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This Policy Brief documents research performed by FREE researchers:

Byrne et al. (2015). A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul, Renewable and Sustainable Energy Reviews, Volume 41: 830-844

Byrne et al. (2016). 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. WIREs Energy & Environment 5(1): 68-88.

Byrne et al. (2017). Multivariate analysis of solar city economics: impact of energy prices, policy, finance, and cost on urban PV power plant implementation. WIREs Energy & Environment 6:e241.

Byrne J., Taminiau, J. Seo, J. Lee, J., & Shin, S. (2017) Are solar cities feasible? A review of current research, International Journal of Urban Sciences, 21:3, 239-256.

Urban Energy Transformation through Solar City Strategies

Large-scale design and installation of city-wide sustainable energy technologies combine the 'distributed' opportunities of renewable energy and energy efficiency with infrastructure-scale investment. City governance efforts to pursue such deployment are termed here 'solar city' strategies. This FREE Policy Brief explores research papers written by FREE researchers on the topic (see sidebar for references). In short, the papers highlight the value of the 'solar city' concept in the context of city-wide deployment of solar photovoltaics (PV), explore its potential for six cities across the world, and provide early insight into the practicality of the idea. Combined, the three papers suggest that the challenge of implementation can be satisfactorily addressed. The power plant of the future, as such, could be located in dense urban centers making use of existing but currently under-utilized assets – including but not limited to a city's rooftop real estate for PV deployment, the built environment for energy savings, and transport systems for energy storage. The focus throughout this Policy Brief is on solar energy.

Restructuring the urban energy infrastructure: The solar city concept

Assessments of urban solar energy potential have thoroughly and repeatedly demonstrated the significant promise of currently underutilized assets in large urban centers – namely, an abundance of rooftop real estate, which absorbs but does not productively utilize incident solar energy (Byrne et al., 2015). For instance, one study found that implementing the solar cities concept in Seoul could meet 66% of the city's typical daylight energy demand and significantly lower peak grid consumption (Byrne et al., 2015). The same study found that city-wide application of the concept could even make the 10.5 million people mega-city 'energy neutral' during certain times of the year (Byrne et al., 2015).

The introduction and research of the concept is timely as cities have taken up a prominent role in driving global energy sustainability (ARUP & C40, 2014; Aylett, 2014). A global survey effort, for instance, found that 75% of cities globally now seek to actively address climate change and energy issues (Aylett, 2014). Policy and finance experimentation takes place across the world to improve urban energy use profiles (Castán Broto & Bulkeley, 2013). The solar city concept could help drive this transformation. [1]As such, the practicality of the idea needs to be tested.

One way to approach this question of implementation is to position the 'solar city' concept as a city governance option that promotes public sector-led, infrastructure-scale design and investment of sustainable energy installations and measures in the urban environment. To illustrate the widespread opportunity, Figure 1 provides an overview of the rooftop solar electricity generation potential across a global assessment of cities. Focused here on solar energy, such a positioning of the concept of the

[1] The vision of the city as the 'power plant of the future' is not limited to solar energy as such strategies can include energy efficiency, wind energy, biomass energy, etc. Indeed, municipalities have abundant energy conservation potential. For instance, a recent study found a 33% energy reduction potential for the city of Stockholm (Shahrokni, Levihn, & Brandt, 2014).

'solar city' builds on sustainable energy finance strategies developed by FREE. [2] In particular, the four research papers together focus on the strategic option to securitize energy production capacity on cities' rooftop real estate. Such a financing pathway would be consistent with 'green bond' finance principles. [3] Ultimately, the transformation of urban energy economies along these lines draws infrastructure-scale private capital to drive and capture the 'distributed' public and private benefits of solar energy, including peak shaving, grid decongestion, hot spot' resolution, sustainability and health attributes, avoided costs for additional power, etc.

