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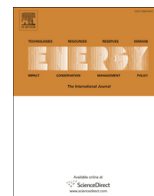
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A comprehensive analysis on development and transition of the solar thermal market in China with more than 70% market share worldwide

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ABSTRACT

China is the second-largest economy country, and the largest country worldwide in total solar energy system capacity installed. More than 70% of total solar collector capacity worldwide is installed in China. The production of solar collector in China had decreased significantly from 64 million m² in 2012 to 37 million m² in 2017, corresponding to a reduction of around 40% of the market in 2012. There are very limited comprehensive studies in existing literature, which have investigated the reasons on the decline of Chinese solar thermal market. This study aims to identify the reasons from both the demand and the supply sides in details. Furthermore, with the rise of emerging markets, such as the rapid development of the “Clean Heating Initiative” for space heating in North China, solar heat industrial process, and the mandatory installation of solar domestic hot water system for residential buildings below 100 m in urban area, the Chinese solar thermal market is expected to recover soon, called “U-shaped curve” in this study. The market share of flat plate collector and evacuated tube collector is predicted to change in the near future. The research and development of flat plate solar collectors will increase continually in the market other than evacuated tube solar collectors like the past 10 years. The main driver for the solar thermal market development in China in the near future will be the demand from the urban area.

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1. Introduction

Solar thermal industry in China has developed rapidly since 1995 [1]. In 1998, 3.4 million m² solar collector was produced, while in 2002, 10 million m² were produced, corresponding to an average yearly increase rate of around 31%. China's total installed solar thermal capacity (cumulative total) has accounted for approximately 70% of the whole world's capacity since 2013 [2], with a significant difference of more than ten-times as the capacity of the second largest country. Fig. 1 and Fig. 2 show the market share of the newly installed solar collector capacity worldwide and yield of unglazed and glazed solar collectors in 2015, respectively. China was far ahead of the other countries, which accounted for more than 75% of total newly installed capacity worldwide in 2015. It is found that solar domestic hot water systems have great economic

benefits (e.g. saving fuel costs) [3,4], environmental benefits (e.g. reducing fossil fuel consumption and pollutants emission), and social benefits (e.g. cheaper, cleaner and safer hot water supply for daily life) compared to conventional heat source (gas and electric) [5,6]. The utilization of solar thermal systems can significantly contributes to China's transition to green energy society [7].

Hu et al. [8] presented the overview of the development of solar water heater industry in China from 1998 to 2009. The following reasons why solar heat water systems are successful in China can be summarized as following: (1) The central government is proactively promoting their application [9]; (2) China's economy is developing rapidly and its living standards are on the rise, especially in rural areas, more and more households need 24-h's domestic hot water; (3) China's solar thermal industry was comprised of a complete industrial chain that extends all the way from processing the raw materials to manufacturing, sales and servicing of water heater products; (4) China central government and local governments promote solar domestic hot water systems with subsidies [9,10]. There're even mandatory installation policies of solar water heater for urban residential buildings below 12 floors, which were published by some local governments in recent years.

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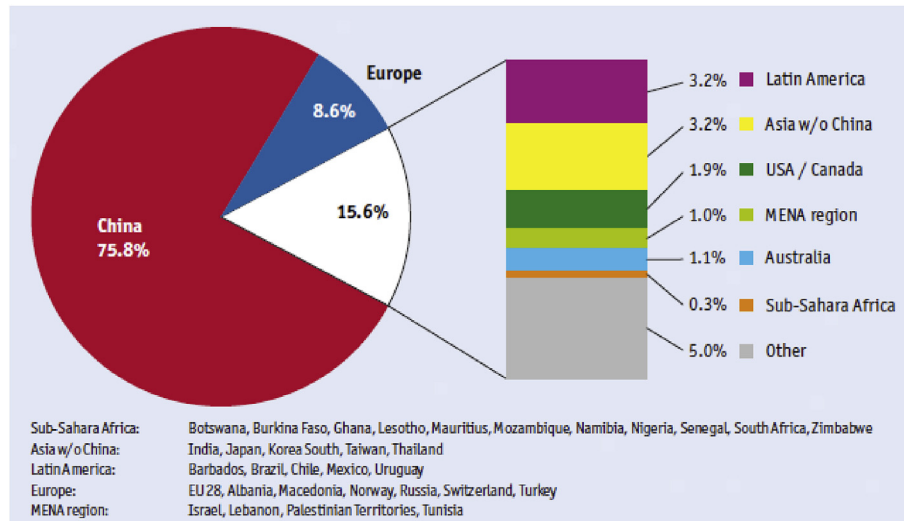


Fig. 1. Share of newly installed capacity (glazed and unglazed water and air collectors) by economic regions in 2015 [20].

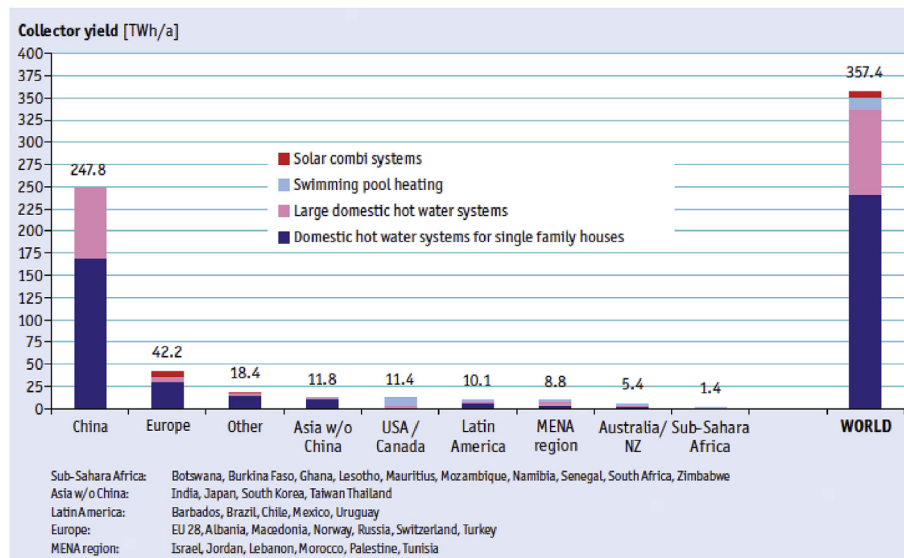


Fig. 2. Annual collector yield of unglazed and glazed solar collectors in operation in 2015 (Source: IEA-SHC).

Evacuated tube collector is a widely used and cheap technology used in solar water heater (SWH) products that is found almost everywhere in China, especially in rural areas [11,12]. Evacuated tube collector is one of Chinese homegrown technologies [13–15]. Most of solar collectors in Chinese solar thermal market were water-in-glass evacuated tubes SWHs [16]. Evacuated tube SWHs with low initial costs and short payback periods are very popular in China [17]. Most of the SWH products are not only installed domestically within China, but also they are exported to newly emerging countries in Africa and the Central and South America, and a small part of the SWH products are even exported to Europe as well.

Generally, Chinese SWH manufacturers have dominated the market of evacuated tube collector worldwide [18]. Furthermore, the ranking of the world's largest flat plate collector producers in 2017 also shows the market dominance of Chinese companies, where the Top 4 are all Chinese related companies [19]. Many solar collector manufacturers in Europe are also seeking to expand their

market in China.

The investigated solar thermal market in this study includes domestic solar hot water products in urban and rural areas, solar space heating systems and solar heat industrial processes, while products for solar thermal power generation (electricity) were excluded.

As shown in Fig. 3 left, solar radiation resource is rich in most places of China. The highest yearly global radiation on the horizontal surface in China is more than 2000 kWh/m² in Tibet. Even though the lowest yearly global radiation on the horizontal surface in China is around 900 kWh/m² in Chuan-Yu area (Si Chuan & Chong qing), passive solar houses have attracted lots of attention in these local rural areas [21]. Fig. 3 right shows that the places with rich solar radiation source are mainly located in the cold regions of China with large heating demand. Therefore solar space heating systems have a huge potential in the severe cold and cold regions of China [22].

