficiency cell technologies such as silicon heterojunction (SHJ) with higher use of Ag will be more economically competitive in Europe and China in the future.

**Pre-2011**

China’s research PV technology have launched several type of solar cell such as high efficiency crystalline silicon cells, amorphous silicon, thin film, batteries, CdTe, CIS thin film and polysilicon thin film battery.

In the future, intelligence, light weight and combination with building are other important thing to a PV product other than efficiency and reliability.

**Pre-2014**

the comparison of the efficiency of various types of PV power generation technologies; for silicon cells in China, it is already relatively the same as the international level (mono 19%, poly 1717.5%), but for amorphous it is slightly different where the international standard has reached 10% while the technology in China has only reached 8%.

there was a start to research on third generation of solar cell, in example the Oceans King Lighting which the company focused on organic cells.

**Pre-2015**

China was still lacking a complete technical standard regulation for system distributed generation power station of PV. However, China had same spending with EU in research and development of renewable energy for the first time and by 2010, Chinese government has given almost two of third of its total research and development to technology of renewable energy each year.

PV industry is more open to global explicit knowledge, meanwhile wind industry is far less innovative.

The PV industry has revolved around two main channels of transfer that play only a minor role in the wind energy sector - trade in production equipment and the return of foreign-trained Chinese professionals to China.
China succeed in producing high efficiency crystalline silicon solar cell which in the same level of the world, with highest efficiency reach around 25% [29]. Technological innovation leads to a decrease in PV costs, which makes the contribution rate of R&D inputs greater than physical capital and labor factors, and the endogenous driving forces for China's PV industry output growth have been changed from factor-based to innovation-driven [33].

Points that can be learned from technological development of production, research and development status, subsidies, and policies related of PV industry in China are:

- Stronger Intellectual Property (IP) protection could make the US an attractive location to commercialize disruptive c-Si PV technology, while China's track record of rapidly upgrading new technologies might make it attractive [34].
- A report from [35] find the most suitable intermediaries for innovation can be viewed from hierarchical structure, which are: (1) In first tier, in conceptual stage in midstream supply chain, should be able to provide the greatest guidance of strategic policy and facilitate transfer of core technology, (2) The second tier is located at the development stage of upstream supply chain, midstream supply chain, and at conceptual stage of downstream. They can facilitate the highest transfer of core tech, human resource and information flows, (3) The third tier is located at production stage of up, middle and downstream supply chain should stress specific knowledge transference within engineering function.
- Thin film solar cells in China have to be more advanced because of many of its advantages, such as the less materials use than conventional silicon solar cell [15,30].
- The government should give more funds to support research and development of distributed PV technology. Especially in areas that have abundant sources of solar energy, natural resources need to be utilized optimally through technical progress. Technological innovation and market regulation are required for further efficiency improvements and cost reduction, also accelerate the formulation and implementation of distributed PV operation and maintenance standards, as well as research in smart grids and microgrids [31,36].
- Report from [37], the R&D and FIT investment is conducive to technological innovation of China's photovoltaic power generation industry. Also, a higher level of R&D investment can lead to more cost reductions in the photovoltaic power industry [7,11,37]. In future, China should be more focused on using their research and development policy in reducing price, not only increasing PV production capacity [7,11,38].
- The “Government-Enterprise-University Research and Application Institute” cooperation mode should be applied in China's PV industry [39].
- The performance of industrial growth mainly depends on the frontier technological progress, whereas technological innovation cannot be done without high capital input of enterprises [40,41]. In the science community, researchers with either central funding are more likely to engage in research collaboration (co-science and co-international) than researchers without funding. However, Government funding is positively and significantly related to collaboration within the science community but is related negatively to science–industry collaboration [20].
- The innovative capabilities of Research and Development (R&D) personnel are critical to achieving sustainability and maintaining product competitiveness at the forefront of the market [42].
- Research shows that grassroots innovation, by doing, using and interacting (DUI), can create a short-term market development model that relies on China's traditional industrial model, but cannot create a long-term international leading innovation model; only the integrated combination of science, technology, innovation mode (STI), and DUI innovation mode is likely
to result in international leadership in innovation. The reason why Chinese PV industry is emerging because they use both STI and DUI mode; in compare with SHW which has innovation in early days (1990s) which only use DUI mode [43].

