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Review

Renewable electricity finance in the United States: A state-of-the-art review

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ABSTRACT

This paper discusses a range of existing and emerging options for financing renewable electricity. We use the United States as a reference case study. To contextualize the discussion, we begin with scenarios for the deployment of various renewable energy technologies globally, followed by coverage of the United States renewable energy supply, supporting policies, and an introduction to renewable electricity finance for the non-specialist reader. We subsequently cover several prominent historical delivery mechanisms for the provision of renewable electricity finance, as well as key emerging opportunities. Further research in this area is encouraged.

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1. Introduction

Electricity from renewable energy sources such as wind, solar and biomass energy has gone far beyond its humble roots as a costly alternative to fossil fuel generation to become the fastest growing source of electricity in many regions. This rapid growth is especially pronounced in the United States (U.S.). The 2017 Annual Energy Outlook from the U.S.-based Energy Information Administration (EIA) envisions renewable energy growing rapidly as a result of dramatic decreases in the levelized cost of renewable electricity generation - particularly for photovoltaic (PV) electricity [100]. This is part of a general phenomenon where some forms of solar, wind, and other renewable electricity are now competitive with fossil fuel electricity in terms of unit electricity costs (in what Sanzillo et al. [79] refer to as a deflationary cost curve) and favourable policy environments continue to spur this trend along.

At the same time, there is increasing pressure to move away from fossil fuels in response to the threat of catastrophic warming of the climate due to anthropogenic emissions of greenhouse gases, as exemplified by the evolving framework supporting the recent international Paris Agreement under the ***United Nations Framework Convention on Climate Change*** (UNFCCC) [93]. Due to the combination of increasing economic competitiveness and policy push, continued rapid growth in the rate of deployment of renewable electricity generation is anticipated over the coming decades. Although the investment cost per unit of renewable electricity generation capacity is expected to continue to decrease,[1] the growth in deployment rates needed to meet climate policy goals is so large that the annual financing requirements will continue to grow substantially.[2]

Renewable electricity power plants have a host of financing options. This paper reviews the various ways in which large-scale renewable electricity generation can be or could be financed privately by using the United States (a destination for $58.8 billion in direct and indirect investment in 2016, according to the Sustainable Energy in America Factbook [12]) as a case study. The U.S. was chosen due to it a) being a deep and active market for financing, b) being a home to some of the world's largest financial centres (such as New York City and San Francisco), c) having a long history of renewable electricity deployment and technological innovation, and d) being the source of several new and innovative financing tools.

This paper is intended as a primer for non-specialists that will contextualize emerging private financing opportunities within an awareness of historical financing mechanisms, delivery methods, and policies. While acknowledging that there is no "one size fits all" and that any mass renewable electricity deployment effort would be greatly abetted by greater government-provided direct investment, significant scope exists for private investment. Accordingly, this paper constitutes a discussion on the private financing alternatives available in competitive markets, rather than a definitive "ranking" or hierarchy. Each renewable electricity developer's situation is inherently different, and determining the optimal financial structure for a renewable electricity project depends on a large number of factors that range from the size of the transaction to the risk-appetite of the investor. This article reflects that diversity.

We do, however, see this work as a mobilizing effort. If we are to ensure the integration of an ever-greater percentage of renewable electricity into the supply mix and reach $1 trillion of annual investment in clean energy,[3] it is crucial that the outstanding past and present work in renewable energy finance (coming out of both the private sector and a variety of academic centres, national research laboratories, international entities, and government institutions) is tapped, implemented, and, where appropriate, modified to suit on the ground demands. This work, which is part of a broader research synthesis effort designed to outline the renewable electricity finance environment of different regions (see, for example, [27,47,73]), attempts to facilitate this knowledge transfer.

2. Trends, financing, and policies

2.1. Status of renewable electricity deployment (global)

Fig. 1 shows the trend from 2000 to 2015 in the global installed capacity of onshore and offshore wind, solar PV, and CSTP (concentrating solar thermal power) – 4 dominant renewable electricity technologies. The global capacity of wind and solar reached 552 gigawatts (GW) by the end of 2015, along with 1055 GW of hydropower, 93 GW of biopower, and 13 GW of geothermal power, for a total 2015 renewable electricity capacity of 1713 GW. By comparison, fossil fuel and nuclear capacity was 4277 GW by the end of 2015 [95].

Jacobson and Delucchi [42] argue that all new energy could come from renewables by 2030 and all energy could be renewable-derived by 2050. The International Energy Agency [37] argues that up to 45% penetration of variable renewable energy sources is possible, with minimal additional cost compared to a thermal-heavy electricity supply.

In our scenarios regarding theoretical deployment of renewables necessary to mitigate anthropogenic climate change, we have

[1] Again, solar photovoltaic modules are perhaps the best example of this potential for further declines. Their prices have dropped in cost by a factor of about 2330 since 1956, according to Farmer & Lafond [25], with additional declines forecast. Richard Swanson, the founder of the US solar company SunPower, argued that a standard learning curve would lead to a 20% drop in panel cost for every doubling in total volume produced [19].

[2] The Organisation for Economic Co-operation and Development (OECD) believes that over $50 trillion USD will be required in the near future for global energy supply infrastructure and energy efficiency. See, for example, the report *Mapping channels to mobilise institutional investment in sustainable energy*, which lays out a 20 year timeline for this cumulative capital expenditure if the world is to have even a small chance of staying below a 2 °C warming limit [70].

[3] The "Clean Trillion" was put forward by the non-profit CERES [14].

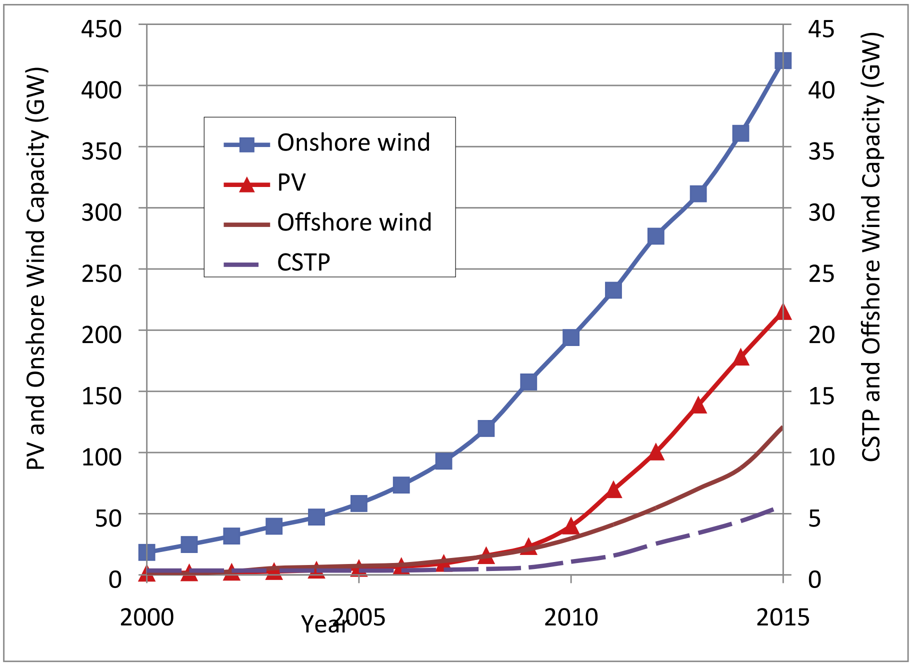

Fig. 1. Variation in the global installed capacity of onshore wind and solar PV (left axis) and offshore wind and CSTP (right axis) from 2000 to 2015. PV = photovoltaic, CSTP = concentrating solar thermal power.

