

Key factors of China's leading in Solar Photovoltaic market

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Abstract:

This research highlights the pathway of China in building a modern and clean energy system. This research focused on solar photovoltaic and its targets, which were established by the government under its five-year plans.

As a result, the analytical review confirms that in few years, in line with the vision of the country's 13th FYP and 14th FYP, China surpassed the government's target for solar PV, and became the world's leader country in the renewable power capacity, and plays a principal role in the clean technologies market, especially in solar PV. The major keys of this success were driven by the contribution of many governmental incentives policies, in addition to the augmented importance given by the government to the research and development in the solar PV energy sector.

Keywords: Renewable energy, Solar photovoltaic, China, Feed-in tariffs, Incentive policies.

Jel Classification Codes: H25, H54, L52, Q28, Q42.

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I. INTRODUCTION

With an eye toward becoming the world superpower in clean energy, China has led the way in renewable energy. This last has been considered globally an important source of electricity generation in China and many regions in the world for many years.

It has adopted several plans to be an important leader of global environmental issues, including climate change and clean energy. The 12th Five-Year Plan (FYP) was the point when the true beginning of a global green development revolution.

With the 13th FYP (2016-2020), China puts out a promising schema to improving the equilibrium of Chinese economy and advance the citizen's welfare. It aimed to play a pivotal role in achieving specific targets, including targets for the renewable energy by 2020. Without forgetting the principal goals (economic, environmental and social) of sustainable development. And finally, the 14th FYP which is accelerating the China's low carbon energy transitions

Based on the foregoing, it can formulate the principal problematic of this article by asking the next question :

What were the most important keys of China's leader success in achieving its solar PV targets ?

To answer the main question, it can formulate the following hypotheses:

- In its pathway toward achieving the solar PV targets, China focused mainly on incentive policies;

- Increase priority was given to investment on solar PV sector and on research and development for solar PV technology, was one of the major keys of Chines success.

This study derives its importance from the importance of solar Photovoltaic us a fast-growing technology which has taken place in the last years, both in China and in the world. In addition, to the importance of the 13th FYP (2016-2020) which has adopted to play an essential role in achieving the government's target of renewable energy, particularly solar PV. In addition to the role of 14th FYP (2021-2025) in this pathway.

This study aims to highlighting the most important targets of the 13th FYP and 14th FYP for solar PV. In addition to presenting the keys of China's success in realizing its goals of solar PV, including : investments, capacity, production, export, employment and cost's reduction. Finelly, it aims to research and present the major key factors of this leader success.

The previous studies

The first study is of Sufang Zhang and Yongxiu He : "Analysis on the development and policy of solar PV power in China", which was published in the

volume 21st of Renewable and Sustainable Energy Reviews (2013). The paper studied the solar PV incentive policies in China, particularly the FITs structure. It clarified the successful factors of solar PV incentives (stability and predictability, transparency and clarity, streamlined and simplicity...). The researchers concluded that China solar PV had exceptional advantages which could be invested as a potential by China to developed strongly this ambitious sector. This study covered the first year of 12th FYP, while this paper studied the phase of the 13th FYP.

The title of the second study is “The expansion of China's solar energy: Challenges and policy options”, which was published in “Renewable and Sustainable Energy Reviews”, Volume 132, October 2020, of Jianglong Li and Jiashun Huang. This article presented the most important policy options that plays a pivotal role in promotion the development of solar PV in China. With a review of success experiences and initiatives policies that can help the China's renewable transition. The research found that there are many challenges that incombered and impacted the adoption and the future development of solar power. This study focused on providing the optional policies to address and overcome these challenges, by adopting policies of developing technologies and meditate the profits of participants. Also eliminating subsidies by accelerating the learning-by-doing method.

