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Evaluating Fiscal Instruments for Solar Energy Transition: A Comparative Study of Subsidies and Taxes

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ABSTRACT-This study aims to identify the most cost-effective and fiscally sustainable policy models for accelerating solar energy adoption by comparing fiscal instruments, subsidies and taxes, in Germany, the United States, and China over 2015–2025. Using a comparative case study approach, the research analyzed quantitative indicators (yearly installed solar capacity, government fiscal support, fiscal burden as % of GDP, and cost-effectiveness) and qualitative policy contexts drawn from national reports and economic data. Cost-effectiveness was measured as MW installed per million USD of public funds, while fiscal burden captured the share of GDP spent or not collected via solar subsidies or tax incentives. Key findings reveal distinct outcomes: Germany's subsidy-heavy approach delivered early capacity gains but resulted in high, unsustainable fiscal burdens and only moderate long-term expansion. The United States' tax-incentive model had a low fiscal burden throughout the decade and steady growth but lacked rapid adoption acceleration. China's hybrid strategy, evolving from subsidies and FITs, to competitive auctions and contracts for difference (CFD). It achieved the highest solar uptake and spending efficiency, with exponential growth and minimal fiscal strain. The results suggest that a hybrid mix of fiscal instruments, blending subsidies and market-based incentives, offers the best pathway for large-scale and sustainable solar adoption.

Keywords: Solar Energy Adoption, Fiscal Policy, Government Subsidies, Tax Incentives, Fiscal Sustainability, Cost-Effectiveness, Renewable Energy Policy, Feed-in Tariffs (FITs), Competitive Auctions, Contracts for Difference (CfD), Solar Photovoltaic (PV), Energy Transition, Public Expenditure, Germany, United States, China, Comparative Policy Analysis, Sustainable Energy Development, 2015–2025.

I. INTRODUCTION

The shift to renewable energy adoption is central to the fight against climate change. The paris agreement and other global climate change meets have also made it clear that countries need to move to net-zero emissions by 2050. Solar pv (according to iea data provided) has increased by 25% in 2023, reaching a level of over 1600 twh. Thus becoming the fastest-growing renewable source in the world source of renewable energy, set to account for 80% of the renewable capacity globally between now and 2030 (iea). Global investment in solar pv was around 503 billion usd in 2024 as compared to 426 billion usd investments in other generation technologies (iea). Over the past decade the cost of solar pv has fallen from $378 in 2010 to $68 in 2019 (wem). Government policies play a huge role in a country's solar energy adoption. Some rely on subsidies, others on taxes, and some on a mix of the two .For example one of the more effective policies in promoting solar energy adoption is renewable portfolio standard (rps) which states that electric companies must get a fixed share of their power from renewable energy sources including solar power, thus by mandating they ensure the existence of a market for solar energy and an opportunity for further investments in the sector. The different taxation policies and subsidies come with their own advantages and disadvantages, in many cases subsidies can make solar energy adoption more affordable, but they also put a strain on the government's budget. Taxes can discourage fossil fuel use, but they are politically unpopular. This paper compares the effectiveness of subsidies, taxes in promoting solar energy adoption. Cost effectiveness is defined here as the amount of solar capacity

in (mw) installed per million usd of public funds along with overall adoption rates and welfare outcomes. The study looks at three countries—germany, the united states, and china because each one represents a different approach.The aim is to understand which mix of taxes and subsidies works best and to suggest combinations for late-adopting countries like india. Different countries use multiple policy instruments for the promotion of solar energy adoption, for example usa relies on a more tax heavy approach using instruments like investment tax credits (itc) and production tax credits (ptc) which allows for the deduction of a certain percentage of the taxpayer's cost of renewable energy from their federal taxes, as per the united states environmental protection agency website. Also, different state-Level and central programs provide grants and loans to help

Residential and community, or to help with early stage r&d and manufacturing. Germany, one of the first countries to deploy grid-scale pv power alongside japan. Since the 2000s it has relied on feed-in-tariffs (fit) under the renewable energy sources act (eeg) ensuring a fixed payment to any amount of electricity fed into the grid. Over time due to technological advancements the rates decreased. It then made the transition from fits to competitive auctions in 2015 to award fundings for large scale solar projects which has proved effective in driving down costs through intense competition. China in the beginning relied on more subsidy heavy policy instruments like fits to create demand and then gradually shifted to auctions and market pricing as the technology advancements grew. This helped china become one of the world leaders in solar energy adoption.

1. Sustainable Development Goal 7: Affordable and Clean Energy

Sdg 7 ensures access to affordable, reliable, sustainable and modern energy for all. Solar energy adoption plays a direct role in supporting the achievement of this goal, because recent technological advancements and government initiatives have helped solar power in many countries become a low-cost, scalable and clean energy alternative. Investments in solar energy helps aid economic development, health improvements, and climate change mitigation thus making it an important tool for achieving a sustainable future.The solar adoption routes taken by the usa, china, and germany show different strategies and policy instrument implications that affect their growth. In the usa, solar capacity grew steadily from 7 gw of annual installations in 2015 to over 32 gw by 2025. This increase came mainly from the federal investment tax credit (itc). This tax incentive model kept the fiscal burden low, averaging less than 0.04% Of gdp over the decade.