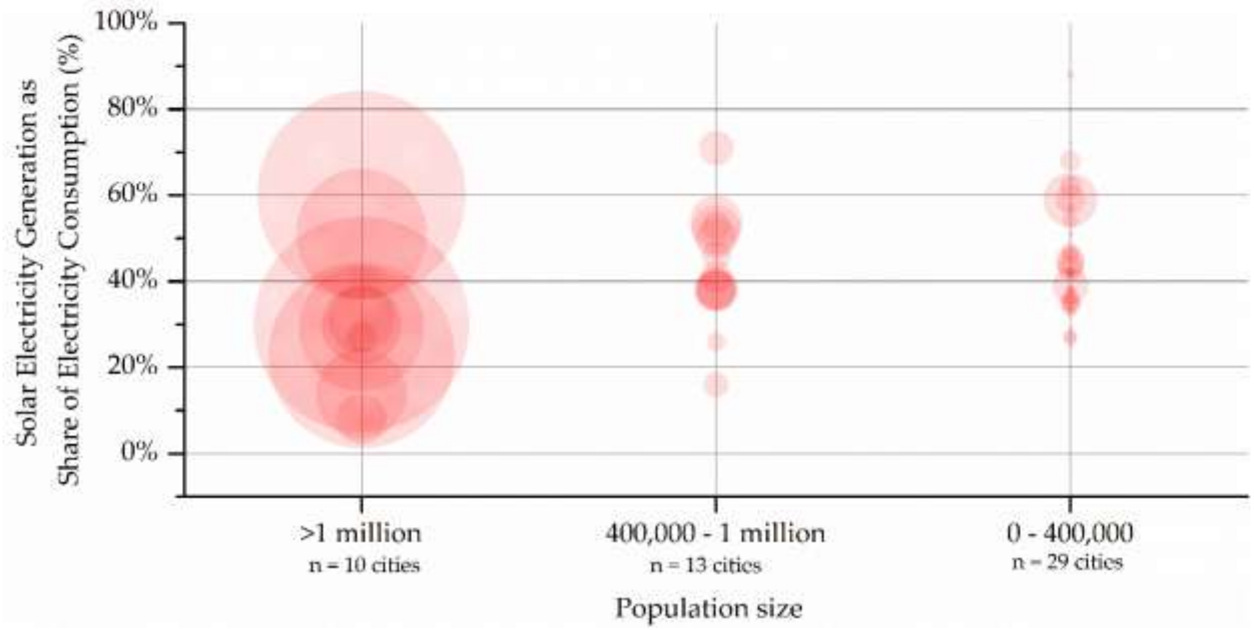

Figure 1. *Technical potential estimate for a selection of cities across the world. Bubble size determined by annual electricity generation of the solar city PV system. Source: Byrne et al. (2017).*

Deployment of such a strategy offers compelling economic advantages: an analysis performed by FREE researchers found that a $10 billion investment opportunity is available in six city case studies (Byrne et al., 2016). Such an investment opportunity is consistent with other

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[2] See FREE's webstie :http://freefutures.org

[3] A previous FREE policy brief discussed the green bond market. See http://freefutures.org/policybriefs/

investigations into overall economic potential of urban climate change mitigation. For instance, a study of four developing country cities, together representing 27.5 million people, found a total cost-effective abatement net present value of $4.3 billion (Sudmant et al., 2015).

Financing Solar Cities: 'Bridging the Investment Gap'

Over the next 15 years, roughly $57 trillion will be spent in financing new infrastructure (Dobbs et al., 2013). To avoid 'carbon lock-in', such investments will need to target sustainable energy options and measures (Erickson & Lazarus, 2015). The renewable energy sector has achieved substantial success in this regard: 85% of low-carbon mitigation expenditures in 2011, 76% in 2012, 78% in 2013, and 81% in 2014 were directed to renewable electricity investment (Buchner, Angela, Herve-Mignucci, & Trabacchi, 2012; Buchner et al., 2013; Buchner et al., 2014; Buchner, Trabacchi, Mazza, Abramskiehn, & Wang, 2015).

Bridging the investment gap is a critical first step towards the practical implementation of solar city strategies

Yet, it has been broadly established that a higher level of funds will need to be directed towards sustainable solutions (Croce, Kaminker, & Stewart, 2011). Bridging this 'investment gap' is a critical first step towards the practical implementation of a solar city strategy: cities, in particular, have indicated that lack of access to low-cost capital is a key barrier to implementing large-scale climate change mitigation measures (Aylett, 2014). To bridge the gap, the emerging and rapidly growing green bond market offers a possible source of funding (Byrne et al., 2016).