1. Renewable energy in the 13th and 14th five-year plans (2016-2025)

FYPs in China are policy tools which set down and clarify national strategy. It works to drive economic development of the country - with its deferent pillars- during the last years, so it played a fundamental role in the pathway of green development. China's entry into a green development era began with the 12th FYP (2011- 2015), when many successes were achieved, particularly in energy saving and pollution reduction. (Angang & Jiaochen, 2023, pp. 17, 21)

The 13th FYP (2016-2020) aimed to achieve several goals about the renewable energy transition. There were ten targets related to protection environment must be realized by 2020. (U.S.-China Economic and Security Review Commission, 2017, pp. 3,16)

It aimed in its energy part to construct clean and more efficient and secure energy system of China. (People's Republic of China, 2016, p. 84)

After adoption of 13th FYP, many related plans with PV sector have published to put and clarify the short-term PV goals, focusing points, particularly policies and innovation. (IEA, 2016, p. 10)

The starting in this study will be primary on the 13th Solar Energy Development FYP (2016-2020), adopting by the National Energy Administration (NEA) on 2016. Important targets for solar energy until 2020 have established . Table (01) includes it :

Table (1) : Target for solar PV capacity by 2020, under the 13th FYP

Technology	Target (2020)	
	Installation	Costs diminutions
Solar PV	105 GW	50% by 2020 in comparison to 2015 costs.

The source : (IEA, 2023)

While the 14th Five-Year Plan was published by the National Development and Reform Commission in 2021. It put many targets about solar PV, the most important of it is the following:

Table (2): The main targets for solar energy under the 14th FYP

Targets	Year
Increasing the share of non-fossil energy in primary energy consumption to 20%	2025
18% non-hydro renewables share of electricity output	2025
Raising the share of solar PV in total electricity generation portfolio from a modest 5% in 2022 to a robust 45%	2060
8% renewables in the total energy consumption of urban houses	2025
30% renewables in the total final energy consumption of rural houses	2025

The source : Prepared by the researcher, based on :(SANDALOW, MEIDAN, & ANDREWS-SPEED, 2022, pp. 59, 60), (Energy Foundation China & the Asian Infrastructure Investment Bank, 2024, p. 19) and (REN21 (a), 2024, p. 34)

2. China's achievements in solar PV sector

2.1. Solar PV, capacity and production

It can highlight the generation of solar power in China during the period 2016-2022 in Table (03):

Table (3) : Solar energy, capacity and production in China (2016-2022)

Years	2016	2017	2018	2019	2020e	2021e	2022e
Capacity (MW)	77788	130801	175016	204575	253418	306403	392436
Production (GWh)	67865	118258	178062	224527	261639	327551	

The source : Prepared by the researcher, based on : (IRENA (a), 2023, pp. 48, 49)

This table show that both installed capacity and the annual generation of power by solar PV grew strongly during the period studied. The total capacity

showed increasing by 404 % (2016-2022), while the production of power increased by 382,6 % in 2021 compared with 2016 level.

In the last decade or more, solar PV became the fastest increasing source of renewable electricity. (REN21, 2019, p. 94) Globally, this remarkable fast growing is due mainly to the growing of competitiveness of solar PV, associated with increasing electricity demand, increasing opportunities of this technology in reducing polluted emissions and delivering energy access. (REN21, 2018, p. 23)

As a result, in some places building new solar PV power plants was more cost-effective than continuing to run existing fossil fuel power plants. (REN21, 2019, p. 29)

One year before the adoption of 13th FYP, China installed around 15,15 GW, and again more than the double in 2016 - the first year of 13th FYP - nearly 34,55 GW with increasing by 128% and 53,07 GW in 2017 with increasing by 53.6 %, so that it had the largest additions for the third year in a row. (IEA, 2018, p. 12)

In the mid-year 2017, NEA issued the new application guide for the 13th FYP. It programmed an installation of new PV capacity in order to accounting 240 GW in 2020. (Jäger-Waldau, 2019, p. 27)

By the end of 2017, global capacity of solar PV increased nearly one-third, to approximately 402 GW, China alone added around 53.1 GW (more than half of the new addition), more than the global solar PV addition in 2015. (REN21, 2018, pp. 90, 91) China's total installations approached 131 GW of solar PV, and this last became the leading source of new power capacity in China. (IEA, 2018, pp. 9, 21) As a result, it surpassed the minimum target announced for 2020 (105 GW). (REN21, 2018, p. 91)

In 2018, China's annual solar PV installed declined for the first time since 2014, it installed around 45 GW of new capacity. By year's end, cumulative capacity estimated nearly 175 GW. (REN21, 2019, p. 95)