2. Rationale

China experienced the fastest solar growth in the world becoming one of the world's largest producers of solar energy overall. Annual installations rose from 43 gw in 2015 to 255 gw in 2025, with a total capacity reaching 1,080 gw. Earlier china used feed-in tariffs and direct subsidies. However, in the 2020s, china shifted to auctions and contracts for difference, lowering average fit rates and reallocating subsidies more efficiently. This helped china's fiscal

Burden moved towards a moderate level, at 0.02 -- 0.04% Of gdp, while its cost effectiveness became the highest in the world. Germany, as previously mentioned, was one of the world's leaders in solar energy adoption and invested heavily through guaranteed feed-in tariffs as a part of the renewable energy sources act (eeg). This led to quick adoption but a higher fiscal burden that peaked at 0.25% Of gdp. Later reforms were introduced through auctions for larger projects, which helped lower costs. However, overall subsidy payments remained high compared to installed capacity. As a result, germany's cost effectiveness was much lower than that of both china and the usa. This situation underscores the trade-offs between rapid early adoption, long-term fiscal sustainability, and policy efficiency. While there are many disincentives faced by producers due to tax structures, our main focus remains on the incentives introduced by the government.

Since different countries have used a mix of subsidies, tax incentives, and policy instruments to promote solar adoption, it becomes important to ask which approaches are most effective and cost-efficient. This leads to the following research questions:

- Which fiscal incentive models (subsidies, Taxes, Or Hybrids) Have Been Most Successful In accelerating solar adoption across countries?
- How Does The Cost-effectiveness Of Subsidies (Mw Per Dollar Spent) Compare With tax-based incentives?
- Which subsidy–tax policy configurations minimize market distortions (deadweight Loss) while maximizing adoption and fiscal welfare?

II. LITERATURE REVIEW

The global transition to renewable energy has been advancing at a rapid pace, with solar energy emerging as a cornerstone technology (international energy agency, 2024). The steep cost reduction of photovoltaic (pv) technology, which has been estimated to have fallen by over 80% since 2010, has played a pivotal role in accelerating solar adoption worldwide (ceew, 2024). Key countries reflecting this rapid rise are china, europe, india and the united states. China leading with more than 300gw of solar capacity installed by 2025, followed by developed european markets that are supported by stable policies, india's national solar mission and the united states growing residential and utility scale sectors (iea, 2024) (ceew, 2024).

Adoption trends are often influenced by several external variables. Fluctuation prices of fossil fuels incentivises shifts towards renewable sources, while climate commitments embedded in the paris agreement affirm global intent to decarbonise energy systems (united nations, 2023). Geopolitically volatile regions have further driven solar uptake because of energy security concerns (ceew,2024). Variations in adoption rates between established and emerging markets are also observed. Compared to the more solid institutional frameworks of the developed countries, emerging economies confront obstacles like policy instability, inadequate grid infrastructure, and financial deficits (ceew, 2024). The transition to solar as a dominant

energy source depends heavily on the design and implementation of effective fiscal instruments, primarily subsidies and taxation policies. This literature review critically examines existing research on these fiscal tools, their comparative effectiveness and the lessons drawn from various international contexts, framing the necessity for integrated policy frameworks to optimise solar energy transition.

1. Subsidy Mechanisms for Solar Adoption

Subsidy mechanisms operate as 'direct inducements' to reduce entry barriers and increase solar adoption. They catalyze solar adoption by reducing upfront costs and improving investor confidence.

- *Capital subsidies or upfront grants* Are common in emerging markets such as india And brazil, where they significantly lower initial investment costs for residential and small commercial solar projects (ceew, 2024).
- *Feed in tariffs (fits)* Provide guaranteed payments or premium rates for renewable energy that is produced and fed into the grid. Countries like germany and japan Relied heavily on this method to stimulate the market. Although If They Are Suddenly Withdrawn they can cause market crashes and investor distrust (sdewes journal, 2023).
- The united states uses tax credits such as the *Investment tax credit (itc)* And *Production tax credit (ptc)*. They reduce tax bills for solar investors, making projects financially more appealing, and when paired with accelerated asset depreciation rules They help further by lowering costs dramatically (arka360, 2024).
- Another common mechanism in the us is *Net metering*. Net metering policies Incentivise self consumption by compensating consumers for Excess Generation Of Power sent back to the grid. This enables bill reduction and helps increase small scale solar adoption (perfect sense energy, 2025).
- In emerging economies like india, brazil, southeast asia, there are *Exemptions on Solar equipment tariffs and taxes*, Which significantly reduce Hardware Costs Enhancing System affordability (ceew, 2024).

Behavioral economics research validates that subsidies effectively drive consumer and corporate solar investments by improving affordability (world economic forum, 2023). They play a big role in building supply chains and increasing consumer familiarity. Although long term reliance on subsidies can foster inefficiencies by inflating prices or discouraging innovation to reduce costs (ceew, 2024). Developing economies particularly struggle with subsidy program continuity due to budgetary constraints and competing priorities (ceew, 2024). Countries that

Manage the risk best achieve great results by gradually tapering subsidies and combining them with other policy tools to maintain steady growth.

