Community Solar: Strategies and Implementation for Sustainability

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Community Solar: Strategies and Implementation for Sustainability

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Definitions

Through community solar, a multitude of households share in the electricity output from a nearby solar array (usually called “solar garden”) in the form of credits on their electricity bill or other revenue. Community solar is an umbrella term that encompasses many different models. The community solar featured in this chapter is different from “community solar installations” that are owned by a utility, or others, where passive participants are consumers without control over decision-making. The passive model is sometimes called “shared solar.” This chapter sets a preference for community ownership, what some jurisdictions refer to as “community-owned solar gardens.” A community solar garden is an example of a distributed energy resource (DER), a device or asset largely on the customer side (behind the meter), consisting of distributed generation, energy efficiency, voltage and frequency control, and storage. Distributed energy resources encourage demand side management (DSM), or the planning, implementing, and monitoring activities designed to encourage consumers to modify their level and patterns of electricity usage. When paired with storage and other distributed energy resources, community solar can become part of a microgrid. Microgrids are decentralized grids that can balance supply and demand locally through distributed energy resources. Microgrids can operate with, or independently from, the main power grid. This entry deals largely with community solar systems that are grid-tied, even if off-grid status may be attained temporarily. Although some general principles exist with standalone off-grid systems, readers interested in picogrids, mini-grids, and solar home systems (SHS) are directed towards the relevant literature (e.g., Bisaga 2020; Couture et al. 2019; Salas 2017).

Introduction

Driven by climate change and economics, energy generation is undergoing a necessary and rapid transformation towards non-emitting renewable energy, especially solar and wind. As the world decarbonizes, the energy grid will become distributed, characterized by increased local control and

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decreased transmission losses. The future grid also provides extensive energy security, local employment, and local risk reduction, if coupled with battery storage. Photovoltaics (PV), the direct production of electrical energy by photovoltaic cells, stand out as a key component in the required transition for social and economic reasons: scalability, safety, rapid deployment, longevity, reliability, resilience, and minimal emissions. In the last decade, the cost of solar has decreased precipitously and reached grid parity (costing the same or less than electricity from conventional sources) for most of the world in 2015. In 2019, unsubsidized residential solar was less expensive than most rates charged by utilities, while industrial solar-plus-storage produced electricity at rates that outcompeted all other means of electricity generation. Both residential and industrial solar have a miniscule carbon footprint, as compared with fossil fuels (Fig. 1). Since globally 64% of electricity is generated through the combustion of fossil fuels, the potential to decarbonize through solar and wind is not only enormous, but is a societal imperative. Decarbonization of electrical generation becomes even more essential considering the adoption of heat pumps, electric vehicles, and other electrification initiatives. As shown by Jacobson et al. (2019), using just wind, water, and solar, almost complete decarbonization of energy is achievable before 2050.

PV is a disruptive technology, since it renders obsolete the prevailing model of either state or privately owned, centralized energy production and distribution – a model that relies on socializing externalities. Not unexpectedly, those who are profiting from the current system are fighting hard to maintain this outdated model through campaigns of misinformation, lobbying regulators, and influencing politicians. Some of the persistent and misleading myths are summarized – and debunked – in Figs. 2 and 3. While Figs. 2 and 3 set the record straight on the real potential of solar power, they also depict the scale of the real and imagined barriers to widespread adoption of PV.

Community solar adds an important dimension in the transition to decarbonized energy: the power of collective action. The outcome is local participation in energy generation, which makes it possible for everybody to join the solar revolution: renters, apartment dwellers, and others who cannot, for one reason or another, install rooftop solar. As a communally owned resource, community PV opens exciting new avenues to apportion and lower initial investments in solar technology, tap into sources of funding not available to individuals, and generally lower electricity rates. In conjunction with storage, community solar can inject flexibility and positive interactions between solar gardens, microgrids, and the existing centralized grid.

In this period of multiple crises, the UN's Sustainable Development Goals (SDGs) offer a

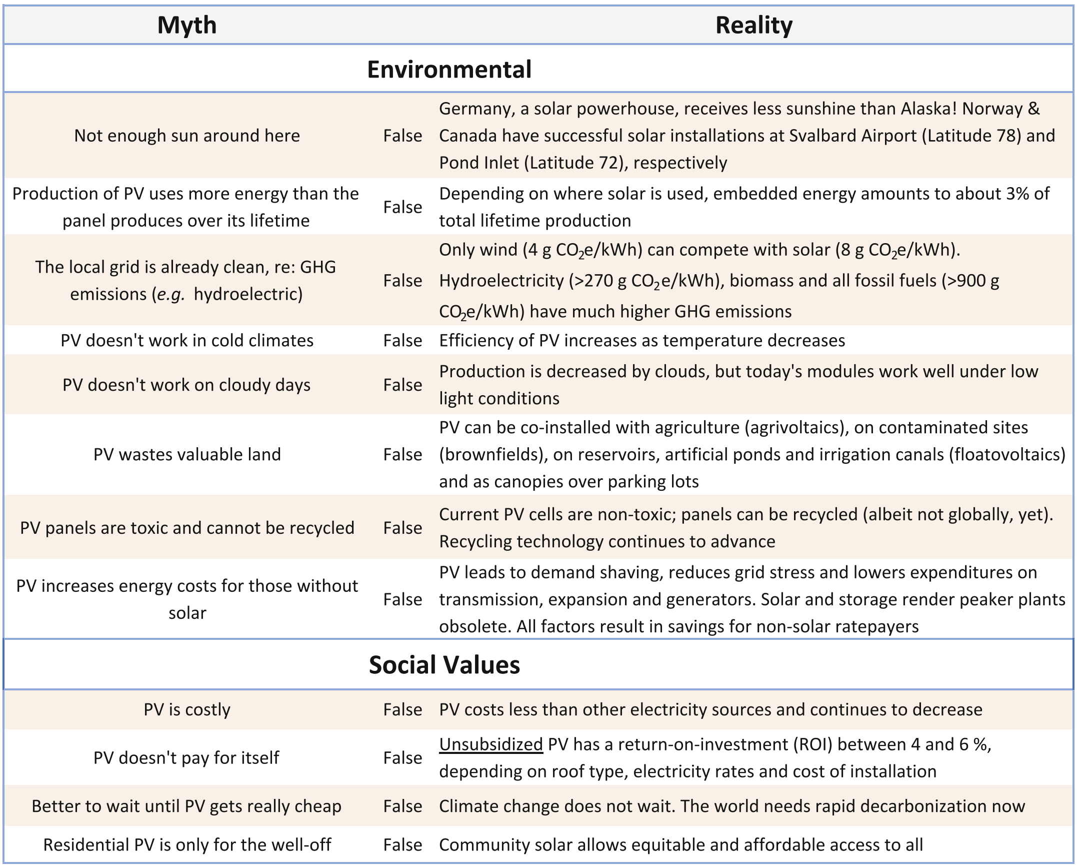
Offshore Wind	Construction & Operation	**~ 5**	g CO_2e/kWh
Photovoltaics	Full life cycle	**< 10**	g CO_2e/kWh
Hydroelectricity	Operation phase[b]	**~ 270**	g CO_2e/kWh
Natural gas/LNG	Combustion phase	**~ 720**	g CO_2e/kWh
Natural gas/LNG	Full life cycle	**> 1000**	g CO_2e/kWh
Gasoline/Diesel	Combustion phase	**~ 750**	g CO_2e/kWh
Coal	Full life cycle	**~ 1100**	g CO_2e/kWh
Biomass	Full life cycle	**~ 1200**	g CO_2e/kWh

Values for common energy generation/carriers emphasize order of magnitude differences between sources and are rounded to the nearest 10 g CO_2 equivalents/kWh, except for offshore wind

[a] contribution of methane emissions based on GWP potential (34x carbon dioxide) over 100 y horizon

[b] does not include emissions from construction, silt removal during operation, decommissioning

Community Solar: Strategies and Implementation for Sustainability, Fig. 1 Total greenhouse gas emissions[a] (carbon dioxide equivalents) from common generators and energy carriers