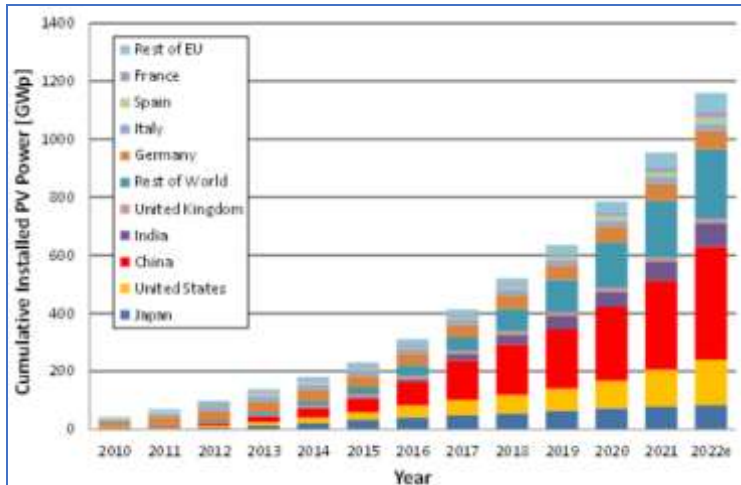
China's solar PV grew slowly in 2019, and the net solar PV additions sharply decreased, this was as a consequence of cuts in quotas (froze PV subsidies) announced in May 2018 for new projects supported by feed-in tariff. (Hove, Wenyun, Kaiming, & Kim Fuerst, 2020, p. 11)

In 2020, for nine following years, China was again in first place by installing more than 48 GW of new solar PV capacity, according to China's NEA. (Jäger-Waldau, 2021, p. 4) due essentially to the running to more installation before the national FIT was phased out by the end of the last year of 13th FYP. (REN21, 2021, p. 119)

China also showed a decline in solar PV installations compared to the previous year as a result of the cut in the FIT quotas. In addition to negative impacts caused by the COVID-19 pandemic. (Hove, Wenyun, Kaiming, & Kim Fuerst, 2020, p. 13)

At year's end, however, China could save its leader place in terms of total installed capacity with 253,6 GW (IEA, 2021, p. 12), more than the programmed target by 2020 (105 GW). (REN21, 2021, p. 119)

Figure (1) : Global cumulative PV system installations in China and rest of world (2010 – 2022 estimates)
(GWp)



The source : (Chatzipanagi, et al., 2022, p. 7)

The figure presents the remarkable growth of China's solar PV from less than 100 GWp in 2016 to more than 400 GWp in 2020, it can observe the international leading position of China in cumulative PV installed capacity, every year, around one third of the global installed capacity was Chinese.

In the end of 2020, China has alone nearly 33,2 % of the global installation, and more than 33,1 % of the global cumulative PV capacity, which make it the world's leader PV market for the eighth year in a row. (IEA, 2021, p. 15) And China's renewable power capacity estimated over 930 GW, much surpassing the target (675 GW) programmed under the 13th FYP. (SANDALOW, MEIDAN, & ANDREWS-SPEED, 2022, pp. 58, 59)

In 2022, China alone added around 86 GW (45% of the global additions). (IRENA (b), 2023, p. 90)

While in 2023, it could double its new installations more than the rest of all the world. (REN21 (b), 2024, p. 15) by year end, its total cumulative capacity surpassed 608 GW. (Energy Foundation China & the Asian Infrastructure Investment Bank, 2024, p. 26) And it was the first country on path to achieve its target of increasing the share of renewables 28% in its energy mix by end of current decade. (REN21 (b), 2024, p. 22)

2.2. Distributed, centralized and residential solar PV

Distributed solar PV has grown strongly because China focused on utility-scale solar PV in isolated regions . (IEA, 2020, p. 39) The strong beginning of installation distributed solar PV was in 2017. In 2019, around 30,6 % of total solar PV was classified as distributed after it was 29% , 22,7% and 13,2% in 2018, 2017 and 2016 respectively. (SANDALOW, MEIDAN, & ANDREWS-SPEED, 2022, p. 67)

While in 2020 - the last year of the 13th FYP - China installed more than 32 GW of centralized solar PV and approximately 15 GW of distributed solar PV. (REN21, 2021, p. 119) This means that 32,15 % total solar PV was distributed.