2. Taxation Mechanisms for Solar Adoption

Tax policies serve two critical functions in promoting solar energy, disincentivising fossil fuel use by increasing their prices accounting for the harm they cause to the environment and enhancing renewable competitiveness through financial incentives (sdewes journal, 2023).

- *Carbon taxation* Effectively prices pollution, encouraging cleaner energy consumption without directly subsidising renewables (sdewes journal, 2023). This can be Observed in nordic countries, canada and japan.
- *Reforms cutting fossil fuel subsidies*, Such as indonesia's fuel pricing changes or India's coal cess, redirecting financial resources previously used to sustain fossil fuels can help create a more balanced energy sector by supporting renewable energy development (sdewes journal, 2023).
- *Electricity duty surcharges* On fossil fuel based power and some regional tax reliefs For solar projects provide additional,though often limited, boosts to the sector.

While taxation fosters long term behavioural change, it often struggles with political acceptance. Its political feasibility is often challenged by lobbying and public opposition (deloitte, 2025). Carbon taxes in particular can be seen as regressive, without accompanying positive incentives, taxes alone maintain only marginal influence on solar adoption limiting their role in rapid deployment phases (arka360, 2024). Taxes also affect grid pricing structures and raise equity concerns, particularly where lower income groups bear disproportionate cost burdens (world economic forum, 2023).

3. Combined and Blended Approaches

Leading solar economies illustrate the power of blending subsidies and taxation in layered policy architectures. In the u.S. The combination of tax credits with grant programs and state level incentives fuels a diversified and resilient solar market (arka360, 2024). Germany's transition from fit dominance to a diversified system integrating tax incentives with self consumption enhancements balanced investor certainty with market efficiency (ceew, 2024). India's model

Merges coal cess taxation with capital subsidies and import duty removals, promoting solar expansion while managing financial stability (sdewes journal, 2023)(ceew, 2024).

Contrarily, countries attempting isolated carbon taxes without coherent adoption frameworks have faced stalled renewable growth and political resistance (world economic forum, 2023).

Spain's abrupt fit cuts resulted in a market freeze, while vietnam's delayed policy adaptation decreased deployment (sdewes journal, 2023).

Hybrid fiscal models address uncertain market conditions better than single instruments by balancing short term affordability through subsidies with long term competitiveness via market correcting taxes (ceew, 2024)(deloitte, 2025). Effective governance, clear communication and political will are essential for navigating transitions and fostering stakeholder trust.

Despite the growing body of literature there are very few studies analysing the dynamic interplay between these instruments and how they interact optimally. Governments lack standardised sequencing frameworks to manage the transition from heavy subsidy dependency toward mature tax based regimes (ceew, 2024). The following review illustrates how subsidies and taxation represent complementary, indispensable fiscal tools in solar energy transition. Combining lessons from diverse international experiences, identifying best practices in fiscal policy that cuts costs, minimises market disruptions and speeds solar uptake.

III. METHODOLOGY

The research approach in this study is based on a comparative case study design, where an inferential investigation of the effectiveness of solar policies in china, the usa, and germany between 2015-25 is concerned. Instead of using formal regression or econometric modeling, the study is based on extensive descriptive and inferential analysis of the major quantitative measures like yearly installed solar capacity, government fiscal support levels, fiscal burden (% of gdp), and cost effectiveness (mw installed per million usd spent).

This strategy entails consistent cross country comparison and over time comparison of these indicators in order to draw inferences regarding the impact of varying configurations of subsidy-tax policies on solar adoption and welfare outcomes. Qualitative evidence on policy

Institutions, market conditions, and institutional change complements the quantitative comparison to yield a rich explanatory story. By combining several data sources, such as national reports, economic data, and policy reports, the research detects converging trends and compares policy effects without depending on sophisticated statistical models.

The methods of research used are as follows:

- *Comparative case study framework:* The study compares three Representative Countries with different subsidy-tax mixes, enabling analysis of policy impacts In Varied Economic and institutional settings. This aligns with Existing Literature Advocating For Cross-context policy evaluations to discern effective strategies.
- *Data collection and metrics:* It utilizes detailed longitudinal quantitative data (2015-2025) On solar capacity installations, government subsidies, tax incentives, solar policy types, Gdp figures, and derived metrics such as fiscal burden and cost effectiveness (mw installed per million usd). This rich dataset supports empirical evaluation of Policy impact over time.
- *Cost-effectiveness And Fiscal Burden Metrics:* The Report Emphasizes Calculating cost-effectiveness (capacity added per fiscal dollar spent) and fiscal burden (% of gdp spent on solar support) to evaluate market efficiency and economic welfare implications of differing solar policy strategies. This quantitative framing is essential to identify policies that balance rapid adoption and fiscal sustainability.
- *Policy context analysis:* Complementing the empirical work, the design Includes qualitative policy analysis tracing historical evolution and institutional frameworks to understand contextual influences on policy outcomes, a best practice for interpreting complex policy impacts.
- All finance data were drawn from national renewable energy support Records (bundesnetzagentur, doe, china nea/irena)

1. Limitations

Limitations to this paper especially pertaining to the methodology sections are:

- The data has been taken from other studies and sites, though they may be credible May not align with the goal of the study and may come along with Biases Of The Researcher Or Organisation.
- When talking about solar adoption and the instruments helping with the adoption(in The paper fiscal incentives) we have not considered factors like the stage of economic development of the country, and technological advancement, in doing so we have not reduced their importance but brought the importance of fiscal incentives on same bar as economic stage of the country.
- Simplified metrics like the fiscal burden and cost effectiveness may not capture the Full complexity of the market or the country because of things like price shifts, market Distortions.
- The data may not be able to capture the long term result of a very recent change in The policy, The Data Time Period While Substantial May Not Be Able To Capture

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The Full Picture As the change had started long ago and has yet to go a long way.

