Enabling policy for solar PV: the gap in the urban global south

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Abstract: This paper critically reviews the state of solar photovoltaic (PV) energy in the urban global south, and highlights the lack of both deployment and policy research in this important segment. The importance and complexity of solar PV uptake and suitable solar PV policy in the urban global south are discussed through the lens of the selected case study: Delhi. This case study includes an analysis of relevant solar PV policy and demonstrates barriers facing existing business models, and the problem of knowledge transfer. The study ends with a look at the prospects for novel business models. Results of the case study analysis highlight the need for an enabling policy environment and innovative business models to increase accessibility and facilitate deployment of solar PV to residential customers. This paper contributes to the under-researched field of urban solar policy in the global south and offers insights into the theory and practice of solar energy business models.

Keywords: solar photovoltaic; PV; solar policy; urban; global south; solar business models; Delhi, India; uneven development; urban-rural divide; north-south divide; barriers to solar PV; lack of urban solar research.

Reference to this paper should be made as follows: Muller, M. and Harnmeijer, J. (2018) 'Enabling policy for solar PV: the gap in the urban global south', *Int. J. Technology Intelligence and Planning*, Vol. 12, No. 1, pp.49–76.

Biographical notes: Michael Muller is a City Economist and post-graduate from the University of Edinburgh. He has experience and a strong interest in the field of urban sustainability, urban energy policy and ecological economics.

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1 Introduction

1.1 Aim and significance of the study

This paper critically investigates the role of urban solar photovoltaic (PV) energy in the global south and aims to establish and discuss the lack of research of urban solar policy. The global south is commonly described along geographical boundaries referring to the south as being the developing and the north being the developed part of the world, with Australia and New Zealand being the only two exceptions (Dirlik, 2007). By analysing both, the north-south and urban-rural divides, this study offers a new lens through which to examine the uneven development of solar PV. While north-south knowledge transfer of new solar policies is common, in this paper it is argued that urban solar energy policies in the global south require distinct contextual consideration.

This paper also establishes that the relative dearth of solar policy research and deployment of solar PV in the urban global south represents an important short-coming from both energy access and climate change mitigation perspectives, and that an enabling policy climate is critical for solar PV deployment. The case of Delhi is examined to point the way towards further – urgently needed – work.

1.2 Solar PV energy

Solar PV refers to the conversion of sunlight into electricity and potentially enables urban areas to move beyond being centres for energy consumption towards generation, distribution and local consumption (Adil and Ko, 2016). The technology is widely regarded as critical in abating CO_2 emissions and anthropogenic climate change. Increasing deployment rates of solar PV will not only reduce the emissions of GHG, but also the emission of other pollutants, such as particulates and noxious gases (Edenhofer et al., 2011). In addition, solar PV has enormous potential to effectively increase access to reliable energy in urban settings and enable an inclusive and sustainable energy production system (Westphal et al., 2017). By broadening energy access, improving the availability of dispatchable power, and providing low-carbon and low-cost energy, both off-grid and grid-connected solar PV are considered to be especially suitable for the urban global south (Engelmeier et al., 2013; Westphal et al., 2017).

1.3 Deployment and policy

Although global solar PV deployment has experienced strong growth, and the potential market in urban areas is deemed to be considerable (IRENA, 2016a), patterns of deployment have been highly unequal. In particular, both deployment and solar PV research have been highly concentrated in the 'developed' North relative to the 'global south', where in turn they have been concentrated in rural areas (IEA, 2009; Kumar Sahu, 2015; Norman et al., 2016). Solar PV policy research, in particular, seldom focuses on the urban global south, even though the policy context has been identified as a key factor for enabling (or inhibiting) the deployment of solar energy (Cox et al., 2015). A wide variety of solar policies such as feed-in-tariff (FIT), renewable portfolio standard (RPS), tax incentives, quotas, or trading systems have been designed and implemented around the world. However, this study highlights the necessity for a fit-for-purpose and enabling policy climate that reflect the distinct local requirements as a necessary condition for solar PV deployment. Such an enabling climate provides the space required for business models to operate and evolve (Bergek et al., 2008; FORA, 2010; UN Global Compact, 2012). Business models have been identified as highly important in making solar PV more financially and physically accessible to residential users, particularly in urban settings and will therefore play a key role in this study.

In this study, Delhi, India is used as a case study to demonstrate the complexity and challenge of residential solar PV uptake in the urban global south. With a dedicated commitment to increase deployment and production of solar PV, Delhi has recognised the importance of renewable solar energy and has consequently announced and implemented the 'Delhi Solar Policy 2016' and set ambitious solar generation targets of 1GW by 2020 (GNCTD, 2016). This case study not only offers a critical analysis of Delhi's solar policy, but also highlights barriers specific to the urban Indian context. Furthermore, by analysing the role of different solar business models and their impact on residential solar PV deployment, this study not only aims to contribute valuable knowledge to the under-researched field of urban solar policies, but also offers new insights into critical factors such as ownership, financing and contract enforcement issues related to solar PV deployment.

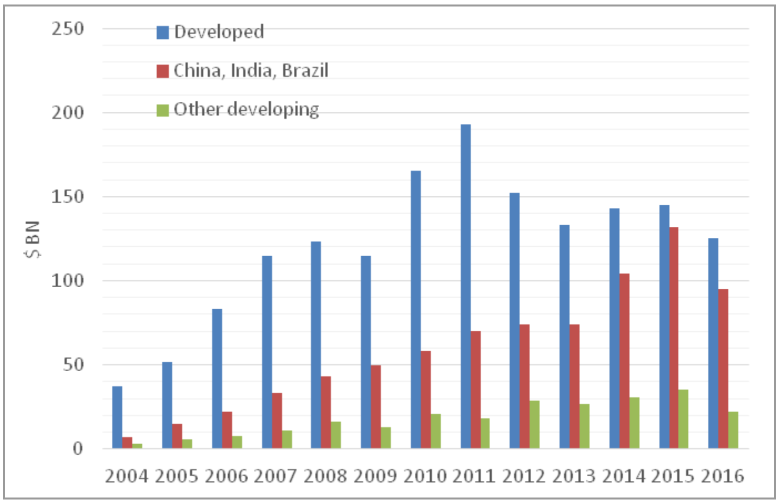
This paper begins with critically investigating the north-south and the urban-rural divide, before the gap in urban solar policy research in the global south is established. This section is followed by the case study: Delhi, which commences with an analysis of the city's solar PV potential and the city's current solar energy policy. Subsequently, barriers to residential solar PV deployment and the role of solar energy business models in Delhi are discussed, before problems of knowledge transfers are examined. The study ends with an outlook for new business models through an enabling policy climate.