There are special factors for the change of distributed solar in China : (Hove, Wenyun, Kaiming, & Kim Fuerst, 2020, p. 42) Removing local borders to new project approvals for distributed solar PV; The declining costs of distributed solar PV projects for developers; Indirect support to distributed projects, even though the subsidy phase for these projects gradually ended.

As result of shifting investments to larger utility-scale projects as subsidies froze for distributed PV projects, this last does not completely return to the level growth of 2019. (IEA, 2020, p. 37)

By 2022, the new distributed PV installed capacity accounted around 58% of new total PV installations. (Energy Foundation China & the Asian Infrastructure Investment Bank, 2024, p. 21)

Of the total installed capacity in China during 2023, distributed capacity estimated around 254.4 GW (or 42%), and the new additions accounted around 216.3 GW , 45% of it was distributed. (Energy Foundation China & the Asian Infrastructure Investment Bank, 2024, p. 26)

Next figure illustrates the changing in installation of distributed PV in China during the period 2016-2023 :

Figure (2) : Total China's Distributed PV Capacity Installed (2016 – 2023)



The source : (Energy Foundation China & the Asian Infrastructure Investment Bank, 2024, p. 27)

The figure shows that the distributed installed capacity folded twenty-five times than the level of 2016.

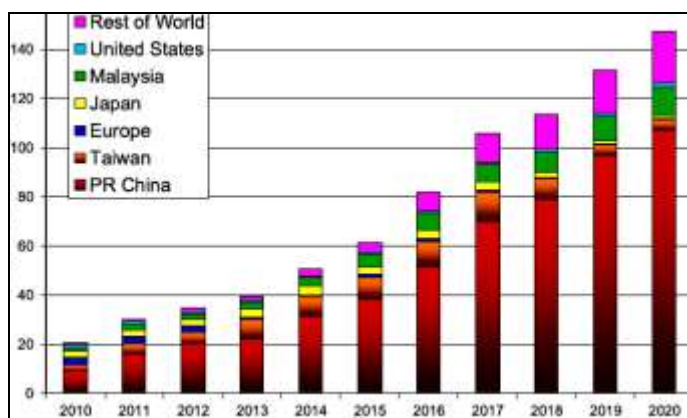
2.3. Solar PV cells and modules production

China became the world's leader producer for solar cells and modules for the 12th year running in 2020, around 135 GW of solar cells in this year was Chinese, accounts for 77,7% of the total, and its solar cell production capacity was approximately 200 GW/year by year end. (IEA, 2021, p. 46)

The same thing about PV modules, Chinese companies have 62 % of the global shipments of PV modules in 2019. (Chatzipanagi, et al., 2022, p. 64) It produced alone around 244 GW, accounted nearly 70 % of the total capacity produced of PV modules in the end of 2020. (IEA, 2021, p. 46)

Figure (3) : Annual production of PV cell/ thin film module in China and rest of world (2010 -2020)

(GW)



The source : (Jäger-Waldau, 2021, p. 2)

As shown in figure (3), China was the world's leader manufacture for solar cells and modules during all the first decade of this century.

Nearly, all the top solar cell and module production companies are Chinese. In 2018 for example, the top three manufacturers were Chinese companies: JinkoSolar, JA Solar and Trina Solar. (REN21, 2019, p. 105)

While in 2020, the top five cells production companies are Chinese, and the top four module production and module shipments companies are also Chinese. (Chatzipanagi, et al., 2022, p. 64)

In 2023 too, China produced nearly 80% of the global solar cell capacity, and all the top ten producers of solar PV equipment were Chinese. (REN21 (b),

2.4. Employment in solar PV sector

As it was the frontrunner of PV products and installation market, China was strongly leading PV employment with around 2,216 million jobs (65 % of global PV jobs) in 2017, an increase of 13 % over 2016, nearly 1.4 million jobs were in manufacturing side. (IRENA (b), 2018, p. 15)

But the slower speed of new installations driven by change in subsidy policies in mid-year 2018, caused a small change in employment, to 2.19 million jobs in 2018. (REN21, 2019, p. 46)

The COVID-19 pandemic also had its impacts on renewable employment in 2020, but China stilled the world's leader with around 2.3 million jobs, accounting nearly two third of the global PV employment. (IRENA & ILO, 2021, p. 22)