Myth		Reality
Environmental		
Not enough sun around here	False	Germany, a solar powerhouse, receives less sunshine than Alaska! Norway & Canada have successful solar installations at Svalbard Airport (Latitude 78) and Pond Inlet (Latitude 72), respectively
Production of PV uses more energy than the panel produces over its lifetime	False	Depending on where solar is used, embedded energy amounts to about 3% of total lifetime production
The local grid is already clean, re: GHG emissions (*e.g.* hydroelectric)	False	Only wind (4 g CO_2e/kWh) can compete with solar (8 g CO_2e/kWh). Hydroelectricity (>270 g CO_2e/kWh), biomass and all fossil fuels (>900 g CO_2e/kWh) have much higher GHG emissions
PV doesn't work in cold climates	False	Efficiency of PV increases as temperature decreases
PV doesn't work on cloudy days	False	Production is decreased by clouds, but today's modules work well under low light conditions
PV wastes valuable land	False	PV can be co-installed with agriculture (agrivoltaics), on contaminated sites (brownfields), on reservoirs, artificial ponds and irrigation canals (floatovoltaics) and as canopies over parking lots
PV panels are toxic and cannot be recycled	False	Current PV cells are non-toxic; panels can be recycled (albeit not globally, yet). Recycling technology continues to advance
PV increases energy costs for those without solar	False	PV leads to demand shaving, reduces grid stress and lowers expenditures on transmission, expansion and generators. Solar and storage render peaker plants obsolete. All factors result in savings for non-solar ratepayers
Social Values		
PV is costly	False	PV costs less than other electricity sources and continues to decrease
PV doesn't pay for itself	False	Unsubsidized PV has a return-on-investment (ROI) between 4 and 6 %, depending on roof type, electricity rates and cost of installation
Better to wait until PV gets really cheap	False	Climate change does not wait. The world needs rapid decarbonization now
Residential PV is only for the well-off	False	Community solar allows equitable and affordable access to all

Community Solar: Strategies and Implementation for Sustainability, Fig. 2 Debunking myths about Photovoltaics – Environmental and Social values

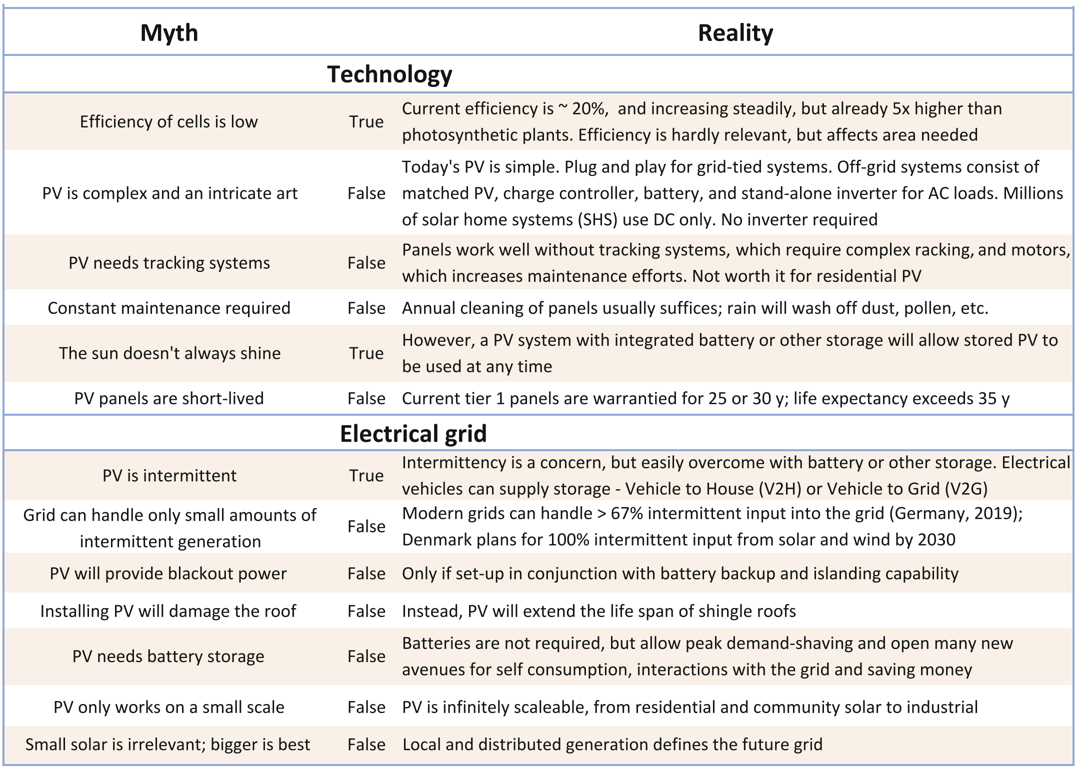
framework to understand and address global issues concurrently. The framework also ensures that tackling one goal does not incidentally hinder or reverse achievement of the others. Community-owned solar, especially with added storage, contributes to climate change action, pollution reduction, and energy security, while reducing the relatively high energy burden for low income households. Before addressing avenues to and challenges of community solar, it is necessary to briefly summarize the many benefits of PV, separating societal benefits from benefits to an existing electrical grid (Fig. 4).

Solar Energy

Solar Energy: Technology Landscape

Positive media attention to solar power has focused on the extraordinary drop in costs (85% over the last 10 years (Lazard 2019)), although annual decreases have slowed recently. Equally impressive are many other technological improvements, including:

- A doubling of PV efficiency from 10% to around 20% in the last decade (and still increasing)
- The recent advent of 500 W+ modules which will also help decrease balance of system (BOS) cost
- Canopy modules transmitting a predetermined percentage of light



Myth		Reality
Technology		
Efficiency of cells is low	True	Current efficiency is ~ 20%, and increasing steadily, but already 5x higher than photosynthetic plants. Efficiency is hardly relevant, but affects area needed
PV is complex and an intricate art	False	Today's PV is simple. Plug and play for grid-tied systems. Off-grid systems consist of matched PV, charge controller, battery, and stand-alone inverter for AC loads. Millions of solar home systems (SHS) use DC only. No inverter required
PV needs tracking systems	False	Panels work well without tracking systems, which require complex racking, and motors, which increases maintenance efforts. Not worth it for residential PV
Constant maintenance required	False	Annual cleaning of panels usually suffices; rain will wash off dust, pollen, etc.
The sun doesn't always shine	True	However, a PV system with integrated battery or other storage will allow stored PV to be used at any time
PV panels are short-lived	False	Current tier 1 panels are warrantied for 25 or 30 y; life expectancy exceeds 35 y
Electrical grid		
PV is intermittent	True	Intermittency is a concern, but easily overcome with battery or other storage. Electrical vehicles can supply storage - Vehicle to House (V2H) or Vehicle to Grid (V2G)
Grid can handle only small amounts of intermittent generation	False	Modern grids can handle > 67% intermittent input into the grid (Germany, 2019); Denmark plans for 100% intermittent input from solar and wind by 2030
PV will provide blackout power	False	Only if set-up in conjunction with battery backup and islanding capability
Installing PV will damage the roof	False	Instead, PV will extend the life span of shingle roofs
PV needs battery storage	False	Batteries are not required, but allow peak demand-shaving and open many new avenues for self consumption, interactions with the grid and saving money
PV only works on a small scale	False	PV is infinitely scaleable, from residential and community solar to industrial
Small solar is irrelevant; bigger is best	False	Local and distributed generation defines the future grid