2 The geography of solar PV

2.1 The north-south divide

Even though solar energy deployment has experienced strong growth around the world (IRENA, 2016a), there is a strong tendency that several factors have led to an unequal development between the global south and the 'developed' north (Kumar Sahu, 2015). While the literature covers a wide range of factors and theories aiming to explain this divide, following a political geography approach has been widely identified as highly important in understanding this geographic differentiation (Baker and Sovacool, 2017). Concepts integral to technological capabilities, such as technology and knowledge transfers to developing countries or related knowledge spillovers (Bell and Pavitt, 1993) are necessary to comprehend these structural inequalities. Global investment patterns in solar energy are widely considered to provide valuable insights into knowledge transfer and global solar PV deployment patterns (Baker and Sovacool, 2017). Figure 1 demonstrates global investments in renewable energy in different regions of the world.

Figure 1 Investment in renewable energy – different regions of the world (see online version for colours)

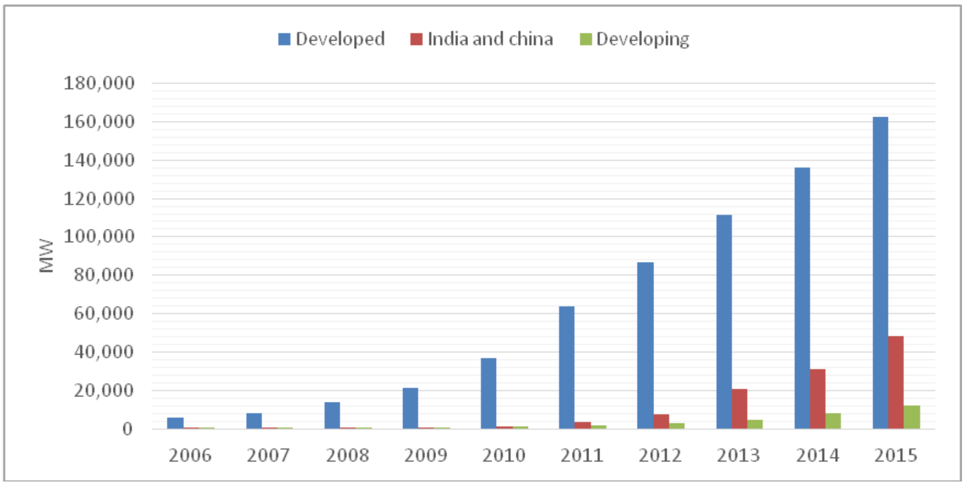


Source: McCrone et al. (2017)

Investment in renewable energy has been considerably larger in the developed world between 2004 and 2014 in comparison to China, India, Brazil, or other developing nations (Figure 1). This is in accordance with solar PV deployment rates, as developed countries show significantly higher deployment rates throughout the same period (Figure 2). As developed countries experienced strong investments earlier in the development of solar PV, these countries acquired expertise and decisive knowledge, gaining a leading role in the industry (Fu and Zhang, 2017). More recent investments in China, India and Brazil, and in other developing countries to a much lesser extent, point to environmental leapfrogging and related knowledge transfer (Iizuka, 2015). By increasingly investing in and adapting a relatively mature technology, these countries are in a position to integrate external knowledge and leapfrog to a more sustainable mode of energy production.

China and India have become global leaders in the solar industry. While investment has been particularly high in these countries in the last years (see Figure 1) and can be considered a key factor, Fu and Zhang (2017) argue, that adopting a strategy of mixing and sequencing different technology transfers and indigenous innovation mechanisms have played a decisive role. These authors analysed the role of knowledge transfer and argue that patent licensing, joint ventures and acquisitions, and in-house R&D have been particularly critical for India's success. Incentives encouraging innovation and supportive policy climate also played important roles (ibid).

Figure 2 Global solar PV deployment rates (see online version for colours)



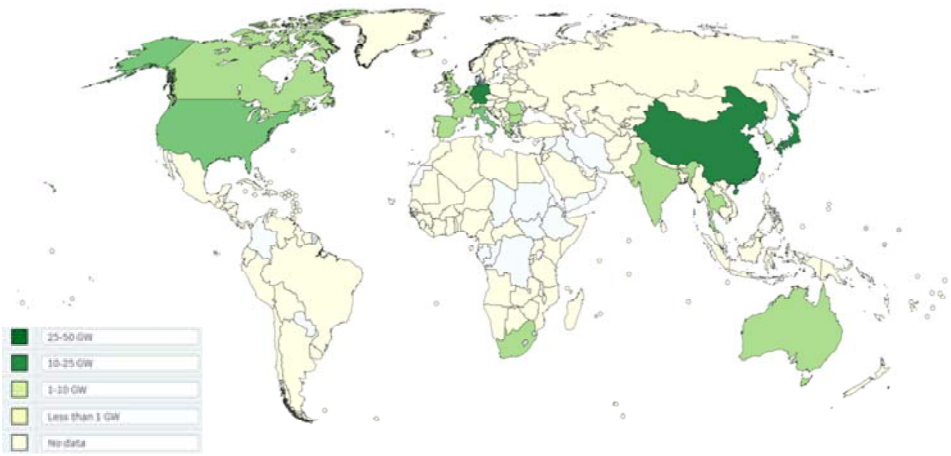
Source: IRENA (2016b)

However, overall solar PV deployment in the global south remains comparatively low (Figure 3) and the assumption that developing countries could readily integrate technologies and expertise through exposure to external knowledge, investment flows and trade proved overly optimistic (Perkins, 2003; Fu and Zhang, 2017; Westphal et al., 2017). The acquisition of new technologies also requires the (local) presence of appropriate human resources, supply chain synergies and a suitably stimulating and supportive institutional climate (Perkins, 2003). Schmidt and Huenteler (2016) argued that, despite considerable renewable energy deployment and technological diffusion in the global south, it remains an open question whether these countries will be able to successfully expand deployment. In sum, the pre-existing policy-and technological landscape in developing countries crucially affect prospects for the integration of external knowledge (see Baker and Sovacool, 2017 for a review).