While in 2021, It could increase its PV employment share in the global market to 63 % with more than 2.7 million jobs. (Chatzipanagi, et al., 2022, p. 50)

2.5. Export of solar PV products

China adopts opening-up policy which encourages the participation of Chinese companies in the import and export era. In 2020, solar PV goods were exported to nearly 200 countries and regions. (Wang, Yang , & Xu , 2021, p. 10)

Figure (4) : Volume of exported solar PV products (2016–2021)



The source : (Wang, Yang , & Xu , 2021, p. 11)

From the figure it can say that there is a big growing in both volume and share of exported solar products. The start with 2016, when the export volume was 21.3 GW or 39.6% of total solar PV production volume, going to 2021, when the volume was around 100 GW or 66.6 % of total solar PV production volume. Having said that there was growth in the share of the exported volume, and growing of the export products from 21.3 GW to 100 GW between 2016 and 2021, or 369.5 % increasing.

So that, China became the first exporter of solar good in the world, to surpass more than USD 4.1 billion in March 2022. (Chatzipanagi, et al., 2022, p. 61)

3. The most important keys of Chinese success in solar PV

3.1. Research and Development (R&D) for Solar Power

The continual decrease of solar PV costs is a major key condition for large-scale PV deployment in China. To achieve the targets of the 13th FYP, there was an increased priority given to the clean energy and RE R&D, particularly for solar power. The government's investment in renewable energy R&D doubled from 2015 to 2019. (SANDALOW, MEIDAN, & ANDREWS-SPEED, 2022, pp. 70, 189)

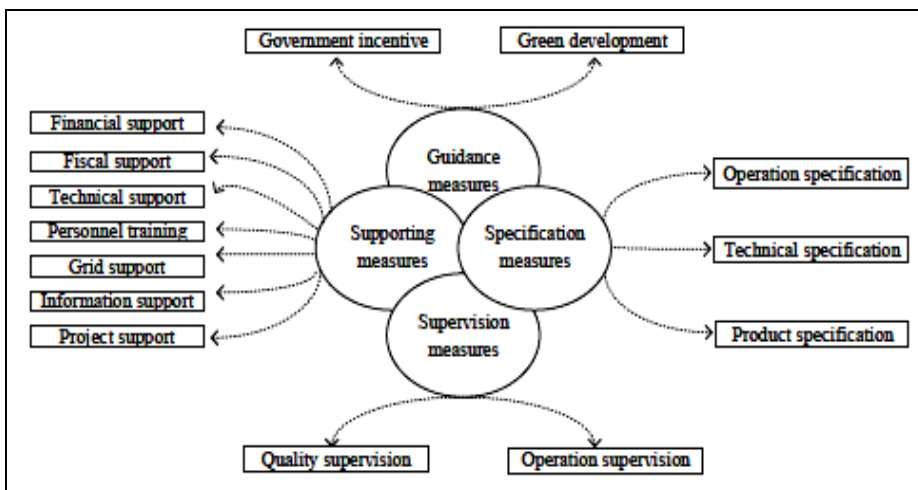
As consequence, in 2021, China became one of the three world's leading states in the field of PV innovations. (Chatzipanagi, et al., 2022, p. 4)

Similarly, during the 14th FYP, solar PV sectors was one of the essential sectors which benefited from R&D efforts, especially after the establishing of many plans like the Action Plan for Innovative Development of the Intelligent Photovoltaic Industry (2021), And the Plan for Technological Support for Carbon Emissions Peaking and Carbon Neutrality (2022-2030) by nine governmental departments. (Energy Foundation China & the Asian Infrastructure Investment Bank, 2024, p. 89)

3.2. Incentive policies

There are four kinds of the PV industry policy measures, next figure illustrates these types:

Figure (5) : The PV industry policy measures



The source : (Long , Cui , & Li, 2017, p. 4)

The four aspects include a total of 14 group as shown in the figure.