opted for an even longer-time frame. Harvey [33,34] constructed scenarios that achieve elimination of fossil fuel CO_2 emissions by 2100. For the scenario with the most stringent application of energy efficiency measures and relatively low population and GDP/capita growth, a total deployment of wind and solar capacity of 15,000 GW is required by 2100 (at which point global energy demand is stabilized or falling slowly). Fig. 2a (created by the authors) shows an illustrative scenario for the growth in wind and solar energy that continues smoothly from the 2014–2015 trend to final installed capacities of 4000 GW each for onshore wind, PV and CSTP, as well as 3000 GW for offshore wind. Fig. 2b shows the annual rate of installation of new capacity in this scenario; the rate of installation of new onshore wind and solar PV would need to increase by factors of roughly 3 and 5, respectively, by mid-century. Similar peaks in the rate of installation of offshore wind and CSTP occur, but about 20–30 years later. Fig. 2c shows the total rate of installation of these renewable electricity sources. The maximum rate of installation peaks at about 430 GW/year in the late 2030s – about 4 times the rate of installation in 2015.

Given these rates of deployment and future investment costs, the total investment requirement for the scenario can be computed. For example, according to the Global Wind Energy Council [29], 63.3 GW of new wind capacity were installed worldwide in 2015 at an average cost of $1947/kW, while 39.2 GW of solar PV were installed in 2014 at an investment cost of $149.6 billion, giving an average cost of $3820/kW (Ren21, 2015). We used the following costs in 2015: $1880/kW for onshore wind, $4000/kW for offshore wind (which recovers the $1947/kW global average cost), $3820/kW for solar PV, and $6000/kW for CSTP. We assume that these costs approach mature costs of $1200/kW, $2000/kW, $1500/kW, and $2000/kW for onshore wind, offshore wind, PV, and CSTP, respectively.[4] Fig. 3 shows the resulting variation in the annual investment requirements for expansion of these four renewable electricity sources. This variation is a product of annual capacity expansion and a declining cost per unit of capacity.

Annual investment peaks at $740 billion per year, or about 3 times the investment in 2015. This is a purely illustrative scenario, but indicates the magnitude of investments that would be needed to expand renewable electricity supply in a scenario consistent with stabilizing atmospheric CO_2 concentrations at a level that could limit global mean warming to 1.5–2.0 °C – the internationally-agreed target in the Paris Agreement [93] – if also accompanied by large negative emissions from mid-century onward. Additional investments would be needed for an expanded transmission grid, as well as for measures in other sectors – such as deep retrofits of the pre-existing building stock over a period of 40–50 years [31] and investment in urban rapid transit infrastructure [32]. Combined, these measures would easily bring the peak required annual investment to in excess of $1 trillion/year.

2.2. Status of renewable electricity deployment (U.S. only)

Total U.S. renewables installed capacity stood at 244 GW as of the end of 2016 [12] compared to a total installed US electricity generating capacity of over 1100 GW [24]. According to the EIA [101], renewable generation capacity made up over half (63%) of U.S.-based utility-scale generating capacity additions in that year. This is the third consecutive year where renewables made up over 50% of the new installed capacity additions, as 22 GW of new renewable generating capacity was added to the grid [6]. Solar made up the bulk of this renewable capacity (12.5 GW total, of which 8.9 was utility-scale), with wind at 8.5 GW [6]. The EIA envisions an additional 70 GW added between 2017 and 2021 [23].

Of course, we acknowledge that installed capacity in electricity differs from overall contribution to energy supply. While impressive gains continue to be made, renewable energy's share of primary energy is approximately 10% [43]. This will almost certainly rise substantially in the near future across all segments, as the

[4] Specifically, we use a modified learning curve, whereby cost in year t is given by $C(t) = C_{oo} + (C_{2015} - C_{oo})\,PR^{(P(t)-P2015)/P2015}$, where C_{oo} is the final cost and PR is a progress ratio (assumed to be 0.8 for all technologies).

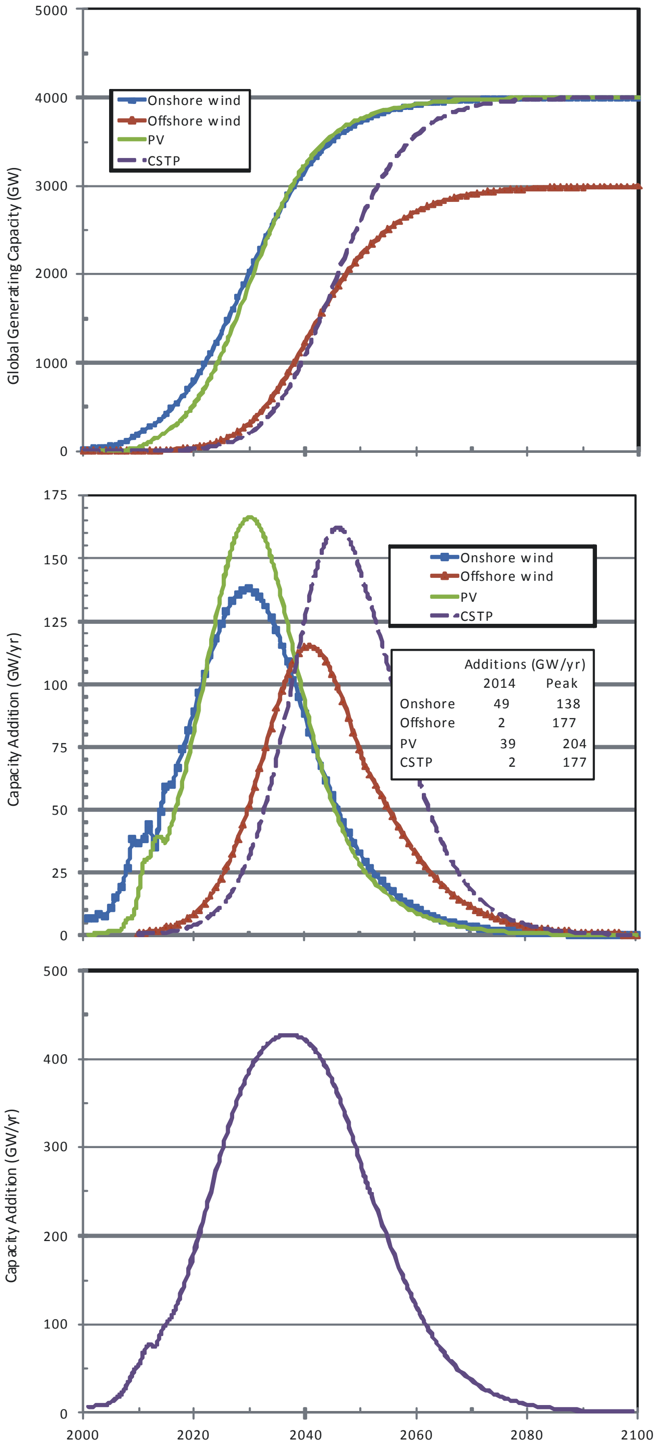

Fig. 2. A scenario for the deployment of wind and solar electricity generation that continues from observed deployments up to 2015 and is consistent with elimination of electricity-related fossil fuel emissions by 2100 if strong efficiency measures are also taken in all end use sectors. (a) Capacity of individual solar and wind technologies, (b) rate of deployment of individual wind and solar technologies, (c) rate of deployment of total wind and solar generation capacity.

aforementioned learning curve has dramatically reduced renewable generators' costs to the point where they are often competitive with conventional generators. Overall, a strong future appears to exist for steady renewables growth nation-wide.