2.2 The urban-rural divide

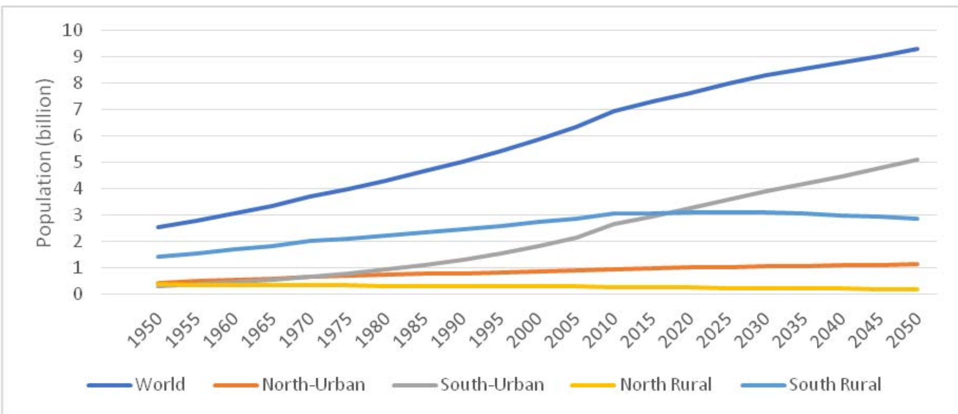
Interestingly, the patterns of solar deployment (Figure 3) are also in line with general global energy consumption and GHG emissions (UN-Habitat, 2011). According to Sethi (2015), the most visible distinction in energy consumption and related emissions can be observed along the lines of the global north and the global south. On a per-capita ratio, the Climate Debt proposal quantifies the emission divide between these regions as 10:1 (United Nations, 2009). However, in addition to this north-south divide, stark asymmetry also exists between urban and rural settings within and across countries (Sethi and Puppim de Oliveira, 2015). This has led to new understandings of the distribution of global emissions and energy consumption indicating that these levels are dependent on local circumstances within countries (ibid). According to Sethi (2015), this urban-rural disparity pattern is reflected in most parts of the world as urban areas generally have higher energy consumption rates and emissions above their national average. As the global south is confronted with the double challenge of rapid urbanisation (Figure 4) and strongly differing energy consumption rates between urban and rural environments, a disaggregated analysis of urban and rural footprints has become increasingly important (Sethi and Puppim de Oliveira, 2015). According to the International Energy Agency (2008), 89% of the CO_2 emissions growth in cities between 2006 and 2030 are expected to be caused by cities of the global south. This illustrates the importance of distinguishing between urban and rural areas when considering patterns of emission and energy consumption.

Figure 3 Global solar PV deployment (see online version for colours)



Source: IRENA (2016b)

Figure 4 Global demographic patterns (see online version for colours)



Source: UNDESA (2012)

2.3 The urban-rural divide and solar PV policy research

The urban-rural divide is also highly important in the context of solar PV and has to be taken into consideration for successful policy formulation and application (Li and Yi, 2014). A wide variety of solar policies and supportive tools such as FIT, bidding/tendering schemes, RPS, tax incentives, or net metering have been implemented around the world (Table 1) (Solangi et al., 2011; Del Río and Mir-Artigues, 2012).

Table 1 Global solar policies

Policy	*Description*	*Sources*
Feed-in-tariffs (FIT)	Generation-based-incentive: long-term contracts are offered to solar PV producers by utilities that are required to purchase the energy produced. A tariff that has been established by public authorities and that is guaranteed to be paid for a fixed period to the solar PV producer	Couture et al. (2010) and Ren 21 (2014)
Net-metering	Enables a two-way flow of electricity wherein the produced solar energy can be used for self-consumption, while a potential surplus of the energy generated can be fed into the grid. The customer is then billed for the net electricity consumed.	Cox et al. (2015), Dusonchet and Telaretti (2015) and Kumar Sahu (2015)
Direct capital subsidies	Government payments that aim to reduce the cost of the initial investment; highly relevant for off-grid applications.	Dusonchet and Telaretti (2015)
Renewable portfolio standards (RPS)/renewable electricity standards (RESs)	A certain amount of electricity generated within a given area has to derive from eligible renewable resources. Targets are typically established to support solar deployment	Cox et al. (2015) and Dong et al. (2016)
Auctions/tendering processes	Governments or local authorities request bids for projects that produce electricity derived from solar PV under the guarantee that a utility or distribution company will purchase the electricity. Competitive bidding processes can potentially lead to lower project costs compared to FITs and are often most advantageous for larger-scale projects	Cox et al. (2015)
Interconnection standards	Specific conditions that must be met by power generating entities that want to connect to the utility grid. These standards are intended to provide well-defined guidelines to ensure grid reliability and are widely considered a prerequisite for the success of solar policies that support grid-connected solar PV.	Cox et al. (2015)
Investment tax credits (ITCs)	Aims to reduce the tax liability of solar project owners. ITCs depend on the capital investment in the project and aim to address the barrier of high initial investment	Cox et al. (2015) and Dong et al. (2016)
Production tax credits (PTCs)	The tax incentive received is dependent on the amount of electricity generated by the project. This support policy incentives optimal performance.	Cox et al. (2015) and Dong et al. (2016)

Table 1 Global solar policies (continued)

Policy	*Description*	*Sources*
Clean renewable energy bonds (CREBs)	Aim to support and stimulate renewable energy project financing. The Bondholders are solar energy project companies (this also includes local governments, municipal units, and other institutions), which receive tax credits that lower the effective interest rate.	Dong et al. (2016)
Energy saving bonds	Bonds can be used by solar PV project developer in order to facilitate project financing	Dong et al. (2016)
Accelerating depreciation policy	Aims to promote solar investment and accelerate investment cost recovery	Dong et al. (2016)
Tradeable green certificates (TGCs)	Cap and trade system that aims to stimulate investment in renewable energy. The system requires a certain quota of electricity consumed/produced from renewable energy sources. Based on energy generation (MWh), certificates are allocated to energy producers that can then be traded on a market. TGCs aim to increase overall renewable energy deployment by using market structures to allocate certificates and quotas to energy producers who can most efficiently produce electricity from renewable energy sources.	Darmani et al. (2016)

FIT has been commonly used as a policy tool around the world, with 98 countries both in the Global North and the global south (by 2014) having implemented the solar policy (Ren 21, 2014; Ismail et al., 2015). Quotas/RPS in combination with TGCs, capital subsidies, and tax incentives are also widely considered to be relevant and regularly implemented to support solar PV deployment (Del Río and Mir-Artigues, 2012). In addition, while bidding/tendering have been identified as very beneficial with large-scale solar energy projects, net-metering has been found to be particularly important to residential consumers (Cox et al., 2015).

However, the success of support schemes not only depends on the policy chosen, but also on intra-instrument design elements (ibid). Specific contexts and environments contain distinct requirements, which need specific design elements (ibid). In particular, local institutions have been identified as highly important in understanding these characteristics (UN Global Compact, 2012); Li and Yi (2014) argue that municipal and local governments play a critical role for the deployment of solar PV. Authors demonstrate that cities of the USA with local policies and specific financial incentives realise 69% more solar PV deployment than urban areas without such policies. These findings are in line with Mendonca et al. (2010), who found out that municipal FIT policies have a significant impact on urban installed solar PV generation capacity. White et al. (2013) also support these outcomes as authors have shown that implementing specific urban solar policies to New Zealand cities could stimulate solar PV growth and provide a stable environment for future investors. Despite the importance of urban solar policies, much emphasis in the Global North is placed on national level solar policies (Sarzynski et al., 2012; Shrimali and Jenner, 2013).

In the context of the global south, solar PV research also focuses primarily on policies at the national level, whilst a wide range of literature is available on stand-alone and off-grid systems in rural areas.(Pepermans et al., 2005; Srivastava and Rehman, 2006; Kanagawa and Nakata, 2008; Mandelli et al., 2016). Solar PV research in urban settings, however, lacks sufficient attention.

