



A solar city strategy applied to six municipalities: integrating market, finance, and policy factors for infrastructure-scale photovoltaic development in Amsterdam, London, Munich, New York, Seoul, and Tokyo

John Byrne,^{1,2} Job Taminiau,^{2*} Kyung Nam Kim,^{3*} Jeongseok Seo² and Joohee Lee²

Policy support platforms like the Feed-in Tariff and the Renewable Portfolio Standard have been very successful in accelerating renewable energy development around the world. Nonetheless, the sustained and consistent transition to a renewable energy future required, e.g., to avoid further climate change, continues to elude societies. To achieve substantial energy transformation, reconsideration of the finance–policy–market interaction is required and is contemplated here by positioning the build-out of a particular renewable energy technology, photovoltaic (PV) energy, as a commitment to infrastructure-scale development. A so-called ‘solar city’ strategy is analyzed in which large-scale deployment of PV throughout the urban fabric essentially constructs an urban renewable energy power plant by utilizing the vast rooftop real estate available in all cities. The article explores a capital market strategy for practical implementation of urban PV in six case study cities—Amsterdam, London, Munich, New York City, Seoul, and Tokyo. This study demonstrates the substantial potential of the solar city concept in each location and outlines a financing strategy to realize the potential. © 2015 John Wiley & Sons, Ltd

How to cite this article:

WIREs Energy Environ 2015. doi: 10.1002/wene.182

INTRODUCTION

The global photovoltaic (PV) market continues to experience significant global growth with over

150 gigawatts (GW) PV capacity installed in the last 4 years, more than the cumulative installation volume in the previous four decades (Ref 1, p. 7). Projections of share of PV installations have been revised upward significantly—from 11% by 2050 to 16%—motivated by the observed rapid decrease in system prices, the lower cost of capital, and PV’s market maturation (Ref 1, p. 18). Global installed capacity is likely to more than double over the next 5 years—in fact, PV is being installed faster than any other renewable energy technology option globally.² Similarly, PV is the fastest growing source of new electricity supply in the United States, accounting for 31% of all U.S. electric power installations in 2013.³

*Correspondence to: jtam@udel.edu, i005034@korea.ac.kr

¹Foundation for Renewable Energy and Environment (FREE), New York, NY, USA

²Center for Energy and Environmental Policy, University of Delaware, Newark, DE, USA

³Green School, Korea University, Seoul, Korea

Conflict of interest: The authors have declared no conflicts of interest for this article.

However, the pathway to a sustainable energy future is still long: modern energy economies remain reliant on fossil fuel energy sources and nonmodern energy economies are too often crippled by high rates of energy poverty as about 1.3 billion people live without affordable and accessible electricity.^{4,5} Projections of energy development, furthermore, envision substantial extra demand for energy resources moving forward, thus complicating the challenge of a sustainable energy future. A fundamental transformation of the energy system will require the positioning of policy, finance, and markets in dramatically different configurations, compared to conventional uses of these tools already in place.⁶ It would appear that significant action and new thinking are needed to deliver a sustainable energy future.

A useful way to consider the integration of policy, finance, and markets to support the roll-out of a sustainable energy future is to revisit the build-out of the current electric power system. The construction of the modern energy economy relied on a public commitment of support similar to the commitment to public infrastructure such as roads, railways, and so on: political, financial, and market support centered around a guiding principle that access to electricity was to be treated a public necessity, that electricity was to be cheap and abundant to all, and that large-scale infrastructure deployment was a suitable pathway to deliver these promises.⁷ Regulatory support, rate-of-return guarantees on infrastructure investment, and tax credits—these are just some of the many policy tools employed to deliver the current massive carbon economy.

However, due to its modular nature and easy scalability, end-use solar energy installations continue to receive characterizations aligned with ‘distributed’ and ‘decentralized’ energy systems. Indeed, the viability of PV as a distributed or decentralized source of electricity supply can be counted as one of its key advantages.^{8–11} However, the energy investment community has evolved in a system based on the precepts of centralization and often is ill equipped to understand and weigh the value of distributed generation.⁷ This has resulted in end-use solar energy installations being treated as ‘add-on’ options rather than integral components of public infrastructure. The question then becomes: how can policy, finance, and markets be positioned in such a way to support infrastructure-level deployment of PV?

This question guides this paper as *Policy Platforms Affecting Solar Finance* section considers the operation of the two key policy platforms currently in use around the world: Renewable Portfolio Standards (RPS) and Feed-in Tariffs (FITs). In particular,

this section evaluates the capacity of these policy platforms to support infrastructure-level, i.e., GW-scale, deployment of PV. The two considerations that are of particular interest in this section are: (1) the focus of both policy platforms on PV projects and (2) their focus on costs and permitting for individual system owners’ cost profiles. *PV at the Infrastructure Scale: the Solar City Concept and Promise* section broadens the perspective from the conventional PV policy–market–finance platform often limited to single projects and sites. It introduces a different scale via the concept and promise of the ‘Solar City’ previously discussed in Ref 12. City-wide deployment of PV on rooftops^a would effectively transform the urban fabric into a distributed PV power plant sized for infrastructure scale financing and policy-enabled to set infrastructure scale targets. Six case study cities are evaluated in order to illustrate the Solar Cities perspective: Amsterdam, London, Munich, New York City, Seoul, and Tokyo. These cities are selected because of their established reputations as sustainability leaders (discussed below).

Finally, the paper discusses a methodological approach to realize the Solar City promise by highlighting policy and financing strategies, focusing in particular on infrastructure bond finance (*Exploring Investment in the Solar City Concept* section). *Exploring a Solar City Application in the Case Studies* section concludes the paper with thoughts on how the infrastructure platform might be further defined.

POLICY PLATFORMS AFFECTING SOLAR FINANCE

Policy platforms have been the subject of extensive investigation to assess their capability to advance renewable energy. The two most commonly deployed policy platforms, FITs and RPS,² have been found to effectively support renewable energy deployment in several countries.^{13–15}

A popular academic endeavor has been to assess which policy platform better supports the roll-out of renewable energy and these generally find that FIT outperforms RPS, e.g., Refs 16,17. However, both platforms possess essential policy virtues that support renewable energy development rendering investigations about which is the better platform a less relevant exercise than perhaps an effort to synthesize these policy virtues into platforms tailored to their context.¹⁸

RPS and FIT both seek to enable project development by addressing financial and transactional challenges that inhibit the procurement of clean distributed generation in conventional energy markets. Hurdles addressed by both platforms include: high

transaction costs, insufficient market liquidity, and a lack of access to low-interest capital.^{18,19} In particular, in relation to the overall question of infrastructure-scale development, the RPS and FIT essentially fulfill similar roles: they set enabling economic conditions for project development to occur, either by directly offering remuneration in the form of an electricity tariff to ‘fill the gap’ or by a utility obligation to acquire renewables according to a long-term schedule.^b Supported by mechanisms such as net metering and favorable interconnection policies and financed by vehicles such as power purchase agreements, a project-to-project development pathway emerges, which makes distributed generation dependent on project economics.²⁰

While attention to supply chain requirements and creditworthy investment support (sometimes aided by utility sector involvement) can improve private finance project by project, especially when articulated along a ‘loud, long, and legal’ framework,²¹ this development pathway is inescapably incremental, promising smoother and quicker market entry. But it is unable to assure sizable market development and is poorly positioned to pool projects into large investments. This realization is especially significant in light of the globally relevant finance shortcomings to reach stated targets and ambitions. For instance, despite rising private investment,²² the European Union (EU) faces an emerging funding gap on the order of €500 billion for energy supply and transmission alone²³ in part due to perceptions of insufficient levels of return on investment in renewables and problematic risk profiles associated with the new technologies.²⁴ Other analysts similarly forecast a significant investment deficit without a transformation in finance market perspective on renewables.^{25–27} Multitrillion dollar capital shortages are projected worldwide unless the finance model is changed.^{28–30} In the case of RPS, budget constraints experienced by states and local governments in the United States (Ref 31, p. 14) have led to a leveling of targets; and burgeoning costs associated with FIT payments have dimmed the EU outlook.^{c,32,33} Current low oil and natural gas prices might further spell difficulty for renewable energy investment.

In line with Newell’s conclusion relating to energy governance in the context of energy poverty and climate change,³⁵ it appears that current policy structures are geared toward governance *for* energy finance rather than a focus on governance *of* energy finance. Focusing on setting the enabling conditions for project finance to occur, both policy platforms are unable to govern energy finance itself directly. We offer a different suggestion on the role and behavior of the investment community: one which conceives

renewable energy as an infrastructure for social progress, considers the architecture of not only policy development but institutional change to enable infrastructure-level investment, and designs new governance models to implement a transition to renewables-based social development. One practical expression of this approach is ‘solar cities’ which we have revised to mean the use of city governance vehicles to catalyze public sector-led, infrastructure-scale design and investment of a solar city. Mobilizing, for example, a key energy asset of cities—notably, their rooftop ‘real estate’ which can account for a substantial portion of the developed area of cities—can create an infrastructure-scale investment market, public governance of relationship between society and renewable energy, and readily change a city’s energy profile.^d The use of sovereign commitments can complete the strategy by dramatically lowering the cost and risk of solar city investment.^{e,12,37–39}

The strategy agrees with Wüstenhagen and Menichetti who offer this perspective on the issue: ‘while mobilizing private investment is obviously not trivial, the true challenge policy makers are facing is not primarily about ‘paying a green premium’, but one of influencing strategic choices of those investors who will deploy capital anyway, and are selecting between opportunities in conventional and renewable energy projects’ (Ref 24, p. 3). Governments and public authorities can significantly influence the underlying infrastructure investments that make energy investments possible (Ref 40, p. 261). The fact of their influence opens up the possibility to leverage these institutional actors and the assets they govern to expand opportunities for large renewable energy investment. Combining control of infrastructure with the role of sovereign pledges on creditworthiness, solar cities can attract private capital for investments in renewables that considerably enhances acceptance of the major innovations needed to realize a genuinely low-carbon social development pathway. The next sections explore such a pathway, trying to address conceptual challenges while exploring practical steps available to local governments to realize solar city status.

PV AT THE INFRASTRUCTURE SCALE: THE SOLAR CITY CONCEPT AND PROMISE

Restructuring the urban energy infrastructure has been identified as a key element in strategies to address climate and sustainability challenges.^{41–45} Additionally, due to the vacuum left by unproductive international negotiations on climate change, energy-focused climate

change policy is being revised from top-down architectures toward ‘polycentric’ structures of action (J. Taminiau, unpublished data).^{46–48} Cities have both shaped and been a target for much of this activity.^{49,50} For instance, local level governments are responsible for 75% of expenditures relating to environmental protection and cities have relatively large margins of authority to advance transport, housing, and environmental protection in a green direction.⁵¹

Recently, three of this paper’s authors proposed a focus on cities, capitalizing on an underutilized asset in large urban centers—namely, an abundance of rooftop real estate which collects but does not productively utilize solar energy.¹² The calculation of the potential for such a strategy found favorable outcomes for the City of Seoul: the technical potential of urban deployment of PV at the city-wide level was estimated at over 11 GW, a volume sufficient to generate over 14 terawatt-hour (TWh) and cover 66% of Seoul’s daylight hours energy demand (Ref 12, p. 841). Indeed, many investigations have consistently highlighted the substantial potential for PV in the urban fabric, e.g., Refs 52–55.

The ‘solar city’ promise and potential can be calculated for cities using the step-by-step methodology introduced by Ref 12. For this paper, it is applied to estimate the electric power potential for Amsterdam, London, Munich, New York City, Seoul, and Tokyo. With the exception of Munich, these cities have taken up the role of a ‘global city’ through their membership of the C40 Network. Munich, meanwhile, actively participates in the European POLIS-solar project to identify and capitalize on existing resources within urban boundaries to advance solar energy implementation.⁵⁶ Additionally, each of these cities have either published

self-reported estimates of suitable rooftop area that is consistent with the method in Ref 12 or studies and databases in the extant literature allow for such calculation (Table 1).^f

As reported in Table 1, more than 300 million square meters of rooftop area are estimated to be available for PV installations by these six cities. Including spatial consideration, such as panel-to-panel shading and service, maintenance, and safety requirements, Table 2 reports the remaining space available when PV is deployed at various tilts. Importantly, even for relatively small cities, such as Amsterdam and Munich, several million square meters are available for rooftop PV installation.