IV. KEY FINDINGS

This study compares the solar adoption outcomes of three countries - china, the united states and germany over the time period 2015 to 2025. The analysis is based on 3 key indicators: cumulative installed capacity, fiscal burden as a share of gdp and the cost-effectiveness of new solar capacity installed per million dollars of government funding. These measures clarify not only the amount of solar capacity deployed but also how efficiently and sustainably public funds were utilized.

The *Cumulative installed capacity* Ref29ers to the total stock of new solar power capacity that has been installed and remains operational up to a given year, measured in megawatts (mw) and highlights the long-term scale and persistence of solar adoption. It captures how quickly a country is building its solar base and indicates whether annual additions are turning into

Sustained growth and renewable energy in the overall combinations of electricity generation in the country.

The *Fiscal burden* As a share of gdp is the share of a country's total economy (gdp), either spent on the provision of subsidies or forgone through providing tax incentives to incentivise solar energy adoption, in a given year, calculated as:

$$\text{Fiscal Burden (in \%)} = \frac{\text{Annual Solar Subsidy or Tax Incentive Value (in USD Billion)}}{\text{GDP (in USD Billion)}} \times 100.$$

It is expressed as a percent of the total gdp of the country and indicates the weight of solar energy adoption on the nation's finances, where a higher burden will be unsustainable to the country due to the amount of expenditure, and low burdens with a higher solar adoption rate reflects efficiency.

The *Cost-effectiveness* Of new solar capacity refers to the amount of solar capacity (in mw) installed per million usd of public funds, in a country in a given year, indicating the feasibility of policy expenditure. This is calculated as:

$$\text{Cost-Effectiveness} = \frac{\text{Installed Capacity (in MW)}}{\text{Annual Subsidy or Tax Spending (in USD)}}$$

It explains how much solar deployment is achieved per dollar, with higher values reflecting more productive use of public funds and reduced fiscal deadweight loss. By combining the various measures, this analysis captures both the quantity of solar power deployed in these countries and the quality of the policy design behind the adoption of solar power.

1. Germany's Path to Subsidy Reliance: High Costs, Moderate Returns

Germany's solar journey is often remembered for its pioneering role in renewable energy policy. Through early fits, which is a long-term policy measure implemented by the government guaranteeing renewable energy producers a fixed price (usually higher than the prevailing market price) for every unit of electricity they supply to the world, providing investment security, germany positioned itself as a global leader in solar power in the 2000s, inspiring similar

Policies worldwide. The early leadership soon transformed into a lesson in the risks of subsidy dependence, highlighting the limits of a subsidy-heavy policy. During 2015 - 2025, despite strong support from the government, the country struggled to scale solar installations efficiently, carrying a rising fiscal burden while achieving moderate growth in capacity.

Germany's commitment to solar was strengthened by a consistently high fiscal burden, reflecting the consequences of its fit-based subsidies on its national finances, and overall gdp. Since germany supported the solar energy sector, mainly through fits, the fiscal burden on the government remained high. In 2015, the government spent usd 8.2 Billion on subsidies, which is equivalent to 0.24% Of the gdp. This was a far higher contribution than other countries were making to their solar sectors. Over the following years, this share kept increasing, peaking at 0.26% In 2020. Only after 2021, when older fit commitments were phased out, and the new auction policy took greater effect, the fiscal burden declined to 0.16% In 2025. The auction policy forced a competition in the market, and the producer with the lowest cost-bid got the contract. This ensured that prices are grounded, and the investors are still attracted to the market. The fiscal burden of germany from 2015 to 2025, can be tracked with the help of figure 1.(A).

Year	GDP	Solar Subsidy	Fiscal Burden
Unit	USD Trillion	USD Billion	%
2015	3.37	8.2	0.24
2016	3.5	8.8	0.25
2017	3.68	9.2	0.25
2018	3.98	9.8	0.25
2019	4.08	10.2	0.25
2020	3.8	9.8	0.26
2021	4.16	9.2	0.22
2022	4.12	8.6	0.21
2023	4.17	8.2	0.20
2024	4.53	7.8	0.17
2025	4.6	7.2	0.16

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(Figure 1.(A): Germany's Fiscal Burden Of Solar Support, 2015 - 2025)

The impact of this heavy reliance on subsidies becomes clearer when analysing other key indicators for germany's solar adoption. By 2015, annual installations were as less as 1.5 Gw that year, even though government expenditure was more than usd 8 billion in subsidies.