2.4 The gap in urban solar policy research in the global south

To highlight this gap of urban solar policy research in the global south, we conducted a quantitative assessment of the literature. The technique of co-occurrence of keywords has been chosen as the analytical tool to reveal publication patterns in the field of solar policy research in the global south. This method refers to the common presence and occurrence of keywords across multiple entries or publications (Romo-Fernández et al., 2013). In our study, the technique has been applied to identify co-occurrence across peer-reviewed article publications. The databases used for this assessment are Web of Science and Elsevier, which are widely considered as particularly comprehensive bibliographic databases (ibid). Both databases allow the option of 'advanced searches' to search for the co-occurrence of keywords. The keywords chosen for this analysis are: 'solar PV' and 'urban' and 'developing countries'; and: 'solar PV' and 'rural' and 'developing countries'. Two separate assessments for publications covering solar PV research in rural and urban settings in the global south (represented by 'developing countries') have been conducted. The outcomes of this analysis can be found in Table 2.

Table 2 Results co-occurrence of keywords: urban-rural solar energy research in the global south

Database	*# of publications of solar PV research in the global south*	
	Urban	*Rural*
Elsevier	201	291
Web of Science	20	133

The results of the co-occurrence of keywords analysis (Table 2) reveal that, solar energy research in the global south has been highly skewed towards the rural context Improved understanding of the urban-rural divide in the global south is thus especially important, as not only energy consumption and greenhouse gas emission rates differ strongly along this division, but also does the availability of research. However, while rural electrification has become central to the objective of improving global electricity access (Mandelli et al., 2016), solar PV has also enormous potential to effectively increase access to reliable energy in urban settings and enable an inclusive and sustainable energy production system (Westphal et al., 2017). Additionally, urban areas do not contain some of that constraints experienced by rural populations. Having generally higher rates of electrification and access to a central grid, urban environments in the global south have a better scope for exporting surplus power to distribution networks (UN Global Compact, 2012). Furthermore, some key barriers facing rural off-grid solar PV in the global south, such as proximity to supply chains (maintenance and repairs) or financial services (access to financial capital) do not apply as strongly to urban settings (Koh et al., 2014; Harnmeijer et al., 2015; Mazza et al., 2017).

It appears that a disaggregated analysis of urban characteristics is needed to successfully formulate and implement urban solar policies. The next section will outline the solar policy of Delhi, India as a case study, before barriers to solar PV deployment are discussed.

3 Solar energy policy and its implementation in the urban global south: the case of Delhi

3.1 Methodology

In this section, the potential importance of suitable solar PV policy as well as the current policy context for the urban global south is discussed through the lens of a case study. Explorative case study research in combination with document analysis was chosen as the appropriate method as it allows the analysis of complex issues through comprehensive contextual analysis (Zaidah, 2007). This method aims to explain multi-faceted situations and provides pathways for further analysis around particular observations. The approach often includes analysing specific geographical areas (ibid). In the context of solar energy research, cities have regularly been chosen as the geographical context (e.g., Colenbrander et al., 2015; Wu et al., 2016; Lau et al., 2017; Qureshi et al., 2017) making the method highly appropriate here. The method enables the researcher "… to go beyond the quantitative statistical results and understand the behavioural conditions…" [Zaidah, (2007), p.301] in a specific environment which is highly important for the context of solar PV uptake. However, although case studies provide in-depth and comprehensive knowledge of the case examined, the method might be criticised for its inability to generalise results (Zaidah, 2007). According to Tellis (1997), a generalising conclusion can hardly be reached by a single case exploration. Nonetheless, the method's ability to rigorously analyse an interlinked phenomenon, especially one that entails barriers and challenges at different levels makes it appropriate for the task at hand.

Delhi was selected as it represents one of a few cities in the global south where solar energy policy is implemented. Because of its rapid urbanisation, increasing energy demand and related GHG emissions, as well as its urgent need for reliable and accessible energy (Engelmeier et al., 2013), and its enormous potential for solar PV deployment (Figure 6), Delhi is well suited for an analysis contributing to the under-researched field of solar PV in the urban global south. A separate section discusses barriers facing existing business models, and the problem of knowledge transfer. The case study section ends with a look at the prospects for novel business models in Delhi.

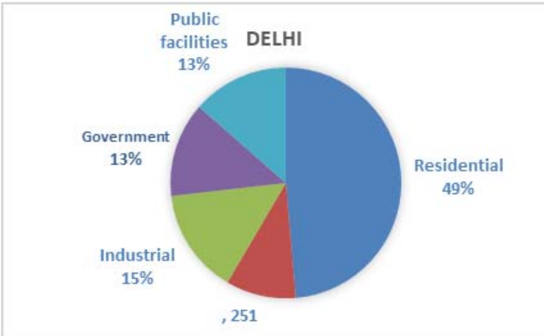
3.2 Solar PV potential in Delhi

Delhi is considered well positioned to lead India's urban rooftop solar strategy and has consequently established solar energy production targets of 1GW by 2020 and 2 GW by 2025 (Engelmeier et al., 2013).

According to the Government of National Capital Territory of Delhi (GNCTD, 2016), renewable energy investments have been declared as highly necessary to combat climate change, improve air quality, and strengthen energy security. Given its land-locked position, its low potential for wind or hydro energy, and its low space availability for ground-mounted solar PV, rooftop solar PV has been identified as Delhi's most important source of renewable energy (ibid).

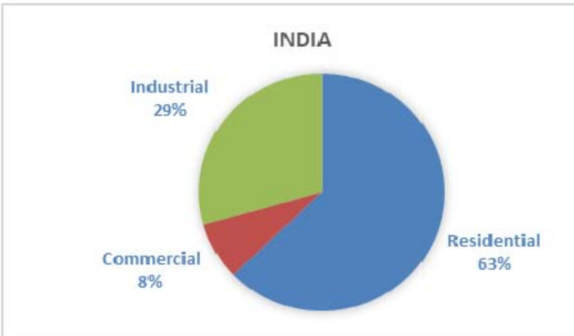
Delhi is facing a structural power deficit as existing power plants cannot meet local energy demand forcing power companies into long-term power purchase agreements (PPA) with power generators in other states. This makes the city's power supply highly dependent on other states' grid infrastructure and management, and incurs extra charges because of longer transmission (Engelmeier et al., 2013). In addition, market conditions have become more favourable as solar energy tariffs have decreased 7% per year on average since 1998 while conventional energy tariffs in Delhi have been rising around 7% per year on average since 2007 (GNCTD, 2016). These developments have led to grid parity in the commercial and industrial sector.