Targets, regulations, public financing and fiscal incentives are often found at many levels: the sub-national, national, regional, and finally the international level. (REN21, 2019, p. 50)

The PV industry in China was strengthened with the cooperation of deferent policy measures which are: governmental incentive; operation supervision; fiscal support; and technical support...But the government focused in the primary phase of China's PV industry mainly in incentive policies and technical supports. And next stage by providing the substantial financial and tax support, to develop of the PV industry. (Long , Cui , & Li, 2017, p. 6)

The government of China began strongly supporting the development of PV industry since 2004, when the scale of this industry started. It has announced related industrial policy from the several perspectives of monetary subsidies, incentive taxes and technical support. (Long , Cui , & Li, 2017, p. 1)

The 13th FYP was employed with several subsidized grid feed-in tariffs, government policy banks and other deferent policies... But the FITs phased out in 2018 to control the increase cost of solar subsidies, which estimated nearly USD15 billion in 2017. (SANDALOW, MEIDAN, & ANDREWS-SPEED, 2022, pp. 59,70)

In 2020, the policy changes resulted from an increasing deficit in China's Renewable Energy Development Fund, which caused a backlog of outstanding FITs expenditures for current projects, in the other hand, from the government's vision that solar PV power was able without subsidies of competing with coal-fired power. (REN21, 2019, p. 119)

It can resume the three phases of FIT policy in Table (04) :

Table (4) : Timeline for solar PV incentives

Phases	Years	Solar incentive policies
2009-2014 RE (solar PV) sector was heavily subsidized	2009	The Golden Sun Demonstration Project Announcement special fund for RE to support solar PV projects.
	2011	Solar FIT NDRC announced rules for setting solar PV FIT
	2012	Subsidy for the distributed solar announcement of regulations regarding distributed Solar Subsidy by MOF
2015-2018 Subsidy slowly phased out	2014	The Solar PV poverty alleviation projects The implementation of the work plan for the Solar PV poverty alleviation project
	2015	The Solar PV auction pilots A 0.2 GW project in Hohhot was used as a pilot for solar PV auction.
	2016	Solar PV auction pilots The solar PV FITs must be determined through tendering.
	2018	Cut in FIT quotas announced
2019 – 2020 Grid parity	2019	First price-parity projects awarded The announcement of the first batch price-parity for wind and solar PV projects.

The source : Prepared by the researcher, based on : (Hove, Wenyun, Kaiming, & Kim Fuerst, 2020, p. 41)

After phasing out of feed-in tariffs for most solar PV projects by the starting year of 14th FYP. The government continued to offer limited subsidies (national feed-in price premiums to some residential PV projects, such as residential rooftops and poverty-alleviation projects (rural projects). (SANDALOW, MEIDAN, & ANDREWS-SPEED, 2022, p. 61)

3.3. Public and private investment in PV sector

It can highlight the contribution of public sector on financing the renewable energy during the period 2014 - 2020 in China through Table (06) :

Table (5) : Public renewable energy finance flows in China (2016-2021)

Years	2016	2017	2018	2019	2020	2021
2020 USD million	1312.35	383.39	327.48	207.20	114.58	96.18

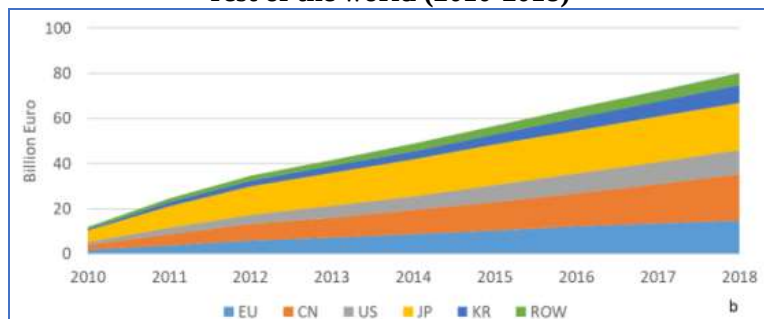
The source: Prepared by the researcher, based on: (IRENA (a), 2023, p. 402)

The table shows that the year 2016 was the most important year in funding severely the RE when the start of the 13th FYP.

The private investment in PV sector also had an important role in the

China's leading, figure (06) presents the top five countries in term of cumulative private investment in PV:

Figure (6) : The global cumulative private investment in solar PV, China and rest of the world (2010-2018)



The source : (Chatzipanagi, et al., 2022, p. 27)

Figure shows that the contribution of the private sector in China was the first worldwide during the period (2010-2018), with around 26 % of the global cumulative investments.