Infrastructure-scale strategies capable of delivering on the solar city vision can expect significant impacts. Figure 1 indicates the technical potential for PV deployment in the six case study cities. Such a deployment would accrue benefits associated with decentralized and distributed energy architectures such as grid decongestion during peak demand periods, location flexibility to address ‘hot spots’, energy supply tailoring to customer load demand, and avoided costs for additional power and/or transmission.^{2,8,12} In brief, city-wide deployment of PV offers the potential of substantial energy independence, city leadership, and energy democratization.

One way to put the findings into perspective is to contrast these outcomes with national expectations for solar energy development. Based on the assumption that 30% of the solar city can be completed by 2020 with the right financing and policy strategy in place, Table 3 shows that a Solar City strategy in many cases exceeds the national installation of PV on a per capita basis. However, from Table 3 it also becomes clear that

TABLE 1 | Suitable Rooftop Area for PV Implementation Using Methodology from Ref 12

City	Pop. (millions)	Pop. Density (thousand/km ²) ¹	Total Rooftop Space Available	Suitable Space (million m ²) ¹	Suitable Rooftop Area (m ² /capita)	Source Data
Amsterdam	1.08	6.7	22.0	11.0	10.2	57
London	3.1	10.0	74.9	34.9	10.9	58
Munich	1.4	4.5	40.2	18.7	13.4	Munich Environment and Municipal Services (personal communication). ²
NYC	8.4	10.7	181.9	83.5	9.9	59 ³
Seoul	9.8	16.2	187.1	89.5	9.2	12
Tokyo	9.0	14.5	204.3	96.4	10.7	60
Total	32.8		710.4	334		

¹ The following city area inputs were used: Amsterdam (165 km²), London (321 km²), NYC (789 km²), Seoul (605 km²), and Tokyo (623 km²).

² Data cross-referencing with Refs 61 and 62 strengthens our confidence in the input data.

³ Cross-referencing of data with Ref 63 supports the numbers presented here.

TABLE 2 | Rooftop Area (million m²) after Accounting for Ground Coverage Ratio (GCR) and Service Area (SA)¹ at Different Tilt Angles Using Methodology from Ref 12

City	Tilt (degrees)						
	0	5	10	15	20	25	30
Amsterdam	8.8	6.9	5.8	5.2	4.9	4.7	4.6
London	27.9	21.9	18.5	16.5	15.4	14.9	14.7
Munich	15.0	11.8	9.9	8.9	8.3	8.0	7.9
NYC	66.8	52.5	44.3	39.6	36.9	35.6	35.3
Seoul	71.6	56.3	47.5	42.4	39.6	38.2	37.8
Tokyo	77.1	60.6	51.2	45.7	42.3	41.1	40.8
Total	267.2	210.0	177.2	158.3	147.4	142.5	141.1

¹ For additional information on the GCR, please see Ref 64. SA accounts for maintenance and safety requirements associated with on-roof installations such as described in the International Code for Fire Safety.^{65,66}

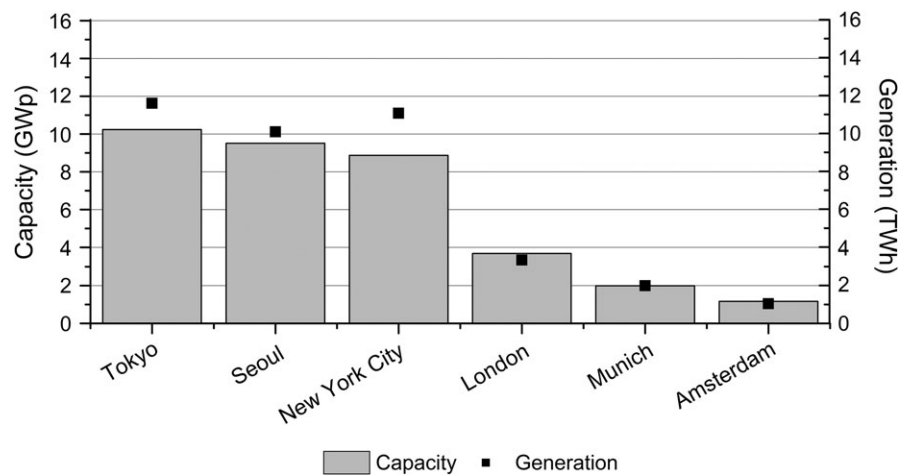


FIGURE 1 | Overview of electrical generation potential through the application of Solar City concepts. Notes: Available rooftop area derived from sources run through methodology provided by Ref 12. Assumptions: south-facing flat panels at 20% efficiency and 10 degree tilt. Solar resource data obtained from Ref 67 run through PV Planner software.⁶⁸

both Germany and Japan—two nations that have aggressively pursued solar energy—are expected to realize higher per capita numbers at the national level in part due to their already high installed PV capacity levels. Table 3 also reports a more limited application of the solar city strategy, focusing on commercial rooftops including those of public agencies, schools, and hospitals.

A solar city vision of energy development, aggregating and bundling the potential of many rooftops into infrastructure-scale applications, requires access to substantial amounts of capital and needs to be supported by a clear and consistent policy strategy. Importantly, many cities report a lack of funding or limited access to affordable capital as a key challenge in moving sustainable energy and climate change strategies forward, complicated further by competing priorities

for other areas of public administration.⁴⁹ For example, London has calculated that the ambitious target set by its mayor to reduce CO₂ emissions by 60% by 2025 will cost approximately GBP 40 billion whereas the existing climate change mitigation framework of London is projected to cost GBP 14 billion by 2025.⁷⁶ The 100 million GBP London Green Fund (LGF) is a first step at providing financial resources to mobilize green energy investment in the city and the fund seeks to attract additional funding.⁷⁷ Investment need is further illustrated by looking at realized costs of several urban green projects.⁷⁸ For instance, the capital costs of a solar center receiver station in Seville, Spain, is estimated at \$41 million,⁷⁸ which can dwarf the public budget for renewable energy of a city of this size. Other constraints to meaningful city planning are: (1) the significant decline in subnational

TABLE 3 | Comparison of Solar City Applications and National Projections for PV Market Development

City	Pop by 2020 (millions)		Solar City by 2020				Year 2020 National Comparison	
	City	National	30% of Commercial & Public buildings		30% of All Buildings		GWp	Wp/cap
			GWp	Wp/cap	GWp	Wp/cap		
Amsterdam	1.14	17.0	0.11	92	0.35	307	4.0	238
London	3.3	66.0	0.33	101	1.11	337	10.0	152
Munich	1.50	80.1	0.18	119	0.60	397	52.2	652
New York	8.33	333.8	0.8	96	2.66	319	45.0	135
Seoul	9.82	51.4	0.86	87	2.85	290	4.4	86
Tokyo	9.16	123.5	0.92	101	3.07	335	48.8	395
Total	33.25	671.8	3.2	99 (average)	10.64	331 (average)	164	276 (average)

Sources: National PV capacity projections taken from IEA's Medium Term Renewable Energy Market Report 2014.⁶⁹ PV capacity for the Netherlands was not included in the IEA report and is based here on a report by the Dutch Planning Agency for the Environment.⁷⁰ National population estimates from the World Bank's *Health Nutrition and Population Statistics*.⁷¹ City population for Amsterdam, Munich, and Seoul taken from the United Nations World Urbanization Prospects 2014.⁷² For New York, data are taken from Cornell University's Program on Applied Demographics⁷³ while Tokyo population numbers data are derived from the Tokyo Metropolitan Government (Ref 74, p. 25). London data are obtained from the UK Office of National Statistics on subnational population projections.⁷⁵

investment, (2) the lower credit rating of some local governments vis-à-vis the national government, and (3) sovereign borrowing constraints which limit the ability of cities to increase public investment.^{79,80}

EXPLORING INVESTMENT IN THE SOLAR CITY CONCEPT

Evaluating PV installation at the infrastructure level, in contrast to single rooftop projects, introduces several additional considerations. These include: significant upfront capital costs, long-term investment horizons, opaque project risks, irreversible and possibly illiquid investment, and the 'public good' nature of these investments.^{81,82} Traditional routes for infrastructure investment have typically relied on private capital and suggestions to close the energy and climate funding gap often look to private finance.^{83–85} Institutional investors represent over \$92 trillion in assets⁸⁶ and are seen by some as a major pool of untapped finance for green projects (e.g., Ref 85) in part due to their long-term asset allocation in light of expected climate change risks.^{87,88} However, current asset portfolios of investors such as pension funds and insurance companies remain only limitedly directed toward infrastructure despite large funding potentials and observed high levels of interest.^{84,89}

Increasingly, climate-sensitive energy strategies seek capital through bond markets. Pioneered by supranational organizations and agencies like the World Bank the fledgling market of 'green bonds' has rapidly expanded since its 2007 inception and 2014 performance was particularly boosted due to

the increased issuance of municipal and corporate green bonds.⁵ Indeed, in 2014, so-called 'climate bonds' and 'green bonds' markets issued \$36.6 billion and the total market is now estimated at \$502 billion.⁹¹ This observation is underscored by the estimate that the total bond market (at \$100 trillion in outstanding debt) is significantly larger than the estimated \$63 trillion equity market.⁹² Importantly, the green bond market is expected to grow considerably over the next several years.^{h,93} Of particular relevance to the discussion in this article, the municipal bond market as a vehicle for large-scale investment has experienced rapid growth recently.^{i,91,93} For instance:

- Massachusetts issued the first labeled green bond by a municipality (\$100 million);
- Gothenburg issued a \$79 million (SEK500 million) bond;
- The City of Johannesburg (South Africa) issued a \$136 million bond (ZAR1.45 billion); and
- The State of Delaware in the urban belt of the east coast of the U.S. issued a \$73 million bond.^j

Substantial benefits are expected to accompany a move towards the bond markets for financing⁸⁴:

- Bonds represent standardized capital market instruments, enhancing the liquidity of the instrument particularly for sufficiently large issue sizes. Additionally, large issue sizes can be included in bond indices further enhancing investor attractiveness.

- A wide target audience is available in the bond market.
- Bonds can be issued with long maturities, further enhancing their profile for the long-term investor.
- A well-structured bond can attract low-cost financing and maintain less stringent covenants.

In addition, asset-backed securities like those in place with a solar PV bond offering, once installed, offer a low, postcompletion risk profile further showcasing the potential advantage of a bond approach^{84,94,96}:

- The PV systems serve as a predictable source of revenue that can moderate the possibility of default;
- Default recovery rates are higher for bonds;
- Low, postcompletion risk profiles can be accompanied by stable credit ratings; and
- *Standardization*: the coupon structure of bonds is familiar to investors.