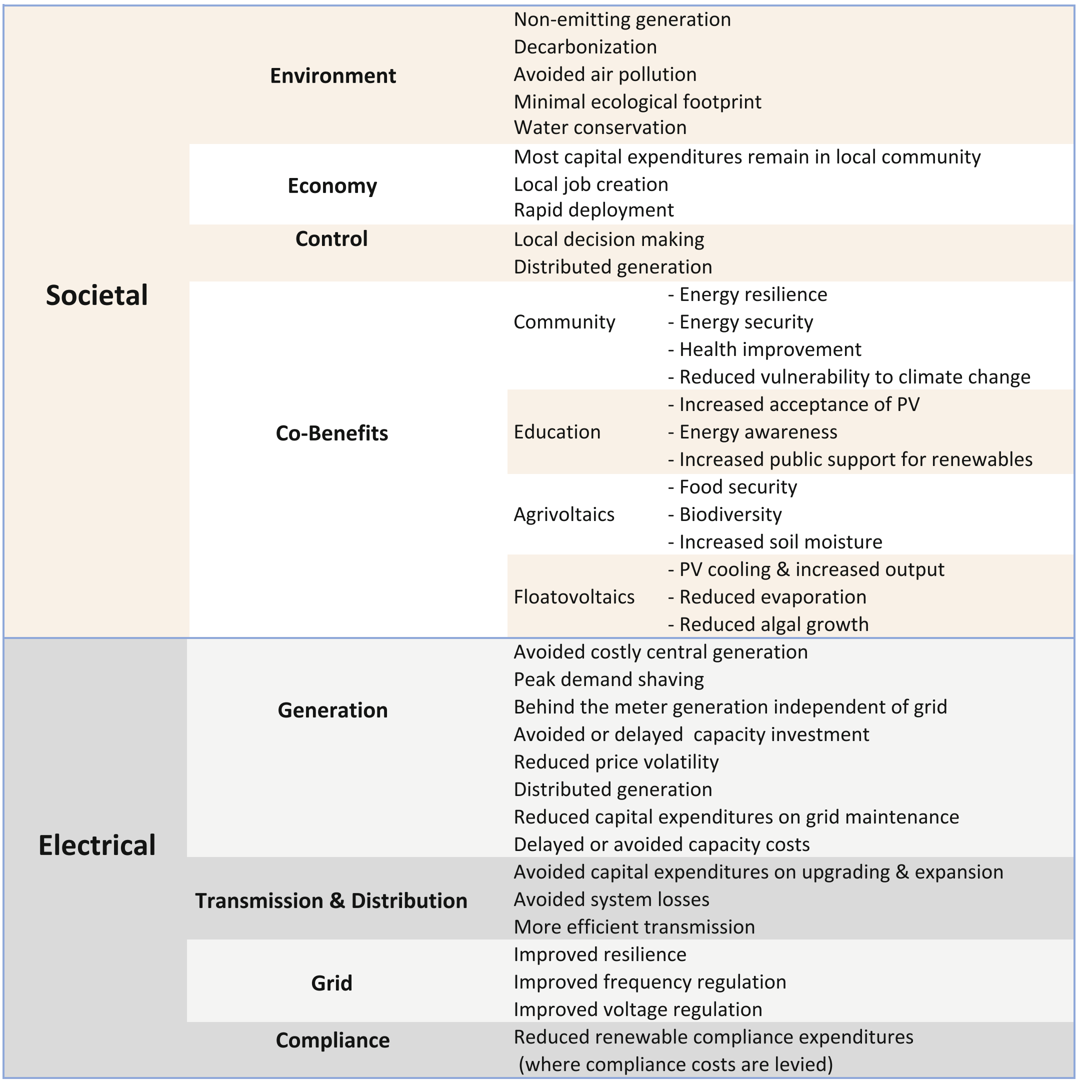
Community Solar: Strategies and Implementation for Sustainability, Fig. 3 Debunking myths about Photovoltaics – Technology and Electrical Grid

- Building integrated PV (BIPV)

Innovative approaches to co-locating PV arrays with other uses are creating co-benefits for food and water security as well as biodiversity. For example, agrivoltaics – co-locating PV on active farms – overcome the limits to solar expansion imposed by the cost of land and the concern about removing productive agricultural land. Similarly, floatovoltaics – that are often cheaper than land-based arrays – offer the advantages of combining power production with reduced evaporation, cooling of modules, reduced algal blooms, and reduction in water temperature by shading. The results are a more productive use of drinking water reservoirs, irrigation ditches, hydroelectric reservoirs, and canals, without expenses for land. Cooler waters and decreased algal growth also decrease the substantial greenhouse gas emissions associated specifically with hydroelectric reservoirs (Deemer et al. 2016; Prairie et al. 2018) (see also Fig. 1). Both agrivoltaics and floatovoltaics are therefore ideal candidates for community-based solar. Depending on ownership for agrivoltaics, community solar can share land with agricultural production, either through a discount on the lease or by sharing profits from agricultural production. Floatovoltaics would be possible on public reservoirs for low nominal leasing costs. Fig. 5 lists other technological areas under active research and development that will drive down the costs for solar installations and drive-up co-benefits for other SDGs.

Pairing Solar and Storage Technologies

Ideally, community solar should also be designed to function in islanding mode, which allows disconnection from the larger grid. This is especially relevant in case of grid disruption – an increasing reality in a climate change world characterized by extreme weather events, or by utilities proactively



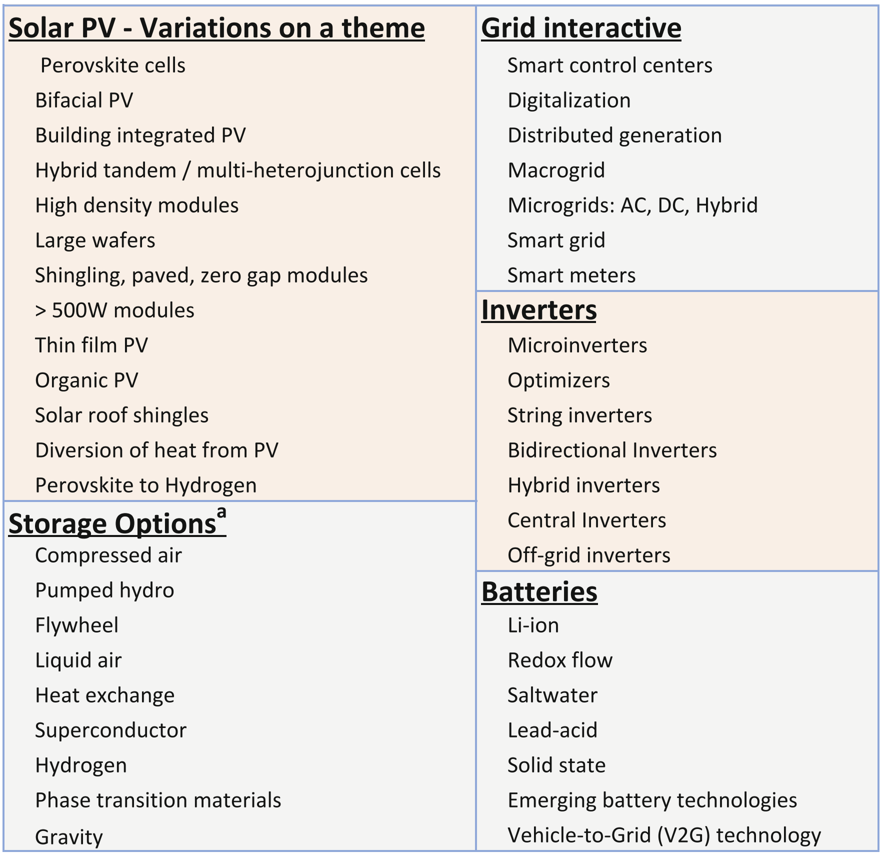
Societal	**Environment**		Non-emitting generation Decarbonization Avoided air pollution Minimal ecological footprint Water conservation
	Economy		Most capital expenditures remain in local community Local job creation Rapid deployment
	Control		Local decision making Distributed generation
	Co-Benefits	Community	- Energy resilience - Energy security - Health improvement - Reduced vulnerability to climate change
		Education	- Increased acceptance of PV - Energy awareness - Increased public support for renewables
		Agrivoltaics	- Food security - Biodiversity - Increased soil moisture
		Floatovoltaics	- PV cooling & increased output - Reduced evaporation - Reduced algal growth
Electrical	**Generation**		Avoided costly central generation Peak demand shaving Behind the meter generation independent of grid Avoided or delayed capacity investment Reduced price volatility Distributed generation Reduced capital expenditures on grid maintenance Delayed or avoided capacity costs
	Transmission & Distribution		Avoided capital expenditures on upgrading & expansion Avoided system losses More efficient transmission
	Grid		Improved resilience Improved frequency regulation Improved voltage regulation
	Compliance		Reduced renewable compliance expenditures (where compliance costs are levied)

Based on Weissman et al. 2019

Community Solar: Strategies and Implementation for Sustainability, Fig. 4 Societal and electrical grid benefits of photovoltaics (PV)

disconnecting customers in anticipation of these events. Figure 6 provides an overview of how community PV microgrids, especially when paired with battery storage, will affect local energy generation and its interaction with the central grid.