2.3. Financing introduction

We turn now to a brief financing introduction for the non-expert. There are two basic sources of finance for any project that requires upfront funding but generates a long-term revenue stream: ***equity*** and ***debt*** [49,67]. Equity refers to direct ownership in the project or company and, as such, a claim to some portion of the profits generated by the project or company. Debt, on the other hand, refers to money lent to a project at a specified rate of interest, which is paid irrespective of whether or not the project generates a profit. Debt payments might be subtracted from the taxable profits (whereas equity would not be), in which case the effective rate of the fixed debt obligation will be reduced.[5] The cost of equity and after-tax cost of debt are combined with the proportions of equity and debt financing to give the ***weighted average cost of capital*** (WACC), which is computed as:

$$WACC = (C_E * P_E) + (C_D * P_D * (1 - t)) \tag{1}$$

where:

C_E=Cost of Equity (%/year)
P_E=Percentage of Equity (out of 100)
C_D=Cost of Debt (%/year)
P_D=Percentage of Debt (out of 100)
t = tax rate

Computing the cost of debt is straightforward — it is simply the rate offered by the lender. At the time of writing, interest rates are at historic lows. The US Federal Reserve has consistently demonstrated a remarkable willingness to maintain unconventional monetary policy, which is likely to hold inflation and keep debt relatively inexpensive for renewable electricity developers in an age of 'secular stagnation' [88]. The US has been in a sustained period of growth for many years and unemployment has fallen dramatically, but historical market cycles suggest that a decline is likely to arrive eventually. Any scenario involving reduced economic growth would further entrench a lower cost of debt for renewable electricity developers, even though it may have negative consequences in terms of availability of capital providers, liquidity, and other financial contributors to renewables viability.

To compute the cost of equity, companies must determine what the shareholders of their company will expect as their return. In developed countries, the cost of equity is commonly computed using the ***Capital Asset Pricing Model*** (CAPM). According to the CAPM, the expected cost of equity is given by:

$$C_E = R_f + Ba\left(R_m - R_f\right) = (B_a * R_m) + \left((1 - B_a) * R_f\right) \tag{2}$$

where:

C_e = Cost of equity
R_f = Risk-free rate
B_a = Beta, a weighting factor for R_m that serves as a measure of an investment's risk[6]
R_m = Market rate of return for the investment in question

[5] Modigliani and Miller [64] famously argued that the tax shield benefits of debt will lead to an increase in firm value while decreasing the debt service costs.
[6] Beta is calculated through regression analysis, with 1 being an investment that moves with the market [78]. This would make an investment with a beta of 1.5 50% more volatile than the market (a measure of covariance relative to benchmark variance).

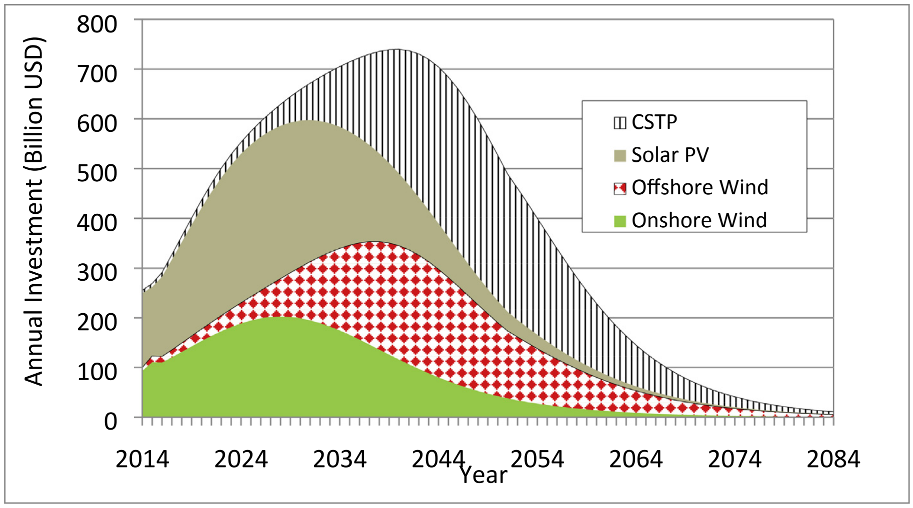

Fig. 3. Annual global investment requirements for expansion of wind and solar electricity generation technologies for the illustrative deployment scenario shown in Fig. 2.

$(R_m\text{-}R_f)$ = Expected risk premium attached to the equity in a low-risk jurisdiction

The WACC,[7] therefore, is determined by a combination of the market and an investor's perceptions. This is important for renewable electricity developers, as Ondraczek et al. [72] found that realizing favourable economics for renewable electricity generators is highly dependent on the cost of capital.

The ***levelized cost of electricity*** (LCOE) constitutes the single fixed cost of electricity that would recoup all costs, including return on investment but excluding transmission, distribution, and grid services. It is computed (according to the International Energy Agency [38]) as:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + O\&M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (3)$$

where:

I_t = Investment in year t ($/kW/year)
$O\&M_t$ = Operations and maintenance (O&M) ($/kW/year)
F_t = Fuel cost ($/kW/year)
E = Electricity output (kWh/kW/year)
r = discount rate
t = lifespan (years of the project)

Considerable insight into the role of different cost factors can be obtained if the initial investment cost is annualized; that is, if it is converted into a fixed annual payment that is sufficient to exactly pay back the initial investment plus interest on the unpaid (but diminishing) principle at an interest rate i. The fixed fraction of the initial investment that must be paid back each year is called the annuity factor or ***cost recovery factor*** (CRF), and is given by:

$$CRF = \frac{i}{1-(1+i)^{-N}} \quad (4)$$

where:

N = lifespan of the project (years)

Assuming the annual O&M costs and annual electricity generation to be fixed, LCOE is given by:

$$LCOE = \frac{(CRF + INS) * I_o + O\&M}{8760 * f_a * CF * PC} \quad (5)$$

where:

INS = insurance rate (year^{-1})
$O\&M$ = annual operation and maintenance cost (as $/kW/year)
8760 = number of hours in a year
CF = capacity factor (the annual production as a fraction of the production that would occur if the plant ran at peak capacity all the time)
PC = plant capacity – this should be formatted in the same way as the others
f_a = availability factor (the fraction of time that the plant is available; that is to say, not out of service due to routine maintenance or failures)

The denominator in Eq. (5) is the annual generation of electricity, equivalent to E_t in Eq. (3) but assumed to be fixed in the simpler Eq. (5).