3.4. Efforts of China in minimizing the costs of Solar PV

The period 2010-2020 represented an important period of cost reduction for solar PV power technology in the world and especially in China. Which was one of the major factors of China's leading in solar PV market. This was due largely to many causes, it can gather the most important of them in the next notes: (Chatzipanagi, et al., 2022, p. 15)

- The intense research and development (R&D) efforts ;
- The public incentive support schemes of solar PV ;
- Technological advancement;
- The lessening borders for producers and developers in the industry.

(REN21, 2018, p. 23)

The global weighted-average total installed cost of solar PV projects decreased 13% from 2017 to USD 1210/kw in 2018. (IRENA, 2019, p. 20) While in 2020, it fell by 12 %, to just USD 883/kW, (IRENA, 2021, p. 12) when India had the most competitive costs accounted USD 596/kW, a cost 8 % lower than in China which estimated around USD 651/kW, it declined 19% between 2019 and 2020. (IRENA, 2021, p. 72)

The variances in total installed costs are largely due to the installation and soft costs. In 2016, China had the fourth low cost after India, Germany and Italy with more than 1100 USD2016/ KW. (IRENA (a), 2018, p. 67) While in 2020 it reduced the total cost to 651 USD2020/KW to was be in the second rank after India. This reduction came from lower both installation costs, soft costs and

hardware costs. (IRENA, 2021, p. 74) But in 2022, China had the fifth low cost in the world with 715 USD 2022/KW, an increase of 6 % than 2021 . (IRENA (b), 2023, p. 99)

II. Methods and Materials

This study employed a descriptive analytical approach to clarify the concepts related to the study and to present more understanding of the subject. In addition to the case study approach, which was adopted to link the theoretical part with the practical part to abstract the main results and conclusions, with a particular importance on the PV market in China.

III. Results and discussion

The most important results abstracted from this research paper are the following:

- The 13th FYP together with the 14th FYP played a key role in the transition of China to renewable energies ;
- By the last year of the 13th FYP plan, China was surpassing the solar PV target for 2020, and became the global leader in solar PV for many years in a row ;
- China is the world's leader manufacturer of PV products and installation, the world's leader in PV employment, and had the projects with one of the firsts competitive total installed costs ;
- The current plan "the 14th FYP (2021-2025) which began in 2021 and will continue to 2025, represented a critical time of China for defining the rapidity of low carbon energy transitions ;
- The excellent success of China in solar PV sector, was driven by the contribution and the cooperation of deferent key factors ;
- The first key factor is the policy tools (regulations, fiscal incentives, subsidies...), which were found at many levels from national to international ;
- China's government focused mainly on incentive policies, particularly on feed-in tariffs ;
- The second important key is the intense research and development (R&D) efforts in renewable energy, which almost doubling during the period studied in this research ;
- The third key was the positive achievements in minimizing the costs of solar PV ;
- The last major key is the hight public and private investment in PV sector.

The pervious results confirmed that the first hypothesis is right, as China focused mainly on public incentive support schemes of solar PV like feed in tariffs;

Also, China's excellent success is resulted by the augmented governmental priority to the investment in solar PV R&D, to achieve a continual decrease of solar PV costs, because this last is a major key condition for large-scale PV deployment in China. As a result, it can say that the second hypothesis was confirmed.

IV. Conclusion

The 13th FYP (2016-2020) played a pivotal role in China's achieving specific targets, renewable energy by 2020. Also, the 14th FYP played a major role on accelerating the China's low carbon energy transitions. Both installed capacity and the annual generation of power by solar PV grew strongly during the period studied, and in few years, solar PV became the fastest increasing source of renewable electricity in China.

By the finishing of 13th FYP, China could save its leader place in terms of total PV installed capacity for nine following years, and surpassed the target planned.

In the last years of the 14th FYP, China could also continue its leading in solar PV market. Particularly in 2023, it could double its new installations more than the rest of all the world, to became the only country on pathway to meet its target of 28% share of renewable energy in its energy mix by 30.

These excellent results were due largely to the intense research and development R&D efforts, and the great governmental and private investments in PV sector, in addition to the public incentive support schemes of solar PV.

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