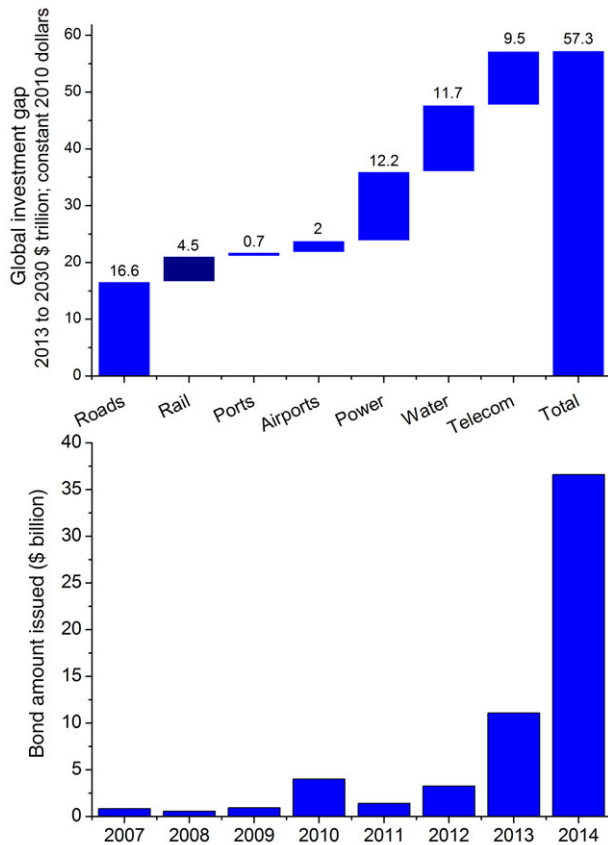


FIGURE 2 | (a, b) The infrastructure gap²⁵ and green bond market growth.⁹¹

Figure 2(a) and (b) presents an estimate of the infrastructure gap for electric power at a \$12.2 trillion deficiency (a) and the rapid growth of the green bond market (b).

Finance Conditions in the Case Study Cities

The challenge for an infrastructure-level strategy for municipal PV begins with the analysis of a viable economics for the option, including possible policy framework needs. As Ref 90 points out, only relying on the ‘green’ character of the bonds substantially limits the audience for the capital offering to, e.g., socially responsible investment (SRI) and ethical funds. Access to the broader capital markets will be necessary to substantially accelerate the mass-deployment of renewable energy options. To do so, cities are actively exploring options. In September 2014, New York City, for instance launched its Green Bond Program in order to expand the investor base available to the city, to create a model for other municipalities across the United States to reproduce, and to encourage a greener capital character for the city.⁹⁷ Tokyo, similarly, is to benefit from a green bond program launched by the Development Bank of Japan as this \$315 million bond issuance at 0.25% and 3-year maturity will help finance green projects in the city—indeed, as an indication of significant investor interest, the bond was over thrice oversubscribed.⁹⁸

The cost of capital is a critical consideration in the option for solar city financing. To assess the cost-of-capital, bond yield curves were established for each city (Figure 3). Bond sales data were screened to avoid inclusion of general obligation or refinance issuances. Tax-exempt revenue bonds were used and, when information permitted, the data were screened to include utility or infrastructure investments. Tax-exempt

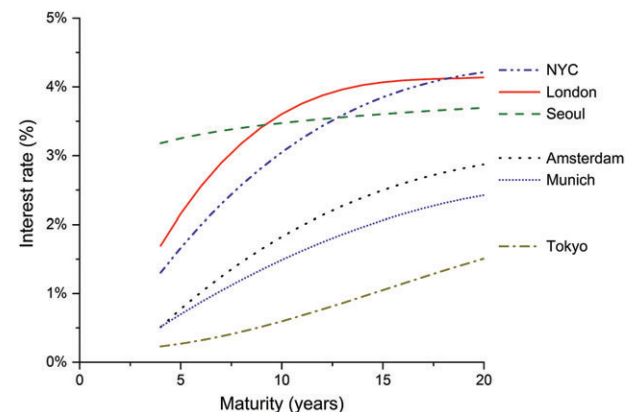


FIGURE 3 | Bond yield curves used to calculate the cost of capital for each city.

revenue bonds allow for municipal pooled financing without affecting the municipality's debt ceiling as Solar City measures will be paid from the revenues that accrue from Solar City operations. The bond yield curve is created by evaluating the bond issuances during 2013 and 2014 to offer representative cost of capital estimates. However, the United Kingdom stands out as local governments rely on a central government agency called the Public Works Loan Board (PWLB). This statutory body lends money to local governments for capital investments in transport, water-sewer infrastructure, and housing. Unlike capital markets, interest rates are centrally determined by the Treasury and have traditionally been relatively low.⁹⁹ However, a recent rapid interest hike has spurred interest in alternatives and some local governments are now investigating the creation of a municipal finance bond agency.^k This position is further strengthened by the recognition that cost of capital could be lower through direct issuance of municipal bonds: the Greater London Authority issued a GBP 600 million bond in 2011 which ended up 17 basis points cheaper compared to the PWLB.⁹⁹ Nonetheless, to determine the bond curve with which to further assess the potential of a solar city application in London, data from the PWLB were used which, for now, remains the main source of capital for large-scale projects.

Subnational government finance pathways are also being suggested for Germany.¹⁰² Indeed, German Lander and local authorities raise 47% of their debt via the capital market.¹⁰¹ Implicit shared liability of the German Federation ensures small differences between credit ratings among and across subnational governments and the German national government.^{101,103} Nonetheless, despite this 'bündisches Prinzip' (the principle of mutual financial support between levels of government), credit spread between the national government and the Lander can be substantial due, in part, to a liquidity premium.¹⁰⁴ Due to the low frequency, relatively low issuance volume, and the fact that average benchmark yields are unavailable for the Lander, the bond yield curve was determined using the national track record of 2013–2014 bond issuances to determine a proxy bond curve for Munich. Comparing this bond curve with past issuances in Bavaria, Berlin, Hamburg, and Bremen (as found on the Stuttgart Stock Exchange) strengthens our confidence in the appropriateness of this curve for Munich.

In the Netherlands, subnational tax-exempt bond issuances are maintained by the Bank of Dutch Municipalities, a Dutch public sector agency with a rating of AA+ by Standard & Poor. This bank functions on behalf of local authorities and public sector institutions, specifically designed to minimize the cost of

public services. Established in 1914, the bank is a statutory two-tier company under Dutch law where the Dutch state maintains a majority share (50%), the eleven provinces own 3.6%, and 406 municipalities own 46.4%. The bank maintains an overview of previous bond issuances on its website (www.bngbank.nl/). Focusing on 2013–2014 bond issuances in Euro produced the yield curve.

New York City's capital program is one of the largest in the United States. The city deployed its main borrowing vehicles—general obligation bonds, the Transitional Finance Authority, and the Municipal Water Finance Authority—to issue over \$8.0 billion of long-term bonds in FY2014.^{1,105} The city plans to deploy a Green Bond Program to fund climate change mitigation and adaptation programs and it has stated it will utilize its three key borrowing vehicles to raise capital.⁹⁷ To arrive at a yield curve, tax-exempt bond issuances during 2013–2014 were analyzed.

Tokyo Metropolitan Government issued 19 bonds for the 2013–2014 period at 630 billion Yen. The yield curve for Tokyo was derived from these local issuances by the Tokyo Metropolitan Government.

Finally, for Seoul, bond data from the Korea Electric Power Corporation (KEPCO) and the Korea Gas Corporation (KOGAS) were used to construct the yield curve.

Policy Conditions in the Case Study Cities

As reported in Table 4, each location presents quite a different track record of PV implementation and performance. For instance, while Korea has strong irradiation it only has 445 MW of PV installed; a penetration rate of 0.4%. This performance pales in comparison to some of the countries with a more robust policy support framework in place such as Germany and Japan. This section briefly covers the main policy conditions in effect in each of the cities and their parent countries.

Amsterdam

The 2013 Netherlands' Energy Agreement sets the Dutch ambition to realize 14% of renewable energy in the energy mix by 2020 and uses the Sustainable Incentive Scheme (SDE+) as the key support mechanism.¹⁰⁷ The SDE+ is a market-sensitive FIT with a technology neutral budget (set at €3.5 billion in 2014) financed through an end-use energy bill surcharge.¹⁰⁸ Least-cost renewable energy technology options have been particularly able to take advantage of the support mechanism.^{107–109} Nonetheless, the 2013 installed PV capacity nearly doubled to about 700 MWp in 2014 and projections continue to expect strong growth to

TABLE 4 | Status of the PV Market in Each of the Locations in 2013¹⁰⁶

Country	Pop. (million)	PV Installation in 2013 (MWp)	Cumulative PV Installed Capacity (MWp)	Cumulative Wp/capita	PV Penetration (%)
Netherlands	17	360	723	43	0.6
Germany	81	3305	35,766	442	6.4
UK	64	1546	3377	53	1.0
Korea	50	445	1475	30	0.4
Japan	127	6968	13,599	107	1.4
USA	316	4751	12,079	38	0.4

4 GWp in 2020 and 20 GWp by 2030.⁷⁰ PV policy support through SDE+ will be restricted to installations of over 15 kWp in 2015. For this category, the SDE+ provides a 14.1 €¢/kWh (18.47 \$¢/kWh) ‘base’ rate in 2015.¹¹⁰ Actual compensation is market sensitive—for 2015, the ‘base’ rate is corrected with €0.045/kWh (0.058 \$/kWh) resulting in 12.58 \$ ¢/kWh of actual support. Applications for compensation are structured in multiple phases per year with the earlier phases offering lower financial support but a higher likelihood of award. The program award amount is capped at €3.5 billion. Critically, the favorable investment tax incentive can no longer be applied by commercial entities when receiving SDE+ support.¹¹¹ The City of Amsterdam has outlined its own strategy: the ambition is to have 160 MWp of installed PV capacity by 2020 (up from a current estimated 8–10 MWp).⁵⁷ A main finance option made available by the city is a revolving fund that currently manages €137 million of which €45 million is available for climate change related investments on commercial property in the form of loans and guarantees set at market rates.⁵⁷

London

The PV market in the United Kingdom has largely been driven by a generation tariff (FIT) coupled with a feed-in premium and a quota system with tradable certificates.^{112,113} The UK FIT has been designed specifically to support small scale renewable energy installations (≤ 5 MW) while the quota incentivizes large-scale projects.¹¹⁴ In terms of the FIT, three financial benefits accrue from solar energy installation: the generation tariff, the export tariff for excess solar electricity, and electricity bill savings.¹¹³ The export tariff’s attractiveness is limited as it is only available to PV systems smaller than 30 kW and the fact that retail electricity prices are considerably higher thus incentivizing self-consumption over export.¹¹² The latest FIT payment information as published by OFGEM sets PV FIT rates for an efficient commercial scale (50–100 kW) system at 9.98 pence/kWh (0.16 \$/kWh).¹¹⁵

Munich

Germany has fundamentally reformed its system for supporting renewable energy development. Shifting from an initial *market introduction* phase of policy support, Germany now focuses on a *market penetration* phase of renewable energy deployment.¹¹² While it will remain the key policy support mechanism, the German FIT has similarly experienced much reform over the past years.¹¹⁶ For instance, over 2007–2013, average FITs paid to new solar energy installations fell from about 0.47 to 0.12 €/kWh (0.61–0.16 \$/kWh) reflecting its evolution to a ‘grid parity’ future.¹¹⁶ Commercial scale operations can now no longer sell more than 90% of their electricity under FIT support to the market but must either be self-consumed, sold at wholesale prices, or at spot prices.¹¹⁶ FIT support is now volume-responsive in line with a ‘corridor’ where FIT rates decrease based on installed volume in previous periods.¹¹⁶ These reform efforts have substantially reduced the PV business case as 2013 and 2014 capacity installation levels were 75% lower compared to the annual installation levels in 2010–2012 (the years prior to the most recent reforms).³⁴

New York City

U.S. federal support for PV primarily comes in the form of the 30% investment tax credit.¹¹⁷ Public and private electricity suppliers of the NYC area have furthermore operated performance-based incentives. For instance, the Long Island Power Authority used to run the Clean Solar Initiative Feed-in Tariff during 2012–2014 and supported solar at 0.17–0.22 \$/kWh.^{117,118} As of 2013, the total installed solar PV capacity of New York State was equivalent to 271 MW including 33 MW installed in New York City (Ref 119, p. 5). Under the New York Sun Initiative, the State of New York has launched several incentive programs in an effort to establish a more favorable investment environment for PV in New York, particularly through a PV system rebate called the MW Block Initiative (<http://ny-sun.ny.gov/>). This initiative follows a

block-by-block support pattern, offering higher incentives for first blocks of installed MW—our calculations of the incentive scheme indicate that the rebate covers roughly 6% of the installed system costs.