Cost-effectiveness was at 0.18 Mw per million dollars. This indicates a very high gap between the amount of government expenditure due to subsidy provision and the amount of solar capacity installed. The cost-effectiveness being a low figure suggests that public funds were barely used to purchase barely any new solar capacity. The cumulative capacity of solar energy installed in 2015 was nearly 40 gw, displaying the success of germany's early policies and subsidy incentives. However, this head-start came with a high fiscal cost as the decade progressed. Germany tried to correct its course by shifting focus from fits to competitive auctions. This transition improved cost-effectiveness from 0.18 Mw per million dollars to around 2 mw per million dollars in 2024, utilising more of the public funds for solar capacity installations. Yet, despite the policy reforms, solar adoption remained slow-moving, with the cumulative installed capacity only reaching around 107 gw by 2025. Annual installations rarely exceeded 17 gw, with a brief spike only in 2023-24. Meanwhile, fiscal burden remained consistently high at approximately 0.25% Of total gdp, and not accompanied by proportional gains in solar capacity.

Germany's experience shows that while a subsidy-heavy focus on policies can provide an initial momentum, it is not sustainable in the long run. By locking into expensive fit commitments, the country carried a heavy fiscal load, without being equipped to offset it with a corresponding increase in solar adoption. The later shift to auctions helped reduce costs, however could not entirely reverse the inefficiencies caused due to the initial subsidy-only strategy. The german case highlights how a failure to recalibrate a subsidy-based system in time, can make solar adoption an expensive and unsustainable process, which does not aid overall growth.

Years	Installed Capacity	Cumulative Capacity	Primary Policy Type	FIT rate	Tax Credit	Annual Subsidy Spendings	Cost-Effectiveness
Units	MW	MW	-	USD/kWh	%	Millions - USD	MW/ USD millions
2015	1458	39700	FIT	0.25	2	8200	0.18
2016	1520	41200	FIT	0.22	2	8800	0.17
2017	1750	42900	FIT + Auctions	0.19	2	9200	0.19
2018	2960	45900	Auctions	0.16	3	9800	0.3
2019	4000	49900	Auctions	0.14	3	10200	0.39
2020	4900	54800	Auctions	0.12	3	9800	0.5
2021	5300	60100	Auctions	0.1	4	9200	0.58
2022	7200	67300	Auctions	0.088	4	8600	0.84
2023	14600	81900	Auctions	0.082	5	8200	1.78
2024	16900	98800	Auctions	0.078	5	7800	2.17
2025	7020	107400	Auctions	0.075	5	7200	0.97

(Figure 1.(B): Germany's Solar Adoption Indicators, 2015 - 2025)

2. The United States' turn to Incentives: Consistency without Accelerations

The united states followed a very different path as compared to germany, relying almost entirely on the federal investment tax credit (itc) as an alternative to subsidies as incentives for solar adoption. Rather than directly paying producers, itc was a tax break, which allowed producers to lower their federal tax bill by a percentage of their solar project investment. Since this model did not require cash payments on the government's part, the fiscal burden was low, and more politically stable. This strategy created a steady, predictable market for the solar energy sector, however the trade-off was that it did not trigger large-scale expansions.

The fiscal burden data in figure 2.(A), highlights how lightweight this approach was for public finances. In 2015, solar tax incentives cost the government a meagre amount of usd 2.2 Billion, which represented 0.01% Of the gdp. Even at the peak of investment in 2024, with costs rising up to usd 10.6 Billion, yet, the share of gdp used for solar energy was only 0.04%. This illustrates how the itc model worked, even though it didn't require a large amount of public expenditure. In other words, the u.S. Government encouraged solar deployment by giving up tax revenue rather than paying out subsidies directly, keeping budgetary pressures low.

Year	GDP	Solar Tax Incentives	Fiscal Burden
Unit	USD Trillion	USD Billion	%
2015	18.21	2.2	0.01
2016	18.62	4.4	0.02
2017	19.61	3.1	0.02
2018	20.61	3.2	0.02
2019	21.43	4	0.02
2020	20.93	5.8	0.03
2021	22.99	7.1	0.03
2022	25.46	5.5	0.02
2023	26.96	9.7	0.04
2024	27.5	10.6	0.04
2025	28.5	9.8	0.03

(Figure 2.(A): The United States' Fiscal Burden Of Solar Support, 2015 - 2025)

Between 2015 and 2025, the annual installed capacity in the u.S. Grew gradually, starting at rising from 7 gw of new installations in 2015 to around 35 gw annually by 2024-25. The cumulative installed capacity expanded from 27.8 Gw in 2015 to around 248 gw by 2025. Over the decade, the itc succeeded in keeping the market alive and growing but without any exponential jumps. Cost-effectiveness remained remarkably consistent at 3.3 Mw per million usd of support

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throughout the entire period. This implies that while the itc was predictable and a stable way to increase solar capacity, it did not push developers to lower costs or compete more aggressively, which also explains why the pattern growth was gradual rather than sudden. The trend of cost-effectiveness displays the consistency of this policy measure but more importantly also sheds light upon the limitations of it. The itc kept the solar sector attractive to investors, creating stability and avoiding the budget crisis faced by countries having a subsidy-heavy strategy. Yet, because support for solar adoption was raised through tax reliefs and not competitive pricing incentives, the system did not generate gains in efficiency or rapid scaling. By 2025, the u.S. Had achieved a respectable but modest trajectory of solar capacity, which proves that a tax-based focus of policy is successful, however at the cost of speed and exponential growth. The indicators can be tracked with the help of figure 2.(B).