In spite of the thrilling developments in solar and directly associated technologies (Fig. 4), even more impressive and relevant advances occur in the area of storage options, specifically in battery technology. Battery storage follows similar patterns in economy of scale and learning curves as solar (Kittner et al. 2017), except that its key contributions to central and microgrids are much more recent and large conceptual advances are likely still to come. The importance of battery storage will accelerate, especially as costs continue to plummet (Nemet 2019) and with the rapid adoption of electric vehicles a crucial co-



Solar PV - Variations on a theme

- Perovskite cells
- Bifacial PV
- Building integrated PV
- Hybrid tandem / multi-heterojunction cells
- High density modules
- Large wafers
- Shingling, paved, zero gap modules
- > 500W modules
- Thin film PV
- Organic PV
- Solar roof shingles
- Diversion of heat from PV
- Perovskite to Hydrogen

Storage Options[a]

- Compressed air
- Pumped hydro
- Flywheel
- Liquid air
- Heat exchange
- Superconductor
- Hydrogen
- Phase transition materials
- Gravity

Grid interactive

- Smart control centers
- Digitalization
- Distributed generation
- Macrogrid
- Microgrids: AC, DC, Hybrid
- Smart grid
- Smart meters

Inverters

- Microinverters
- Optimizers
- String inverters
- Bidirectional Inverters
- Hybrid inverters
- Central Inverters
- Off-grid inverters

Batteries

- Li-ion
- Redox flow
- Saltwater
- Lead-acid
- Solid state
- Emerging battery technologies
- Vehicle-to-Grid (V2G) technology

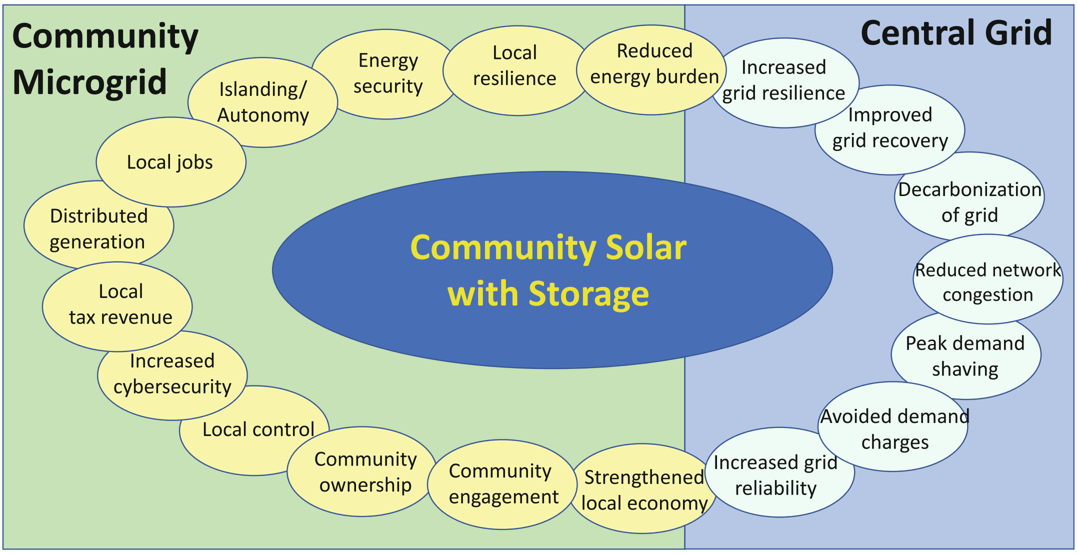
[a] Methane excluded because of its high global warming potential and losses of methane at every step of the industrial methane cycle

Community Solar: Strategies and Implementation for Sustainability, Fig. 5 Advances in solar and associated technologies

contributor to local microgrids through vehicle-to-grid technology.

On purely economic grounds, community battery storage may still appear to be expensive, but actual costs depend on the location and market opportunities. New developments in battery and other storage technologies seem to be announced daily (cf. Fig. 5), while prices for Li-ion batteries seem to follow the steep downward path noticed for PV a decade ago, with even better learning curves (Nemet 2019). Further, the many societal, environmental, and grid benefits of battery storage (Fig. 6) compensate for the additional costs. Attempts should be made to derive the true value of battery/storage integration with community solar, similar to what was done when assigning a value of solar in discussions on rate structures for utilities.

Thus, battery storage in community solar can become a key driver in the world of distributed energy resources (DER). This pairing – at times termed community energy storage (CES) – takes community solar to a new level. With the inclusion of storage to a community solar garden, the participants have quietly evolved from passive electricity consumers into their own local utility ("prosumagers" (Sioshansi 2019)) that manages generation, consumption, and storage. Decisions on energy issues have shifted from remote boardrooms to the local level (cf. Fig. 6), empowering the community on many planes and democratizing energy in the process. Local microgrids with



Community Solar: Strategies and Implementation for Sustainability, Fig. 6 Interaction between a community solar plus storage system with a community microgrid and the central grid

added storage improve control over loads and contribute to grid decarbonization, while optimizing self-consumption and stabilizing grid frequency and voltage. CES positions local storage solutions somewhere between residential and utility scale. The risk of quickly adopting this evolving – behind the meter – technology is more than justified by its many benefits (Fig. 6).

Solar Energy: Policy Landscape

As they come to grips with the urgency of climate change mitigation and the crucial imperative to decarbonize the energy industry, national, regional, and community institutions create solar incentives. Many government solar incentives are targeted to commercial and industrial solar operations. In nations that require utilities to meet a threshold of their portfolio with renewable energy, the state establishes markets for tradable renewable energy credits. In the USA, it is rare for portfolio standards to specify what type of renewable energy, leaving markets saturated with wind power. When a solar target is set, the market for solar energy credits incentivizes large-scale generation facilities (Timilsina et al. 2012). This top-down incentive does little to extend solar technology ownership to most ratepayers. Other incentives are more accessible by small-scale solar development, but require a certain ownership: land, a sunny rooftop, or the capital for an up-front investment. A federal solar investment tax credit only helps those whose tax liability exceeds the credit (Timilsina et al. 2012). Though these incentives have stimulated the solar industry, they primarily make solar more feasible for those who can already afford to participate. Rebates and subsidies may incentivize distributed solar installations, but come at a cost to the government and can be politically unpopular. Instead, complex incentives for solar can be condensed into rules that guarantee compensation for solar generation, i.e., net metering without a cap or a feed-in tariff. Programs can then be designed to enable local proposals for community solar, distributing incentives to a wider audience and establishing a more equitable “bottom-up” route to meet climate targets.

The Role of Distributed Solar in the Energy System

Around the globe, electric grids largely operate in a “top-down” fashion. While the exact system varies, the model, and the thinking behind it, remains the same. It is a model that has been static for a century: large power plants generate electricity and feed it into high-voltage transmission lines. Along the route, electricity splits off to substations, which reduce the voltage and pass the electricity off to local distribution lines. Now diffused throughout the region, transformers reduce the power's voltage once again and the power enters buildings through their respective meter. This model has sufficed for an electric grid supplied mostly by large-scale generating plants, owned by a few market participants. However, the model falters as smaller entities generate their own energy locally.