Table 1 shows how the CRF varies with the cost of capital and the lifespan of the project. For shorter project lifespans, CRF is significantly larger than the interest rate. For a given project lifespan, increasing the cost of capital from 3%/year to 15%/year multiplies the required annual payments by factors of 2.4 and 3.5 for 20- and 40-year project lifespans. As noted earlier, the cost of capital is an important factor in the overall cost of renewable electricity - Table 1 shows why this is case.

A typical lifespan for solar and wind electricity generators is 25 years, while an average rate of return is 7.5%/year in OECD countries and 10%/year in non-OECD countries (where perceived risk is

[7] Helms et al. [35] explain that in cases where the cost of capital is determined by an investor, the WACC can also be called the ***discount rate*** (if an investor is using a ***Net Present Value*** (NPV) financial analysis) or a ***hurdle rate*** (if an investor has opted for an ***Internal Rate of Return*** (IRR) financial analysis). Either type of assessment — NPV or IRR — tries to ascertain an investor's opportunity cost of capital; that is, what the investor could earn in the market for other investments, and whether the investment under consideration exceeds other investments in terms of the return. Obviously, the discount rate and hurdle rate involve a level of subjectivity, and different investors may arrive at differing discount rates depending on their assessments of risk and relative opportunity.

Table 1
Variation of the cost recovery factor with interest rate and project lifespan.

Interest rate	Project Lifespan (years)				
	20	25	30	35	40
0.03	0.067	0.057	0.051	0.047	0.043
0.04	0.074	0.064	0.058	0.054	0.051
0.05	0.080	0.071	0.065	0.061	0.058
0.06	0.087	0.078	0.073	0.069	0.066
0.07	0.094	0.086	0.081	0.077	0.075
0.08	0.102	0.094	0.089	0.086	0.084
0.09	0.110	0.102	0.097	0.095	0.093
0.10	0.117	0.110	0.106	0.104	0.102
0.11	0.126	0.119	0.115	0.113	0.112
0.12	0.134	0.127	0.124	0.122	0.121
0.13	0.142	0.136	0.133	0.132	0.131
0.14	0.151	0.145	0.143	0.141	0.141
0.15	0.160	0.155	0.152	0.151	0.151

greater) [40]. Many governments, especially in OECD countries such as the United States, can borrow at 3%/year or less, resulting in a CRF of 0.043–0.067 for project lifespans of 40 (low CRF) to 20 (high CRF) years. For a capital cost of $2000/kW, a CRF of 0.05–0.10, and a capacity factor of 0.2 (all characteristic of solar PV in a sunny location), the contribution of the capital cost to the cost of electricity is 5.7–11.4 cents/kWh. O&M of $30/kW/year would add another 1.7 cents/kWh to the cost of electricity.

2.4. Common policies

The rapid expansion in the rate of deployment of renewable energy sources outlined in the preceding section can be attributed in large part to government policies that have stimulated or mandated their deployment.[8] In the United States, ***tax credits*** (especially ***Investment Tax Credits*** (ITCs) & ***Production Tax Credits*** (PTCs)) and ***quotas*** are the two most common tools, with tax credits acting as the crucial anchor for renewable electricity developers. Other forms of policy support, such as ***subsidies*** and ***financial de-risking*** tools, are less common, but have nevertheless helped attract additional sources of capital to U.S. clean power projects.[9] These are laid out in Table 2.

2.4.1. Tax credits

ITCs and PTCs are key federal tax-related renewable electricity policy measures that have been widely used in United States electricity markets[10], and the evolution of the industry has been inextricably linked to their availability (or, in some years, lack of availability). The two credits provide tax advantages at different stages - ITCs at project inception, PTCs throughout the life of the project. The ITC (which has proven especially useful for solar facilities) is realized in the same year as project commissioning and is returned to the investor in a linear fashion over 5 years. Credits earned during the initial 5-year period are subject to Internal Revenue Service (IRS) "recapture" if the project is sold to a third party prior to the conclusion of the vesting period [10]. The PTC, meanwhile, provides a 10-year, inflation-adjusted production tax

Table 2
Type of supportive policy and example(s).

Type of policy	Example(s)
Tax credits	Investment Tax Credit (ITC)
	Production Tax Credit (PTC)
	Accelerated Depreciation
Quotas	Renewable Portfolio Standards (RPS)
	Renewable Energy Certificates (RECs)
Subsidies	Feed-In Tariffs (FiTs)
Financial de-risking tools	Grants
	Loan Guarantees
	Loan Concessions

credit for generation by select renewable electricity types (such as wind, biomass, geothermal, landfill gas and municipal solid waste, certain hydropower, and a range of niche technologies).

In the United States, tax law provides for these tax credits to be paired with ***accelerated depreciation***. ***Straight-line depreciation*** is an accounting tool that recognizes wear and tear on an asset, leading to a reduction in the annual taxable profits associated with a given asset. Accelerated depreciation, by contrast, allows renewable generators to capitalize on the time value of money and benefit from tax credits earlier in a project's operational history. Accelerated depreciation simply allows for these benefits to be recognized sooner, and is primarily undertaken over 5 years through a system known as ***Modified Accelerated Cost Recovery System*** (MACRS). Other depreciation rates are available and determined by the IRS [41], covering a range of years and rates depending on the technology type involved.

PTCs and ITCs share some shortfalls. For one, most project developers cannot fully take advantage of (that is, 'monetize') the credits, requiring them to depend on expensive and sometimes difficult to secure tax equity strategies (a financing strategy detailed in Section 3.2.). Second, tax credits are potentially of little use to institutional investors who maintain a tax-exempt status (such as state pension funds for retirees). Finally, the credits require approval and renewal from U.S. lawmakers. Political issues have sometimes led to the tax credits being allowed to lapse, only to be reinstated at a later date (or in some cases, reinstated retroactively). This creates significant uncertainty that harms market sentiment.[11]

2.4.2. Quotas

Quota-driven systems involve political mandates wherein utilities are required to generate a certain percentage of their output from renewable sources. The popular ***Renewable Portfolio Standard*** (RPS), which is currently available (in various forms) in 11 American states [22], is an example of a quota-driven system, and there are many variants of RPSs (certain call for distinct technologies, while others maintain geographical restrictions). Market participants such as utilities can directly comply with their clean power procurement requirements, or compliance can be purchased through a tradable mechanism known as ***Renewable Energy Certificates*** (RECs).[12] RECs represent the environmental attributes associated with the generation of a unit of renewable electricity in the U.S.

[8] Increasingly, this is changing as renewable electricity deployment is driven by economic competitiveness rather than tax policy.

[9] For those seeking additional information on U.S. supports, DSIRE [22], a database funded by the U.S. Department of Energy, provides comprehensive, state-by-state information on the policies and incentives that are currently available. As of the date of writing, over 2600 programs and incentives are in place in the U.S. alone, including rebates, standards, easements, and purchasing.

[10] Other tax credits are sometimes available, such as in the form of sales tax exemptions, manufacturing tax credits, and excise tax exemptions.

[11] Randall [76] explains that this latter barrier's significance has been reduced by the U.S. Congress initiating a five year extension of the tax credits – a move which was tied to a new bipartisan agreement that also reversed a ban on oil exports. The implications of the tax credit extension are significant, as the same article estimates that nearly $75 billion in new renewables investment will be unlocked before the credits are permanently phased out at the end of the extension period.

[12] RECs are only one of the products in the environmental markets, which also include credits for carbon (compliance, offsets), Sulphur Oxide, and Nitrous Oxide.