Years	Installed Capacity	Cumulative Capacity	Primary Policy Type	FIT rate	Tax Credit	Annual Subsidy Spendings	Cost-Effectiveness
Units	MW	MW	-	USD/kWh	%	Millions - USD	MW/USD millions
2015	7260	27870	ITC 30%	0	30	2200	3.3
2016	14625	42470	ITC 30%	0	30	4400	3.3
2017	10200	52670	ITC 30%	0	30	3100	3.3
2018	10600	63270	ITC 30%	0	30	3200	3.3
2019	13300	76570	ITC 30%	0	30	4000	3.3
2020	19200	95770	ITC 30%	0	30	5800	3.3
2021	23600	119370	ITC 30%	0	30	7100	3.3
2022	18200	137570	ITC 30%	0	30	5500	3.3
2023	32400	169970	ITC 30%	0	30	9700	3.3
2024	35300	205270	ITC 30%	0	30	10600	3.3
2025	32500	248000	ITC Phase-out	0	30	9800	3.3

(Figure 2.(B): The United States' Solar Adoption Indicators, 2015 - 2025)

3. China's Hybrid Approach: From Subsidies to Market Reforms

China entered the 2015-2025 decade as the fastest emerging solar market, well-equipped with state-led initiatives and strong policies. Unlike many countries, which were not very successful in scaling renewable resources, especially when it came to sustaining the usage and not compromising on overall economic growth, china combined rapid industrial growth with deliberate policy measures, which allowed the solar energy sector to expand its capacity at an unprecedented pace while also simultaneously maintaining a control over fiscal costs. It is notable that despite supporting the world's largest build-out of solar energy, the government fiscal burden remained modest, never rising beyond 0.05% Of the total gdp (observed in figure 3.(A)). This indicates that china was able to mobilise large-scale solar adoption in a fiscally sustainable manner, achieving unprecedented growth, without compromising its overall economic stability.

Year	GDP	Solar Subsidy	Fiscal Burden
Unit	USD Trillion	USD Billion	%
2015	11.06	2.5	0.023
2016	11.23	3.2	0.028
2017	12.14	4.1	0.034
2018	13.89	4.8	0.035
2019	14.28	5.2	0.036
2020	14.73	5.8	0.039
2021	17.73	6.2	0.035
2022	17.88	6.8	0.038
2023	17.8	7.2	0.040
2024	18.8	7.8	0.041
2025	19.23	6.5	0.034

(Figure 3.(A): China's Fiscal Burden Of Solar Support, 2015 - 2025)

In 2015, the country already stood out with solar installations of over 43 gigawatts (gw), supported by generous feed-in tariffs (fits). These fits ensured early success for china. However, by 2018, the system was showing strain. Expenditure on subsidies had increased to 4.8 Billion, as solar deployment scaled up while cost-effectiveness reduced to just 9.2 Mw per million usd. The fixed fit payments failed to reflect falling solar costs, causing subsidy outlays to increase faster than the gains from the solar capacity generated. It was clear that relying solely on fixed subsidies could not sustain the current pace of expansion in the solar energy sector. Rather than slowing down, china shifted gears. Competitive auctions were introduced, allowing market forces to set prices and pushing down the costs. This was a kind of policy mechanism where the government invited solar developers to bid for contracts, and only those offering the lowest cost per unit of electricity were supported. The auction set-up of this policy forced producers to compete, which helped bring down the costs, and the government is liable to then pay a lesser subsidy per mw of solar capacity, increasing the cost-effectiveness overall. Within a few years, the impact of this policy decision was seen. Solar installations surged, driven by lower subsidy rates which reduced government expenditure while still keeping the solar projects attractive to investors. The fiscal expenditure leveled off as a result of the downward pressure on the costs, due to the forced competition and cost-effectiveness was on the track of growth.

By 2023, merely 5 years after the system was considered unsustainable and inefficient, china was adding approximately 216 gw of solar power in a single year, with every million dollars of

Support translating into 30 mw of solar capacity, almost thrice the amount it was in the late 2010s. Yet, despite these

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gains, producers still faced uncertainty from the fluctuations in market prices of electricity, threatening long-term investment confidence as well. To address this concern, the final step came with the adoption of contracts for difference (cfds) in 2025. This policy was a mechanism which gave investors predictable revenues without requiring heavy government payouts. This was ensured by a contract where the government guarantees the producers a fixed 'strike price' for electricity they generate. If the prevailing market price falls below this 'strike price', the government will pay the producer the difference, protecting them from losses, and similarly, if the market price rises above the 'strike price', the producers will pay back the difference to the government, preventing excess profits at public expense. By this point, china was installing around 255 gw of solar power annually, with cost-effectiveness peaking at 39 mw per million usd, the fiscal burden still hovering around a modest 0.03% - 0.05% Of the total gdp. This outcome marked the culmination of a decade-long policy evolution, which proved that china's shift from fixed subsidies to competitive auctions and finally to contracts for difference created a model that combined sustainable, rapid growth with an efficient use of public funds.