- Create appropriate and scientific technical standards to encourage technological development, strengthening technology Research and Development to avoid technology risk [36,44].
- Regarding the innovation efficiency, financial leverage and ownership concentration have significant positive impact, while firm size has significant negative effect [40].
- Make research and development policy for supporting the increase of conversion efficiencies and grid integration technology for PV system is necessary [7].
- Government should boost the financial supporting system, broaden the financing channels of enterprises, lead more private investment, and increase investment intensity of technological development fund [40].
- Upgrading the existing production line of battery for solar cell, promoting diamond wire cutting for reduce the cost of manufacturing and research in new materials are necessary [29].

3.2.1.2 PV market and producent, installment, and trade dispute growth. China is rich in solar resources. Its annual continental solar potential is estimated at 19,536,000 terawatt hours (TWh), with an annual area of over 1,050 kWh (kilowatt hours) per square meter. The most abundant supply of solar energy is found in northwestern regions such as Tibet, southern Xinjiang, Qinghai, and Gansu, with an annual solar radiation of more than 1,750 kWh/m² [18], making the development of PV installment in China have a big potential.

Table 3. Data extraction from A2 topic articles

| Period of time | Status and Innovation | Source of Literature |
|---------------|-----------------------|----------------------|
| **Before 2000** (1980s) | China imported production lines for solar cells, and established the first monocrystalline silicon cell manufacturing plant. During this time, there were only fourteen factories producing PV cells. The major companies founded during this period were Yingli, Suntech, Canadian Solar, and Trina | [22,45] |
| **2000-2010** | The international demand of PV was booming, China took opportunities, local and central government provided vital support to the PV manufacturing industry and aim to become world leader in technological and economic for low carbon energy production China has become the largest producer of PV cells and module from 2000 to 2010 However, in the earliest of this period, there were a serious shortage of high-purity silicon material which 95% were imported and the major market was abroad (95% export). | [8,21,22,46] |
| 2002-2003 | Suntech Company and Yingli Green Energy Company start to built 10 MWp solar cell production lines respectively in 2002 and 2003. Since then, China's annual solar cell production has increased significantly. | [22] |
| 2004 | Japanese and German companies dominated the global market, but in 2007 the picture changed dramatically when three Chinese manufacturers, Suntech, JA Solar and Yingli, entered the top ten PV companies worldwide | [47] |
| 2006 | The PV market in China mainly focused on household off-grid systems used in western China | [48,49] |
| 2007 | China's solar cell production capacity had grown to 3000MW or more | [28] |
2008 90–95% of PV products were exported which was primarily oriented towards the markets in Europe and the US [47]. China's first grid-connected solar power plant built in the desert was put into operation in Wuwei, northwest China's Gansu Province [23]. The largest integrator in China, Yingli, commissioned a polysilicon facility in December 2009 [13].

2009 Domestic market of PV were too small, cannot meet the market demand, and can be neglected, which more than 90% of raw materials such as polysilicon was imported [10,13,15,21,28,49-51]. Cumulative installation in China only equal to 3.3% of Germany and 11.6% of Japan (18,27).

After 2010 The global financial crisis damaged every sector in the world, including PV industry and overall demand of PV in the world was reduced sharply. The findings suggest that the future healthy development of China's solar PV market will depend on enforcing central policies and aligning policy objectives and incentives between central and local levels [52].

2007-2016 There were 239 cities in China that exported PV products. Coastal cities accounted for a high percentage of PV exports in 2007-2011 [53].

2011 US-China trade war of solar PV begins [54].

2012 Heavy investment led to overcapacity of in China solar panel, resulting in wasted investment [46,47,50].

2014 The Chinese government-imposed tariffs on US polysilicon imports in retaliation for US tariffs on 2013 imports of Chinese modules. Due to the impact of US and EU anti-dumping and countervailing duties on China, the PV market is gradually shifting from the international market to China's domestic market [30,55,56].