Seoul

The RPS scheme in South Korea, since the termination of the national FIT in 2011, is the key support policy for PV in the country. The RPS mandates a PV carve-out which incentivizes the solar renewable energy certificate (SREC) market; this market is further supported by a credit multiplier for PV as 1 MWh yields 1½ SREC.¹²⁰ In addition to the national RPS, some local governments, including the Seoul Metropolitan Government (SMG), provide subsidies to electricity produced from PV systems. The SMG supports small-scale solar PV—installed capacity smaller than 100 kW—through a FIT premium that offers an additional 100 Korean Won per kWh (10 cents/kWh).³⁶ Seoul, furthermore, has pioneered an ambitious energy strategy termed One Less Nuclear Power Plant which advances prospects for energy autonomy and further demonstrates political leadership to pursue a sustainable energy transition.¹²¹

Tokyo

Japan's national FIT scheme for renewable energy entered into force in July, 2012. For the Tokyo metropolitan area, it is operated by the Tokyo Electric Company (TEPCO). The FIT mandates 10 electric utilities of Japan to purchase excess electricity from grid-connected renewable energy systems at fixed prices determined annually. By March, 2015, the national FITs for solar PV generation are 0.31 \$/kWh for systems no greater than 10 kW and 0.27 \$/kWh for systems greater than 10 kW.¹²² Both the Tokyo metropolitan government and the national government, further, provide subsidies and other incentives for residential system developers. As of 2013, the cumulative solar PV capacity installation reached 13,599 MW in Japan and 260 MW in the Tokyo metropolitan area.¹⁰⁶

EXPLORING A SOLAR CITY APPLICATION IN THE CASE STUDIES

To investigate the actual application of the solar city concept in the six case study cities, a scenario analysis was conducted using PV Planner software.⁶⁸ This scenario analysis combines the data presented in the previous section and computes the essential financial metrics to gage the consequences of a solar city application. To determine solar city feasibility, we show two main results:

- *Finance*: a scenario that offers insight into the financing benefits of the bond market; and
- *Policy*: a scenario where policy benefits are included to reflect on improvement of the business case of PV in each city when current policy conditions are applied.

To calculate these conditions, the following city-specific inputs have been used (Table 5). Other assumptions and specific inputs are presented in each section separately.

Finance

Using the earlier yield curves in Figure 3, we calculate for each city the payback period (PBP), the benefits-to-cost ratio (BCR), and the net present value (NPV) without applying any policy benefits. However, a critical assumption in our calculation—based on the notion that the solar city vision applies PV to substantial portions of the city—is that all electricity generated is available for self-consumption. In other words, the city operates as a unit where electricity consumption at any point of the day is higher than electricity generated. PV generation thereby fully offsets city electricity bills, creating a revenue stream equal to system output multiplied by the city's average commercial electricity retail price. Such price setting could occur in the form of an

TABLE 5 | City-Specific Inputs

City	2013 Turnkey installed system price (\$/W) ¹	System cost input (\$/W) ²	Commercial electricity retail rate (cents/kWh) ³
Amsterdam	\$1.99	\$2.14	14.8
London	\$2.40	\$2.55	16.8
Munich	\$1.90	\$2.05	23.3
NYC	\$3.57	\$3.72	22.4
Seoul	\$2.30	\$2.45	11.6
Tokyo	\$3.44	\$3.59	19.4

¹ The 2014 IEA PVPS trends report provides data for system costs excluding installation costs for the year 2013 for the Munich, NYC, Seoul, and Tokyo.⁶⁸ In order to include installation costs and update the data to 2013 for Amsterdam, data from the Dutch PV monitoring agency were used.¹²³ The United Kingdom is not included in recent IEA PVPS updates. For this reason, the IEA PV Technology Roadmap (2014) was used for the UK.¹

² Inverter replacement is a major cost in the cash flow of a PV project. Here, we assume inverter replacement cost is covered under warranty for the lifetime of the entire project. This warranty cost is calculated as the current inverter cost of 22.3 cents/Wp discounted against a 3% rate for 13 years. This estimate neglects negotiation benefits which should be substantial at the discussed scale.

³ National commercial retail electricity rates for Amsterdam, GLA, and Munich were used.¹²⁴ For NYC, ConEdison's commercial retail rate to commercial entities in New York City was extracted from EIA Form 861. For Seoul, data from the Seoul Metropolitan Government were used. For Tokyo, the Tokyo Electric Power Company (TEPCO) Fact book 2014 was used.¹²⁵

TABLE 6 | Overview of Financial Metrics under Certain Financing Conditions in Each Case Study City

City	Financing Period (years)	Interest Rate (%)	PBP	BCR	NPV (millions)
Amsterdam	25	3.02	21.48	1.13	\$33.9
London	Not financeable in 25 years (see Figure 4)				
Munich ¹	12	1.74	10.84	1.89	\$209.1
NYC	23	4.29	19.45	1.23	\$107.5
Seoul	Not financeable in 25 years				
Tokyo	20	1.51	17.21	1.35	\$126.2

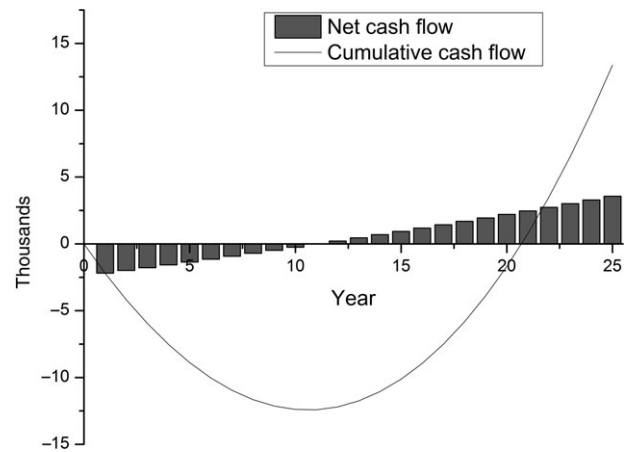
Notes: NPVs reported for a 100-MW installation; PV tilt optimized for each location with PV Planner: Amsterdam (37 degrees), Greater London Authority (36 degrees), Munich (33 degrees), New York City (26 degrees), Tokyo (21 degrees), and Seoul (22 degrees). All are south-facing; Estimates for O&M costs vary considerably in the literature. Several sources, however, appear to converge at around 20 \$/kW/year which is used here. For instance, for the Netherlands, the Energy Research Centre of the Netherlands (ECN) applies about 22 \$/kW in their calculations to determine the necessary level of policy support.¹¹⁰ Lazard, a global investment firm, uses 13–20 \$/kW/year to calculate PV leveled cost of electricity (LCOE) improvements over time¹²⁶; A large-scale application of a solar city vision should be able to negotiate state-of-the-art equipment. PV module efficiencies in the market display ever greater efficiencies.^{127–129} As such, we assume a 20% module efficiency. State-of-the-art inverters are documented at 98.5% efficiency.¹²⁹ Furthermore, we applied a 90% power derate factor and a 0.5% degradation factor; Rising electricity prices are observed in most regions of the world.¹³⁰ Here, we assume an across-the-board electricity price escalator of 2% which corresponds with published estimates¹³¹ or is conservative—Ref 112, e.g., assumes a 3% electricity escalator for Western Europe. Inflation, for instance for O&M, is set at 2%/year.¹³² Overall, a 3% discount rate is used in the cash flow calculations.

¹The recent update to the renewable energy sources act in Germany (EEG 2014) established a 40% tax on the EEG surcharge for the self-consumption of generated electricity which is applied here.¹³³ This lowers the commercial electricity retail rate from 23.3 to 20.08 cents/kWh.

administered price set by the local government; administrative pricing of this nature would resemble actual commercial retail price setting through regulatory dockets. Table 6 provides an overview of the results when calculated along these lines. The shortest possible financing period is presented where the PBP is shorter than the financing period. The results show that, if financing on the capital markets for this purpose is available under the conditions specified in the table, Amsterdam, Munich, NYC, and Tokyo could engage in a solar city project that would pay itself back over the course of the project. London (due to a combination of relatively high interest rates and low electricity generation per kWp) and Seoul (due to the relatively low average commercial electricity price of 0.11 \$/kWh), would be unable to finance a PV project and expect a positive cash flow in each year of the project. More detail on London is provided in Figure 4 showing the cash flow for a 25-year financing period. While London offers a PBP of just over 24 years which is within the financing period, commercial retail prices are insufficient to cover debt service payments in early years. In Seoul, commercial retail prices are too low throughout the lifetime of the project to make a solar city pencil.

Policy

A second scenario analyzes solar city applications when a level of public financial support for the project is provided consistent with the direction in *Finance* section. Primary policy inputs are taken from the policy analysis section summarized in Table 7. In light of the above-mentioned assumption that PV electricity can be applied to the electricity bill savings against average commercial electricity retail prices for the city

**FIGURE 4** | London Net Cash Flow under a 25-year financing.

as one operating unit, cities that offer policy benefits that only apply for excess electricity but are lower than commercial retail prices—like is the case for Munich—produce the same results as in the above scenario. In light of the rapid decline in PV system prices, rising grid parity conditions, and observed retrenchment of policy support (consider especially the case in Germany), policy support conditions are assumed to only be held in place for a ten-year period despite current use of 15- to 20-year FIT contracts.

Table 8 reports the findings of the policy benefits analysis. The application of policy benefits improves the business case for solar energy in each city. In the case of NYC, the improvement is large. The 30% federal investment tax credit and the 6% rebate provided by New York together reduce the initial capital costs considerably, allowing for a much shorter financing period without negative net cash flow in any year.

TABLE 7 | Summary of the Policy Scenario Inputs

City	Policy Measures	Input	Other
Amsterdam	FIT	\$0.114/kWh	Market sensitivity: -3%/year in FIT payment level
London	FIT	\$0.16/kWh	
Munich	FIT	\$0.14/kWh ¹	Self-consumption levy of 40% of EEG surcharge
NYC	ITC	ITC: 30%	ITC applied after deduction of other rebates
	NY Sun Initiative	NY SUN: 6%	Percentages of installed cost
Seoul	SREC market	\$0.126/kWh	Market sensitivity: -3%/year in SREC price
	Local FIT	\$0.10/kWh	
Tokyo	FIT	\$0.27/kWh ²	

¹ The FIT rate for Germany is lower than the commercial electricity retail rate. As such, the analysis assumes that all electricity generated will apply against electricity bill savings.

² Tokyo's FIT applies only for excess electricity. However, generators are offered the choice for either self-consumption or grid feed-in. Considering the FIT payment is higher than commercial electricity retail rates, the policy benefits calculation performed here uses the FIT payment rate.

TABLE 8 | Overview of Financial Metrics under Bond Financing and Current Policy Conditions

City	Financing Period (years)	Interest Rate (%)	PBP	BCR	NPV (millions)
Amsterdam	21	2.92	13.68	1.46	\$117.3
London	25	4.14	14.17	1.40	\$134.7
Munich ¹	12	1.74	10.84	1.89	\$209.1
NYC	11	3.25	9.67	2.14	\$335.1
Seoul ²	Not financeable within 25 years				
Tokyo ³	16	1.15	12.88	1.58	\$205.2

Notes: NPVs are reported for a 100-MW installation.; Same assumptions and inputs apply as documented in the notes of Table 6; Policy benefits assumed to only run for 10-year period.

¹ The results for Munich are the same as in Table 6. Due to recent cut-backs in the FIT payment levels, commercial retail electricity rates are higher than the FIT. As such, self-consumption of the generated electricity becomes favorable vis-à-vis opting for the FIT. Considering the city-wide application level, self-consumption is assumed to always be available and, as such, the reported results are the same as all generated electricity continues to be compensated against commercial retail electricity rates.