2.4.3. Subsidies

Subsidies are another useful tool, of which ***Feed-in Tariffs*** (FiTs) – wherein a power off-taker (usually a major procurer such as a government or utility) specifies a guaranteed premium price for all renewables output over a specified time period (such as 20 years) - are the most prominent. Globally, FiTs have been proven highly successful in bringing new renewables capacity online (e.g. Germany saw installed renewable electricity capacity (excluding hydropower) grow from 8% to 34% of net electricityconsumption from 2005 to 2015, according to Wirth [105]). Currently, utilities or governments in four US states (California, Hawaii, New York, and Indiana) as well as the U.S. Virgin Islands maintain FiT electricity policies [22].

FiTs can spur economic behavior. ***Price digressions*** (enacted through stable declines in the tariffs offered for new projects) can ensure that investors receive reasonable rates of return commensurate with the increasingly lower risk levels associated with a technology's advance in maturity. Shrimali [84] identified long duration and high revenue certainty as key considerations for developed country investors; unsurprisingly, FiT schemes are tremendously attractive to investors in developed countries such as the United States.

The premiums associated with FiTs can create financial burdens on electricity ratepayers, utilities, and/or states. In such circumstances, a more economically sustainable FiT variant involves a ***FiT premium***. Under such a scheme, renewable power producers receive a top-up on the wholesale price. Traditional FiT projects are given priority dispatch at all times (in which the price received for power generated remains constant), but a FiT premium provides no such assurance. This has the benefit of reducing wholesale market price distortion (which inevitably arises in a FiT scenario that sees generators being paid different prices and FiT-secured renewable electricity projects receiving guaranteed dispatch rights) but with the downside of substantially increasing risk for the power producer [74].

2.4.4. Financial de-risking tools

Less costly tools can be used by public sector actors seeking to entice greater private investment. For example, replacing tax credits with one-time ***grants*** can be a particularly useful tool for matching subsidies with the substantial upfront capital expenditure needs facing renewable energy developers. In the ***American Recovery & Reinvestment Act*** (ARRA), a stimulus enacted by the Obama Administration in response to the 2008 credit crisis, the Section 1603 cash grant program allowed for tax credits to be realized early in project development [4]. The program drove the installation of 16.9 GW of new renewable electricity capacity. The program's popularity stemmed from the fact that the benefits gained by the developer were immediate, as they were not required to incur costs associated with tax equity.

Another low-cost tool involves subnational or national states leveraging their own creditworthiness. Two methods include providing ***loan guarantees***[13] (which constitute a promise by one party to assume the debt of a defaulting borrower in the event of a missed payment) and ***loan concessions*** (which involve a state using their borrowing power and creditworthiness to reduce a smaller borrower's cost of capital by allowing them to leverage the more creditworthy party's credit). Loan guarantees are particularly effective for supporting innovation and promoting the inclusion of non-traditional generators, as even loan programs with unsuccessful investments can have strong returns [20].

3. Prominent historical delivery mechanisms for renewable electricity finance

This section will cover examples of dominant renewable electricity financing structures in the renewables markets to date. Fundamentally, financing can be arranged at the scale of an individual project, or at the scale of the organization carrying out the project. In the former case, only the risk of the specific project would be taken into account when determining the WACC, whereas in the second case, the overall risk of the corporation or other entity involved would be the relevant risk parameter – the assumption being that if the project fails to perform as expected, the corporation can draw upon its wider financing resources to honour its commitments to the creditors of the particular project in question.

To give a sense of overall commitments in the sector, we have compiled Table 3:

Table 3
Type of capital, overall volume, and estimated costs (Primary Source is Martin [56], with gaps filled from Refs. [11,13,53] and author discussions with sector participants). Respondents to our queries emphasized that cost of capital is a competitive advantage (meaning that many will be reluctant to disclose it), so costs are generally estimates.

Type of capital	Overall volume in 2015	Cost
Tax equity	$11.5 billion - $5.1 billion ($2.6 billion solar rooftop, $2.5 billion large-scale & commercial and industrial (C&I)) - $6.4 billion (wind)	7-18% (varies significantly)
Bank Debt London Interbank Offered Rate (LIBOR = L)	$17 billion	- Short-term construction - L + 1.5–1.75% - Term debt – L + 1.75–2% - Back-leveraged – L + 2.25–2.75% - Corporate revolver (funds for drawdown, repay, and re-draw) – L + 3.25
Public Market	~$10 billion	Varies (Yieldcos – 5–7%)
Term Loan B	$3.3 billion in overall power sector (much less in renewables)	L + 4.25–6%
Venture Capital/Private Equity	~<$2 billion	Varies
Distributed Generation (Solar)	$8.7 billion	4–7.5% (depending on tranche)
Project bonds	Unknown	L + 2–3%

3.1. Corporate finance

Perhaps the simplest method of financing a renewable energy project is through the balance sheet of a corporation, known as ***corporate finance***. This can be done through projects driven by electric utilities or non-utility generators (such as ***independent***

[13] Bolinger et al. [10] reference the aforementioned ARRA's expanded loan guarantee program's ability to support between $60–100 billion in loans to renewable energy projects as a useful stimulator of renewables deployment.

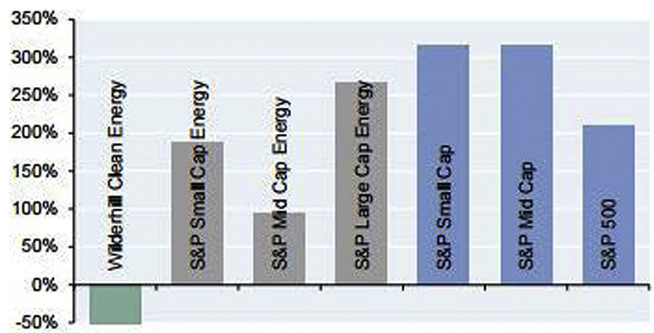

Fig. 4. Cumulative return for renewable stocks, conventional energy stocks, and the broader market between 2003 and 2016 (Source: J.P. Morgan Asset Management [43]).

power producers (IPPs)). The basic accounting equation that defines a corporate balance sheet can be described as follows:

$$A = L + E \quad (6)$$

where:

A = Assets
L = Liabilities (or “debt”), where L < 0
E = Equity

Corporate equity is primarily found in publicly traded ***securities*** (also known as ***shares***). If the market demand and exchange mechanisms for trading these securities are strong, investors will call such a market ***liquid***. Individual investors (called ***retail investors***) can purchase shares, as can larger investors (such as ***institutional investors,*** which are covered in later sections). Equity is also held by founders or management, and can be offered to managers by shareholders as an incentive for managers to achieve strong returns.

The shares of many leading renewable energy companies (including manufacturers, utility-scale developers, and residential-oriented developers) are traded on public exchanges globally. The United States is home to the two largest stock exchanges by total ***market capitalization***[14] – the ***New York Stock Exchange (NYSE)*** and ***NASDAQ Stock Exchange (NASDAQ)***. For those looking for greater diversification within a single investment, equity can also be found in ***yieldcos*** (covered in-depth in a later section), the aggregation vehicles known as ***clean energy exchange-traded funds*** (ETFs, which can combine a mix of small, mid-capitalization, and large-capitalization domestic stocks with foreign stocks), and ***clean energy mutual funds***.