The majority of the solar companies in China mainly focused on

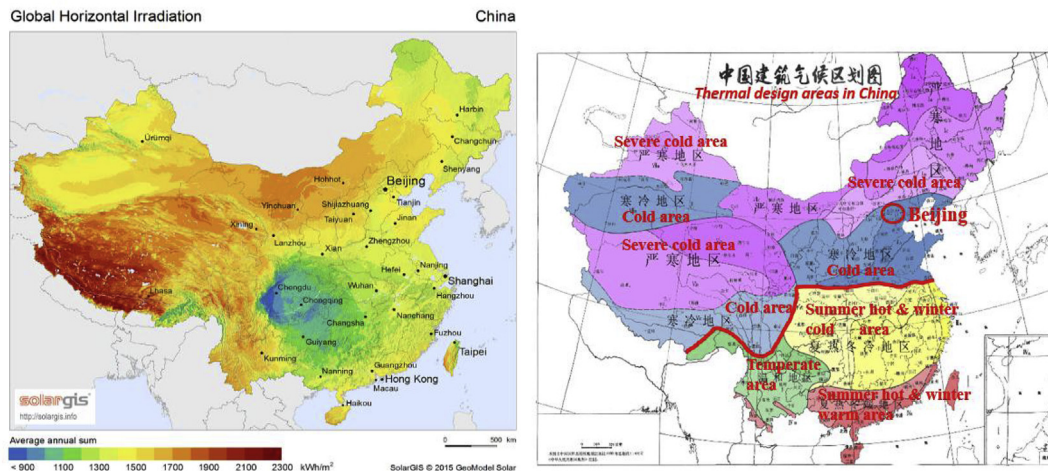


Fig. 3. Global radiation in the mainland of China (Source: Solargis) and climate zones of the building sector in China.

the rural market before. Wang et al. [23] used a sequential decision approach to investigate solar energy adoption in rural China. The barriers for further application of solar hot water systems in urban environments have not been addressed clearly so far. An case study suggests that the capacity of local government institutions to translate policy into real urban changes cannot be taken for granted because pre-existing spatial arrangements shape socio-technical experimentation and urban political processes [24]. Zheng et al. [25] investigated the penetration of solar hot water systems from rural areas to urban cities and identified problems and barriers obstructing the use of solar hot water systems in cities. It was found the niche market in cities is still not mature enough, and the urban regime is still powerful in terms of building infrastructure, consumer demand, policy coordination and vast interests. Huang et al. [26] investigated the application of solar hot water systems in urban China via the Dimensions of Urban Energy Transitions (DUET) framework. One case study of a city in Shandong showed that the transition possibilities for solar hot water systems in urban China are continuously influenced by the ongoing conflicts and alignments between solar enterprises and local governments. Ma et al. [27] also carried out an economic feasibility analysis on the application of SWHs in 27 provincial capital cities of China.

The previous studies mainly focused on the solar domestic hot water market in the rural areas or PV market [28–30]. It is also concluded that distributed wind and solar PV power generations should be feasible on in China [31]. However, solar space heating market was not included in the existing investigations. Limited literature have been found with a comprehensive quantitative analysis on the overall Chinese solar thermal market. This paper will present a detailed analysis of the influence factors on the Chinese solar thermal market from both demand and supply sides. This is the first research that has conducted a whole market segment analysis in accordance with the four major application areas for Chinese solar thermal industry (urban domestic hot water market, rural domestic hot water market, urban and rural space heating market, industrial and agricultural process market). This study aims to identify the driving forces of industry development from both the demand and the supply sides in details. Furthermore, with the rise of emerging markets, such as the rapid development of the “Clean Heating Initiative” for space heating in North China, solar heat industrial process, and the mandatory installation of solar domestic hot water systems for residential buildings below 100 m in urban cities, the Chinese solar thermal market is expected to recover soon. The market structure will also undergo major

changes. The research and development of flat plate solar collectors will increase continually in the market other than all-evacuated tube solar collectors like the past 10 years. The main driving force for market development will shift from rural to urban areas. This study analyzes the future trend of solar thermal market and the changes in market structure, and points out the direction for the sustainable development of China's solar thermal industry, and provides a reference for solar thermal enterprises.

The novelty of this article is stressed as followed: (1), This is the first quantitative study on the solar thermal market in China; (2), Reasons for market downturn was analyzed in details from both demand and supply sides; (3), Prediction of the structure of solar thermal market in China for the short and long terms was carried out.

The structure of this paper is organized as followed: Section 1 and 2 are introduction and methodology, respectively. Section 3 is the analysis on the current solar thermal market. Reasons for market downturn from both demand and supply sides are investigated. Potential driven factors for recovery also are included. Section 4 presents the transition of the solar thermal market in short and long terms. Section 5 is the conclusions and policy implications.

2. Methodology

The solar thermal market in this study includes four major areas: urban domestic hot water market, rural domestic hot water market, urban and rural space heating market, industrial and agricultural process market. This research does not include solar thermal power generation, solar air conditioning and other markets that do not have a significant contribution to the solar thermal industry in China currently.

A time series model and an inertia principle were used in this study to elucidate the development trend of the solar thermal market. By means of a regression prediction method and by the relevance principle, a transition probability matrix is constructed based on expert questionnaire surveys with an aim to predict the development trend of evacuated tube collectors and flat plate collectors in China. To make sure that the results presented in this study are reasonable, expert evaluations on the conclusions have been carried out. A flow chart of the analysis method is shown in Fig. 4.

In Fig. 4, the analysis was carried out to investigate the solar thermal markets by political, economic, socio-cultural and

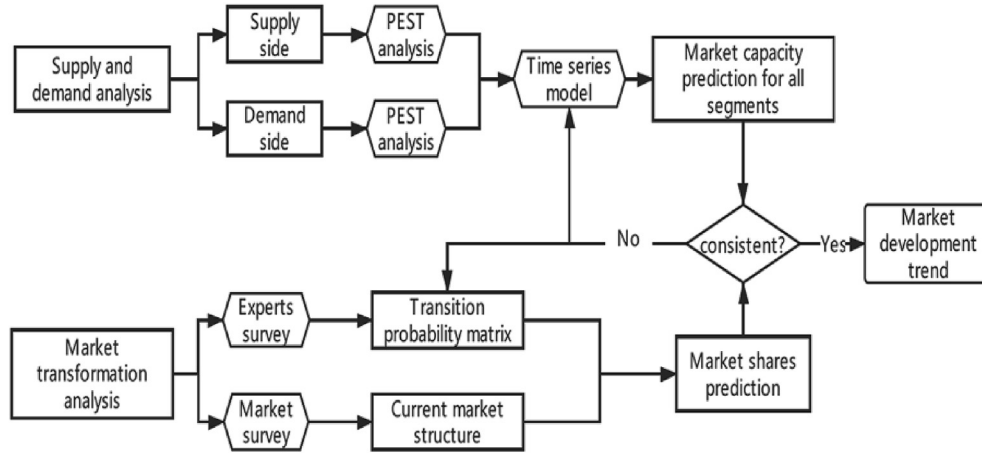


Fig. 4. The flow chart of the method in this study.

technological factors (PEST). It is a strategic tool for determining growth or decline of the market.