2018-2019 The EU officially ended five years of anti-dumping and countervailing measures for China's PV industry. In 2019, the domestic and foreign PV markets returned to a stable situation, and Chinese manufacturers have been promoting the rapid expansion of production capacity based on their significant cost advantage. In 2018, the total installed capacity of solar PV surpasses the 2020 solar PV national goal, three years ahead. Then, the government has considered that PV industry in China is ready to achieving grid parity. Distributed PV increased to 19 GW [46,57].

Points that can be learn from China’s PV market and producent, installment, and trade dispute growth are:

- Develop upstream and downstream vertical integration strategies (where the vertical chain of the PV industry from upstream to downstream has high interdependence), the industrial chain should be expanded upstream and downstream and collaborative optimization will further reduce costs [20].
- Price advantage of a China-based factory relative to US is because of development of supply-chain in China, not driven by country specific advantages [34].
- polysilicon module supplier should increase the relationship and coordination with PV assembler and installer [58].
- a low discount factor can improve the performance of PV supply chain and the components cost reduction and the assembling cost cutting can also improve the performance of PV supply chain [58].
- At oversupply situation, relying on government's funding is not a sustainable way for the PV industry improvement. The PV subsidy policy should be phased out, and industrial development
should be encouraged in other ways, such as R&D investment, reducing land use costs. The supply chain members should speed up industrial reorganizing and technological progress by mergers and reorganization, eliminate backward production capacity and improve technology and equipment [58, 59].

- The economic performance of distributed PV projects varies from territory to territory. When choosing a location for a distributed PV project, investors should pay sufficient attention to geographic factors [31].

- Report from [60] by simulating generation, investment and capacity during 2012-2032 are: (1) PV power generation still hardly occupy a big proportion due the difficulty of grid integration, (2) China’s distributed generation of PV mostly gain advantages from subsidy not power generation, and this indicates there are blind investment and low-level expansion, (3) Installed PV capacity will experience accelerated growth because of the rush of investment in distributed PV, (4) Technological breakthroughs is needed if the government want to stop its investment subsidies for distributed PV generation.

- China’s distributed PV power plants are mostly distributed in the central and eastern regions where the electrical load is concentrated. In order to promote distributed PV applications, the government is putting most of its efforts into building a distributed PV pilot industrial estate under the planning and management [31].

- For innovation in distributed energy in developed countries, the successful experience concludes three aspects as following [61]: (1) At the political, and regulation level, define and detail overall development goals, (2) Increase inputs of research and development subsidies to find solution for technical problem of distributed grid connection, (3) The power enterprises, power users, and grid enterprises must have clear tasks and behaviors to ensure the effectiveness of the PV market.

- The government must wisely lead the development of distributed energy, such as establishing a funding and investment environment, then developing macro planning and regulation of distributed energy, improve the laws governing the licensing of distributed energy and increase financing channels, which distributed PV generation shall increase domestic demand and help reduce overcapacity [58,61].

- The advantages that the PV industry currently has in China are probably largely related to the larger scale of production combined with a wider enabling environment for low-cost manufacturing rather than the more durable technology-based advantages [24].

- The characteristics of the leading PV enterprises that are likely to have a prominent position in the face of fierce competition are; most of them produces basic product such as polycrystalline silicon and PV glass in their early stages, gradually develop a complete industrial chain and expand the construction of middle and lower stream of solar application product and PV power station, and have core technology [62,63].

- Social environmental awareness in China help the development of new energy, including PV, in China [64].
3.2.1.3 Incentives, fund, installment and industrial development policies and government domestic-international relation