Moving beyond conventional project-to-project finance – motivated by green premiums established through policy – the successful use of the green bond option could drive infrastructure-scale deployment (Byrne et al., 2016). One key aspect in this equation is that the green bond market could offer financing at much lower cost. As Richard Kauffman, former senior adviser at the U.S. Department of Energy and now spearheading New York's energy finance efforts, notes:

> *"Projects in the U.S. rely upon an old fashioned and anachronistic form of financing that is different than how other parts of the US economy are financed. Rather than use bond or stock markets, projects depend on non-*

capital market sources of so called tax equity, bank debt, and private equity where rates of return can approach typical private equity rates of return of 12-15 percent. [New strategies}… don't require going to the lab; they Involve applying financing techniques that have already been invented and are used widely in other parts of the economy." [4]

Other, associated, benefits are that bonds represent standardized capital market investment instruments that are well known to the targeted investor base.

Rating agencies: PV securitization should be structured with 7-10 year maturities

Securitization of a solar city project, however, needs to be responsive to capital market preferences (Hall, Foxon, & Bolton, 2015). For example, in response to a 'mock' solar securitization filing, rating agencies indicated that the typical 20-year contract lifetime is too long and introduces too much uncertainty (Mendelsohn et al., 2015). As part of their feedback, the rating agencies proposed to structure securitization terms with maturities of 7-10 years.

Shorter maturities, however, can complicate solar city financing: a case study sample of six cities around the world shows that for all six cities a financing pathway is available under current conditions but is dependent on the allowed length of financing (Byrne et al., 2016). A 13-year financing timeframe could allow all six cities to implement a solar city option. However, for consecutively shorter maturities, more and more of the six municipalities struggle to maintain a positive cash flow throughout the lifetime of the project. For instance, for a ten-year maturity, only New York City appears capable of implementing a solar city project under current conditions.

[4] Richard Kaufman, former Special Adviser to U.S. Department of Energy Secretary Chu (July 25, 2012). See also Statement of Richard L. Kauffman, Chairman of Energy and Finance for New York State and Chairman of the New York State Research and Development Authority before the Senate Energy and Natural Resources Committee Hearing on Clean Energy Financing, July 18, 2013, http://www.energy.senate.gov/public/index.cfm/files/serve?File_id=0488fbd8-d2b9-4fae-962f-04833e7f78d5

Realizing Practical Implementation of Solar Cities around the World

Cash flow limitations restrict shorter financing periods under current conditions. However, the current conditions in each city, whether they are financial, technological, social, or otherwise, are not fixed and develop over time. In order to provide a better understanding of key parameters, it helps to visualize the 10-year maturity financing condition for all six cities in more detail (Figure 1). Specifically, Separating out the cities by electricity retail rate, such as in Figure 2, illustrates why, for instance, Seoul has the most difficulty establishing a solar city project: its low retail electricity rate – the basis for which energy revenues for the PV system are calculated – are the lowest in Seoul compared to the five other case studies.