The scientific community has recognized and documented the negative effects the combustion of fossil fuels has on climate, public, and ecosystem health. The top-down electric grid was designed around these large, carbon-emitting resources. Although renewable energy generation provides a clean alternative, it is not enough to simply substitute the technology. New global realities force the industry and policy-makers to re-evaluate the dominant grid model. First, distributed, renewable energy – specifically solar PV and wind – is highly cost competitive with alternatives. Second, as natural disasters increase in frequency and devastation, and the world increasingly relies upon electric technology, a reliable and resilient electric grid is essential. Finally, distributed energy, especially solar, can provide distinct societal, environmental, and grid benefits (cf. Fig. 7).

Ascendancy of the "Economies of Scale" Theory

In the early years of the electric grid, and fossil fuel power generation, building bigger power plants meant lower electricity costs. The mantra continues to be repeated, despite evidence that the scale economies in traditional power plants reached their peak 50 years ago (Hirsch 1999). The economies of scale mantra of "bigger is best" unfortunately persists with renewable generation, despite many operational differences. Underlying are three key assumptions. First, that larger wind or solar installations can generate electricity at a lower unit cost given the same inputs. Second, that renewable energy is most cost-effective if generated in areas with the greatest input conditions, or availability, and transported to where it is needed. Lastly, that the fastest deployment of renewable energy depends upon constructing large solar and wind farms, rather than small, distributed power plants (Farrell 2019).

Disputing the Dominance of the "Economies of Scale" Rationale

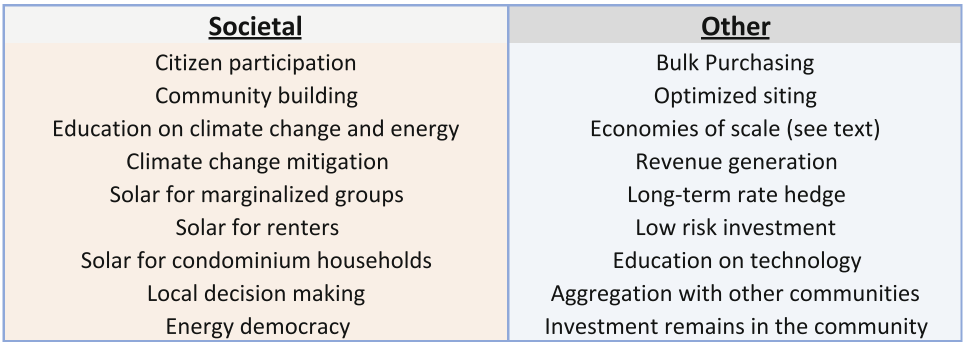
Contrary to common belief, renewable energy generation is cost competitive with alternatives at most sizes (Lazard 2019). The decreasing cost of solar PV has benefitted installations large and small, allowing distributed solar to compete with fossil fuel-generated electricity. Utility-scale PV with two-axis tracking panels, a technology more expensive than standard fixed tilt systems, can generate about a 30% greater output than a rooftop PV system of the same size (Farrell 2019). The greater output of these PV systems, generally at least 5 MW in size, may result in a lower levelized cost of electricity. However, the energy generated at utility-scale solar installations is transported greater distances. Electric transmission and distribution result in substantial losses (USA 5.9%, Canada 8.7%, 2014 data; WorldBank 2018). The cost of transmission, already high, is rising rapidly; for three major utilities in California, transmission expenditures increased by about 10% annually (California Public Utilities Commission 2016). In contrast, the same California electric grids could accommodate additional distributed solar generation with little grid expenditure (California Public Utilities Commission 2016). Given the extraneous location-related costs of utility-scale generation, solar and otherwise, distributed solar gains a competitive cost advantage. Finally, distributed solar or utility-scale solar can be deployed rapidly. A recent PV auction in Europe commissioned deployment deadlines of 12 months for a project of 1 MW and just 18 months for 20 MW installations (Hanley 2020). Over similar 5-year periods, Germany installed 22 GW of primarily rooftop solar, while the USA deployed 23 GW of mainly utility-scale solar (Farrell 2019). With assistance of state and utility policy, a utility-associated community solar program has deployed nearly 700 MW of capacity in 6 years in Minnesota (Farrell 2020). Given the proper valuation and resource attribution, distributed energy will be a significant contributor to decarbonization goals.

Within the narrow confines of the economies of scale rationale in renewable energy generation, community solar is the best option. Larger community solar gardens capture the economies of scale benefits, while saving on transmission costs. Given the proper policy support, solar gardens can be deployed rapidly in communities everywhere.

Benefits of Distributed Solar to the Electric Grid, Communities, and the Environment

Distributed solar generation has value to the electric utility, and the grid, that extends far beyond the standard cost-benefit analysis and into societal interests (Figs. 6 & 7). Often, the daytime peak of solar energy generation coincides with peak energy demand. Distributed solar energy can ease a utility's peak load ("peak shaving") and avoid expensive peaker plant energy purchases, or a utility spending capital to build those plants itself (Farrell 2014b). These costly utility-scale investments may never pay off. Dyson et al. (2019) predict that capital expenditures on gas infrastructure in the USA will likely become stranded assets by 2035. In some jurisdictions, utilities are required to meet certain thresholds of renewable generation with renewable energy credits. If peak demand is met by distributed solar energy, instead of gas-fired peaker plants, the utility will not have to pay for renewable energy offsets or credits (Rábago 2013). The benefits of distributed solar energy to the utility and grid are significant, and once acknowledged, will advance the technology.

Though more difficult to quantify and monetize, distributed solar provides benefits to communities and the environment that advance several sustainable development goals: good health and well-being, affordable and clean energy, reduced inequalities, sustainable cities and communities, and decent work. Further, a distributed, localized energy system will build community resilience in the wake of climate impacts. For cities and communities to be sustainable, they cannot be dependent on distant power plants and transmission lines. This top-down energy infrastructure model is vulnerable to natural disasters, as evidenced by Hurricane Maria's total destruction of Puerto Rico's electrical grid in 2017 (Campbell et al. 2017). Localizing the energy system can save communities from widespread outages, especially if paired with storage and islanding technology (Perez et al. 2011). Distributed solar is crucial for communities to alleviate ongoing climate impacts and mitigate the extremity of impacts in the future, since it displaces energy that is being generated with fossil fuels (Perez et al. 2011). Since peaker plants are some of the most polluting and often sited in low-income communities (Wilson 2016), displacing peakers with non-emitting solar reduces the amount of pollutants and greenhouse gases entering the atmosphere, reduces local air



Societal	Other
Citizen participation	Bulk Purchasing
Community building	Optimized siting
Education on climate change and energy	Economies of scale (see text)
Climate change mitigation	Revenue generation
Solar for marginalized groups	Long-term rate hedge
Solar for renters	Low risk investment
Solar for condominium households	Education on technology
Local decision making	Aggregation with other communities
Energy democracy	Investment remains in the community

Community Solar: Strategies and Implementation for Sustainability, Fig. 7 Value of community solar pollution, and improves public health in marginalized communities.

Distributed solar can provide even more benefits that align with the sustainable development goals, but attaining these benefits becomes a matter of participation and ownership. When generating power is owned by the community itself, the opportunity arises to advance affordable clean energy and reduce inequalities.

Community Solar Capitalizes on the Benefits of Distributed Solar

The capacity of a community solar garden (CSG) may range from kilowatts to dozens of megawatts, depending upon restrictions sometimes imposed by policy or the utility. For instance, the 2013 community solar bill for Minnesota limited project size to 1 MW (Paulos 2019). Community solar gardens can be installed as ground mounts or on rooftops and utilize otherwise unusable space, i.e., the roofs of houses of worship, parking lots, and landfills (Fig. 8).

Building a Democratic Energy System with Community-Owned Solar

To develop truly sustainable cities and communities with decreased economic inequalities, owning renewable energy cannot be a luxury for the few. Participation is crucial to building an energy system that is distributed in ownership, fueled with clean generation, and equitable: what some call energy democracy (Farrell 2017). Whether it is done through a utility, outside developer, nonprofit, or cooperative, community solar is providing renewable electricity to individuals who are otherwise left out. However, opportunities for ownership and participation in decision-making are preferable.