Even if a variety of publicly-traded options exist, challenges remain. The renewable energy sector has performed poorly relative to broader energy stocks and the market as a whole since 2003. Fig. 4 compares the Wilderhill Clean Energy Index with returns from other sectors to demonstrate that renewables show an overall negative return over the last 13 years, while both energy-specific and general indices have earned large and positive returns.

Corporate debt can come in a variety of different forms. The cost of debt is dependent on a large number of factors, including the creditworthiness of the borrower and the anticipated use of the funds. A common source used in the renewable electricity sector is ***back-leveraged debt***, which is a loan structure used late in the construction cycle (that is to say, at the first available entry point where the risk level is perceived to be suitable for lenders) as a way to replace higher-cost equity with lower-cost debt [5]. Back-leveraged debt has proliferated in the US in order to accommodate the particular demands of tax equity investors.

Corporations have other debt-based options as well. They can issue ***corporate bonds***, which involve long-term bonds rated by ratings agencies like Moody's or Standard and Poor's. There are also ***convertible bonds***[15] and ***high-yield debt*** (with the latter also known colloquially as “junk bonds”). Debt can be short-term, as in the case of short-term debt securities called ***commercial paper*** (a form of debt that is usually repayable within less than 9 months and is used to meet day-to-day corporate expenses such as payroll). Those with a higher risk appetite can initiate ***leveraged loans,*** which is a type of lending to highly indebted companies [46].

Strictly speaking, the simple equation for corporate finance presented at the start of this sub-section does not allow for ***off-balance-sheet financing*** (i.e., financing that does not appear on the previously introduced balance sheet formula), even though corporations are capable of holding assets off-balance-sheet through accounting conventions. This leads to the primary disadvantage of corporate finance: that lenders have ***recourse*** (meaning access in the form of collateral) to the other assets of the borrower. This can distort the WACC, as the assigned risk profile of a project becomes dependent on a corporation's overall holdings or activities. Therefore, a project's cost of capital may not reflect the risks associated with that specific project; a corporate WACC may, for example, incorporate a project pool covering different regions, political contexts, and technologies. Helms et al. [35] contend that this shortcoming has hindered renewable electricity expansion, as utilities have utilized valuation techniques that use discount rates attached to ***greenfield***[16] fossil facilities. This tendency may make ownership of greenfield or ***brownfield*** renewable electricity facilities appear less attractive, even though greenfield fossil fuel facilities are arguably riskier than greenfield renewable energy facilities due to fuel-related uncertainties (such as future climate policies).

3.2. Banking and financial institutions

Banking institutions comprise commercial and investment banks,[17] both of which can extend loans to de-risked and mature renewable electricity technologies.[18] ***Tax equity*** is a domain in which banking institutions have been very active. Tax equity is a type of upfront capital provision in which renewable electricity developers partner with select institutions capable of taking advantage of the credits associated with a renewable electricity project (often a financial institution with significant tax liabilities). These institutions possess specialized legal and financial staff who can structure the prospective renewable electricity deal in such a way that government-directed tax advantages and accelerated

[14] Total market capitalization simply refers to the total value realized when adding up each piece of the constituent firm's value. Individual firm market capitalization can be calculated by multiplying the number of shares by the current share price.

[15] Convertible bonds are hybrid bonds that have debt-like characteristics (such as yields) but also maintain the potential for conversion to equity, such as integrated energy company Tesla's $600 million 2013 offering [89].

[16] Greenfield is a common industry term that refers to a project that is in some stage of construction, as opposed to an operational (or brownfield) site.

[17] International banks (e.g. Spain's Banco Santander) and domestic banks (e.g. J.P. Morgan) are active in the space.

[18] An example would be a post-commissioning re-financing of an operational solar array whose risk profile meets the bank's risk management standards. These banks typically specialize in providing construction debt for infrastructure projects of all kinds (e.g. toll roads and liquefied natural gas export terminals, in addition to renewable electricity projects).

Risk Type	Example Scenario
Sponsor Risk	Sponsor of the transaction goes bankrupt.
Technology Risk	Insufficient historical irradiance data for a solar array.
Completion Risk	A wind project is not completed on schedule.
Input/Supply Risk	Fuel for a biomass project is constrained due to supplier issues.
Operating Risk	O&M is higher than expected.
Environmental Risk	Toxic substances are found at the build site for a new project.
Approvals Risk	A project does not receive a timely approval.
Off-Taker Risk	A purchasing utility defaults on its obligations to purchase all power.

Fig. 5. List of risks and example scenarios adapted by the authors from Ref. [63].

depreciation benefits are maximized. The three main tax equity structures include the most popular version (known as a partnership flip), as well as the sale-leaseback and inverted flip [54, 58].

Tax equity has some challenges. For one, the number of tax equity providers is somewhat small (approximately 20), a problem which is exacerbated by the fact that there is a distinct rationing to the largest developers [45]. Predictably, this somewhat illiquid market leads to the second concern - expensive capital [53]. Third, regulatory hurdles[19] stand in the way of tax equity use optimization.

Banking institutions are active in non-lending facets of the renewable electricity sector, such as acquiring operational assets with stable cash flow profiles [66], and have been active in other ***project finance*** (that is, the direct financing of individual projects) transactions besides tax equity investment.

Project finance is among the longest serving types of financing method in renewable electricity, having been used extensively since the 1980s [106]. In an early analysis of renewable energy project finance, Mills & Taylor [63] provide several common motivations for sponsors to seek to use project finance:

1) It improves debt-to-equity ratios by allowing debt to be carried "off-balance-sheet" (that is, a debt-heavy renewable electricity project will not show up on the corporate balance sheet);
2) It can allow for increased levels of comparatively low-cost debt in a project's capital structure;
3) It is useful in joint ventures that have sponsors of uneven financial strength;
4) It facilitates better risk allocation between sponsors; and
5) It is often the only tool available to less financially sound sponsors.

Non-recourse project finance is usually dependent on the creation of a ***special purpose vehicle*** (SPV) that is ***bankruptcy-remote*** (that is, the creation of a dedicated asset holding instrument that, in the event of a bankruptcy, would not allow for the creditor to have recourse to other assets of the parent company). Such a vehicle is distinct from the asset's corporate holding vehicle - in this case, renewable energy project developers and/or their venture partners - and involves repayment of a loan that is tied to the contractually derived cash flows from the project's output. Project finance can involve only one lender, or can be a ***syndicated*** loan that involves multiple institutions. The risks and benefits of the project are solely tied to the aforementioned SPV, with project financiers evaluating the feasibility of a proposed project through an assessment of a variety of factors (a sample of which are outlined in Fig. 5).