Figure 5 Rooftop solar PV power generation potential in Delhi for different sectors (2013) (see online version for colours)



Source: Engelmeier et al. (2013)

Figure 6 Rooftop solar PV potential by space availability for residential, commercial and industrial buildings in India (see online version for colours)



Source: SRPC (2016)

According to Engelmeier et al. (2013), another key factor that makes Delhi suitable for solar energy generation is its high levels of solar irradiation of 5 kWh/m^2. The report 'rooftop revolution: unleashing Delhi's solar potential' (Engelmeier et al., 2013) demonstrates the strong potential of Delhi estimating the total potential rooftop solar PV capacity to be around 2.6 GW. It has been estimated that the residential sector could contribute 1,243 MW (49%) to this overall potential (see Figure 5). However, residential deployment rates of rooftop solar PV in Delhi is very low, generating only 3 MW in 2016

(Bridge to India, 2016). This is in line with results obtained for the whole of India. In 2016, the residential sector only contributed 260 MW to the total installed capacity of 1,020 MW in India, despite estimated potential of 64 GW (Figure 6). Therefore, this unexploited potential points to the need for policies and models that make solar energy more accessible to residential users.

Table 3 India central solar energy policies

Incentives	*Description*	*Relevance for residential solar PV deployment*
Tax benefits	Indirect: excise duty exemptions and custom duty exceptions (reduced by 2.5%–5% dependent on the solar project)	Low relevance. No direct benefits.
	Direct: exemption from income tax on earnings derived from selling solar power produced (in first ten years of operation)	Low relevance. No direct benefits.
Feed-in-tariffs (FiT)	FiT are determined tariffs in a cost-plus manner and have been introduced at the central level in 2010; It entails long contracts (20–25 years), priority purchase, and priority access to the grid	High relevance. Residential customers directly benefit.
Accelerated depreciation (AD)	Solar projects can be depreciated by 80% in the first year for commercial and industrial entities	Low relevance. No direct benefits.
Renewable energy certificates (RECs)	RECs have been implemented as market-based instruments in 2011 in order to deal with the mismatch between availability and requirement of the obligated entities to meet their state-level renewable purchase obligation (RPO).	Low relevance. No direct benefits.
Renewable Purchase obligation (RPO)	DISCOMS (utilities) are required to purchase a minimum percentage of energy from renewable energy sources.	Low relevance. No direct benefits.
Net metering	29 states (incl. Delhi) and 7 union territories have implemented grid connectivity regulations with provision for net or gross metering.	High relevance. Residential customers directly benefit
Viability gap funding	Government support for infrastructure projects including solar projects through capital grants or other incentives to make them commercially viable. A maximum of 20% can be funded to ensure financial viability.	Low relevance. No direct benefits.
Additional benefits	Lower wheeling or transmission charges for solar energy projects.	High relevance. Residential customers directly benefit.
Capital subsidies	30% capital subsidy; The subsidy is available to residential, government, social and institutional segments.	High relevance. Residential customers directly benefit.

Source: Shrimali et al. (2013), Rohankar et al. (2016) and Bridge to India (2017)

3.3 Solar PV Policy in Delhi

Indian national policies relevant to solar PV in Delhi are summarised in Table 3. Above and beyond these central government policies, the Government of the National Capital Territory (NCT) has introduced an ambitious set of policies and targets called the Delhi Solar Energy Policy 2016 ('DSEP') (GNCTD, 2016). This urban solar PV policy package has ten broad objectives, including reducing Delhi's reliance on conventional energy while promoting the growth of rooftop solar PV through an extensive set of generation targets, regulations, and incentives (Table 4).

Table 4 Objectives of the Delhi solar energy policy, 2016

Objective	*Description*
Reduce reliance on conventional energy	By promoting rapid growth of rooftop solar power via a combination of generation targets, regulations, mandates and incentives, energy security and independence shall be increased.
Raise awareness to drive demand and adoption	Market-based approaches and public-private partnerships shall be encouraged to drive demand and adoption and initiatives developed to raise public awareness
Fairness for all stakeholders	Fairness for all stakeholders in the solar ecosystem must be ensured, including roof top owners, DISCOMS (utilities), investors, consumers of non-solar power, technology and services providers
Regulatory mechanisms to drive demand and adoption	Among other, mandating solar system deployments on government rooftops, requiring in-state solar RPO targets for DISCOMS, modifying building bylaws to facilitate solar plant deployment, specifying and more should drive demand and adoption
Promoting net metering/group metering/ virtual net metering	By simplifying and streamlining processes and methods and by establishing necessary legislation metering shall be encouraged.
Generate employment	Employment in the solar energy sector must be created through skill development especially for youth.
Generation-based incentives	Generation-based incentives for the domestic segment as well as tax exemptions and waivers for all consumers shall be provided
Promote a robust investment climate	Preferable investment structures that enables multiple financial models, including CAPEX and third-party owned (RESCO) models shall be promoted
Periodic review	A framework for policy implementation, monitoring and compliance framework shall be established to ensure efficient execution and periodic review
Power to all citizens	Solar energy is considered as part of an overall strategy of providing affordable, reliable, 24X7 electricity to all citizens, incorporating demand side management, energy conservation, energy efficiency initiatives, quality assurance and longevity of projects, distributed renewable energy generation, and smart grid development

Source: Adopted from GNCTD (2016)

Delhi's solar PV policy includes specific wide-ranging incentives to promote grid connected rooftop systems for multiple stakeholders in the solar ecosystem, as well as mandatory deployment of solar systems with net metering on all government and public buildings, and encouraging such installations on commercial and industrial buildings. However, regulations and incentives targeting the household solar sector are analysed in more detail in this case study.

The key promotional measure established though the DSEP is a generation-based-incentive (GBI) of INR 2.00 per unit (kWh) of gross solar energy generated which is being offered for three years for existing and future net metered connections in the residential segment. Thereby, the policy also aims to promote and establish net metering, virtual net metering (VNM) and gross metering, and grid connectivity for all solar plants. As the residential sector contains strong potential for future solar PV deployment (Figure 7) and as grid parity has not been reached yet for domestic users, the GNCTD aims to foster residential solar PV adoption through the implementation of these measures (GNCTD, 2016). Other critical incentives include the exemption of Electricity Tax (currently 5%) for solar energy units generated for both, self-consumption or being fed into the grid, the exemption of conversion charges requirement of the house tax, and the establishment of a framework for the exemption on wheeling, banking and transmission charges for solar power generated or consumed within the city. And last, by establishing legislation and promoting preferable investment structures that enable multiple solar business models, including CAPEX and third-party owned (RESCO) models (see Table 4), the policy aims to make solar energy more advantageous to residential users (GNCTD, 2016). Characteristics of different solar models have been identified as highly important to overcome several barriers and make solar energy more accessible to a wider range of customers. Therefore, it is necessary to understand the distinct barriers experienced in Delhi and the role of different business models and its interplay with enabling policies in overcoming these barriers.

3.4 Barriers to residential solar PV deployment in Delhi

Table 5 provides an overview of general barriers to solar energy relevant to the global south context (see also Rohankar et al., 2016).