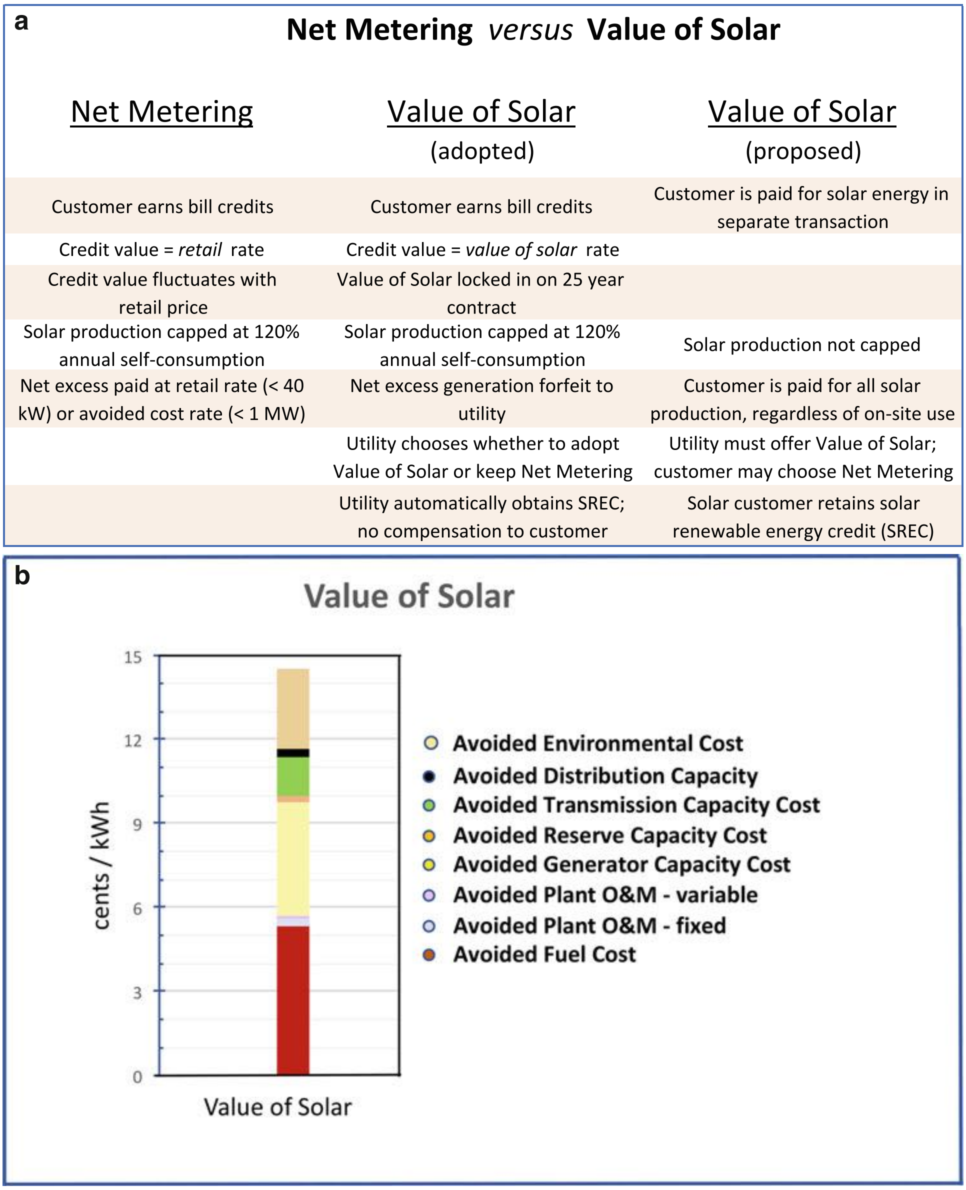
Locally owned renewable energy is not only necessary for a sustainable, democratic energy system, it is highly desired. For instance, members of a German town with a locally owned wind farm were more likely to support expanding wind power production than those in a town with a wind farm that was not locally owned (Musall and Kuik 2011). Similarly, significantly more community support for renewable energy generation is noted if it comes from local initiatives (Berka and Creamer 2018).

Community Ownership Means More Community Benefits

Local solar power itself provides a local economic benefit, but community ownership can multiply that benefit, as shown for a wind power plant in Missouri, where local ownership was estimated to provide a multiplier of three. In the same study, local ownership multiplied the economic benefit of local solar power in Washington, D.C. threefold (Farrell 2014a). Most solar panels are manufactured in China, but since the modules themselves account for less than 20% of a solar installation, community solar offers many opportunities in project development, engineering, manufacturing, and installation. In 2018, “solar installer” was the fastest growing job in Minnesota with the majority of jobs in community solar (Paulos 2019). Solar garden developers can direct and influence these benefits by training and hiring local installers. One Minnesota-based community solar cooperative installed its first community solar garden using 90% minority labor and many workers from the neighborhood (Paulos 2019).

Community Solar Benefits for Those with the Most to Gain

Designed properly, community solar programs will result in bill savings for participants, including low-income customers, which helps alleviate inequalities. On average, low-income households spend three times more on energy as a portion of their income (the financial energy burden) than higher income households, which is attributed to poor quality housing stock for low-income families (Drehobl and Ross 2016). Though community solar does not tackle home inefficiency problems, it can reduce the cost associated with energy use. Project developers can target subscribers facing an undue energy burden by including subscribers with poor credit, as the two situations may coincide. Additionally, community solar policy can stipulate a certain proportion of low- to moderate-income and marginalized community participation. If the subscriber is a public institution,



Net Metering *versus* Value of Solar

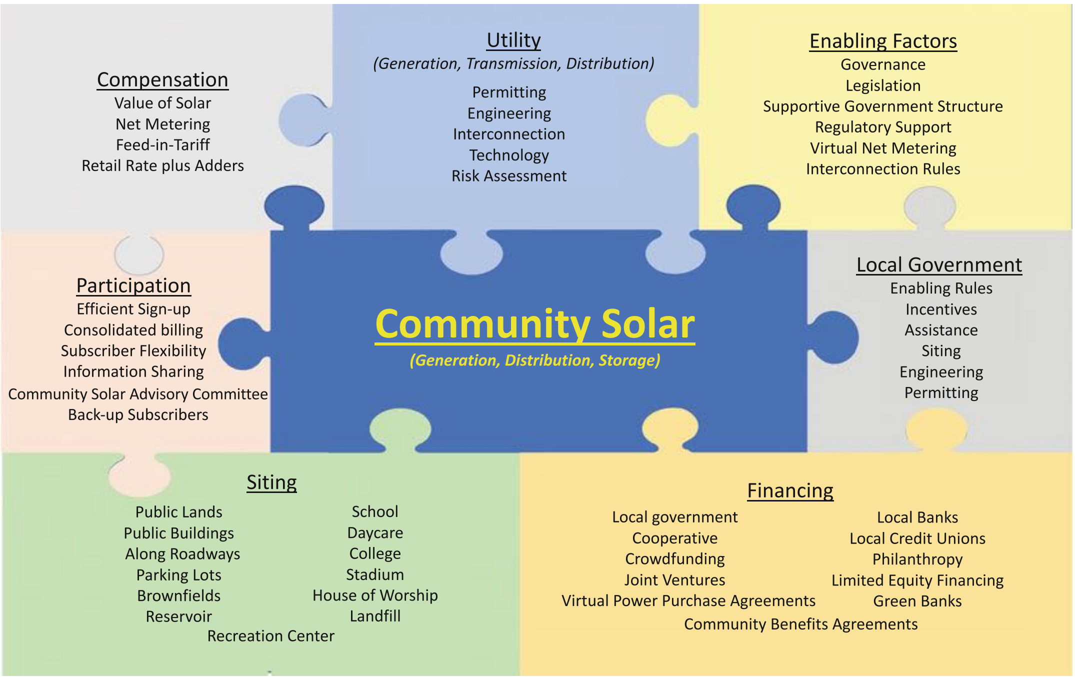
Net Metering	Value of Solar (adopted)	Value of Solar (proposed)
Customer earns bill credits	Customer earns bill credits	Customer is paid for solar energy in separate transaction
Credit value = *retail* rate	Credit value = *value of solar* rate	
Credit value fluctuates with retail price	Value of Solar locked in on 25 year contract	
Solar production capped at 120% annual self-consumption	Solar production capped at 120% annual self-consumption	Solar production not capped
Net excess paid at retail rate (< 40 kW) or avoided cost rate (< 1 MW)	Net excess generation forfeit to utility	Customer is paid for all solar production, regardless of on-site use
	Utility chooses whether to adopt Value of Solar or keep Net Metering	Utility must offer Value of Solar; customer may choose Net Metering
	Utility automatically obtains SREC; no compensation to customer	Solar customer retains solar renewable energy credit (SREC)