Equation (1) [32] was used to calculate the shares of different market segments,

$$M_{2022}(a_1, b_1, c_1, d_1) = M_{2017}(a_0, b_0, c_0, d_0) \times \begin{bmatrix} P_{aa} & P_{ab} & P_{ac} & P_{ad} \\ P_{ba} & P_{bb} & P_{bc} & P_{bd} \\ P_{ca} & P_{cb} & P_{cc} & P_{cd} \\ P_{da} & P_{db} & P_{dc} & P_{dd} \end{bmatrix} \quad (1)$$

where.

a_0, a_1 , the market share of urban domestic hot water in 2017 and in 2022 respectively, %

b_0, b_1 , the market share of rural domestic hot water in 2017 and in 2022 respectively, %

c_0, c_1 , the market share of urban and rural space heating in 2017 and in 2022 respectively, %

d_0, d_1 , the market share of industrial and agricultural thermal utilization in 2017 and in 2022 respectively, %

M_{2017} , the market structure by market segments in 2017, sequence of number.

M_{2022} , the market structure by market segments in 2022, sequence of number

$P_{aa}, P_{ab}, P_{ac}, P_{ad}$: the transfer probability from market segment of a to market segment of a, b, c and d at a specific time period, %

$P_{ba}, P_{bb}, P_{bc}, P_{bd}$: the transfer probability from market segment of b to market segment of a, b, c and d at a specific time period, %

$P_{ca}, P_{cb}, P_{cc}, P_{cd}$: the transfer probability from market segment of c to market segment of a, b, c and d at a specific time period, %

$P_{da}, P_{db}, P_{dc}, P_{dd}$: the transfer probability from market segment of d to market segment of a, b, c and d at a specific time period, %

Equation (2) [32] can be employed to calculate the market shares of evacuated tube solar collectors and flat plate solar collectors in the whole solar thermal utilization market:

$$M_{SC,2022}(VT_1, FP_1) = M_{SC,2017}(VT_0, FP_0) \begin{bmatrix} P_{VV} & P_{VF} \\ P_{FV} & P_{FF} \end{bmatrix} \quad (2)$$

where.

$M_{SC,2022}$, the market structure by collector types in 2022, sequence of number

$M_{SC,2017}$, the market structure by collector types in 2017, sequence of number

VT_0, VT_1 , the market share of evacuated tube solar collectors in 2017 and 2022, %

FP_0, FP_1 , the market share of flat plate solar collectors in 2017 and 2022, %

P_{VV}, P_{VF} , the probability of keeping evacuated tube solar collectors and the transfer probability from evacuated tube solar collectors to flat plate solar collectors at a specific time period, %

P_{FV}, P_{FF} , the probability of keeping flat plate solar collectors and the transfer probability from flat plate solar collectors to evacuated tube solar collectors at a specific time period, %

3. Analysis of current solar thermal market

The solar thermal markets in China in the period 2010–2017 were investigated. Fig. 5 shows the development of the production of solar collectors (flat plate collector and evacuated tube collector) in China in the past 8 years. The whole solar thermal market has shrunk from 2012. Fig. 6 and Fig. 7 show the development status of evacuated tube collectors (ETC) and flat plate collectors (FPC) during the period 2010–2017, respectively. As shown in Fig. 6, the annual production of evacuated tube collectors has been declining continuously since 2012 with an average rate of –11.4% annually. A dramatic decrease of around 20% for evacuated tube collector took place in 2014 and 2015. While the production of flat plate collectors fluctuated in the period 2010–2017, an annual increase 8.9% on the production of flat plate collectors was observed in 2017.

3.1. Reasons for market downturn

Since China has the largest solar thermal market worldwide, the development of the market in China will have a significant impact on the worldwide market. Therefore, it is necessary to have a detailed analysis of the Chinese solar thermal market. Chinese solar thermal market have declined since 2012. The reasons for market downturn was determined in details from demand and supply sides in this section.

3.1.1. Demand side

3.1.1.1. Reduction of rural population. With the fast development of urbanization and economy in China in past decades since 1980s, many rural residents have moved to cities. The rural population has reduced by 68 million every five years based on the investigation of

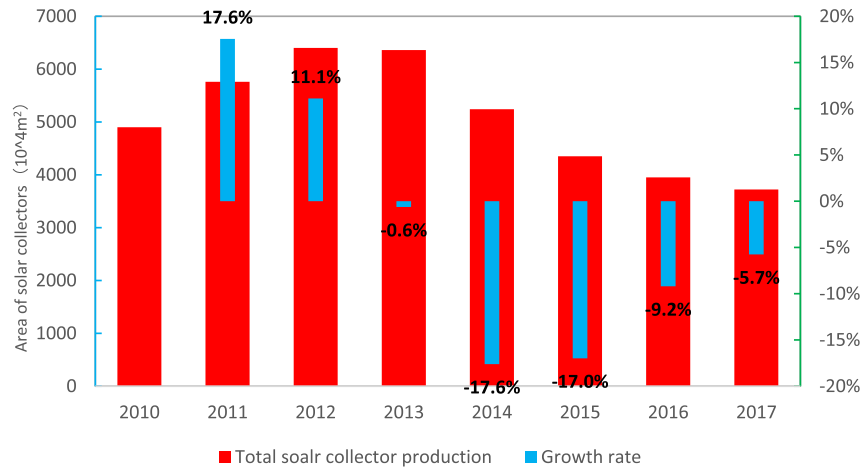


Fig. 5. Development trend of solar collector (flat plate collector and evacuated tube collector) in China for the period 2010–2017.

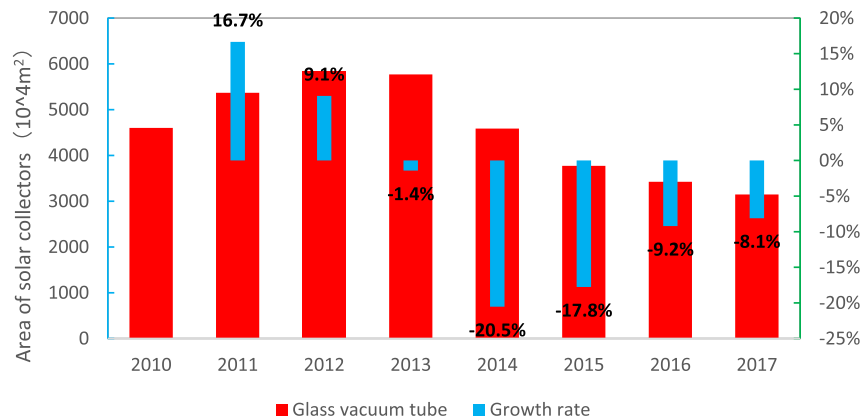


Fig. 6. Development trend of evacuated tube collectors for the period 2010–2017.

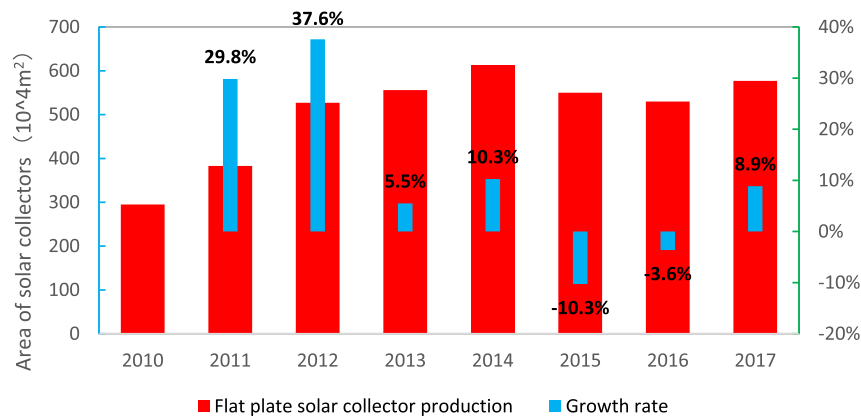


Fig. 7. Development trend of flat plate collectors for the period 2010–2017.

National Bureau of Statistics of China. The retail market of solar collector peaked at 2013 in the rural areas. Market saturation and continuous reductions of rural population result in a decreased low demand for SWHs in the rural areas.