Table 5 Overview-barriers to solar PV deployment

Dimension	*Barriers*	*Sources*
Institutional/ regulatory	• Complicated policy environment: frequent changes of solar incentives • Bureaucratic red tape 1 Procedural problems such as the need to work with several public-sector agencies 2 Complicated application procedures to receive state incentives and procedures for interconnection, metering and billing • Lack of capabilities for an adequate skilled workforce	Radulovic (2005), World Bank (2010), IDFC (2011), Martin and Rice (2012), Timilsina et al. (2012), Altenburg and Engelmeier (2013), CEEW and NRDC (2014), Kapoor et al. (2014) and Goel (2016)

Table 5 Overview-barriers to solar PV deployment (continued)

Dimension	*Barriers*	*Sources*
Institutional/ regulatory	• Lack of adequate financing mechanism provided by national or local institutions • Complex planning and zoning • Policy uncertainty of GBIs, quotas and fossil fuels • Enforceability of renewable energy quotas • Poor financial condition of distribution companies • Capacity restrictions to single developers • Weak contract enforcement	Radulovic (2005), World Bank (2010), IDFC (2011), Martin and Rice (2012), Timilsina et al. (2012), Altenburg and Engelmeier (2013), CEEW and NRDC (2014), Kapoor et al. (2014) and Goel (2016)
Economic	• Economically unattractive compared to fossil fuels • High initial investment cost • Low bankability (for ease in financing) • Lack of access to cheap and long-term domestic debt • Weak industry networks	IDFC (2011), Timilsina et al. (2012), Altenburg and Engelmeier (2013), CEEW and NRDC (2014) and SRPC (2016)
Social	• Lack of awareness of technology and incentives • Affordability of low-income households • 'Free-riding' – perception of unfairness by imposing the capital intensive and high cost burden on the majority portion of society that does not have access to derive direct benefits of such programs • Renters lack ownership of property (roof) • Share of population lacks access to the grid	Rüther and Zilles (2011), Kapoor et al. (2014), Alstone et al. (2015) and Goel (2016)
Environmental	• Supply limitations of raw materials such as silicon or cadmium and tellurium	Woditsch and Koch (2002), European Photovoltaic Industry Association (2011) and Timilsina et al. (2012)
Technical	• Low conversion efficiencies of PV modules • Performance limitations of PV system components such as batteries or inverters • Quality solar radiation data • Grid-interconnectivity • Infrastructure constraint: rural or remote areas lack connection to the grid • Absence of a structured disposal/recycling process for batteries	IDFC (2011), Martin and Rice (2012) and Bridge to India (2017)

As outlined in Table 5, several obstacles have been identified as highly relevant factors that can potentially impact and hinder deployment rates of solar systems in the global south. For the specific context of Delhi, however, the grid interconnectivity of solar energy, the poor financial condition of distribution companies, the lack of adequate financing mechanism provided by national or local institutions, weak contract enforcement, and the policy uncertainty of GBIs, quotas and fossil fuels, have all been identified as critical factors (Engelmeier et al., 2013; Goel, 2016; Bridge to India, 2017).

Remarkably, even though a highly supportive solar climate could be established in Delhi, including GBIs, net metering and VNM policies, and preferable investment and financing structures that aim to overcome the discussed barriers (GNCTD, 2016; Fu and Zhang, 2017), residential solar PV deployment rates are still comparatively low (Greenpeace, 2017). Although there is strong willingness to install solar PV in the domestic segment, barriers to residential users are considered as more obstructive than in other market segments (Engelmeier et al., 2013). The report 'Indian Cities slacking on rooftop solar' (Greenpeace, 2017) assessed the performance of Delhi and other major cities against their solar PV deployment targets and concluded that Delhi is far away from meeting its rooftop solar goals and that it is particularly lacking sufficient growth rates in the residential sector. Among other, the main reasons for the poor performances of the city includes the perception that high initial capital investment is required making rooftop solar PV only accessible to high income households, lack of ownership of the roof, insufficient information and knowledge of financial incentives, or fear of bureaucratic red tape. This outcome is also supported by the 'India Solar Handbook 2017' (Bridge to India, 2017) report which outlines reduced growth rates and shortcomings of solar PV deployment targets. Goel (2016) also highlighted that high initial investment represents the key barrier to residential customers. This has led to rising perceptions of 'free-riding' – of significant cost burdens on a vast majority of the population that does not enjoy direct benefits from solar energy programs (Rüther and Zilles, 2011).

Consequently, the high initial cost in combination with the requirement of ownership of property have been identified as key factors that are holding back solar PV deployment in Delhi (Meier, 2014; Feldman et al., 2015). According to Meier (2014), under these conditions, business models can play a key role in increasing or limiting accessibility of solar PV to residential customers. Consequently, it is not only policy that is needed to enable and promote solar PV deployment, but it is also business models that can be decisive in making solar PV more favourable. Therefore, barriers inherent to business models existing in Delhi will be discussed in the next section.

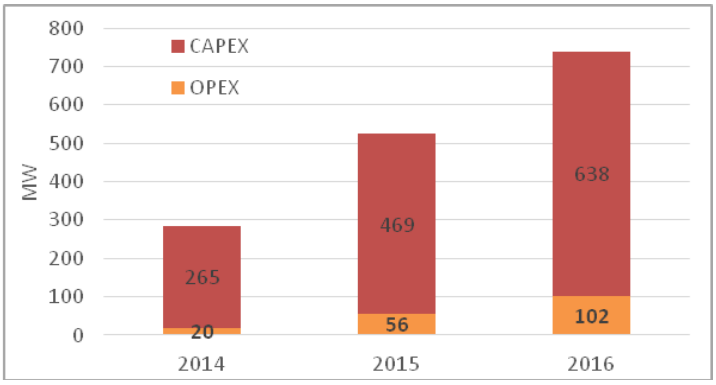
3.5 Barriers to solar PV business models in Delhi

Currently the most prevalent business model for solar PV installations in Delhi is the capital expenditure (CAPEX) model (Engelmeier et al., 2013). This model also represents the dominating business model India, accounting for nearly 87% of total installed capacity (Bridge to India, 2017). The CAPEX model requires the purchase of the PV system by the rooftop owner implying full ownership of both, the solar system including exclusive rights to the PV system and the electricity generated (SRPC, 2016). The operational expenditure (OPEX) model, where upfront costs are recovered alongside ongoing payments for energy services, represents the second major solar model in Delhi as well as in India, accounting for around 13% of the total installed capacity of rooftop solar PV in India (ibid).

In Delhi, examples of businesses making use of the OPEX model include renewable service companies (RESCOs) such as electric utilities, cooperatives and private sector companies which retain ownership and responsibility for the installation, maintenance and servicing of systems (Urmee and Anisuzzaman, 2006). Electricity is sold to rooftop owners and other users at a tariff below the general retail rate but at a price that enables the RESCO to make profit (SRPC, 2016). This model typically requires the service provider and consumer to agree on a power purchase agreement (PPA). The term for PPAs is typically between 15–25 years (Engelmeier et al., 2013).

While OPEX schemes are still relatively uncommon in Delhi and India more generally, this class of business model has achieved considerable growth over the last years with the installed capacity having increased from 20MW in 2014 to 102 MW in 2016 (Figure 7).