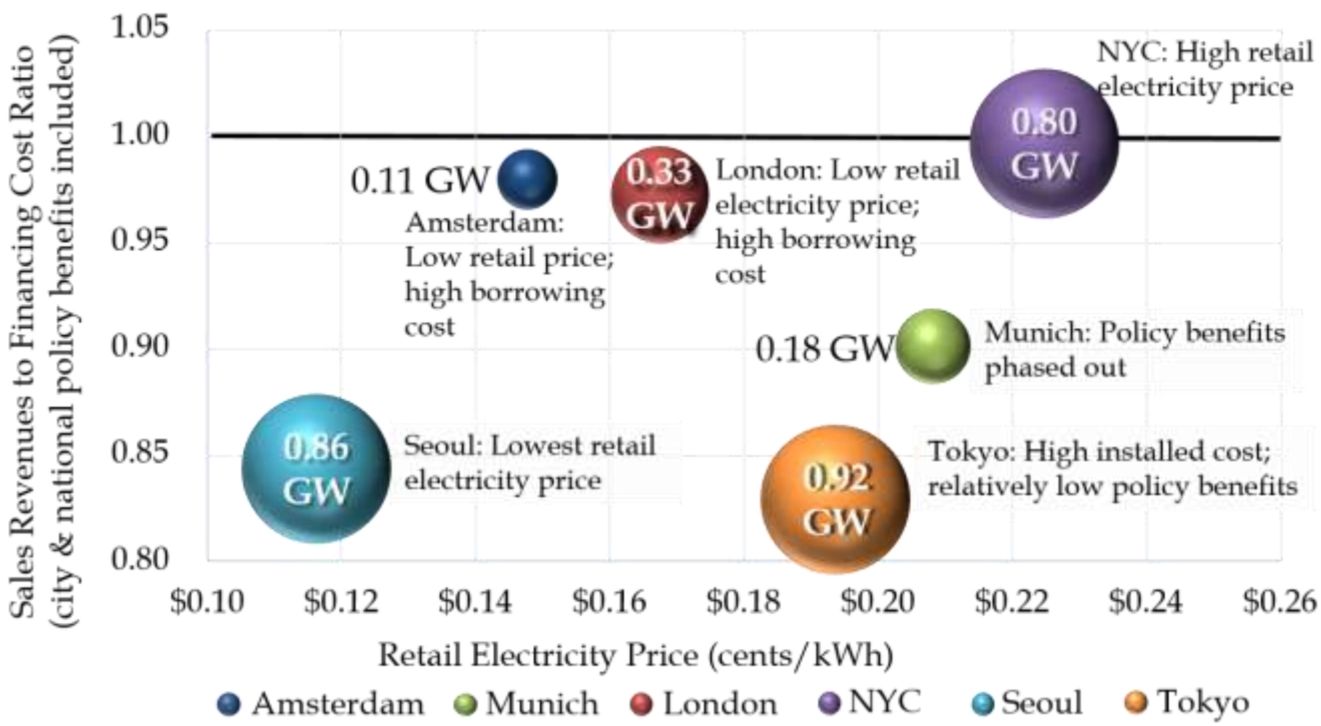

Figure 1. Solar city implementation options for the six municipalities under a 10-year financing maturity. Source: Byrne et al. (2016).

Figure 1 suggests that modification of existing conditions could improve the practical implementation potential of the solar city option. A solar city strategy that can 'de-risk' its profile, for instance, could perhaps extract a lower cost of capital from the bond market (Ondraczek, Komendantova, & Patt, 2015). Such 'de-risking' could be performed using a variety of techniques including overcollateralization, guarantees, or by using loss reserve funds.

Similarly, considerable heterogeneity exists in system costs even within single categories (Gillingham et al., 2014). Critically, albeit with diminishing returns, increasing system size can be identified as *the* key cost reduction option: increasing system size from 5^{th} to 95^{th} percentile reduces pre-incentive price points by about $1.5/W (Gillingham et al., 2014). The unique character of a solar city strategy – identifying suitable rooftop space for, in total, multi-GW installations –supports the idea that more attractive price points should be available for negotiation.

Gillingham et al. (2014) also show that, next to system size, there are a wide range of factors that cause price variability. One important component of PV system cost is the "soft" cost profile. The soft cost profile consists of price reduction options such as customer acquisition, permitting, and licensing. Considerable soft cost differences can be observed between locations. For instance, a commonly cited study in 2012 showed that residential systems in Germany were half the cost of same-size residential systems in the United States due to differences in soft cost profiles (Seel, Barbose, & Wiser, 2014). Similarly, a more recent analysis regarding U.S. soft costs found an 8-12% price reduction potential for a lowest-scoring municipality in relation to the highest-scoring soft cost environment (Burkhardt, Wiser, Darghouth, Dong, & Huneycutt, 2015). Mimicking soft cost profiles such as currently exist in Germany, for instance through the strategic deployment of new software solutions, local level streamlining of permitting, simplified project financing, etc., could significantly reduce the cost of a solar city project. Roadmaps for such options have been developed (Ardani et al., 2013).

Realizing such variation in conditions, the six-case study analysis performed by FREE researchers provides useful insights (Byrne et al., 2016, 2017). Using Monte Carlo techniques, Byrne et al. (2017) conducted extensive parameter modification and sensitivity analysis. The results of the analysis provide confidence to urban planners and decision-makers that solar city strategies are, indeed, a practical idea: all six cities could confidently implement solar cities under the right circumstances. In particular, New York City and Munich come very close to the 7 – 10 years preferred by credit rating agencies.

In Short…

First and foremost, urban solar energy potential is significant and has been thoroughly assessed in cities across the world (Byrne et al., 2015). Research targeting the practical implementation of solar city options suggest its feasible character (Byrne et al., 2016, 2017). The solar city option, in other words, provides a valuable and feasible strategy to contribute to the implementation of the 2015 Paris Agreement to address climate change.

Second, solar city modeling shows that significant opportunity exists in the six case study cities: New York, Seoul, Amsterdam, Tokyo, London, and Munich. With slight modification of existing conditions, financial feasibility of solar city options is within range.

FREE has been actively researching the potential of the solar city concept and will continue to further explore the value of this proposition. Risk assessment modeling of the solar city option is a next major step in the research direction within this topic.

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