The installed capacity of solar domestic hot water systems in rural areas has decreased from 19,330,000 m² in 2013 to 2,310,000 m² in 2017, see Fig. 8. The rural market only contributes to 6.2% of the total solar thermal market in 2017. With a decrease of

the population in rural areas and a saturated market, the rural market will remain to shrink in the future. It is estimated that the installed capacity would be only 90,000 m² in 2022.

3.1.1.2. Increase of residential income. The income gap between urban and rural areas in China has declined in recent years, even though the gap still exists. The annual income of rural residents in 2017 is 13,500 CNY per person, while that of urban residents is

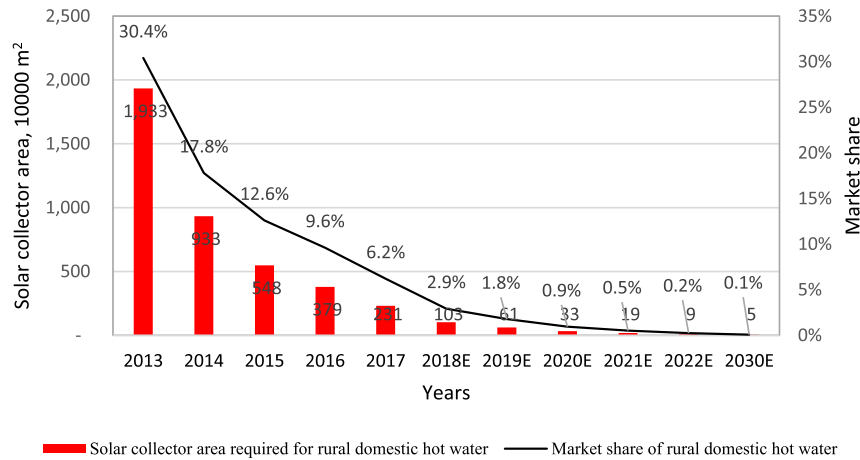


Fig. 8. Development trend of solar collector area for domestic hot water in rural areas for the period 2013–2022 (10,000 m²).

36,500 CNY per person [33]. The income of rural residents in 2017 is two times as that in 2010. More income means higher requirements on living standards in rural area. In the past, there were no natural gas networks in the most rural area of China. Residents used SWH to save electricity bills. In recent years, many rural residents prefer to use more reliable electric or gas hot water heater when they can afford it, rather than solar hot water heater.

3.1.1.3. Expires of the subsidy program. With the expiration of the subsidy program “Home Appliances Going to the Countryside”, the performance-cost of domestic SWH cannot compete with electric or gas water heaters, at least to some degree.

3.1.1.4. “Coal to gas” policy. According to the proposal on the 13th Five-Year Plan (2015–2020) on the development of natural gas issued by the Chinese central government, the share of natural gas in the total primary energy consumption would be 8.3%–10% by the end of 2020. By the end of 2017, 3.2 million families in northern China has completed “Coal to Gas” renovation for domestic hot waters and space heating systems after the local governments installed natural gas networks. The national policy of “Coal to Gas” accelerates the construction of natural gas infrastructures. Natural gas networks compress the market for SWH naturally.

3.1.1.5. “Coal to electricity” policy. To reduce air pollution in the north China, the Chinese central government also initiated “Coal to Electricity” policy. The market of air source heat pumps and

regenerative electric boilers benefit significantly from subsidies initiated by the “Coal to Electricity” policy. Residents also receive subsidies from the central and the local governments for electricity bills, if they choose to install air source heat pump. End-use consumers have better, more cost-effective choices for domestic hot water, other than SWHs.

3.1.1.6. Stagnant real-estate market. With social and economic advancement, China’s demographic dividend is diminishing gradually. The Chinese real-estate market reaches a period of stagnation. The number of constructions of new residential buildings will be limited in future. A decrease of on the floor area of newly constructed buildings results in a decreased market for the balcony-hang SWHs. The annual newly constructed floor area of residential buildings in China is shown in Fig. 9 for the period 2011–2017.

3.1.2. Supply side

3.1.2.1. Lack of attractive products. The manufacturing cost for a flat plate SWH is 4000–4500 CNY. The sale price including transportation and installation will reach 6000–7000 CNY. Compared to gas water heaters and electric water heaters, flat plate SWHs without subsidy currently do not show much more advantages on initial investment. In addition, the weight of a flat plate SWH is around 200–350 kg, which could exceed the load-bearing capacity of some rural building roofs. Therefore there is a strong demand for the solar thermal industry to come up with better solutions and products that can meet the requirements of domestic hot water

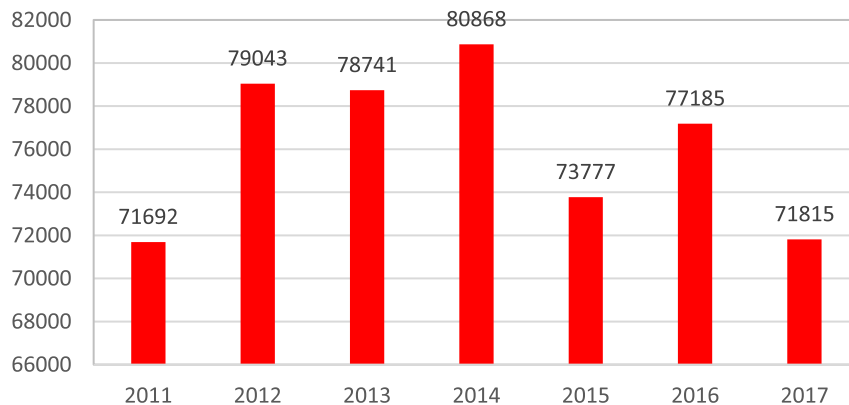


Fig. 9. The annual newly constructed floor area of residential buildings in China (100 million m²) for the period 2011–2017.

services in the rural areas of China.

3.1.2.2. High maintenance costs. The installation of SWHs in rural area is not standardized and unprofessional, creating a lot of hidden defects, even dangers. All-evacuated tubes need to be cleaned every 2–3 years to remove lime deposits in the tubes. Besides, leakages often occur due to ageing of the collector. Moreover, the possibilities on the breakage of vacuum tube are higher. The price of a single evacuated tube is only 12 CNY. But the cost to replace a tube with transportation and labor reaches up to 100 CNY, while the price of the water heater itself is only 1000–3000 CNY.

3.1.2.3. Lack of monitoring data. Due to the decoupling of construction and operation of the real estate industry in China, SWH manufacturers can receive more than 80% of the total cost after installation of the systems. The solar industry does not pay attention to after-sales service and will not take the initiative to monitor performance of the systems.

The lack of monitoring systems and the industry's misuse of "Attention to the construction, management contempt" make it difficult for both real estate developers and end-users to figure out how much energy the solar hot water systems contribute, which limits market confidence on solar hot waters [34].

3.1.2.4. Lack of R&D. Many SWH manufacturers pay more attention to marketing than R&D on the products in order to expand the market quickly. Due to a lack of R&D, the companies cannot put forward new product for emerging markets, for example, the market for large-scale solar district heating and industrial solar heating process.

3.2. Potential driven factors for market recovery

3.2.1. Potential urban domestic hot water market

The annual installed capacity of domestic solar hot water systems in cities and towns in China has been declining year by year since 2013. In 2013, the newly installed area of domestic solar hot water systems in cities and towns reached 43.88 million m², and in 2017 it dropped to 33.19 million m². However, just as shown in Fig. 10, the contribution of urban domestic hot water market share to the whole solar thermal industry increased from 69.0% in 2013 to 89.2% in 2017.

With an expansion of the commercial domestic hot water market and further development of urbanization, it can be

predicted that the market share of urban domestic hot water systems will cease to increase in 2018, and then declines afterwards due to the rising market of solar space heating systems.