3.3. Private equity/venture capital, family offices, and hedge funds

Private equity[20] and ***venture capital funds*** are pooled investment vehicles that raise money from wealthy individuals and large investors such as pension funds to make targeted investments. In contrast to public securities, these types of investments are private. Bringing a long-term bias and investing in illiquid assets, immature technologies, and/or cash-poor companies, these funds are generally managed by practitioners who possess some sort of advantage (typically financial or managerial) that can allow them to earn superior returns. An outline of the continuum of private equity and venture capital vehicles is presented in Fig. 6:

Private equity was a crucial driver of growth in the U.S. renewable electricity industry over the last decade. Some of the capital came from major investment banks, which used private equity funds to launch public companies[21] [3]. Later, large mainstream funds launched dedicated funds.[22]

For earlier-stage renewable electricity company financing, venture capital has been disbursed through both diversified partnerships and dedicated clean energy investors. Modern venture capital is defined by many factors, including the high rate at which target companies consume cash, the types of business that attract the bulk of investment interest (mainly early-stage technology companies), the higher risk profile of target investments, and the clustered locations of much of the capital (Silicon Valley in California being the most prominent). A venture capitalist leverages sector expertise and financial resources to not only provide capital, but also to optimize the investee company's operations. Valuation techniques in the venture capital industry differ considerably from those found in cousins like buyout private equity, as limited financial modeling of past returns is available. Venture capital firms must rely on assessments of a potential investments' management team, product markets, and other qualitative and quantitative factors identified by a venture capital firm's leadership.

In alternative investing (that is, investment styles outside of mainstream equities and bonds), two other groups are also worth

[19] For example, the ***Community Reinvestment Act*** (CRA) incentivizes depository institutions to invest their limited capital in projects within communities where they operate. More specifically, it endeavours to facilitate credit extension to communities (including low-to moderate-income neighbourhoods — [9]). Specific projects are supported through it; however, it cannot be used with renewables tax credits such as the PTC and ITC. Until measures are undertaken to ensure that investors can access renewables-focused tax credits within the CRA, it is difficult to tap into the significant potential pools of capital that banks allocate to the CRA.

[20] Private equity refers to a project not traded on a stock exchange (that is, ***public equity***), which should not be confused with public spending/ownership (which is controlled by the government).

[21] For example, Goldman Sachs helped launch First Solar. This higher-risk move, described by a former employee as a major investment in a firm which "went on to become the most successful solar company in the world" [3], represented a seed of things to come for Goldman Sachs. In 2015, the powerful bank committed $150 billion to the renewable electricity sector by 2025 - nearly quadruple the bank's original 2025 goal of $40 billion.

[22] For example, Riverstone Holdings, the largest solely energy-focused private equity investor, has dedicated $4.1 billion in equity capital to 18 companies [77].

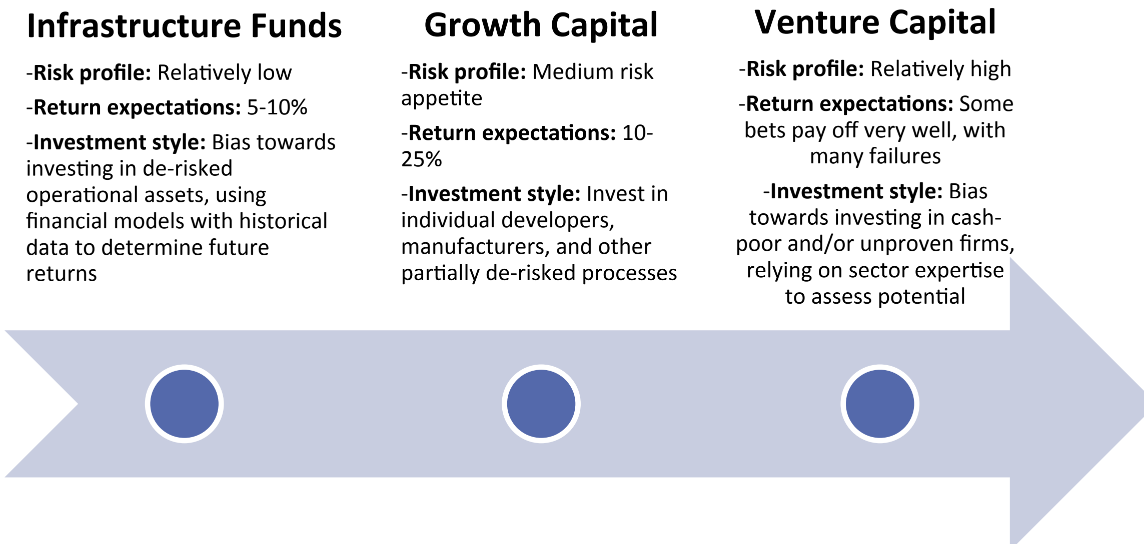

Fig. 6. The private equity - venture capital continuum within the broader renewable energy space (Source: Adapted by the authors from Ref. [74]).

mentioning: non-public ***family offices***, which are dedicated investment professionals making investments on the part of ***high-net-worth*** (HNW) individuals, and ***hedge funds***, a multi-purpose private investment vehicle that uses active investment strategies to earn returns above a passive benchmark ("***alpha***"). These private investment entities have played a small but noteworthy role in renewable electricity investing. Most notably, hedge funds contributed to buying and shorting the equities of firms.[23] They have also directly purchased stakes in developing wind and solar assets [21]. Family offices are also operating in this space, with some making attempts to amplify their influence.[24]

3.4. Institutional investors

Institutional investors (a term that encompasses actors as diverse as pension funds, insurance companies, sovereign wealth funds, university endowments, and charitable foundations) are crucial anchors in global capital markets. Institutional investor holdings in OECD countries alone approach $100 *trillion* in assets under management [70], with U.S.[25] investors comprising $45 trillion of that total [82]. Of course, this theoretical availability of funds would never be entirely directed to renewable electricity in practice, but even a relatively modest $250 billion annual allocation to climate-protecting direct investment would nearly double the annual clean energy investment figures of approximately $300 billion found in recent years (such as in Ref. [7]). The feasibility of reaching 0.25% of $100 trillion (the $250 billion referenced in the previous sentence) in new institutional investment is backed by research found in Nelson [68]. Between the various investments vehicles available (indirect investments into corporate equities and bonds or pooled investment vehicles, as well as direct investment into projects themselves), Nelson argues that such an allocation (with some combination of debt and equity) is reasonable given the liquidity, diversification, and investment scope of institutional investors. Nelson [68] also finds that direct investment has the most potential to drive down the cost of capital for renewable electricity generation.[26]

The first way that an institutional investor can invest in renewable electricity infrastructure is through direct investing, although this market is not a major constituent of portfolios (current total allocations to the broader asset class of infrastructure are less than 1% of total assets under management). Another common method for investing is through ***Term Loan B*** markets, which are higher yield securities available to institutional investors. Institutional investors can invest through bond channels as well; private placement ***project bonds*** are one such option.

4. Emerging opportunities for mainstream renewable electricity finance

To maximize cash available to the sector, the refining and evolution of existing approaches will need to continue (the "all of the above" capital strategy discussed previously). Public market finance - that is, capital provided and subsequently transacted through public markets – is among the most promising options, as it involves tapping into new sources of capital and practicing better risk allocation. In Table 4, we provide examples – vetted and discussed with industry practitioners – of some of the most important options. Sections (i) to (iii) cover public market debt and equity vehicles that are either currently available or likely to contribute to shaping the future of renewable electricity finance, while sections (iv) to (vi) cover delivery entities capable of encouraging greater renewable electricity investment activity.

4.1. Securitization through asset-backed securities

As previously stressed, operating renewable electricity facilities maintain a relatively low risk profile with stable long-term cash flows. This inherent structure lends itself well to the process of ***securitization***, wherein illiquid but cash generating assets are pooled, bundled,

[23] This shorting has had impacts on yieldcos, as well as publicly traded firms such as (now-bankrupt) SunEdison and SolarCity (now Tesla).