² The scenario uses both the national SREC market (12.6 cents/kWh) and the local FIT payment (10 cents/kWh). This is allowable under existing policy conditions. However, the Seoul FIT is specifically designed for small-scale installations. Here, we assume that the FIT is available under this solar city application for the first 10 MWp of the installation as presented in Table 3 (commercial only: 0.86 GWp). National SREC market prices are assumed to de-escalate at 3%/yr. When a full FIT is applied for all the electricity generated throughout the first 10 years, the system becomes financeable in a 10-year timeframe.

³ Assumes that all generated electricity is available for the 27 cents-kWh FIT payment for a 10-year period. After that, electricity generated is compensated against commercial electricity retail rates.

Ten-year policy benefits, such as FIT and SREC contracts, in contrast, only allow for faster payback of the debt service and do not reduce the debt service itself. This is, e.g., the case for Seoul: when local and national benefits are applied in full for 10 years, these offer sufficient policy support to cover the debt service in less than 10 years. However, the Seoul FIT is designed for small-scale installations and the results reported in Table 8 assume only partial application of this policy benefit. Once benefits expire after 10 years, the remainder of the debt service still needs to be repaid. However, commercial retail electricity prices for Seoul (lowest among the six case study cities) are insufficient to cover outstanding costs. Similarly, London's benefits, under these scenario assumptions, are almost sufficient to pay back the debt service in 10 years. However, since that is not the case, the financing needs to have a much longer maturity in order to pay it back with energy bill savings once policy benefits expire.

Primary options to improve the business case for PV in each city are to: (1) lower the installed system cost (through, e.g., a rebate, market development, or by following the German policy model for soft costs¹³⁴), (2) increase the average electricity price avoided by PV through a FIT-style incentive, or (3) increase the policy benefit payment through an RPS-style SREC incentive. The changes necessary to bring the PV business case to a 10-year financing period were calculated for each variable individually and for each city (Table 9). A combination of modifications is also possible but is not presented here. The findings show that it is possible for each city to finance a solar city application in a 10-year period by modifying existing parameters. However, some of these parameters are more open to modification than others: e.g., increasing electricity prices may be politically infeasible in some jurisdictions.^m Especially, system cost reductions required to allow a 10-year financing are in line with year-on-

TABLE 9 | Required Policy and Other Modifications to Ensure a 10-Year Financing of the Solar City Option through the Bond Market

City	Retail Electricity Price (¢/kWh)		FIT payment (¢/kWh)		SREC Price (\$/MWh) ¹		Required System Cost Reduction (%)
	Current	Required	Current	Required	Current	Required	
Amsterdam	14.8	16.4 (↑10.8%)	11.397	13.8 (↑21.1%) ¹			↓7.2
London	16.77	17.6 (↑4.9%)	16	16.81 (↑5.1%)			↓2.6
Munich	23.3 (before tax)	22.5 (↓2.1%) ²	Recent national FIT policy reform has dramatically reduced the PV tariff to a point below retail rates, incentivizing self-consumption				↓11.7
NYC	22.4	22.6 (↑0.9%)	—	1.0	126	209 (↑65.9%)	↓0.9
Seoul ³	11.6	16.9 (↑45.7%)					↓23
Tokyo	19.35	24.5 (↑26.6%)	27	32.15 (↑19.1%)			↓16.9

¹ These variables maintain a 3% de-escalator in compensation in order to remain market sensitive. The possibility of fixed contracts, however, due to the scale of the project involved could lower the required compensation level.

² This finding corresponds with lowering the recently enacted self-consumption levy from a current 40% of the EEG surcharge to a new 10% of the EEG surcharge.

³ As reported in Table 8, the calculation relies on both the national SREC market and the local FIT payment. Again, FIT payment levels are calculated for the first 10 MW only.

year declines in observed costs over the past years—e.g., the system cost of residential and commercial PV systems in the United States declined by about 6–7% per year throughout 1998–2013 but decreases have accelerated in recent years.¹³⁵ Moreover, a large-scale application of solar energy in cities, organized as an infrastructure program, should be able to drive manufacturers and construction corporations to lower system prices. For instance, initial generation costs could be reduced substantially if a large pool of potential energy projects could be identified at the outset, ensuring a consistent supply of high-quality, early installations of PV. The application of strict and rigorous qualification practices from the beginning, furthermore, could continuously encourage additional high-quality projects to join the pool, thereby drawing down costs throughout the lifetime of the Solar City project. It is also possible to achieve reductions by learning lessons from Germany and other countries on how to reduce soft costs.¹³⁴

Applying a solar city vision to 30% of all commercial and public buildings by 2020 as reported in Table 3 provides insight into the cost profile of a solar city vision. Calculated against a future 2020 population, it becomes clear that a solar city vision on commercial and public buildings only requires \$200–\$360 per person living in the city to reach about 100 Wp/capita (Table 10). While multibillion dollar investment opportunities are available in the case study cities, particularly when the analysis is extended to noncommercial and public buildings, bond offerings can be scheduled in series in order to manage investment flows of this magnitude. Solar city applications could also utilize recent innovations such as yield-co spin-offs or other innovative refinancing schemes in order to sustain capital flows.^{138,139}

Substantial benefits can be accrued from a solar city strategy, also reported in Table 10. Employment opportunities that accompany solar city strategies are calculated with a job multiplier. Research on such a multiplier for solar PV has been conducted by a variety of analysts with oftentimes substantially differing outcomes.^{136,140–142} For instance, Ref 140 in their literature review on green jobs in the United States reports direct employment findings ranging from 0.23 to 1.42 job-years/GWh with an average of 0.87 job-years/GWh. A recent comprehensive literature census conducted by Ref 136 analyzed 70 reports on the topic and found that solar PV generally results in higher employment levels compared to other renewable energy technologies and that renewable energy technologies typically result in more jobs compared to conventional energy technologies. Noting the significant differences between the many literature sources, where

TABLE 10 | Overview of the Cost Profile of a Solar City Vision When Applied on 30% of the Commercial and Public Buildings in the Case Study Cities by 2020

	PV (GWp)	Wp/capita	Capital Investment (\$ billions)	\$/capita	Direct Employment Benefits ¹			System Benefits ²	
					M (person-years)	I (person-years)	O&M (jobs)	Value of Electricity Generated (\$ billions)	Net Benefits to the Sector and Its Customers (\$ billions)
Amsterdam	0.11	92	0.24	207	2068	1233	33	0.98	0.74
London	0.33	101	0.95	288	6205	3695	99	2.99	2.04
Munich	0.18	119	0.37	246	3385	2015	54	1.80	1.43
NYC	0.8	96	2.98	357	15,040	8960	240	10.03	7.05
Seoul	0.86	87	2.11	215	16,168	9633	258	8.92	6.81
Tokyo	0.92	101	3.30	361	17,295	10,305	276	10.45	7.15
Total	3.2	99 (average)	9.94	279 (average)	60,160	35,840	960	35.18	25.23

M, manufacturing; I, installation; O&M, operation and maintenance; person-year, the full-time employment of one person for the duration of 1 year.

¹ Median values for solar PV employment factors as found by Ref 136 were used. The findings are illustrative as employment conditions differ substantially by location.

² System benefits are calculated over the lifetime of the installation (25 years of electricity production with a 0.5% degradation rate and 90% power derate factor) using the numbers provided by Ref 137 on the upper bound for NYC/Long Island (41 cents/kWh) for each city. Net benefits include environmental and health benefits, decongestion and resilience benefits, and so on as defined in Ref 137—minus the investment and installation costs for the solar city vision.

many report findings in separate ways or apply findings from other contexts without consideration, Ref 136 arrived at the following numbers:

- Manufacturing (person-years/MW): 6.0–34.5 with a median of 18.8;
- Installation (person-years/MW): 6.4–33.0 with a median of 11.2; and
- O&M (jobs/MW): 0.1–1.65 with a median of 0.3.

A range of additional economic benefits apply. For instance, a range of ancillary benefits of distributed PV for the New York City/Long Island area utilities and ratepayers have recently been estimated at \$0.41 per kWh and includes fuel price mitigation, distribution loss savings, and transmission loss savings (about 25 cents/kWh). Additional benefits that accrue to society at large include environmental, health, and grid security benefits are estimated to be about 0.16 \$/kWh.

CONCLUDING REMARKS

A sustained but substantial transition to a renewable energy future requires careful consideration of the policy–market–finance interaction. While policy efforts in the last 10–15 years have initiated a successful growth pattern for renewable energy, we argue that a sustainable energy transition of the kind needed to avert

further climate change will require rethinking the interaction so that the advantage of decentralized solar PV is realized through a commitment to its infrastructure-scale development. The investigation presented here is intended as an early investigation into city-wide solar potential. Specific city profiles will need to be drafted when detailed project proposals are being considered in order to explicitly account for several details not addressable in this research. For instance, factors like building portfolio, building age, zoning, and so on, or particular cost considerations (e.g., prevailing wage, unions, etc.), need to be examined. The solar city concept serves as a possible iteration of an infrastructure application of PV by empowering municipalities to become the designers of their own distributed power plant.

The operation of a Solar City program along the lines discussed in this article would require substantial administrative capacity to, among other things, execute the bond issuance process and maintain quality control so that direct revenue streams throughout the project's lifetime are sufficient to cover debt service. Administrative capacity could be housed within a special purpose entity that performs these tasks as has been done successfully in other green bond issuances such as was the case for the Delaware Sustainable Energy Utility.⁹⁵

The bond financing pathway assisted by discrete policy support defined in the article offers insight into the economic feasibility of the solar city concept. Future research on this pathway should include the investigation of 'hybrid bonds' where cash flow is securitized in

separate tranches as a risk management strategy.¹⁴³ Such a hybrid bond application could also enable pursuit of a bond portfolio approach where municipalities team together and explore a joint bond issue that is structured to overcome specific obstacles and/or to complement administrative capacities among participating agencies.¹⁴³

NOTES

^a This infrastructure perspective can include ground-mount, carport, and other methods of installation. Our focus on ‘rooftop real estate’ is intended to illustrate the broader infrastructure platform and not to favor rooftop installations over other options.

^b Usually, compliance with this obligation is facilitated by the purchase of market-based certificates to ‘fill the gap’.

^c For instance, as the German government attempts to limit remunerations paid to PV system owners by drastically reducing FIT payments and by introducing other limitations, the industry has responded and has installed 55% fewer PV systems in terms of capacity compared to previous years with 2014 showing even lower installed capacity levels.³⁴

^d Our 2015 paper found that a high density, vertical city like Seoul could receive 30% of its annual electricity demand and 66% of its daylight electricity need from conservatively estimated rooftop PV (Ref 12, p. 841). If a rigorous building efficiency strategy is matched with the PV initiative, such as Seoul’s Phase 2 Sustainable Energy Plan,³⁶ city self-reliance is within reach.

^e As described below, the type of sovereign commitment may not need to be of the ‘general obligation’ kind which is backed by the jurisdiction’s tax authority. Rather, performance-based guarantees can back-stop a pledge to maintain the jurisdiction’s energy appropriations during the period of debt service.

^f When estimates are not directly available or the estimation method in the case of a specific city is not consistent with Ref 12, the methodology developed by Ref 12 for the computation of rooftop space from total floor space was employed to compute suitable rooftop area and PV generation of electricity.

^g The emergence of corporate and municipal ‘green’ bonds has also given rise to potential complications in opening up the bond market to strategies to mitigate or adapt to climate

change or otherwise address energy challenges. One key problem is that corporate and municipal issuers of green bonds self-label these securities as ‘green’, giving rise to the question ‘what is green?’ Environmental integrity is critical in such a nascent market. In response, some have called for the institution of agencies capable of policing the green bond market⁹⁰ and ‘Green Bond Principles’ have been introduced as a means to maintain integrity. In addition, verification of bonds by organizations such as CICERO could advance the cause of market integrity.