3.2.2. Rapid urbanization

84% households in urban China are capable to install a typical solar hot water system from both energy and economic perspectives [35]. The urbanization rate in western countries is about 70%, while it in China was only 58.52% in 2017, see Fig. 11. To some degree, continuous urbanization still will be the main driving force for the real-estate industry in China. The solar thermal market will benefit from the urbanization in China for a long period, even though the real-estate sector is not so good as before. Households located near urban centers have a higher probability to install water heaters, particularly solar water heaters [36]. It have been found that the building-integrated SWHs in the urbanized areas are economically viable over the entire Yangtze River [37].

3.2.3. Mandatory installation policy

More than 21 provinces and province-level municipalities in China have implemented mandatory installation policies on domestic solar hot water heaters, such as Jilin, Beijing, Tianjin, Hebei, Shandong, etc. The most common rule of these policies is that installation of solar hot water systems is mandatory for all the buildings lower than 12-floors. In some cities it is required for buildings lower than 18-floors or 6-floors.

The mandatory installation policy has been implemented for many years in some pilot cities of China, promoting integration of solar thermal components in buildings. With a further development of urbanization and increasing contradictions between human and land, limited new buildings will be planned and constructed. At the same time, the government tends to encourage the real estate industry to construct higher high-rise residential buildings, which results in fewer new residential buildings under 12 floors. Many local housing and construction departments have found that under the current trend, they will not be able to accomplish the target of building integrated solar heating area specified in the 13th- Five-Year plan for building energy conservation and green building development (2015–2020). The application of solar domestic hot water systems in typical high-rise apartments can be feasible if this is addressed during the architectural design [38]. As a result, local governments, such as Ji'nan, has begun to implement the mandatory installation policies of solar hot water systems in high-rise residential buildings, and has also put forward

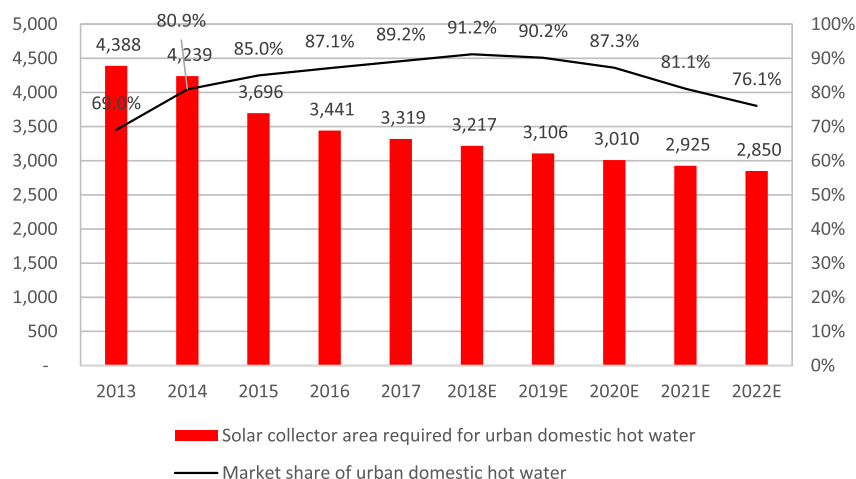


Fig. 10. Development trend of solar collector's area for domestic hot water in urban areas (10,000 m²) for the period 2013–2022.

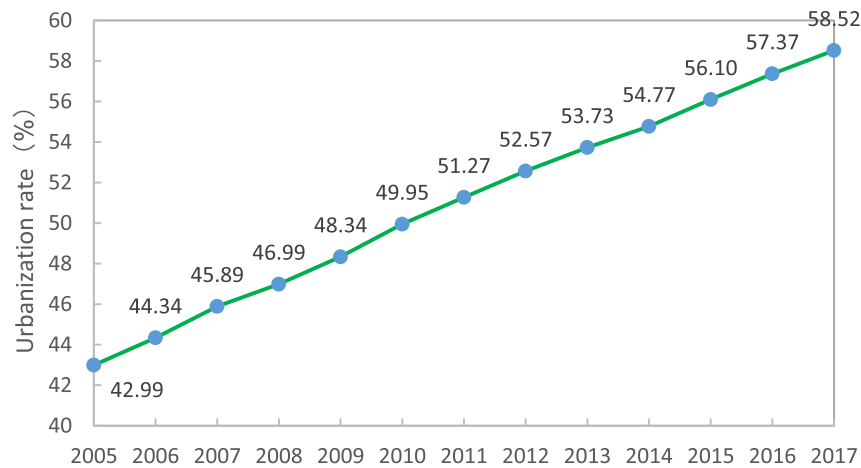


Fig. 11. Development trend of urbanization rate in China for the period 2005–2017.

a new mandatory installation policy for new public buildings with centralized hot water supply and new residential buildings lower than 100 m (so-called “100-m mandatory installation policy”). With the success of “100-m mandatory Installation” policy in Ji’nan, the policy is not only implemented in the whole Shandong Province, but also attracts attention from Wuhan, Hangzhou, and Yinchuan. Detailed documents on implementation and relevant technical support in these cities are being formulated.

If the 100-m mandatory policy on the installation of solar domestic hot water systems is implemented throughout the whole country, it will greatly stimulate technological innovation and wide application of the solar thermal collectors in urban domestic hot water market. For further development of the solar water heater, China should clarify the compulsory installation policy [39].

3.2.4. Rapid development of green buildings and zero energy buildings

From the release of the first edition of the “Green Building Evaluation Standard” in 2006 and “National Green Building Action Plan” in 2012, green buildings have significant developments thanks to a mandatory policy for 1-Star Level certification and an incentive policy for 2-Star Level or 3-Star Level certification. China’s green building market still maintain a rapid growth under the state’s incentive and mandatory policies that have been prolonged several times.

Both the domestic green building evaluation standards and US LEED green building rating system clearly require a certain percentage of solar energy utilization. In the national standard, it is stipulated that if “the ratio of domestic hot water provided by renewable energy sources is larger than 80%”, the project can get 10

points. According to LEED v4-New Construction green building rating system, if renewable energy accounted for 5% of total energy consumption, the project can get 3 points.

The central government also promotes zero energy buildings on national level in recent years. With the rapid development of green buildings and zero energy buildings, more and more attention will be paid to the application of renewable energy, particularly solar energy.

3.2.5. Aging population

The population who is elder than 65 years old accounted for 10.5% of total population in China in 2015. It is estimated that the aging population will be more than 400 million in 2050, around 20% of the whole population in China. The trend of aging will be serious in China soon in the near future. Aging people have higher requirements for hot water than the youth. Therefore, hot water consumption is expected to increase, which increases the demand for solar DHW systems.

3.2.6. National clean heating initiative

By the end of 2016, the floor area with space heating in north China is 20.6 billion m² (14.1 billion m² for urban area and 6.5 billion m² for rural area). China central government aims to reach 3.5 billion m² space heating area using renewable energy by the end of 2020, while the area of space heating using renewable energy by the end of 2016 was only 700 million m².

3.2.7. Increased demands from space heating

It is predicted that in 2022 the newly installed solar collector areas for space heating for China’s cities, county towns, and

Table 1
Solar heating policy in Chinese local and central governments.

| National Policies | Items related to solar thermal energy |
|--|--|
| Clean heating plan in winter in northern China (2017–2021) | Clean heating system, including geothermal energy, biomass, solar energy, waste heat: in total 800 million m ² , 4% of total heating area. |
| Guideline on space heating with renewable energy (2015–2020) | Promotion of building integrated solar heating systems. Build central solar heating plants with seasonal storage. By the end of 2021: Solar thermal systems 50 million m ² . |
| National Building Energy Efficiency & Green Building Development (2015–2020) | Promotion of solar heating public building. Solar thermal system in urban area: 2 billion m ² . |
| National solar energy development (2015–2020) | By the end of 2020, the number of solar district heating plants should be above 200, 4 million m ² ; solar domestic hot water & space heating in rural area: 300 million families; solar heat industrial process: 20 million m ² . |
| National renewable energy development (2015–2020) | Solar thermal energy area for buildings by the end of 2020: 800 million m ² . |

township villages are expected to be 1.69 million m², 0.89 million m² and 0.61 million m² respectively [40]. In addition, swimming pool is also another potential market for solar thermal systems [41,42].