Table 4. Data extraction from A3 topic articles

| Period of time | Status and Innovation | Source of Literature |
|---------------|-----------------------|----------------------|
| **Before 2000** | Since 1950, Chinese government had considered the rural electrification to be a long-term development priority. Due to these programs, the PV cells installed capacity was improved significantly from 6.63 MWp in 1995 to 45 MWp in 2003, and domestic demand for PV systems grown rapidly in the late 1990s | [46] |
|                | Chinese government introduces "New Energy and Renewable Energy Development Outline for China" (1996) aimed at development of PV cell and machinery | [8] |
| **2000-2010**  | Before Feed-In Tariff on-grid power pricing method come, the sales price of PV generated electricity were designed by local governments. Then in 2002, the “Song Dian Dao Xiang” program made regulates local governments to set the selling price of electricity generated by PV based on the consideration of the affordability of people living in rural areas | [45] |
| **2002-2004**  | The Chinese government initiated the Rural electrification Program to supply electricity to villages; the program uses mostly PV systems and provides electricity to more than 700 villages | [21,49] |
| **2005**       | In on 28th February 2005, China by National People’s Congress issued the Renewable Energy Law, showing its resolution to support and regulate the development of renewable energy industry. It is a legal basis for market policy design and private investment in renewable power in China | [8,21,23,45,56] |
|                | One form of support that local governments use to lure PV producers is cash subsidies. For example, in 2005, the Xinyu city government provided $30.8 million (200 million RMB) to the newly established LDK Solar. | [52] |
| **2007**       | China issued "Renewable energy medium- and long-term plans", planning to install solar power to 1800 MW in 2020 and solar power to 300 MW in 2010 | [21] |
| **2009**       | Because of the overcapacity, in March 2009, China enacted the “Golden Sun Project” (2009-2011) by the Ministry of Finance (MOF), the National Energy Administration (NEA) and the Ministry of Housing and Urban-Rural development (MOHURD). Several Chinese municipal governments issued various refund policies to promote new plant investment in the PV industry, including incentives for promoting research and development by the manufacturer | [13,45] |
|                | the division of responsibilities and powers between the national energy board and the state development and reform commission has not yet been clearly defined | [51] |
| **2010**       | China officially announced that solar energy such as PV was one of the fundamental back-bone of strategic emerging industry | [45] |
The main factor limiting PV development is cost which because China is a developing country [49]. China needs to bring up policy such as tax policy (tariff reduction, reduction of fixed asset tax, value-added tax and income tax reduction) [51].

**After 2010 (2011)**

In 2011, “The twelfth five-year plan for economic and social development” came out and has purpose to build security, stability, economy and clean modern energy industry system, accelerate the development of new energy, actively develop the energy industry now [9]. FIT is a new model of distributed PV subsidies in recent years. In August 2011, the National Development and Reform Commission (NDRC) announced the formulation of a national integrated solar PV feed-in tariff [45].

China has several policies regarding the distributed generation of PV in manner of specific rules for development target, subsidies, grid connection and price-fixing [31,48,57,61].

531” new policy, which has purpose to mitigate the supply demand mismatch problem of solar power and leave room for innovation of advanced technology and high-quality SPV generation projects [46].

Land price policy has been greatly affecting the development of PV industry development [45]. There are obstacles in PV industry advancement in regards of its policy and regulation [38,50,64].

2012

many supporting policies for distributed generation have been issued as respond of the needed to increase domestic demand [58].

2013

From 1st October 2013 to 31st December 2015, the implementation of the 50% reduction policy of VAT (Value Added Tax) is given to taxpayers who sell solar power products [31].

2014

China’s policy focuses on government regulation, concentrating mainly on the product popularization and application stage, with insufficient investment in research and development in the early stages [65].

2018

However, due to the severity of PV overcapacity in China, the central authority abruptly canceled all national-level subsidies for PV power generation in June 2018 [52].

China began to use less industrial policies while focusing on domestic commercial applications of new energy and the friction caused by solar PV cells between China and the US is almost over [66].

Apart from manufacturing overproduction, the problem currently plaguing China’s domestic PV market is curtailment. Excess installation capacity and the resulting discrepancy in supply and demand were important factors leading to curtailment, along with other technical constraints [52].

Points that can be learned from China’s incentives, fund, installment and industrial development policies and government domestic-international relation in PV industry are:

- Coordinate local manufacturing policies at the central level. Local government policies are necessary and important to encourage the development of PV manufacturing [21].
• Encouraging international cooperation which can provide advanced technologies, outstanding professional, and knowledge and management mechanisms of each participant [21].
• Deployment planning should be line up with grid planning [21].
• a shift in policy focus towards innovation is needed to achieve further cost reductions in a timely and cost-effective manner [67].
• Create an environment of PV industry from supply driving into consumer driving by increase financial subsidies in actively implement the PV tariff subsidies, improve the attractiveness of the user’s investment [64,65]. Such as designing the predetermined degression of incentives for distributed PV can help which make the market play a pivotal role in allocation of resource [21,31].
• Government should set more ambitious targets for medium and long term plans for PV power capacity [39].
• Simplify the approval process of project construction, including the richness and practicality of polices, strengthen legislation and integrate government function, and simplify its policies portfolio [38,64,65].
• Governments need to reduce their administrative interventions and improve institutions for bank lending, also governments need to reduce excessive investments in photovoltaic manufacturing industry and promotion of balanced and healthy development of this industrial chain and reduce bureaucracy inefficiencies [68-69].
• Too much dependence on government can lead to a lack effective coordination to promote rational PV development [71]. Enhance the scientificalness and mandatory planning for better development [38].
• Increase the types of tax policies, combining the nation’s economic situation and specific development of the clean energy industry [38].
• Start to use internet and its big data to improve management and financing method of distributed PV generation, such as e-commerce platform to promote equipment development and intelligent management of power generation tools based on internet cloud [64].
• Implement a distributed PV power plant proprietary registration system, and eliminate the inherent risks of statutory distributed power generation, and encourage all types of financial institutions to prioritize the development of distributed PV projects and develop new financial products such as loans and financing [35,64].
• By working to enhance enforcement mechanisms of central policy, penalizing protectionist local governments, and shifting political evaluation goals at local levels so that they better align with healthy power sector development, China can quickly become one of the healthiest solar PV markets in the world [52].
• To fight curtailment, rather than cancelations on subsidies for PV power station, its more efficient to do an enforcement of mandated minimum utilization hours and economic dispatch coupled with added incentives for local governments to reduce curtailment would quickly solve the issue [52].
• Government should give impetus to banks to lend to small and medium-sized photovoltaic power companies and impetus for financial innovation where Banks should improve and innovate their lending models for the PV industry and strengthen risk monitoring and early warning mechanisms [69,70].

3.2.2 SEA countries

Only a small amount of literature based on case studies in Indonesia, Malaysia, and Vietnam as representative of SEA countries, which very different from case study-based literature in China. Most of their articles not directly examine the PV industry, rather they discuss about the PV
system itself and its installation. This result indicates these SEA countries are still lack understanding and knowledge of PV especially its industry. Case study-based literatures in Indonesia discuss the strategy of the PV system utilization [72], the risk of rooftop PV from energy justice and green criminology [73], techno-economic for rooftop PV [74], Life Cycle Analysis of PV system [75], and one literature before 2000 which discuss PV Household Electrification Programs [76]. Malaysia-based literature discusses about transitional energy policy, solar energy scheme and future assessment [77-79], tailoring technology and foreign investment for PV Industry [80,81], PV application including Building Integrated PV [82-84], and PV disposal treatment [85]. Vietnam-based literature discusses about the thriving of PV installation and further solar adoption [86], PV and battery installation profit [87], the rooftop grid-tied PV power system feasibility [88], and PV-fishing tandem [89].

However, the potential of these countries for building PV industry is great. At the level of Southeast Asian countries, solar PV experienced the greatest decrease in investment costs (45% decrease) compared to other renewable energy sources, where from 2012 the installation cost of 3915 USD/kW to 2134 USD/kW in 2016. Then, the weighted average Levelized Cost of Energy (WLCOE) of solar PV in 2012 was 0.31 USD/kWh and became 0.19 USD/kWh in 2016 (down by 39%), and the capacity factor of solar PV decreased from 17% in 2012 to 15% in 2016, indicating new projects in areas with low sunlight due to the growing PV market. In 2016, solar PV contributed 59 thousand jobs/labor, making it the third largest in the renewable energy sector after liquid biofuel and hydropower. Through strong investment in solar PV, it is estimated that jobs in this sector will continue to grow to 333 thousand jobs in 2030, namely 50 thousand in construction and installation, 7 thousand in manufacturing, and 3.9 thousand in Operational and Maintenance (O&M). Investment in solar energy projects in Southeast Asia reached 892 million USD in 2016, 1.5 times more than wind energy investment of only 588 million USD [4].