^b Similarly, infrastructure bonds have become increasingly important over time in developing countries, emerging economies, and advanced economies alike.⁹⁴ In particular, China has rapidly expanded its access to infrastructure bonds. Even when China is excluded, bond finance growth remains strong.⁹⁴

ⁱ Other suggestions have been introduced to enhance capital availability for cities, ranging from more active participation in the carbon finance market, a greening of urban taxation, or the use of grants and fees to address climate change.

^j The green bond in Delaware was issued by the Sustainable Energy Utility (SEU), a nongovernmental organization designed by one of the authors of this article (Byrne) who conceived the investment as self-financing through guaranteed contractual savings. The transaction resulted in an all-in cost (including debt service) of \$110 million which was fully paid from \$148 million in guarantees of energy and water bill savings.⁹⁵ The investment led to ‘deep’ retrofits in participant buildings averaging 14 years to pay back. Although the SEU had not previously sold debt into the market, its bond offering received a AA+ rating from S&P.

^k This effort is spearheaded by the Local Government Association (LGA) and equity investment in the Agency has reached about 10 million pounds, indicating a measure of support for such an agency.¹⁰⁰ First bond issuance is planned for 2015 on the order of 250–300 million GBP.¹⁰¹

^l A major portion of these funds, however, were used for refinancing purposes to lower the City’s long-term debt service burden.¹⁰⁵

^m European efforts to withdraw FIT policies are partly driven by PV approaching grid parity, e.g., in Germany and the Netherlands. But political opposition to high electricity prices can also be a factor.

ACKNOWLEDGMENT

The authors acknowledge with appreciation the financial support of the National Research Foundation of Korea (MSIP, University-Institute Cooperation Program).

REFERENCES

1. International Energy Agency (IEA). *Technology Roadmap—Solar Photovoltaic Energy*. Paris: OECD Publishing; 2014. Available at: <http://www.iea.org/publications/>.

2. Renewable Energy Policy Network for the 21st Century (REN21). *Renewables 2014—Global Status Report*. Paris: Renewable Energy Policy Network for the 21st Century; 2014. Available at: <http://www.ren21.net/ren21activities/globalstatusreport.aspx>.
3. Sherwood L. *U.S. Solar Market Trends 2013*. Latham, NY: Interstate Renewable Energy Council; 2014. Available at: <http://www.irecusa.org/publications/>.
4. International Energy Agency (IEA). *Energy for All—Financing Access for the Poor; Special Excerpt from the World Energy Outlook 2011*. Paris: OECD Publishing; 2011.
5. Rozita S, Xiao W, Carlos MJ, Kofi AE. Electricity (in)accessibility to the urban poor in developing countries. *WIREs Energy Environ* 2014, 4:339–353. doi:10.1002/wene.148.
6. International Energy Agency (IEA). *Energy Technology Perspectives 2014—Harnessing Electricity's Potential*. Paris: OECD Publishing; 2014. Available at: <http://www.iea.org/etp/>.
7. Sovacool BK. National energy governance in the United States. *J World Energy Law Bus* 2011, 4:97–123. doi:10.1093/jwelb/jwr005.
8. Pepermans G, Driesen J, Haeseldonckx D, Belmans R, D'haeseleer W. Distributed generation: definition, benefits and issues. *Energy Policy* 2005, 33:787–798. doi:10.1016/j.enpol.2003.10.004.
9. Byrne J, Letendre S, Wang Y-D, Nigro R, Ferguson W. Building load analysis of dispatchable peak-shaving photovoltaic systems: a regional analysis of technical and economic potential. In: Campbell-Howe R, Wilkins-Crowder B, eds. *Proceedings of the American Solar Energy Society Solar'97 Conference*, Washington, DC, 1997. Available at: <http://ceep.udel.edu/publications/>
10. Letendre S, Weiberg C, Byrne J, Wang Y-D. Commercializing photovoltaics: the importance of capturing distributed benefits. In: *Proceedings of the American Solar Energy Society Solar'98 Conference*, Albuquerque, NM, 1998, 231–237. Available at: <http://ceep.udel.edu/publications/>
11. Akorede MF, Hizam H, Pouresmaeil E. Distributed energy resources and benefits to the environment. *Renew Sustain Energy Rev* 2010, 14:724–734. doi:10.1016/j.rser.2009.10.025.
12. Byrne J, Taminiu J, Kurdgelashvili L, Kim KN. A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the City of Seoul. *Renew Sustain Energy Rev* 2015, 41:830–844. doi:10.1016/j.rser.2014.08.023.
13. Mario R, Simone S. Effectiveness and efficiency of support schemes for electricity from renewable energy sources. *WIREs Energy Environ* 2014, 3:213–229. doi:10.1002/wene.85.
14. Sarasa-Maestro CJ, Dufo-Lopez R, Bernal-Agustin JL. Photovoltaic remuneration policies in the European Union. *Energy Policy* 2013, 55:317–328. doi:10.1016/j.enpol.2012.12.011.
15. Avril S, Mansilla C, Busson M, Lemaire T. Photovoltaic energy policy: financial estimation and performance comparison of the public support in five representative countries. *Energy Policy* 2012, 51:244–258. doi:10.1016/j.enpol.2012.07.050.
16. Dong CG. Feed-in tariff vs. renewable portfolio standard: an empirical test of their relative effectiveness in promoting wind capacity development. *Energy Policy* 2012, 42:476–485. doi:10.1016/j.enpol.2011.12.014.
17. Kwon T-H. Rent and rent-seeking in renewable energy support policies: feed-in tariff vs. renewable portfolio standard. *Renew Sustain Energy Rev* 2015, 44:676–681. doi:10.1016/j.rser.2015.01.036.
18. Davies LL. Reconciling renewable portfolio standards and feed-in tariffs. *Utah Environ Law Rev* 2012, 35:311–361.
19. Bull P, Long N, Steger C. Designing feed-in tariff policies to scale clean distributed generation in the U.S. *Elect J* 2011, 24:52–58. doi:10.1016/j.tej.2011.02.009.
20. Timilsina GR, Kurdgelashvili L, Narbel PA. Solar energy: markets, economics and policies. *Renew Sustain Energy Rev* 2012, 16:449–465. doi:10.1016/j.rser.2011.08.009.
21. Hamilton K. *Unlocking Finance for Clean Energy: The Need for 'Investment Grade' Policy*. London, UK: Chatham House; 2009. Available at: <http://www.chathamhouse.org/expert/kirsty-hamilton>.
22. Mills L. *Global Trends in Clean Energy Investment—Rebound in Clean Energy Investment in 2014 Beats Expectations*. Seoul, Korea: Bloomberg New Energy Finance; 2015. Available at: <http://about.bnef.com/presentations/clean-energy-investment-q4-2014-fact-pack/>.
23. Jacobsson R, Jacobsson S. The emerging funding gap for the European energy sector—will the financial sector deliver? *Environ Innov Soc Transit* 2012, 5:49–59. doi:10.1016/j.eist.2012.10.002.
24. Wüstenhagen R, Menichetti E. Strategic choices for renewable energy investment: conceptual framework and opportunities for further research. *Energy Policy* 2012, 40:1–10. doi:10.1016/j.enpol.2011.06.050.
25. Dobbs R, Pohl H, Lin D-Y, Mischke J, Garemo N, Hexter J, Matzinger S, Palter R, Nanavatty R. *Infrastructure Productivity: How to Save \$1 Trillion a Year*. Seoul, Korea: McKinsey Global Institute; 2013. Available at: http://www.mckinsey.com/insights/engineering_construction/infrastructure_productivity.
26. American Society of Civil Engineers. *2013 Report Card for America's Infrastructure*. American Society of Civil Engineers; 2013. Available at: <http://www.infrastructurereportcard.org/>.
27. Asian Development Bank. *Infrastructure for a Seamless Asia*. Tokyo: Asian Development Bank and Asian

- Development Bank Institute; 2009. Available at: <http://www.adbi.org/files/2009.08.31.book.infrastructure.seamless.asia.pdf>.
28. European Commission. *Long-Term Financing of the European Economy—Green Paper, COM(2013) 150 final*. Brussels: European Commission; 2013. Available at: http://ec.europa.eu/finance/general-policy/financing-growth/long-term/index_en.htm.
 29. Organization for Economic Co-operation and Development. *Infrastructure to 2030, Volume 2—Mapping Policy for Electricity, Water and Transport*. Paris: OECD Publishing; 2007. Available at: <http://www.oecd.org/futures/infrastructureto2030/40953164.pdf>.
 30. Fulton M, Capalino R. *Investing in the Clean Trillion: Closing the Clean Energy Investment Gap*. Boston, MA: CERES; 2014. Available at: <http://www.ceres.org/resources/reports/investing-in-the-clean-trillion-closing-the-clean-energy-investment-gap/view>.
 31. Feldman D, Lowder T. Banking on solar: an analysis of banking opportunities in the U.S. distributed photovoltaic market. Technical Report NREL/TP-6A20-62605, National Renewable Energy Laboratory, 2014. Available at: <http://www.nrel.gov/docs/fy15osti/62605.pdf>. (Accessed August 31, 2015).
 32. Kreycik C, Couture TD, Cory KS. Innovative feed-in tariff designs that limit policy costs. Technical Report NREL/TP-6A20-50225, National Renewable Energy Laboratory, 2011. Available at: <http://www.nrel.gov/docs/fy11osti/50225.pdf>. (Accessed August 31, 2015).
 33. Wirth H. *Recent Facts about Photovoltaics in Germany*. Freiburg, Germany: Fraunhofer Institute; 2015. Available at: <http://www.ise.fraunhofer.de/en/renewable-energy-data>.
 34. http://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/ErneuerbareEnergien/Photovoltaik/Photovoltaik_node.html. (Accessed March 7, 2015).
 35. Newell P. The governance of energy finance: the public, the private and the hybrid. *Global Policy* 2011, 2:94–105. doi:10.1111/j.1758-5899.2011.00104.x.
 36. <http://english.seoul.go.kr/policy-information/environment-energy/climate-environment/5-one-less-nuclear-power-plant-2/>. (Accessed March 7, 2015).
 37. Taminiau J, Saul K, Schweitzer G, Mohazzam S, Byrne J. Democratic finance: energy of the people, by the people, for the people. Policy Note No. 2, Foundation for Renewable Energy and Environment, 2014. Available at: <http://freefutures.org/free-policy-briefs/policy-briefs>. (Accessed August 31, 2015).
 38. Foundation for Renewable Energy & Environment. Sustainable energy utility (SEU): understanding the basics. Policy Brief No. 1, Foundation for Renewable Energy and Environment, 2013. Available at: <http://freefutures.org/free-policy-briefs/policy-briefs>. (Accessed August 31, 2015).
 39. Foundation for Renewable Energy & Environment. Sustainable energy utility (SEU): the business model of the SEU. Policy Brief No. 2, Foundation for Renewable Energy and Environment, 2013. Available at: <http://freefutures.org/free-policy-briefs/policy-briefs>. (Accessed August 31, 2015).
 40. World Bank. *World Development Report 2010 – Development and Climate Change*. Washington, DC: World Bank; 2010. Available at: <https://openknowledge.worldbank.org/handle/10986/4387>.
 41. Suzuki H, Dastur A, Mofatt S, Yabuki N, Maruyama H. *Eco² Cities—Ecological Cities As Economic Cities*. Washington, DC: World Bank; 2010. Available at: <http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1270074782769/Eco2CitiesBookWeb.pdf>.
 42. Bulkeley H, Betsill MM. Revisiting the urban politics of climate change. *Environ Polit* 2013, 22:136–154. doi:10.1080/09644016.2013.755797.
 43. Carbon Disclosure Project. *Protecting Our Capital—How Climate Adaptation in Cities Creates a Resilient Place for Business*. London, UK: Carbon Disclosure Project; 2014. Available at: <https://www.cdp.net/CDPResults/CDP-global-cities-report-2014.pdf>.
 44. ARUP. *Climate Action in Megacities—C40 Cities Baseline and Opportunities*. Washington, DC: ARUP; 2014. Available at: http://www.arup.com/projects/c40_cities_climate_action_in_megacities_report.aspx.
 45. ARUP. *Working Together—Global Aggregation of City Climate Change Commitments*. Washington, DC: ARUP; 2014. Available at: http://publications.arup.com/Publications/G/Global_Aggregation_of_City_Climate_Commitments.aspx.
 46. Hoffmann MJ. *Climate Governance at the Crossroads: Experimenting with a Global Response after Kyoto*. Oxford: Oxford University Press; 2011.
 47. Sovacool BK. An international comparison of four polycentric approaches to climate and energy governance. *Energy Policy* 2011, 39:3832–3844. doi:10.1016/j.enpol.2011.04.014.
 48. Ostrom E. Nested externalities and polycentric institutions: must we wait for global solutions to climate change before taking action at other scales? *Econ Theory* 2012, 49:353–369. doi:10.1007/s00199-010-0558-6.
 49. Aylett A. *Progress and Challenges in the Urban Governance of Climate Change: Results from a Global Survey*. Cambridge, MA: Massachusetts Institute of Technology; 2014. Available at: <http://www.urbanclimatesurvey.com/>.
 50. Broto VC, Bulkeley H. A survey of urban climate change experiments in 100 cities. *Glob Environ Chang* 2013, 23:92–102. doi:10.1016/j.gloenvcha.2012.07.005.
 51. Merk O, Saussier S, Staropoli C, Slack E, Kim J-H. Financing green urban infrastructure. OECD Regional