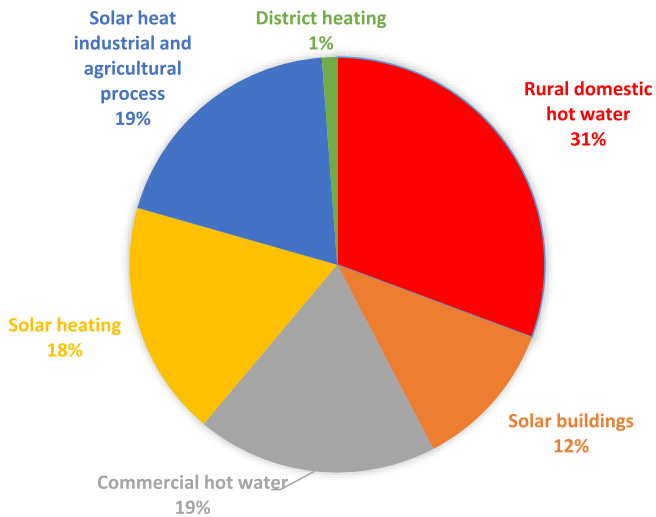


Fig. 12. Solar thermal market segment (before 2017).

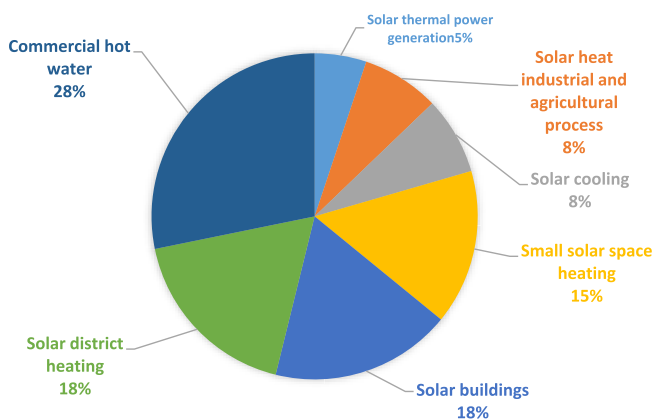


Fig. 13. Solar thermal market segment (after 2017: Prediction).

3.2.8. More favorable policies

Solar district heating systems have gained great success in Europe, particularly in Denmark [43–46]. In Inner Mongolia and Tibet, the central and local governments approved many pilot projects on solar district heating systems. Furthermore, more policies were released by the authorities in order to promote solar space heating in China, as listed in Table 1. Large-scale applications with thousands of m² collectors in solar heating plants may be another huge and emerging market for solar industry in China. Table 1 shows the policies related to solar thermal energy from Chinese local and central governments.

3.2.8.1. Strong solar energy industry in China. Solar industry in China has a good foundation after more than 20 years' development [47]. Solar industry in China has started to pay more and more attention to solar space heating system and commercial solar domestic hot water market in the urban areas. Chinese companies have dominated the world markets of both flat plate collectors and evacuated tube collectors with a huge absolute advantage in 2017.

Another highlight in the solar thermal market in China is international cooperation with pilot companies in developed countries. On the one hand, the saturated market in Europe accelerates the transfer of the high-performance flat plate collectors from Europe to the developing countries, particularly in China. On the other hand, large-scale flat plate collectors are in high demand in emerging solar district heating market in China.

3.2.8.2. Focus on the market of solar space heating and commercial solar water heating. By the comparison between Fig. 12 and Fig. 13, it can be found that dealers also gradually put more attention to the solar space heating market and the commercial solar hot water engineering market after 2017 while the focus was on solar water heaters in rural areas until 2017.

3.2.8.3. Clean heating transformation in industry and agriculture process. Solar heat industrial process (SHIP) started from 2010 in China. SHIP developed slowly and the market share is 1% until 2014. In 2017, the market share of SHIP reached to 4%, see in Fig. 14. It is predicted that the market share will reach 7% and the installed capacity will reach up to 2.61 million m² in 2022.

Based on the analysis of the characteristics of the heat utilization of ten industries and agriculture, including tobacco, textile, medicine, food, paper, wood processing, chemical, plastic and rubber, oil exploitation and metal manufacturing, the potential solar

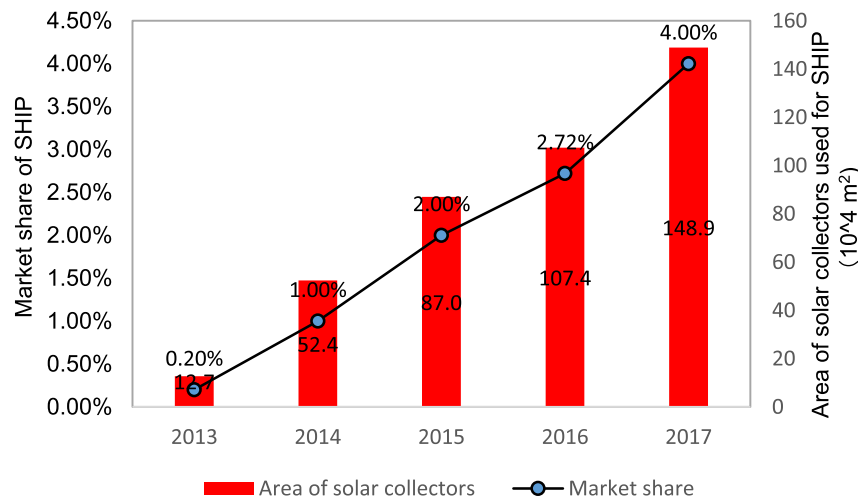


Fig. 14. The development trend of market share and areas of solar collectors used for solar heat industrial and agricultural process heat for the period 2013–2017.

Table 2
Potential solar substitution rate in the industry.

| Industry | Tobacco | Textile | Medicine | Food | Papermaking | Plastic & Rubber |
|----------|----------|---------|------------------|--------|-------------|------------------|
| % | 0.075% | 0.621% | 0.05% | 0.021% | 0.023% | 0.046% |
| Industry | chemical | wood | oil exploitation | metal | Agriculture | |
| % | 0.023% | 0.015% | 0.049% | 0.022% | 0.268% | |

Table 3
Solar collector area demand in SHIP and Agriculture (2017).

| | Total energy consumption (10 thousand tons of standard coal) | Thermal energy consumption (10 thousand tons of standard coal) | The proportion of heat | Solar thermal contribution (%) | Solar collector area (10 thousand square meters) |
|------------------|---|---|---------------------------|-----------------------------------|---|
| Tobacco | 255.72 | 72.77 | 28.5% | 0.075% | 0.300 |
| Food | 3904.82 | 2458.38 | 63.0% | 0.021% | 2.895 |
| Papermaking | 4153.00 | 3917.39 | 94.3% | 0.023% | 4.927 |
| Textile | 7365.72 | 2165.24 | 29.4% | 0.621% | 73.983 |
| Chemical | 44,081.46 | 30,747.94 | 69.8% | 0.023% | 38.896 |
| Wood | 1521.85 | 480.77 | 31.6% | 0.015% | 0.398 |
| Medicine | 2179.11 | 1098.01 | 50.4% | 0.050% | 3.018 |
| Plastic | 4350.01 | 972.75 | 22.4% | 0.046% | 2.442 |
| oil exploitation | 4008.42 | 3637.13 | 90.7% | 0.049% | 9.812 |
| Metal | 4704.49 | 844.11 | 17.9% | 0.022% | 1.003 |
| Agriculture | 8054.80 | 728.00 | 9.0% | 0.268% | 10.749 |