Indonesia accounts for nearly 40% of the total final energy consumption for the ASEAN region. According to the IRENA report in 2017, the use of solar energy through solar PV has the largest potential in Indonesia with a total of 532.6 GW. Solar PV is expected to be used significantly by 2030 in a variety of ways and places, such as utility-scale PV, residential and commercial PV, off-grid PV for remote areas. It was recorded that in 2010-2012, the estimated solar PV installed in Indonesia varied from 42 MW to 80 MW. In mid-2016, PLN (State Electricity Company) made a commitment and an MoU (Memorandum of Understanding) to develop a 700 MW utility-scale solar PV. The solar PV capacity is targeted to reach 0.4 GW by PLN through RUPTL (Electricity Supply Business Plan) 2016-2025 and reach 6.4 GW by the Ministry of Energy and Mineral Resources in KEN (National Energy Policy) 2025 [6]. In the FIT program, the program was first introduced in 2002 when the Minister of Energy and Minerals made a policy for small-scale renewable energy generation (below 1 MW). The auction scheme for a solar power system with a capacity of 172.5 MW was conducted in 2013 but was canceled in 2015 due to TKDN (Domestic Content Level) issues, wherein the TKDN regulation was finally promulgated in 2016 by the Minister of Industry. In 2017, the government agreed to change the FIT, which was originally a fixed tariff that had been determined to a tariff that was in accordance with the price of power plants in each region. Regions with supply costs above the national average will get FIT capped at 85% of the average. The average supply cost in 2016 was 7.4 US cents/kWh (13307 rupiah/kWh), indicating that the new regulations have sufficient effect to reduce solar energy tariffs by almost 50% from the previous FIT which was around 6.511.6 US cents/kWh [4].
Vietnam has potential in developing the use of solar energy, where IRENA (International Renewable Energy Agency) [4], using IRENA's Global Atlas and the zoning and sustainability study method reported Vietnam's potential capacity in utility scale installations of 25.24 GW and off grid of 25.49 GW. In mid-2017, Vietnam started its first program for FIT on solar PV, and a pilot auction for 50 MW PV and a net metering scheme was introduced [4]. In accordance with Vietnam's energy and climate policy, it is targeted that the contribution of renewable energy to the total national energy supply will be 31% in 2020, 32% in 2030, and 44% in 2050 of the total energy supply mix. In the energy modeling conducted by Vietnam's EREA (Electricity & Renewable Energy Authority) and DEA (The Danish Energy Agency) with five scenarios (BaU, renewable energy targets are achieved without energy efficiency, restrictions on coal investment after 2050, penetration of energy efficient technology 50 % in 2030 and 100% in 2050, and all scenarios except BaU combined). The results of the modeling are estimated that solar energy is the second most used renewable energy after biomass, the generator with the highest capacity for all types of power plants (renewable and conventional energy), and energy with the highest consumption in the five scenarios for 2020 to 2050 [90]. Vietnam has been recognized by its rating as one of the countries producing solar PV components and assemblies [91]. Vietnam is one of the countries that has experienced rapid development in solar PV installations recently, where in 2020 the installed capacity reached 11.1 GW and became the country ranked eighth as the largest solar PV capacity installer in the world. The development of solar PV capacity installations in 2019 was largely due to the construction of large ground-mounted projects (driven by the end of the FIT1 scheme), and the development of solar PV capacity installations in 2020 was largely due to the construction of rooftop solar PV systems in order to pursue qualifications from FIT2 before ending in the end of the year. The rapid growth of the use of solar energy also has an impact on Vietnam's inadequate grid, the emergence of curtailment and in early 2021 Vietnam is considering options for allocating funds to upgrade the system as needed [5].