Community Solar: Strategies and Implementation for Sustainability, Fig. 8 (**a**) Net metering versus value of solar as implemented in Minnesota, USA (**b**) Value of solar (initial estimates by a Minnesota utility in 2014). (Modified from Farrell 2014b)

money saved can instead be allotted to programs that advance the public good. Since energy use has become central to human existence, equitable access to electricity is a moral and economic duty.

Implementation of Community Solar

Community renewable energy first took root in Denmark in 1978 with the Danish Wind Turbine Association (Ren21 2016). Now, community solar projects are popping up all around the world, albeit with unique variations on the



Community Solar: Strategies and Implementation for Sustainability, Fig. 9 The intricate web surrounding a successful community solar garden

theme. Particularly in industrialized states, community solar programs work with policy incentives and market mechanisms to provide an alternate and non-emitting source of electricity from existing utility service. In other cases, governments and nongovernmental organizations use community solar, microgrid, or off-grid technologies to electrify areas without prior access to electricity (Ren21 2016). There is no absolute model when it comes to community solar, but certain models do better to serve owners, subscribers, and the community.

In puzzle form, Fig. 9 delineates the intricate web of players and technologies that interface to make community solar a reality. The following sections outline considerations when implementing a community solar program through legislation, a utility program, or third party.

Community Solar Policy in the USA

Though community solar gardens have the power to transform the electric grid, implementation is largely dependent on its current structure and limitations. The top-down structure of the traditional energy-generating system applies to the grid as well; it is controlled by few, who restrict access to it in various ways. The basic structure of the electricity market is either regulated or deregulated. Within each market type, several types of electric utility exist: investor-owned, municipal, or rural electric cooperative. Municipal utilities and rural electric cooperatives have virtually the same operations in both regulated and deregulated markets.

Electricity Market and Utility Type Overview

A regulated electricity market refers to a regulated monopoly: the utility controls all power flow for the region, from generation to transmission to distribution. In the case of investor-owned (for-profit) utilities in regulated territory, the monopoly giants are overseen by public regulatory boards. Board members may be elected by their constituents or appointed by elected officials. Typically, the utility must be forced to implement community solar by legislation or the regulatory board.

For-profit electric utilities make money through returns on capital and by selling more energy. They are generally resistant to alternative forms of ownership, like community solar, because ceding market share may not be profitable. Municipal or provincial electric utilities and rural electric cooperatives are assumed to have a community-centric business model (Brehm et al. 2018), rather than a focus on profits and returns. However, there are many obstacles to implementing community solar under these utilities. Both publicly owned utilities and rural electric cooperatives are run by elected boards. In board-member elections, voter turnout tends to be low, providing a boost to incumbents. Many members of rural electric cooperatives may not know that they are an owner of their electric utility (Farrell et al. 2016). Long-standing board members may be reluctant to implement forward-thinking policies, especially if their job security is rooted in maintaining the status quo. Beyond governance, these utilities may be unable to promote locally generated electricity because of power contracts. Utilities make long-term contracts with electricity suppliers that span decades, some of which restrict local energy generation to a small percentage of the utility's load.

In a deregulated market, the monopoly utility does not own the energy generation or transmission system, but solely provides distribution to the customer's meter, billing, and some grid maintenance. This electricity market structure allows for wholesale and retail competition: the customer can choose their electricity supplier. However, there are still barriers to implementing community solar in a deregulated market.

The Governance of Grid Access

Implementing a community solar program in the USA requires two accommodations: the ability to share the output of one solar installation across multiple subscribers and the ability to connect to the grid. For the most part, legislation makes these allowances. One policy that does both is virtual net metering, sometimes called "shared renewables" or "community net metering." Virtual net metering is an extension of net metering policy, a billing mechanism allowing people generating their own electricity to meet their own demand and feed surplus energy into the grid using a bidirectional meter, credited per kWh. Virtual net metering is a mechanism for distributing energy credits (in kWh) among owners of a shared and grid-tied solar array and may enable community solar on its own. In addition, legislators can develop a more comprehensive community solar program that, beyond net metering, includes rules to encourage desired outcomes: residential participation, low-income household participation, or more democratic program governance. Programming can serve to eliminate the incidental barriers to community solar created by other policies, like securities laws.

Publicly owned utilities are often considered to be a more favorable environment for implementing community solar. However, unique barriers have been erected to democratization of the energy system for state owned utilities, including: a technology bias within the utility management and engineers; historic or cultural myths; lack of appropriate funding (Ostergaard et al. 2014); otherwise captured regulators; and ties between government and utility finances or their donors. To provide fairness for all players, the regulators or commissioners must be fearlessly independent. Absence of bias in the governance structure is essential.

If legislators have not enacted virtual net metering or a community solar policy, community solar could be implemented by the utility or possibly by a mandated regulator, but the overall design still tends to follow the dated top-down model and dilutes the effectiveness of the bottom-up initiatives (Akizu et al. 2018).

Internationally, community solar has been established by setting standard rates and contracts for power that enable community-owned power systems (a feed-in tariff). Participants are not limited by bill credits, but rather can own shares in community renewable energy systems.

Many Models of Community Solar

Community solar projects, enabled by legislation or a utility, can be developed through a business or the utility. The most common businesses include private companies, nonprofit organizations, and member-owned cooperatives (Coughlin et al. 2011). An overview of the intricate interactions between the parties can be found in Fig. 9. In the case of a utility-run community solar program, program structure and governance will depend on the utility type. Although utility-run community solar loses many benefits garnered from community ownership, some utilities have established successful community solar programs.

Developing community solar through a private business incurs the complications and expense of building a business. Additionally, private investors in this model of community solar may be more interested in earning a return than participating in the transition to a decarbonized future (Coughlin et al. 2011). In some instances, privately developed community solar may offer subscribers an ownership stake. Finally, community solar can be implemented by for-profit enterprises, but guided by community or cooperative principles, similar to credit unions.

Non-profits – including community solar developers – have proven to be strong community partners, but since they are exempt from paying federal taxes – at least in the USA – they may be unable to take advantage of solar energy incentives. However, since unsubsidized solar is highly competitive with other generation, the lack of incentives may not matter. At any rate, organizations can circumvent this potential complication by partnering with a private business, but may sacrifice a portion of the incentive in doing so (Coughlin et al. 2011). No standard exists for whether nonprofits offer ownership or subscription models.

Cooperatives rely on the funding of members who earn a return on their membership. Community solar development through a cooperative may be the most democratic, since member-owners participate in the co-op's governance and cooperatives are theoretically held accountable by seven cooperative principles, which include democratic control and concern for the community (Manabe 2016; NRECA 2016). Navigating deeper into the intricacies of each business type is beyond the scope of this chapter, but the reader can learn more in a 2011 report by the U.S. Department of Energy (Coughlin et al. 2011).

Constructing a Successful Community Solar Program

Designing a community solar program will largely depend on the legal and program model stipulations above, but there are certain components to consider that can make or break the program.

Compensation Rates

Subscriber compensation is crucial to community solar implementation. Ideally, customers should receive compensation for the clean energy produced at a rate equivalent to, or greater than, the retail rate of that electricity. At the least, community solar subscribers should see a net financial benefit by the end of their subscription. Creating a compensation model that goes above and beyond the retail rate can be done in one of three ways: a feed-in tariff, a value of solar tariff, or a system of adders to a Standard Offer – also termed "Standing Offer" – energy purchase contract.