- Development Working Papers, Series Number 2012/10, OECD Publishing, 2012.
52. Gautam BR, Li F, Ru G. Assessment of urban roof top solar photovoltaic potential to solve power shortage problem in Nepal. *Energy Build* 2015, 86:735–744. doi:10.1016/j.enbuild.2014.10.038.
 53. Peng J, Lu L. Investigation on the development potential of rooftop PV system in Hong Kong and its environmental benefits. *Renew Sustain Energy Rev* 2013, 27:149–162. doi:10.1016/j.rser.2013.06.030.
 54. Raul FCM, Szklo A, Schaeffer R. Technical-economic potential of PV systems on Brazilian rooftops. *Renew Energy* 2015, 75:694–713. doi:10.1016/j.renene.2014.10.037.
 55. Defaix P, van Stark W, Worrell E, de Visser E. Technical potential for photovoltaics on buildings in the EU-27. *Sol Energy* 2012, 86:2644–2653. doi:10.1016/j.solener.2012.06.007.
 56. POLIS. Available at: <http://www.polis-solar.eu/>. (Accessed March 7, 2015).
 57. Amsterdam Municipality. *Zonvisie Amsterdam—burgers en bedrijven gaan voor de zon (Solar Vision Amsterdam—Citizens and Businesses Pursue the Sun)*. Amsterdam, The Netherlands: Amsterdam Municipality; 2014. Available at: <http://www.amsterdam.nl/wonen-leefomgeving/klimaat-energie/publicaties/zonvisie-amsterdam/>.
 58. Doust M, Daw P, North P, Tudway R, Young A, Price D. *Decentralized Energy Capacity Study—Phase 1: Technical Assessment*. London: Greater London Authority; 2011. Available at: <http://www.london.gov.uk/priorities/environment/publications/decentralised-energy-capacity-study>.
 59. City of New York. *BYTES of the BIG APPLE™ Database*. New York, NY: New York City Planning; 2014. Available at: <http://www.nyc.gov/html/dcp/html/bytes/applbyte.shtml>. (Accessed March 7, 2015).
 60. Tokyo Metropolitan Government. *東京都統計年鑑 (Tokyo Statistical Yearbook) (In Japanese)*. Tokyo, Japan: Statistics of Tokyo; 2014. Available at: <http://www.toukei.metro.tokyo.jp/tnenkan/tn-index.htm>.
 61. POLIS. Urban solar planning—the local state of the art in Munich. Identification and mobilisation of solar potentials via local strategies (POLIS), 2010. Available at: http://www.polis-solar.eu/IMG/pdf/Munich_local_assessment.pdf. (Accessed August 31, 2015).
 62. Available at: <http://maps.muenchen.de/rgu/solarpotenzial>. (Accessed March 7, 2015).
 63. Center for Advanced Research of Spatial Information (CARSI). CARSI presentations. Available at: <http://www.carsilab.org/>; and visualization of the data available at: <http://www.nycsolarmap.com/>.
 64. Whitaker CM, Townsend TU, Razon A, Hudson RM, Valive X. PV systems. In: Luque A, Hegedus S, eds. *Handbook of Photovoltaic Science and Engineering*. 2nd ed. West Sussex, UK: Wiley; 2011, 841–895.
 65. International Code Council. *International Fire Code*. Washington, DC: International Code Council; 2012. Available at: <https://ia700505.us.archive.org/34/items/gov.law.icc.ifc.2012/icc.ifc.2012.pdf>.
 66. California Department of Forestry and Fire Protection Office of the State Fire Marshal. *Solar Photovoltaic Installation Guide*. Sacramento, CA: California Department of Forestry and Fire Protection; 2008. Available at: http://gov.ca.gov/docs/ec/CalFIRE_Solar_PV_guideline.pdf.
 67. Available at: http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm. (Accessed March 7, 2015).
 68. Byrne J, Kurdgelashvili L, Couey J. *PV Planner: A Design and Analysis Tool for Solar Electric Systems—Updated User Manual*. Newark, DE: Center for Energy and Environmental Policy (CEEP); 2011. Available at: <http://ceep.udel.edu/publications/ceep-publications-2011-2012/>.
 69. International Energy Agency (IEA). *Medium Term Renewable Energy Market Report 2014—Market Analysis and Forecasts to 2020*. Paris: IEA; 2014. Available at: <http://www.iea.org/Textbase/npsum/MTrenew2014sum.pdf>.
 70. Lemmens J, van der Burgt J, Bosma T, van den Wijnngaart R, van Bommel B, Koelemeijer R. *PV potentieelstudie—het potentieel van zonnestroom in de gebouwde omgeving van Nederland (Analysis PV Potential—The Solar Energy Potential of the Built Environment in the Netherlands)*. The Hague, The Netherlands: Planbureau voor de leefomgeving (PBL) & DNV GL; 2014. Available at: <http://www.pbl.nl/publicaties/het-potentieel-van-zonnestroom-in-de-gebouwde-omgeving-van-nederland>.
 71. <http://datatopics.worldbank.org/hnp/popestimates>. (Accessed March 7, 2015).
 72. <http://esa.un.org/unpd/wup/>. (Accessed March 7, 2015).
 73. <http://pad.human.cornell.edu/>. (Accessed March 7, 2015).
 74. Tokyo Metropolitan Government. *Tokyo 2020*. Tokyo: Tokyo Metropolitan Government; 2011. Available at: <http://www.metro.tokyo.jp/INET/KEIKAKU/2011/12/70lcm101.htm>.
 75. <http://www.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcM%3A77-335242>. (Accessed March 7, 2015).
 76. Carbon Disclosure Project (CDP). *CDP Cities 2011—Global Report on C40 Cities*. London, UK: CDP; 2011. Available at: <https://www.cdp.net/Documents/archive/2011/CDP-Cities-2011-Report.pdf>.
 77. [https://www.london.gov.uk/priorities/business-economy/championing-london/london-and-european-](https://www.london.gov.uk/priorities/business-economy/championing-london/london-and-european)

- structural-funds/european-regional-development-fund/jessica-london-green-fund. (Accessed March 7, 2015).
78. Kennedy C, Bristow D, Derrible S, Mohareb E, Saneinejad S, Stupka R, Sugar L, Zizzo R, McIntyre B. Getting to carbon neutral: a review of best practices in infrastructure strategy. In: Bose BK, ed. *Energy Efficient Cities: Assessment Tools and Benchmarking Practices*. Washington, DC: World Bank; 2010, 165–184.
 79. Canuto O, Liu L. *Sub-National Debt Finance: Make It Sustainable*. Washington, DC: World Bank; 2010. Available at: http://siteresources.worldbank.org/EXTPREMNET/Resources/C13TDAT_219-238.pdf.
 80. Organization for Economic Co-operation and Development. *Cities and Climate Change*. Paris: OECD Publishing; 2014. Available at: <http://www.oecd.org/env/cc/Cities-and-climate-change-2014-Policy-Perspectives-Final-web.pdf>.
 81. Lane P. External funding and long-term investment. In: Heath A, Read M, eds. *Financial Flows and Infrastructure Planning*. Sydney: Reserve Bank of Australia; 2014, 43–61. Available at: <http://www.rba.gov.au/publications/confs/2014/pdf/conf-vol-2014.pdf>.
 82. Poole E, Toohey C, Harris P. Public infrastructure: a framework for decision-making. In: Heath A, Read M, eds. *Financial Flows and Infrastructure Planning*. Sydney: Reserve Bank of Australia; 2014, 97–135. Available at: <http://www.rba.gov.au/publications/confs/2014/pdf/conf-vol-2014.pdf>.
 83. High Level Expert Group on SME and Infrastructure Financing. *Finance for Growth: High Level Expert Group on SME and Infrastructure Financing*. Brussels: European Commission; 2013. Available at: http://europa.eu/efc/working_groups/hleg_report_2013.pdf.
 84. Organization for Economic Co-operation and Development. *Private Financing and Government Support to Promote Long-Term Investments in Infrastructure*. Paris: OECD Publishing; 2014. Available at: <http://www.oecd.org/daf/fin/private-pensions/Private-financing-and-government-support-to-promote-LTI-in-infrastructure.pdf>.
 85. Croce D, Kaminker C, Stewart F. *The Role of Pension Funds in Financing Green Growth Initiatives*. Paris: OECD Publishing; 2011. Available at: <http://www.oecd.org/finance/private-pensions/49016671.pdf>.
 86. Organization for Economic Co-operation and Development. *Pension Markets in Focus 2014*. Paris: OECD Publishing; 2014. Available at: <http://www.oecd.org/daf/fin/private-pensions/Pension-Markets-in-Focus-2014.pdf>.
 87. Mercer. *Climate Change Scenarios—Implications for Strategic Asset Allocation*. Washington, DC: Mercer; 2011. Available at: http://www.ifc.org/wps/wcm/connect/6b85a6804885569fba64fa6a6515bb18/ClimateChangeSurvey_Report.pdf?MOD=AJPERES.
 88. United Nations Environment Program (UNEP). *Financial Institutions Taking Action on Climate Change: A Report on How Climate Leadership is Emerging in the Finance Sector—And on How Public and Private Actors Need to Work Together to Grow Leadership into a New Normal*. Nairobi, Kenya: UNEP; 2014. Available at: <http://www.investorsonclimatechange.org/>.
 89. Organization for Economic Co-operation and Development. *Annual Survey of Large Pension Funds and Public Pension Reserve Funds*. Paris: OECD Publishing; 2013. Available at: <http://www.oecd.org/finance/private-pensions/survey-large-pension-funds.htm>.
 90. Veys A. The sterling bond markets and low carbon or green bonds—a report to E3G. Available at: http://www.e3g.org/docs/The_Sterling_Bond_Markets.pdf. (Accessed August 31, 2015).
 91. Climate Bonds Initiative. *Year 2014 Green Bonds Final Report—Final 2014 Green Bond Total is \$36.6bn*. London, UK: Climate Bonds Initiative; 2014. Available at: <http://www.climatebonds.net/year-2014-green-bonds-final-report-0>.
 92. Climate Bonds Initiative. *Bonds and Climate Change—The State of the Market in 2014*. London, UK: Climate Bonds Initiative; 2014. Available at: <http://www.climatebonds.net/bonds-climate-change-2014>.
 93. Bloomberg New Energy Finance. *Green Bonds Market Outlook 2014—Blooming with New Varietals*. Washington, DC: Bloomberg New Energy Finance; 2014. Available at: <http://about.bnef.com/white-papers/green-bonds-market-outlook-2014/>.
 94. Ehlers T, Packer F, Remolona E. Infrastructure and corporate bond markets in Asia. In: Heath A, Read M, eds. *Financial Flows and Infrastructure Planning*. Sydney: Reserve Bank of Australia; 2014, 67–91. Available at: <http://www.rba.gov.au/publications/confs/2014/pdf/conf-vol-2014.pdf>.
 95. Byrne J, Taminiau J. A review of sustainable energy utility and energy service utility concepts and applications: realizing ecological and social sustainability with a community utility. *WIREs Energy Environ* 2015. doi:10.1002/wene.171.
 96. Moody's Investors Service. *Infrastructure Default and Recovery Rates, 1983–2013*. New York, NY: Moody's Investors Service; 2014. Available at: https://www.moody.com/research/Moodys-Infrastructure-default-and-recovery-rates-underscore-rating-stability-in-PR_299153.
 97. Stringer SM. *A Green Bond Program for New York City*. New York, NY: Office of the New York City Comptroller—Bureau of Public Finance; 2014. Available at: http://comptroller.nyc.gov/wp-content/uploads/documents/Green_Bond_Program_-September.pdf.
 98. <http://www.climatebonds.net/2014/10/development-bank-japan-issues-green-property-bond-eur-250m-315m-coupon-025-3yr-aa3a-3x>. (Accessed March 7, 2015).