Years	Installed Capacity	Cumulative Capacity	Primary Policy Type	FIT rate	Tax Credit	Annual Subsidy Spendings	Cost-Effectiveness
Units	MW	MW	-	USD/kWh	%	Million - USD	MW/ USD million
2015	43000	43190	FIT + Subsidies	0.13	5	2500	17.2
2016	34500	77420	FIT + Subsidies	0.12	8	3200	10.8
2017	52830	130250	FIT + Subsidies	0.1	10	4100	12.9
2018	44000	174630	FIT + Subsidies	0.087	12	4800	9.2
2019	30100	204730	Auctions + FIT	0.065	10	5200	5.8
2020	48200	252950	Market Reform	0.062	8	5800	8.3
2021	54900	307850	Market Reform	0.06	6	6200	8.9
2022	87410	395260	Market Reform	0.058	5	6800	12.8
2023	216880	612140	Market Reform	0.055	3	7200	30.1
2024	277170	889310	Market Reform	0.052	2	7800	35.5
2025	255000	1080000	CfD Mechanism	0.05	1	6500	39.2

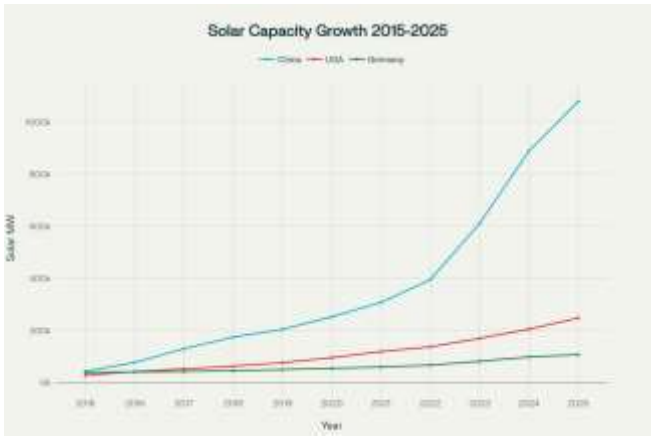
(Figure 3.(B): China's Solar Adoption Indicators, 2015 - 2025)

4. Comparative Insights: Contrasting Policy Models and Outcomes

The experiences of germany, the united states and china between 2015 and 2025 reveal how different policy pathways shape the solar energy sector. As discussed, germany, the once pioneer of solar adoption through its generous fits, became an example of how a subsidy-focused policy can become unsustainable by raising the fiscal burden on the country without being compensated with increased solar capacity, hence not contributing to the growth of the economy. The united states, in contrast, relied exclusively on a tax-incentive based policy through itc. This approach ensured less budgetary pressures, creating a stable environment for investors, however the trade-off was the scale of the sector. China, meanwhile, demonstrated the strength of a hybrid model which integrates subsidies and tax-incentives as a strategy. It began with subsidies to promote early adoption and get the market at a good pace, and further quickly restructured into support from competitive actions and lastly, in cfds. The evolution of policies along with market movement enabled scale and efficiency, with minimal fiscal burden.

Installed Capacity and Market Scale:

Figure 4 makes the contrast in market scale clear. China's solar capacity curve rises exponentially, surpassing 1000 gw by 2025, showing how its policy measure was successful in acquiring the most solar capacity. The u.S. Achieved steady but limited growth, which can be seen as its solar capacity curve is gradually increasing, with the cumulative solar capacity installed reaching around 248 gw. Germany, despite its early headstart, has a slight slope, with the least increase in solar capacity since 2015, peaking at around 107 gw by 2025. This result illustrates that while subsidies may ignite adoption and help develop at a fast pace, and tax-incentives help maintain a stable market in the long-run, the hybrid model which integrates both these policy measures proves to achieve the highest growth in solar capacity across the decade.



(Figure 4: Solar Capacity Growth In China, The United States And Germany, 2015 - 2025)

Fiscal Burden and Solar Support:

Figure 5.(B) highlights the financial efficiency of each model. Germany consistently spent around 0.25% Of their gdp on subsidies, an amount far greater than the u.S. Or china, who were both able to stay below 0.05%. This meant that germany was bearing the heaviest fiscal load yet gained the least in terms of solar capacity. In contrast, china achieved far greater installations at only a fraction of the cost of germany. This suggests that a subsidy-focused policy causes the most burden to the budget, harming fiscal health