Malaysia has been recognized by rated as one of the countries producing solar PV components and assemblies. The growth in solar PV LCOE reduction in Malaysia is the most significant in Southeast Asia [91]. Employment growth in the solar PV sector is growing rapidly and is the largest solar PV labor market in Southeast Asia. The number of jobs that emerged in Malaysia in the PV sector in 2016 was 27.9 thousand jobs, and the workforce increased by 46% and 60% of these workers worked in domestic solar PV module factories. In 2015, Malaysia was the third largest exporter of PV modules worldwide and accounted for 12% of shipments totaling nearly 51 MW [4]. In supporting foreign direct investment (FDI-Foreign Direct Investment), Malaysia implements joint policies to support research and development and education in sectors, such as the solar energy manufacturing sector, these policies are the “Malaysian National Renewable Energy Policy” and the “Malaysia National Renewable Energy Plan”. Malaysian Action". The Malaysian plan focuses on supporting technology and innovation through adequate financing and human resource development on the ground. In 2016, Malaysia managed to attract an investment of USD 400 million for solar energy manufacturing [4]. As of 2019, Malaysia has an annual PV installation capacity of 390.51 MW (5.89 MW for off-grid, 66.00 MW for decentralized PV systems and 318.62 MW for centralized PV systems, all in AC (Alternating Current)). The price of a standard crystalline silicon PV module also continues to decrease every year, where in 2015 the price of a crystalline silicon PV module costs 0.5 USD/Wp, to 0.23 USD/Wp in 2019 with a price variation range of 0.21 to 0.25 USD/Wp. The average price of PV modules for installation of 5-10 kW grid-connected roof-mounted and distributed residential systems is 2.58 MYR (Malaysia Ringgit)/Wp, and for
system installations > 10MW gridconnected, ground-mounted, centralized on average average for 1.65 MYR/Wp [92].

The majority of solar PV plants in Malaysia are owned by international/foreign companies. In 2019, the company that produces raw silicon (silicon feedstock) is OCIM Sdn. Bhd. (South Korea) which produces 27 kilo tons of polysilicon, which produces mono-crystalline silicon wafers and ingots is LONGI Sdn. Bhd. (China) which is located in Kuching and produces 500 MW of ingots and wafers, and which manufactures silicon wafers is Sun Everywhere Sdn. Bhd. which produces 49.8 MW of silicon wafers (IEA PVPS, 2019). The total solar cell production capacity in Malaysia is estimated at 8582.5 MW and solar PV modules at 8898.2 MW. Several jobs related to solar PV have emerged in Malaysia, such as research and development (besides RnD (Research and Development) companies) totaling 50 jobs, product manufacturing (along the PV supply chain, from silicon manufacturing to systems including enterprise RnD) totaling 17731 fields employment, distributors and installation companies and PV systems totaling 8312 jobs, and electricity and government businesses totaling 140 jobs. A rough estimate of the PV business value recorded in 2019 was 1 844 524 535.90 MYR with an off-grid installation capacity of 5.89 MW, grid-connected distributed of 90.86 MW, and grid-connected centralized of 319.19 MW [92].

4. Conclusion and outlook

This study finds that the research on PV Industry is many and growing in China as the giant PV manufacturer and market, whereas is limited in Indonesia, Malaysia, and Vietnam. Using the PRISMA method, the total amount of case study-based articles in China which are used in this study are 71 articles, and most of them are from journal ranked Q1. However, in this study the PRISMA method isn’t used to filter case study-based literatures in Indonesia, Malaysia and Vietnam because of their limited number.

The finding in this study can be a rough idea of how research conditions are in countries with developed and developing PV industries. Most of the research about the PV industry in China is discussing its policy, and the promising advantages of the PV industry that China saw in the 2000s become their driver. Before 2000, China didn’t yet have capabilities to produce PV in a big scale and rather used PV only as research subject and for satellite concern. Only after the Kyoto protocol in 1997 and the rise of PV market in Europe in early 2000, China started to build their PV industry, and around 2008, they become the largest PV producer in the world. However, because of their strong dependence in international market, their overcapacity in producing PV was taking effect after US and EU unleashed the “anti-dumping” and “anti-subsidies” policy. After 2010, China began to construct their domestic PV market for minimalizing the damage of overcapacity.

SEA countries like Indonesia, Malaysia, and Vietnam have great potentials to install PV as the main renewable energy source. Indonesia is the one of the largest populated countries in the world and the biggest energy consumer in SEA. Many reports have shown that PV is the most potential energy source for Indonesia. Malaysia already started their PV installation and production, and according to IEA PVPS, Malaysia is one of the biggest cell and module PV in the world after China. Vietnam itself had already been starting to install a number of PV in 2019. Vietnam is one of the countries experiencing rapid development in solar PV installations in recent times, where in 2020 the installed capacity reached 11.1 GW and became the country ranked eighth as the largest solar PV capacity installer in the world. Therefore, further development of PV industry has to be brought in SEA countries.
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