Feed-in tariffs (FiT), also called standard offer contracts or CLEAN contracts, are a way to simplify renewable energy compensation. Feed-in tariffs have been popular in Germany since 1991 and have been mandated in Spain, Italy, Japan, and the USA (Manabe 2016). The theory behind feed-in tariffs is that by guaranteeing grid connection and a long-term contract for the energy generated, the renewable energy industry will develop with speed. This rationale has been proven: installed solar PV in Germany increased from 1 GW to 26 GW in just 7 years under FiT (Lynch 2013), which resulted (by 2012) in customers owning 51% of renewable energy fed into the grid (Nolden 2013). Generally, a feed-in tariff can replace tax incentives and quota systems with a single concise renewable energy compensation scheme. Nonetheless, feed-in tariffs are waning in popularity. Between 2014 and 2016, the number of countries utilizing feed-in tariffs dropped by 22% (Warren 2016), regrettably easing the return to outdated top-down regulated and centralized generation.

The *value of solar tariff* uses a formula to add the additional benefits of distributed energy onto the retail rate for electricity (Fig. 8) with key case studies in Austin, Texas, and Minnesota (Taylor et al. 2015). The Minnesota policy established a formula to calculate the value of distributed energy: a rate which the utility is required to use when purchasing energy from community solar gardens (Farrell 2016). In Minnesota, once a community solar garden is online, the utility will pay the established value of solar rate for a 25-year contract. Although the value of solar was estimated to be almost $ 0.15/kWh (Fig. 8), the standard value of solar rate offered by a utility was $ 0.12/kWh, just $ 0.02/kWh above average retail price in Minnesota. The Minnesota rate only takes into account community solar's advantages to the utility, grid, and the environment (Figs. 4 and 8), while ignoring benefits to the community at large (Figures 4–6).

Compensation by a system of "adders" credits the benefits of community solar by building onto a base incentive rate; each community solar project is evaluated individually to meet certain criteria. Eligible criteria for adders can be any attribution of a solar installation deemed especially valuable to the grid, environment, or community. Adder criteria may include community ownership, utilization of minority, women, or local workers, project siting on rooftops or contaminated land, inclusion of low- and moderate-income subscribers, and inclusion of residential subscribers in marginalized communities (DenHerder-Thomas et al. 2020). In a Massachusetts initiative, qualified adders are the inclusion of low-income subscribers, storage technology, and location-based, with each adder valued at $0.01–0.06/kWh (SMART 2018).

Subscriber Participation

Community solar programs should strive to ensure ease of participation and a positive experience for the subscriber. The level of participation is somewhat dependent on the model, but tools exist that program governance can utilize to enhance subscriber experience. First, subscribing to community solar should be a simple process for potential customers from the beginning. Sign up should be straightforward and efficient, while still allowing time for the customer to either commit or back out (DenHerder-Thomas et al. 2020). Secondly, billing for energy used and credits for energy generated should be consolidated on to one bill (CCSA 2019). Receiving two separate electricity bills can be confusing and discouraging for customers. Furthermore, considerations should be made for renters or other subscribers who move residence (DenHerder-Thomas et al. 2020). Accommodations for these subscribers will reduce subscriber turnover and increase the program's success rate. An additional safeguard against subscriber turnover is allowing backup subscribers in case a subscriber cannot make their payment. For one community solar garden serving a low- to moderate-income area in Minneapolis, Minn., local businesses and nonprofits provide backup for residential subscriptions (Paulos 2019). Though there are many more intricacies to program design in regards to subscribers, the summary above provides some baseline considerations.

Ensuring Equitable Outcomes

Equitable outcomes can be encouraged through the compensation models, as described in the adders description above, or through program design itself. To ensure residential participation, program implementers can prioritize the approval of CSGs that serve residential subscribers and allow a mix of residential, commercial, and nonprofit subscribers on the same array (DenHerder-Thomas et al. 2020). Within residential participation, effort must be made to extend community solar access to low- to moderate-income households and marginalized communities. Program designers can make similar stipulations for a minimum threshold of low-income household participation in the program and prioritize community solar gardens located in marginalized communities. Illinois Solar for All requires that one-quarter of approved community solar gardens serve environmental justice communities and funding has been allocated for diversity-focused training programs (FEJA 2019). As community solar implementation ramps up, local and diversity-focused job training ensures that people are not being left behind in the renewable energy transition.

Many more tools have been designed to promote equitable outcomes in community solar, but no method is perfect. To bolster the democratic process, legislators or program designers can encourage community participation in determining the desired program outcomes. This can be done by appointing a "Community Solar Advising Committee" that is representative of many stakeholders (DenHerder-Thomas et al. 2020). Either way, it is important not to lose sight of the unique and environmentally urgent imperative to upend the *status quo* by transferring power to the community, by pushing to decarbonize electricity generation, and work towards the common good.

Conclusions: Great Potential but Many Barriers

> We can not solve our problems with the same level of thinking that created them. (Albert Einstein 1921 Nobel Prize winner for discovery of the law of the photoelectric effect)

The need to drastically electrify all areas of energy usage and decarbonize energy generation is paramount (IPCC 2018). Rapid advances in digitalization, renewable energy technology, and the evolution of "smart" components open multiple avenues to the grid of the future (Figs. 5 and 7). Traditionally, flow of energy was unidirectional from central generators to consumers, and control was top-down. The "new" grid is characterized by distributed generation, decarbonized power, multidirectional flow of electrons, and a host of players. Community solar provides a framework to transform the energy industry by combining group ownership, the imperative to decarbonize, and discounts of bulk-purchases, with proven and continually improving technology.

Community solar is transforming the energy industry from the bottom-up. However, it is disruptive to the *status quo*. With technological developments, dropping prices, and public enthusiasm pushing in the direction of shared, cheaper, cleaner, and more equitable electricity, those benefitting from business as usual erect barriers to maintain their influence and income. Government and regulatory inertia are generally on the side of the *status quo*.

Canada and the USA are home to some 3500 utilities involved in generation, transmission, and distribution of electricity. Most of these utilities have different ownership structures, operate under different market conditions, and under unique regulatory requirements. Therefore, it is near impossible to come up with a encompassing model or strategy for all community solar installations.

Given the stark reality of less than 10 years remaining to achieve the SDGs (United Nations 2015), community solar provides a readily available and economically viable solution to multiple SDGs. It targets the elusive middle ground in scale between residential and industrial solar and can deliver electricity competitively and at scale without requiring massive investment in supporting infrastructure. Most importantly, community solar provides more than just affordable and clean energy by democratizing the renewable energy transition. By giving power to the people, communities can utilize community solar programs in providing decent work, reducing inequalities, and increasing local resilience – while making a positive climate impact.

Cross-References

- ▶ Access to Modern Energy Services for the Promotion of Sustainable Development
- ▶ Centralized Versus Decentralized Electrification Pathways
- ▶ Clean Energy Solutions and Sustainable Development
- ▶ Community Renewable Energy Systems
- ▶ Energy Cooperatives: A Comparison of EU and US Cases
- ▶ Energy Prosumers' Role in the Sustainable Energy System
- ▶ Energy Transition to Support the European Green Deal
- ▶ Financing Renewable Energy Sector (RES) Innovations

- ▶ Green Energy and Sustainable Development
- ▶ Grid-Connected Microgrids: From Research to Sustainable Implementation
- ▶ Microgrids: Impact on Development of Sustainable Electric Energy Systems
- ▶ Off-Grid Sustainable Energy Systems for Rural Electrification
- ▶ Residential Distributed Energy
- ▶ Rural Household Energy Systems
- ▶ Smart and Energy Efficient Approaches to Universal Electrification
- ▶ Sustainable Energy Production, Small Hydropower Plant and Solar Photovoltaic Power Plant Hybrid System
- ▶ Sustainable Energy Solutions: Innovations and Technological Advances

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