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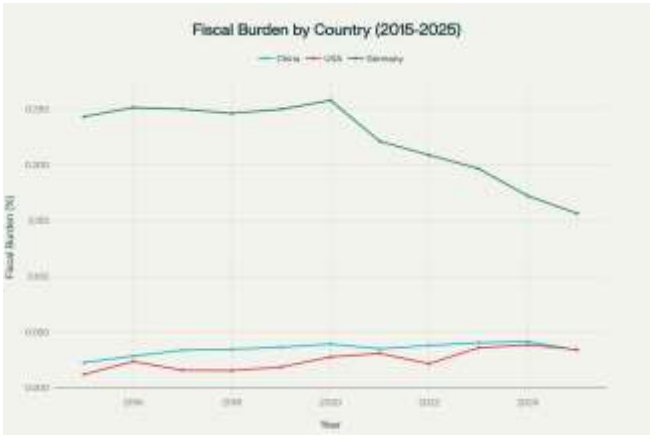
of a country the most. This is mainly due to the amount of money the government becomes liable to pay due to the fit policy adopted here. Compared to this, an exclusively tax-benefit focus, while is good for the fiscal burden as it reduces the liability on the government and budget, it does not accelerate growth as much. China's initiative on combining the policies helped reduce fiscal burden, as the amount paid as solar subsidies to producers was controlled and combined with other incentives, ensuring the pressure on the budget is managed in a sustainable manner. This policy method proved to be the best in terms of fiscal health and long-term stability of the market. Figure 5.(A) highlights the fiscal burdens of the three countries, in a comparative method.



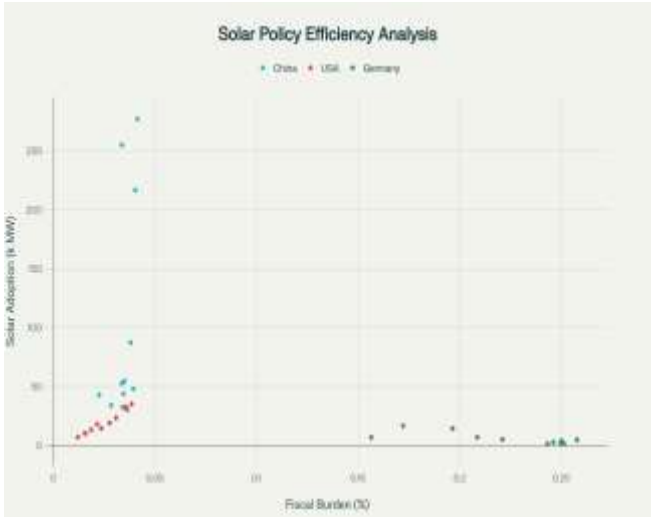
(Figure 5.(A): fiscal burden trends of solar support in china, the united states and germany, 2015 - 2025)

Years	China	USA	Germany
2015	0.02%	0.01%	0.24%
2016	0.03%	0.02%	0.25%
2017	0.03%	0.02%	0.25%
2018	0.03%	0.02%	0.25%
2019	0.04%	0.02%	0.25%
2020	0.04%	0.03%	0.26%
2021	0.03%	0.03%	0.22%
2022	0.04%	0.02%	0.21%
2023	0.04%	0.04%	0.20%
2024	0.04%	0.04%	0.17%
2025	0.03%	0.03%	0.16%

(Figure 5.(B): Comparative Fiscal Burden Of Solar Support (In % Of Gdp), 2015 - 2025)

Cost-Effectiveness and Efficiency of Spending:

The clearest measure of profitability comes from figure 6, a scatter-plot of solar policy efficiency analysis. Here, the cost-effectiveness is mapped against the fiscal burden, to understand the best balance between efficiency and affordability. The most efficient quadrant on the graph would be the upper-left, where there is low-fiscal burden and high cost-effectiveness, and the least efficient would be the lower-right quadrant where high fiscal burden is accompanied by low cost-effectiveness. As is apparent from the figure, china falls in the most-efficient quadrant, with high levels of cost-effectiveness, most mw of solar power purchased per million dollars, and low levels of fiscal burdens, the government expenditure on solar energy sector, is a meagre percentage of the gdp. The united states clusters fall on the lower-left quadrant of the graph, where fiscal burden is low, but so is cost-effectiveness. This shows that while the policy is fiscally light, it is not the most productive per dollar of expenditure. Germany, lies on the lower-right quadrant, where low cost-effectiveness is accompanied by high fiscal burden. The policy here puts a lot of pressure on the budget, is high in government expenditure and has the least amount of mw of solar power purchased per million dollars.



(Figure 6: Solar Policy Efficiency Analysis - Adoption Vs. Fiscal Burden, 2015 - 2025)

On comparing the three countries and their respective policies across the key indicators, a clear conclusion is arrived at. Germany's subsidy-heavy approach offered early success but became fiscally unsustainable and inefficient in the long-run. The united states' tax-heavy approach provided fiscal stability and political durability but lacked incentives for cost reductions and scaling, making it sustainable but limited in its expansion. China's hybrid model was the most profitable in terms of installations and cost-effectiveness while maintaining a moderate-to-low fiscal burden, proving to be both scalable and sustainable in the long-run. Thus, as evidence shows, the hybrid path of policies is the most

effective and is a resilient strategy for achieving large-scale and efficient solar adoption.

V. CONCLUSIONS

China achieved the highest rate of solar adoption through a hybrid mix of fiscal policies, subsidies, auction and contracts for differences, all the while maintaining a low burden on the budget. Germany saw a rapid growth at the beginning of the decade but its subsidy heavy policy resulted in a growth lagging behind with a high burden on the budget and sacrificing fiscal welfare. The united states maintained fiscal stability but saw only modest growth through tax credits at a constant rate of 30%. From the given evidence we can recommend a hybrid approach of subsidies and market based instruments for solar expansion, sustainability and efficiency.

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