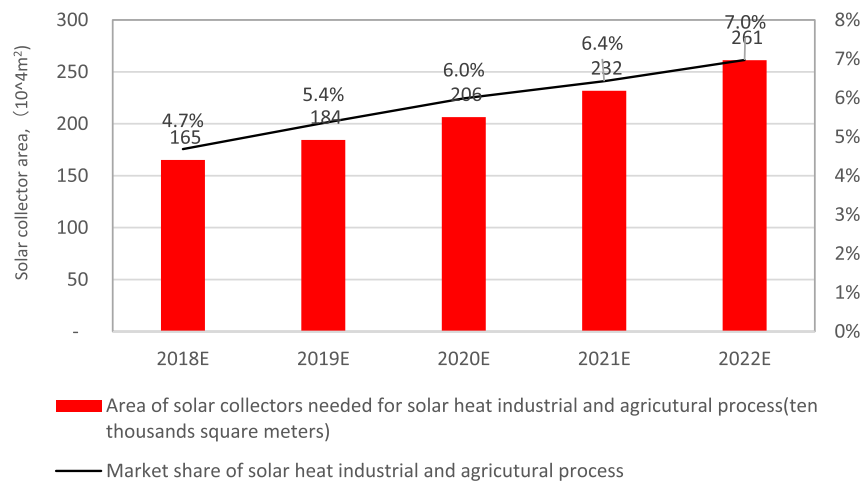


Fig. 15. Market share development of solar heat industrial and agricultural process for the period 2018–2022.

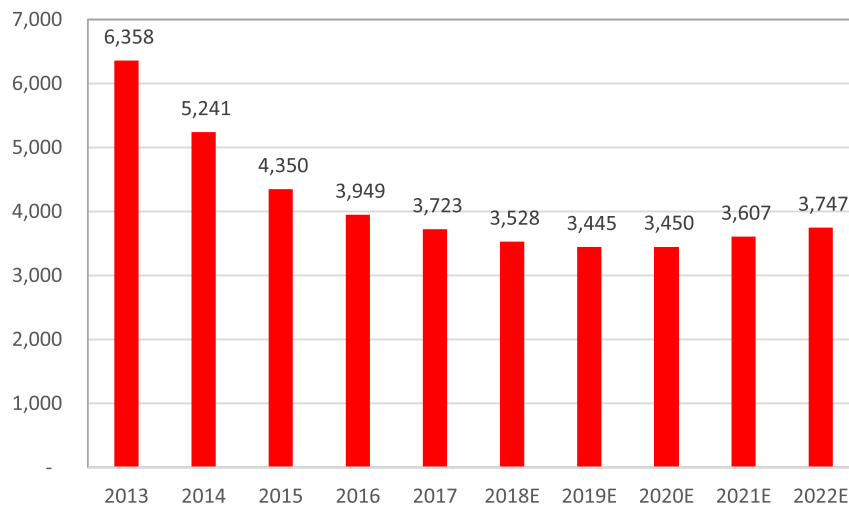


Fig. 16. Development trend of solar collector in China for the period 2013–2022 (10,000 m²).

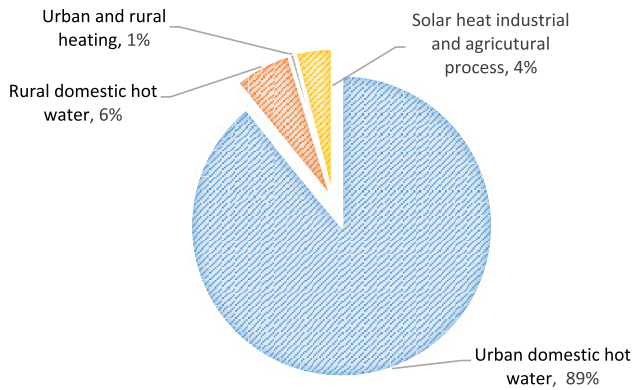


Fig. 17. Market structure of solar thermal utilization in 2017.

substitution rates in each industry are shown in Table 2.

The potential solar collector area is calculated based on the total energy consumption, the total amount of energy consumed in 2013 and the substitution rate of various industries in this study. Then the installed solar collector area for SHIP and agriculture in 2017 is calculated according to the development trend of each industry, with an assumption of 3%–10% growth rate annually for each industry. The total area required for solar collectors is 1.48 million m², which is in line with the development data of solar thermal industry in 2017, as shown in Fig. 14 and Table 3. Based on this model, the solar collector area installed in the next five years is predicted, see Fig. 15.

3.2.8.4. Market in Africa and Asia excluding China. In China, Middle East and North Africa, the solar thermal market decreased by more than 10% in recent years. However, South Africa and Asia excluding

China experienced a growth in solar thermal market. With rapid development of the Belt and Road Initiative, African and Asian countries will be a new potential market for the solar thermal industry in China.

4. Transition of the solar thermal market

4.1. “U” shape recovery

Based on the above analysis of the status quo and trends of various market segments, it is predicted that China's solar thermal industry will start to recover in 2020, driven by new demands. In the long-term perspective, the annual installed capacity will continue to increase, and the overall market will show a “U” shape recovery, as shown in Fig. 16.

4.2. Urban domestic hot water market

Fig. 17 shows the market structure of solar thermal utilization in 2017. Based on the above forecast for various emerging markets, the possible solar thermal market structure between 2018 and 2022 is shown in Fig. 18. By a comparison between Figs. 17 and 18, it can be concluded that the rural domestic hot water market will gradually shrink, and the solar domestic hot water systems in urban areas will still dominate the market. Urban and rural space heating systems, solar heat industry and agriculture process are the new promising driving forces for the solar thermal market. In the long term, urban and rural space heating market will become the main solar thermal market in 2030, see Fig. 19.

4.3. Flat-plate solar collectors

Fig. 20 shows the development of the market of flat plate solar

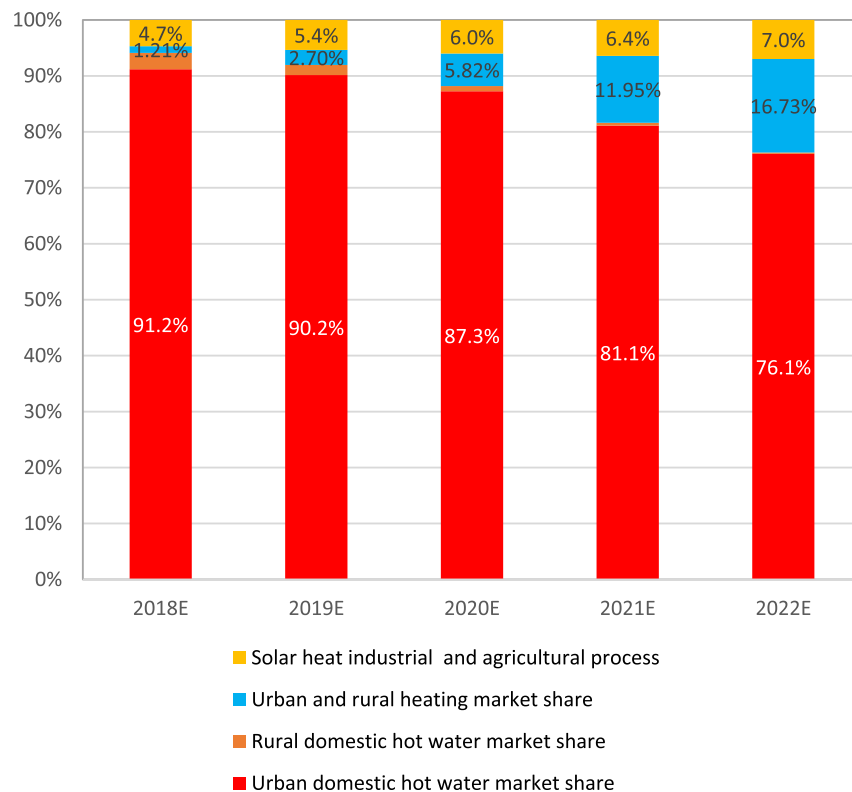


Fig. 18. Development trend of solar thermal market in China for the period 2018–2022.