Figure 7 Rooftop solar market capacity for OPEX and CAPEX business models in India, MW (see online version for colours)



Source: Bridge to India (2017)

According to Feldman et al. (2015), the traditional onsite CAPEX model requires the owner to have unshaded roof space, the independent decision-making authority regarding that roof space, and a strong financial position. In urban settings such as Delhi, a large share of the population lacks ownership of the roof because of rented accommodations (Engelmeier et al., 2013). In addition, a potential customer might lack the required financial abilities or might not have access to low-cost financing.

The OPEX model is widely considered to be very effective for overcoming some of these barriers (Urmee and Harries, 2012; SRPC, 2016). Third-party or utility ownership removes the need for high initial investment, and as technical risks remain with the RESCO and bureaucracy being managed, this model is widely considered as more financially accessible and more suitable for a wider range of consumers (Urmee and Harries, 2012; Goel, 2016).

However, several factors have been identified that hinder and limit successful and large-scale implementations of the OPEX system in Delhi. According to the Solar Rooftop Policy Coalition (SRPC, 2016), key barriers for potential residential solar PV consumers include that RESCOs usually require PPAs of typically 15 years or more, which are regarded as too long by many users. As with onsite OPEX systems, PPAs of 15 years bind customers to the location of the installed systems, thereby hindering users to move accommodations. Additionally, other key barriers include factors such as lack of awareness and knowledge of the technology (Goel, 2016). By contrast, the key obstacle from the perspective of third party developers is high contract default risks (Goel, 2016; SRPC, 2016). These findings are in line with the outcomes of the 'India Solar CEO Survey 2017' showing poor contract enforcement as the most important challenge for growth of the OPEX model using PPAs (Bridge to India, 2017). Additionally, another key concern of third-party investors and distribution companies includes grid integration of growing renewable capacity because of poor financial conditions of DISCOMs (utilities) and grid quality (ibid). Grid quality and large-scale integration of distributed or multiple centralised solar PV systems represent key factors, as bi-directional and reactive power flows may lead to voltage fluctuations throughout the grid causing grid instability (Pepermans et al., 2005). Plus, because of variability of rooftop solar, caused by changing weather conditions, the amount of energy generated by rooftop solar PV systems can vary significantly which requires grid operators to maintain additional energy generation capacities (SRPC, 2016).

Despite those barriers and concerns, consistent with experience in other cities, the OPEX model is expected to play a critical role in the residential rooftop solar PV sector in Delhi (Engelmeier et al., 2013; SRPC, 2016). The OPEX approach has proven to be successful in the Global North, playing now an important in role in many cities and countries (Drury et al., 2012; Meier, 2014). However, as discussed in Section 2, knowledge can only be transferred with caution and might not be directly transferable to the global south.

3.6 Limitations to knowledge transfer in the case of Delhi

According to Meier (2014), solar PV deployment in developing and developed countries alike is dependent on the availability of innovative business models and policies that are adapted to the distinctive regional characteristics. While there has been a strong increase in publications discussing the need for new business models, the majority of this literature relates to the global north (FORA, 2010; Bisgaard et al., 2012; Beltramello et al., 2013). Although the acquired knowledge offers valuable insights for emerging regions, knowledge cannot simply be transferred to the global south, as it must be adapted to its existent and specific socio-economic context. The problem of knowledge transfer is also addressed in the publication of the UN Global Compact (2012): 'policy measures to Support Inclusive and green business models'. This publication highlights that the distinct regulatory, cultural, and socioeconomic situation in a region needs to be well comprehended and reflected in business models.

Several new models including OPEX, leasing, PPA schemes, or solar mortgage, have recently been developed in OECD countries and cities (Meier, 2014). In many areas, these models proved to be attractive to a large range of residential consumers having achieved strong growth rates of solar PV deployment under third-party ownership (TPO) and utility-owned systems (Drury et al., 2012). Some upcoming models not only succeeded in providing market access to low-income households (ibid), but also improve returns to end-users (Navigant Consulting, 2015). As the current solar policy climate in Delhi is widely considered as comparable to cities that adapted these new models, experiences gained in the Global North are generally expected as suitable for the urban Indian context (Fu and Zhang, 2017; Goel, 2016; SRPC, 2016). However, critical barriers continue to prevent such models from taking off in Delhi and elsewhere in India (SRPC, 2016).

PPAs of 15 to 25 years require strong contract enforcement institutions and trust (SRPC, 2016). In the case of India, not only does a large share of the population lack these required strong credit scores, but contract enforcement has also been identified as the most serious concern for third party investors (Bridge to India, 2017). India has been ranked 186 out of 189 countries on contract enforcement in the World Bank ease of doing business ranking highlighting the high risk of disputes between two parties in PPA contracts of 15 years or more. In addition, PPAs of 15–25 years are often regarded as too long by potential customers, as it requires customers to stay at the same location for the duration of the contract. Furthermore, if rooftop solar PV prices continue to fall at predicted 7% per year (Engelmeier et al., 2013), TPO solar customer could enter into a new contract in years' time facing financially favourable conditions, which provides a strong incentive to default (SRPC, 2016).

A key factor that distinguishes many rapidly urbanising areas in the global south from those in industrialised countries is grid quality, and interconnectivity with decentralised renewables (India Brand Equity Foundation, 2015). While grid connection challenges pose problems in many developing countries (see e.g., Hudson and Heilscher, 2012 for the case of California), the challenges are significantly greater in cities such as Delhi (Goel, 2016). By way of example, Delhi's grid can only utilise up to 15% of the peak load from distributed solar PV without becoming destabilised, setting a hard deployment cap (Altenburg and Engelmeier, 2013).

The case of Delhi also illustrates how off-grid solar PV business models could play a role in expanding urban solar PV deployment and energy access (Alstone et al., 2015). One reason for this is that off-grid solar PV can circumvent the need for prohibitively high grid connection charges amongst low-income end-users (Golumbeanu and Barnes, 2013).

There also exist major north-south differences in public awareness. While solar PV markets are increasingly well established in many developing countries, allowing strong and fast response to new policies, potential solar PV stakeholders in Delhi often lack awareness of solar PV technology and policy (Goel, 2016). According to Goel (2016), consumer guidance centres and easily accessible information regarding the process for metering and interconnection with the grid is needed.

In summary, and in line with earlier discussion in Section 2, policy lessons can only be transferred with caution and might not be applicable in the global south.

3.7 Scope for innovative business models through enabling policy in Delhi

Hybrid models adopting the merits whilst avoiding the pitfalls of CAPEX and OPEX approaches are worth considering. Multi-offtaker micro-and mini grids, district – or community energy schemes, peer-to-peer energy trading platforms and other fledgling models contain advantageous features that could contribute to business models that allow access to a wider range of customers (UNEP, 2015; Urban Sustainability Directors Network, 2015). Because grid quality and reliability remain key challenges, off-, micro- and mini grid models might be readily adaptable to the urban Indian context.