99. Cox E, Schmuecker K. *Beyond Banks and Big Government—Strategies for Local Authorities to Promote Investment*. London, UK: Institute for Public Policy Research; 2013. Available at: http://www.ippr.org/assets/media/images/media/files/publication/2013/03/Beyond-Banks-Big-Govt_MAR2013_10545.pdf.
100. http://www.local.gov.uk/finance/-/journal_content/56/10180/3684139/ARTICLE. (Accessed March 7, 2015).
101. Vetter S, Zipfel F, Fritsche J. *Small Is Beautiful? Capital Market Funding for Sub-Sovereign Authorities on the Rise*. Frankfurt am Main: Deutsche Bank; 2014. Available at: <https://www.dbresearch.com/>.
102. Zipfel F, Mann S. *Einer für alle, alle für Einen? Kommunale Finanzagentur—ein Überblick (One for All, All for One? Community Finance Agencies—An Overview)*. Frankfurt am Main: Deutsche Bank; 2012. Available at: <https://www.dbresearch.com/>.
103. Jenkner E, Lu Z. Sub-national credit risk and sovereign bailouts—who pays the premium? Working Paper No. WP/14/20, International Monetary Fund (IMF). 2014. Available at: <https://www.imf.org/external/pubs/ft/wp/2014/wp1420.pdf>. (Accessed August 31, 2015).
104. Zipfel F, Zimmer J. *Länder Bonds—What Drives the Spreads between Federal Bonds and Länder Bonds*. Frankfurt am Main: Deutsche Bank; 2013. Available at: <https://www.dbresearch.com/>.
105. Stringer SM, Levine MM. *Comprehensive Annual Financial Report of the Comptroller for the Fiscal Year Ended June 30, 2014*. New York, NY: Office of the New York City Comptroller; 2014. Available at: <http://comptroller.nyc.gov/wp-content/uploads/documents/CAFR2014.pdf>.
106. International Energy Agency (IEA). IEA PVPS trends 2014 in PV applications—survey report of selected IEA countries between 1992 and 2013. Report No. IEA-PVPS T1-25, International Energy Agency Photovoltaic Power Systems Program, 2014. Available at: <http://iea-pvps.org/index.php?id=32>. (Accessed August 31, 2015).
107. Sociaal-Economische Raad (SER). *Energieakkoord voor duurzame groei: voortgangsrapportage 2014 (Energy Agreement for Sustainable Growth: Progress Report 2014)*. The Hague: SER; 2014. Available at: <http://www.energieakkoordser.nl/publicaties/voortgangsrapportage-2014.aspx>.
108. International Energy Agency (IEA). *Energy Policies of IEA Countries: Netherlands 2014*. Paris: IEA; 2014. Available at: http://www.iea.org/bookshop/470-Energy_Policies_of_IEA_Countries_-_The_Netherlands.
109. Agentschap NL. *Jaarbericht 2012 SDE+, SDE en MEP (in Dutch)*. The Hague, The Netherlands: Rijksdienst voor Ondernemers (RVO); 2012. Available at: <https://www.rvo.nl/sites/default/files/Jaarbericht%202012%20SDE%2B%20printversie.pdf>.
110. Lensink SM, van Zuijlen CL. *Eindadvies basisbedragen SDE+ 2015 (in Dutch)*. Petten, The Netherlands: Energy Centre Netherlands (ECN); 2014. Available at: <https://www.ecn.nl/publicaties/ECN-E--14-035>.
111. Rijksdienst voor Ondernemend Nederland. *Energie Investeringsaftrek (EIA)—Energijlijst 2015 (in Dutch)*. The Hague, The Netherlands: Rijksdienst voor Ondernemend Nederland; 2015. Available at: <http://www.rvo.nl/sites/default/files/2014/12/Energie%20investeringsaftrek%20-%20Energijlijst%202015.pdf>.
112. Dusonchet L, Telaretti E. Comparative economic analysis of support policies for solar PV in the most representative EU countries. *Renew Sustain Energy Rev* 2015, 42:986–998. doi:10.1016/j.rser.2014.10.054.
113. Cherrington R, Goodship V, Longfield A, Kirwan K. The feed-in tariff in the UK: a case study focus on domestic photovoltaic systems. *Renew Energy* 2013, 50:421–426. doi:10.1016/j.renene.2012.06.055.
114. <https://www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies/supporting-pages/the-renewables-obligation-ro>. (Accessed March 7, 2015).
115. OFGEM. *Feed-in Tariff Generation & Export Payment Rate Table for Photovoltaic Installations—FIT Year 6 (2015/16)*. London, UK: OFGEM; 2015. Available at: <https://www.ofgem.gov.uk/ofgem-publications/92754/fitpvtariffablefor1april2015-amended.pdf>.
116. Fulton M, Capalino R, Auer J. *The German Feed-in Tariff: Recent Policy Changes*. Frankfurt am Main: Deutsche Bank; 2012. Available at: www.dbresearch.com.
117. <http://www.dsireusa.org/>. (Accessed March 7, 2015).
118. <http://www.lipower.org/powering/csip.html>. (Accessed March 7, 2015).
119. Burr J, Dutzik T, Schneider J, Sargent R. *Shining Cities: At the Forefront of America's Solar Energy Revolution*. Boston, MA: Environment America; 2014. http://www.environmentamerica.org/sites/environment/files/reports/EA_shining_cities_scrn_0.pdf.
120. http://www.knrec.or.kr/knrec/12/KNREC120700_02.asp. (Accessed March 7, 2015).
121. Lee T, Lee T, Lee Y. An experiment for urban energy autonomy in Seoul: the One 'Less' Nuclear Power Plant Policy. *Energy Policy* 2014, 74:311–318. doi:10.1016/j.enpol.2014.08.023.
122. http://www.enecho.meti.go.jp/category/saving_and_new/saiene/kaitori/kakaku.html. (Accessed March 7, 2015).
123. Van Sark W, Muizebelt P, Cace J. *Inventarisatie PV markt Nederland—Prijsonwikkelingen 2013 (in Dutch)*. Utrecht, The Netherlands: Stichting Monitoring Zonnestroom; 2014. Available at: <http://www.zonnestroomnl.nl/wp-content/uploads/2014/07/markt-inventarisatie-jan2014.pdf>.
124. Ministerie van Economische Zaken. *Prijzvergelijk elektriciteit (in Dutch)*. The Hague, The Netherlands:

- Ministerie van Economische Zaken & PWC; 2014. Available at: <http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2014/06/01/prijzvergelijk-elektriciteit.html>.
125. Tokyo Electric Power Company (TEPCO). *Fact Book 2014*. Tokyo, Japan: TEPCO; 2014. Available at: <http://www.tepco.co.jp/en/corpinfo/ir/tool/factbook/pdf/factbook-e.pdf>.
 126. Lazard. *Lazard's Levelized Cost of Energy Analysis—Version 8.0*. New York, NY: Lazard; 2014. Available at: <http://www.lazard.com/PDF/Levelized%20Cost%20of%20Energy%20-%20Version%208.0.pdf>.
 127. Barbose GL, Weaver S, Darghouth NR. Tracking the sun VII: an historical summary of the installed price of photovoltaics in the United States from 1998–2013. LBNL-6858E, National Renewable Energy Laboratory, 2014. Available at: <http://emp.lbl.gov/sites/all/files/lbnl-6858e.pdf>. (Accessed August 31, 2015).
 128. European Photovoltaic Industry Association (EPIA). *Global Market Outlook for Photovoltaics 2014–2018*. Brussels, Belgium: EPIA; 2014. Available at: <http://www.epia.org/news/publications/>.
 129. Fraunhofer Institute for Solar Energy Systems ISE. *Photovoltaics Report*. Freiburg: Fraunhofer Institute ISE; 2014. Available at: <http://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/photovoltaics-report-in-englischer-sprache.pdf>.
 130. International Energy Agency (IEA). *World Energy Outlook 2014*. Paris: IEA; 2014. Available at: <http://www.worldenergyoutlook.org/publications/weo-2014/>.
 131. U.S. Energy Information Administration (EIA). *Annual Energy Outlook 2014 with Projections to 2040*. Washington, DC, USA: EIA; 2014. Available at: <http://www.eia.gov/forecasts/aeo/>.
 132. <http://www.imf.org/external/ns/cs.aspx?id=28>. (Accessed March 7, 2015).
 133. <http://www.solarwirtschaft.de/en/photovoltaic-market/political-framework.html>. (Accessed March 7, 2015).
 134. Seel J, Barbose GL, Wiser R. An analysis of residential PV system price differences between the United States and Germany. *Energy Policy* 2014, 69:216–226. doi:10.1016/j.enpol.2014.02.022.
 135. Feldman D, Barbose GL, Margolis R, James T, Weaver S, Darghouth N, Fu R, Davidson C, Booth S, Wiser R. Photovoltaic system pricing trends—historical, recent, and near-term projections 2014 edition. NREL/PR-6A20-62558, U.S. Department of Energy SunShot, 2014. Available at: <http://www.nrel.gov/docs/fy14osti/62558.pdf>. (Accessed August 31, 2015).
 136. Cameron L, van der Zwaan B. Employment factors for wind and solar energy technologies: a literature review. *Renew Sustain Energy Rev* 2015, 45:160–172. doi:10.1016/j.rser.2015.01.001.
 137. Perez R, Zweibel K, Hoff TE. Solar power generation in the US: too expensive, or a bargain? *Energy Policy* 2011, 39:7290–7297. doi:10.1016/j.enpol.2011.08.052.
 138. <http://www.thirdway.org/report/energy-finance-101-an-intro-to-yield-cos>. (Accessed March 7, 2015).
 139. <https://renewfund.com/wheel>. (Accessed March 7, 2015).
 140. Wei M, Patadia S, Kammen DM. Putting renewables and energy efficiency to work: how many jobs can the clean energy industry generate in the US? *Energy Policy* 2010, 38:919–931. doi:10.1016/j.enpol.2009.10.044.
 141. Van der Zwaan B, Cameron L, Kober T. Potential for renewable energy jobs in the Middle East. *Energy Policy* 2013, 60:296–304. doi:10.1016/j.enpol.2013.05.014.
 142. Lehr U, Lutz C, Edler D. Green jobs? Economic impacts of renewable energy in Germany. *Energy Policy* 2012, 47:358–364. doi:10.1016/j.enpol.2012.04.076.
 143. Lee CW, Zhong J. Financing and risk management of renewable energy projects with a hybrid bond. *Renew Energy* 2015, 75:779–787. doi:10.1016/j.renene.2014.10.052.