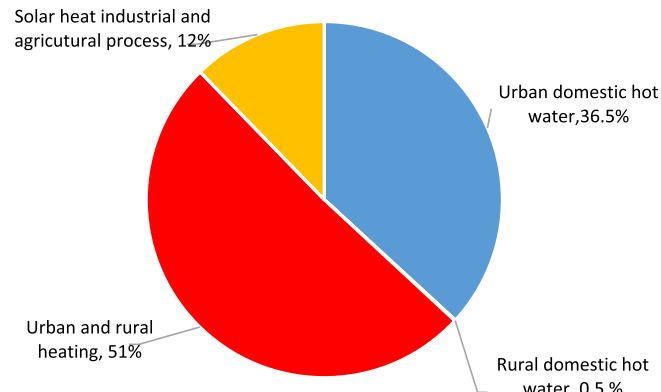


Fig. 19. Prediction of solar thermal market in 2030.

collectors in the past 8 years. The market share of flat-plate solar collectors has increased from 6% in 2010 to 15.5% in 2017. The market share of flat plate collector in 2017 is more than two times of that in 2010. The percentage of flat plate collectors in the whole solar domestic hot water market are gradually increasing.

Compared to a decrease of the production capacity of ETC, flat plate collectors attracted much attention from the pilot solar companies. The production capacity of the new production lines of flat plate collectors in many companies in China is higher than 5 million m², see Table 4. The government introduced corresponding guide policies and incentive measures to encourage the real-estate developers to invest in building-integrated solar water heating systems, as mentioned in previous sections. Furthermore, flat plate collectors have much more advantages than evacuated tube collectors when used in building-integrated solar water heating systems.

According to this trend, by 2022, the market share of flat-plate solar collectors will reach 29.9%, and the total installed capacity will reach 11.19 million square meters. Detailed figures can be found in Fig. 21. In the long term, it is estimated that by 2030, the market share of flat-plate solar collectors will reach 51.8%, and the total installed capacity will reach 31.78 million square meters, occupying the absolute dominant position in the market.

5. Conclusion and policy implications

Although China is the largest solar thermal collector producer and market in the world, installed capacity of solar hot water systems per capita in China are still quite low compared to other countries, which means there is huge market potential in China [48]. The development of solar thermal market in China from 2010 to 2017 was analyzed comprehensively in this study. The influence factors for Chinese solar thermal market from both supply and demand sides were analyzed in detail. Predictions on the trend of development for short-term, middle-term and long-term were also carried out. The following conclusions may be drawn:

- 1) Even though the solar thermal market in China will continue to decline in short and middle term, solar domestic hot water systems in urban areas will dominate the market gradually.
- 2) Solar thermal market in China will recover during middle-long term, which is driven by cleaning heating policy and SHIP.
- 3) The market share of flat plate collector will continue to grow in the coming decades.
- 4) Solar industry will play a critical role in the national clean heating initiative.

Following suggestions on the promotion and development of the flat plate collectors in China are given:

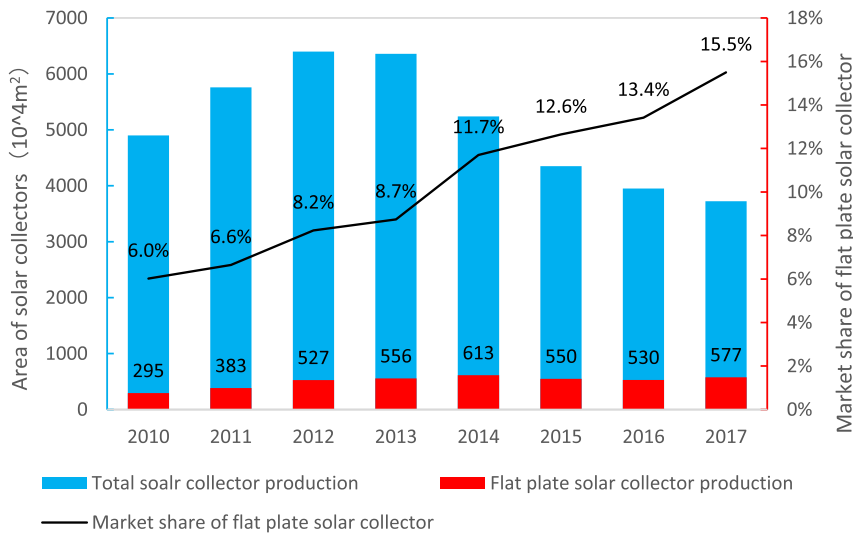


Fig. 20. Market share of flat plate collectors for the period 2010–2017.

Table 4
The development trend of the production capacity of evacuated tube and flat plate solar collector for the period 2014–2017.

| Indicator | | 2014 | 2017 |
|--|---|----------------------------------|--------------------------------------|
| Vacuum tube production capacity | The number of blank tube glass furnaces for SWH production line | 68 (55 in operation) | 67 (42 in operation) |
| Flat plate solar collector production capacity | | 5 million square meters per year | 20.80 million square meters per year |

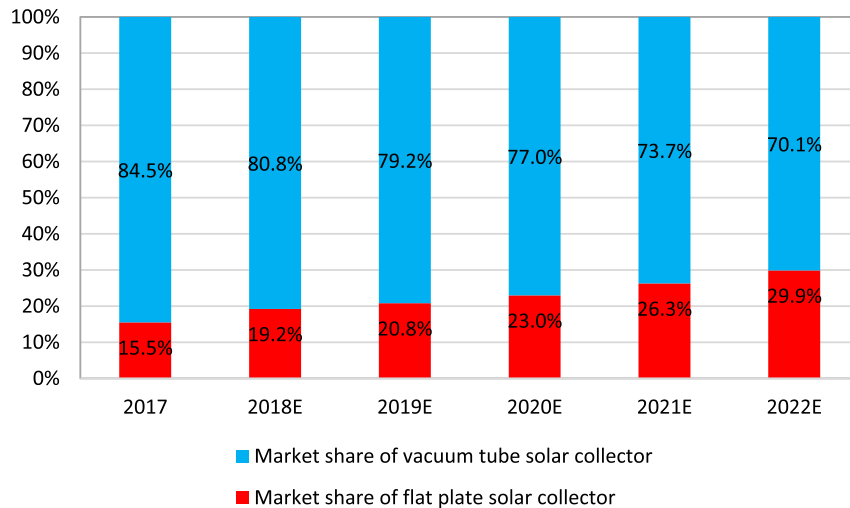


Fig. 21. Market share of Chinese solar thermal products for the period 2018–2022.

- (1) Given that European well-known flat plate collector manufacturers want to expand their market share in China, Central and local governments should stimulate Chinese solar industry to introduce the knowhow from them, particularly the engineering experience in large solar thermal systems. This win-win cooperation can accelerate expansion of flat plate collectors in solar space heating market.
- (2) The non-profit organizations, like solar thermal industry related associations in China, should follow the development of Chinese solar thermal market accurately. The status of the market should be published online timely. These information is not only useful for policy/makers, but also can be used by the international investors who are interested at Chinese solar thermal market.
- (3) Solar thermal industry in China should guarantee the performance of solar collector in the lifetime in order to ensure the market confidence continually.
- (4) China has a vast territory. When planning or implementing solar thermal systems, the cost effectiveness of solar energy systems should be investigated compared to other systems. The final and main aim is to provide the most cost-effective solution for the consumers.

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