Off-grid solar PV business models, such as 'pay as you go' (PAYG) schemes have been proven to be highly successful in the global south (Orlandi et al., 2016). Several distributed energy service companies (DESCOs) have started to implement PAYG systems including specific payment rules, and ownership and financing structures (ibid). These systems commonly allow customers to pay for the solar systems through affordable instalments and enable technology-embedded mechanism to disable the system if payments are overdue. DESCOs usually offer solar PV systems in combination with batteries and control units, phone chargers or other devices. Typically, an initial payment followed by regular payments between \$0.3–\$2, depending on the system size, is required, for the customer to obtain the system. Payments can typically be made through mobile banking or alternative practises including scratch cards, phone credit, or direct cash payments. Ownership structures can vary between lease-to-own or perpetual lease models (Meier, 2014). The latter model includes continuous service payments and ownership remains with the DESCO. While this model has proved to be particularly successful for rural areas, it also contains strong potential for urban settings. Onsite distributed energy systems can strengthen local energy independence and network security (Alanne and Saari, 2006; Alstone et al., 2015). By situating energy conversion units closer to energy consumers, households can potentially have access to more reliable energy supply due to reduced transmission and distribution losses, and have increased control at the local level (Alanne and Saari, 2006). This can be highly important in the context of Delhi, where electricity supply faces strong reliability problems experiencing frequent outages with voltages dropping near to zero (Engelmeier et al., 2013).

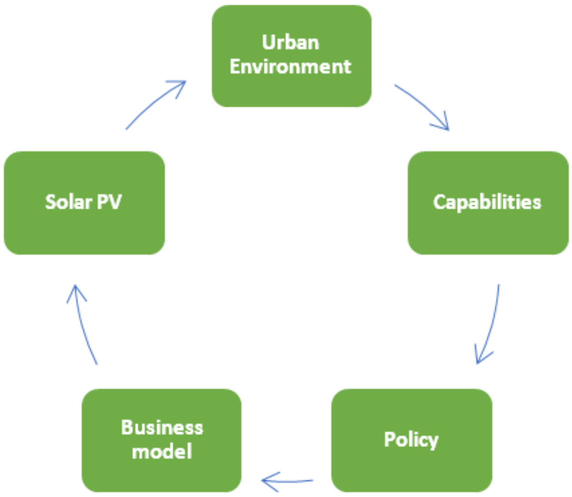
As outlined in Section 4, Delhi is facing a structural power deficit and load shedding becomes increasingly common for electricity consumers connected to the grid. While diesel generators are commonly used for backup, rising diesel costs and frequent fuel shortages have led to increased electricity costs and an increased usage of an environmentally harmful source of energy (Usman et al., 2017). The case study of Gham Power, Nepal provides valuable insights into how existing structures of diesel grids can be used and substituted by solar PV technology. Gham power installed 334 kW of micro-grid connected PV systems for 438 clients connecting urban households, small businesses, and organisations, such as hospitals and schools. Energy customers are offered lease-to-own models with durations of ten years. While Gham power is responsible for identifying projects, developing the system and obtaining permits, their business model requires an additional holding company as the legal owner of the solar PV systems. This holding company receives funds from local and international investors and is responsible for financing the project (Meier, 2014). In the case of this business model, Nepal's Clean Energy Development Bank (CEDB) has provided funding for 70% of the project costs, while 30% remained with the holding company using the physical infrastructure as collateral. The lease costs are then paid to the holding company which is paying one-time fees for project development plus recurrent fees for operation and maintenance to Gham Power. This business model not only provided a wide-range of customers with reliable renewable energy in an urban setting, but it also enabled Gham power as well as the holding company to generate sufficient revenues (Meier, 2014). This model has the advantage of flexible lease-to-own contracts and circumventing the dependence on grid quality and distribution companies.

Lastly, new business models that enable innovative interplays between customers, utilities and third-party developers might also contain strong potential to overcome several barriers. SRPC (2016) suggested that in the case of PPAs between third-parties and private solar energy consumers, utilities can play a critical role. Utilities can act as 'off-taker of the last resort' [SRPC, (2016), p.42] and buy solar energy in case the consumer defaults on the PPA contract. Thereby, the utility and the third party agree on a pre-determined discounted rate that is lower than the solar energy price the utility would normally pay. This discounted rate compensates the utility for high uncertainty of solar energy supply. The third-party on the other hand, would accept lower prices as it would highly benefit from such an agreement by substantially mitigating and decreasing contract default risk (ibid).

4 Outlook

The proposed structure in this study for enabling successful solar PV deployment in the urban global south is summarised in Figure 8. The figure highlights the need for the consideration of the distinct context of urban environments, including technological capabilities and existing knowledge. These characteristics must then be integrated into solar policies that effectively support innovative business models. Business models play a key role in increasing accessibility of solar PV to residential customers and eventually enable successful solar PV deployment, which in turn impacts the urban environment.

Figure 8 Enabling solar PV in the urban global south (see online version for colours)



5 Conclusions

This study aimed to contribute to the under-research field of urban solar policies in the global south; provide important insights into the theory and practise of solar energy business models; and point the way towards further research in the field of urban solar energy that is urgently needed.

The importance and relatively low uptake of urban solar PV in the global south were discussed, as was the lack of existing policy research. It was argued that a more holistic approach, taking account of features specific to the urban global south context, is required to craft policy that enables the uptake of solar PV business models.

The case of the urban-rural divide in India was used to highlight our findings, and a critical examination of solar PV policy in Delhi was used to illustrate the extent to which existing urban policies provide a conducive (or inhibitive) landscape for different solar PV business models.

In the selected case of Delhi, supportive solar policies such as GBIs, net metering and VNM go some way to creating an enabling environment for CAPEX and OPEX business models. However, we find that several factors continue to hinder residential solar PV deployment from taking off in Delhi. For CAPEX models, barriers such as high initial investment, property ownership requirements and high bureaucratic effort continue to present barriers to uptake, and limit access to a minority of urban consumers. OPEX business have achieved a greater degree of accessibility, by removing the need for high initial investment, and shifting technical risks and transaction costs to specialist third parties. However, several limitations could be identified that are distinct to the Indian context. These include contract default risk, lack of public awareness of the technology and financial incentives, and interconnectivity of decentralised renewable energy with the centralised grid.

We suggest that policies catered more specifically to the urban Indian context might provide an enabling environment for business models that lie in between the CAPEX and OPEX end-members, mainly by making solar PV more accessible to domestic households. Incorporating facets of policy friendly towards off-grid and micro-grid business models, such as PAYG (e.g., Gham Power), might boost uptake by fostering new relationships between customers, utilities and third-party developers. Forthcoming policy appropriate to the global south context might borrow certain facets of successful policy from the rural domain, whilst also catering for challenges associated with the urban context. For instance, such policy could be crafted to leave ample space for innovation in business models and technologies that integrate provision of energy services with information communications technology (ICT), whilst also taking account of the relative lack of home ownership found in rapidly urbanising areas across the global south.

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