[24] One notable example of this magnification attempt is the CREO Syndicate, which is working to enhance deal flow and deploy capital by aggregating family offices together to reach capital allocation thresholds (at least $2 billion by 2020 – [17]).

[25] These entities fall on the ***buy-side***. Buy-side refers to firms that purchase assets in the markets, as opposed to firms that facilitate transactions (***sell-side***).

[26] For significant capital cost decreases to be realized, Nelson [68] proposes two necessary pre-requisites. First, the institution must be actively involved in designing the deal so that overall portfolio risk is reduced and asset-liability matching is possible. Second, competition must be present in the market, so that comparable institutions can compete to offer the best terms to developers.

and then transferred to limited liability corporations. In turn, these corporations create ***structured products***, which earn their name from the financial engineering required to build them. Structured products take many different forms; of particular relevance to this paper are ***asset-backed securities*** (or ABSs). Renewable electricity variants, such as those for distributed solar photovoltaic projects, are increasingly viable, with Brandt et al. [11] noting that solar securitizations are emerging as a mainstream financing option.

A simplified example of an asset-backed security (containing an assortment of different but standardized renewable electricity assets) is presented in Fig. 7:

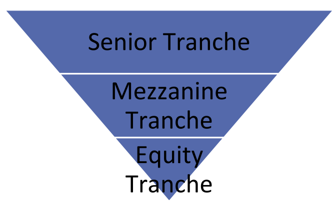

Fig. 7. A simple asset-backed security demonstrating a waterfall distribution (Source: Authors).

There are numerous benefits to this profit and risk allocation structure, which is known as a ***waterfall distribution*** due to the fact that individual levels "spill" in sequence. ABSs are comprised of a structure based on the riskiness of the assets contained within each level; for example, as shown in Fig. 7, the lower tranche would be more speculative and "equity-like". It would likely contain the fewest number of securities, and in the event of default, it would be the first source of investors to encourage losses.

There are significant benefits to an ABS. First, this structure expands the pool of potential investors. Each of the tranches would receive a different credit rating from a third party agency. The senior tranche(s) may be ***investment-grade***, meaning those institutional investors (and others) with investment mandates that restrict their investments to only high-quality assets are able to access them.

Second (and related to the first paragraph of this section), an ABS provides investors with ***risk management*** benefits. In the event of a default occurring in the underlying pool of assets, the first-loss tranche holders will incur the first set of losses. This tranche provides a sort of ***credit enhancement***[27], and the "***tranching***" process allows for return expectations to be the inverse of risk ratings. As each tranche assumes more risk, holders are compensated with progressively higher returns. Lower-risk senior tranches receive returns below the average return of the pool as a whole. This gives the senior tranches more of a debt profile, while lower tranches behave more like equity.

ABS can also allow for capital to be released from corporate balance sheets that cannot hold them "on balance sheet" for reasons such as regulatory limitations or capital constraints. An illiquid asset may be worth more when it is transferred off a balance sheet, as it is now more liquid. Further coverage of the origins of the securitization process can be found in Giddy [28].

Finally, ABS proliferation would allow multiple projects to be aggregated together, even if this brings some ***transaction costs***[28]. This is obviously useful for individual solar assets, wind farms, and others facilities that may not meet the typical $100 million (or more) investment minimums required to attract the low-cost capital typically associated with an ABS. Very small projects, such as distributed solar arrays, would be especially well-suited to aggregation through securitization processes, provided that satisfactory measures could be undertaken to ensure standardization of the underlying contracts and homogenous creditworthiness of the generators. Table 5 provides details on two ABSs of leading distributed system installers – SolarCity (now Tesla) and Sunrun – with information on the nuances of their solar ABS launches.

4.2. Pools and trusts

Like securitization, pools and trusts are public capital vehicles. However, unlike securitization, pools and trusts can benefit from a lack of corporate taxation application if specific criteria are met. Two of the most promising opportunities for expansion in this regard, as well as an example already available in the markets, are provided below.

4.2.1. Master Limited Partnerships and Real Estate Investment Trusts

Master Limited Partnerships (MLPs) are a type of financing instrument that has successfully increased the number of investors in the oil and gas sector in the United States. It could be extended to the renewable energy sector. Investors in MLPs benefit from the advantages of a publicly traded corporation, such as ***limited liability*** for shareholders (meaning an individual cannot lose more than the principal of their investment) and ***corporate governance*** (such as a Board of Directors to oversee management), as well as the added benefit of a tax advantage. Indeed, the primary value proposition of an MLP is predicated on favorable tax policy. So long as MLPs adhere to a set number of restrictions on revenue flows, investors can avoid double (i.e., corporate and individual) taxation.

This benefit is based on the fact that substantial majorities of tax-free yearly revenue are disbursed to external shareholders. The revenue must "pass through" to the shareholders, and to maintain this preferential treatment, external shareholders typically retain a 98% ownership interest. The "general partner" of the partnership, meanwhile, owns the remaining 2% [92]. A typical MLP structure, wherein the ***Limited Partnership*** (LP) would hold an operating company that holds assets and maintains relationships with lenders, would resemble Fig. 8.

The extension of MLP coverage to renewable electricity technologies would be a natural transition in the context of an MLP sector where the bulk (i.e., over 80% percent) of the capital is allocated to qualifying energy and natural resource projects in sectors like electricity transmission, gas pipelines, and upstream oil and gas projects [18]. Simple legislative changes could open MLPs to the renewable electricity industry in the United States [65], with [108] calling particular attention to the term "qualified income". Recent actions are encouraging. Representative Ted Poe introduced the H.R. Master Limited Partnership Parity Act in June 2015 to the House of Representatives [94], building on previous work presented by Senator Chris Coons (the legislator that reintroduced an MLP expansion bill at the same time, according to Martin [58]). A precedent even exists for rapid extension of MLP coverage; in the 2008 Emergency Economic Stabilization Act, Toson [92] explains that the definitions underlying MLP were expanded to include the storage and transportation of ethanol, biodiesel, and other fuels.

Like MLPs, ***Real Estate Investment Trusts*** (REITs) are publicly traded entities (i.e., companies or trusts). These organizations typically own, operate, and—to a limited extent—develop income-producing real estate property. Common REITs include equity and

[27] Credit enhancement refers to the fact that holders of equity tranches voluntarily enhance the creditworthiness of the senior and mezzanine tranches, thereby allowing senior tranches to secure the higher credit ratings from credit agencies.

[28] Transaction costs in the renewable electricity sector includes things such as legal fees or "flotation costs" – the latter being charged by investment bankers as fees associated with the underwriting and issuance of a new security.

Table 4
Key emerging methods for financing and delivering finance to renewable electricity (Source: Authors, [15,51,53,65,96]).

Securitization through asset-backed securities	The process of pooling illiquid assets into liquid and readily tradable securities. One example - asset-based securities (ABSs) - represents rights to cash flows derived from portfolios of real asset loans.
Master Limited Partnerships (MLPs)	Liquid, tax-advantaged limited liability partnerships that have been popular in the conventional energy industry. Hold significant potential for application to renewable energy, but legislative changes are required.
Real Estate Investment Trust (REITs)	Publicly traded entities (companies or trusts) used on several international exchanges that typically own, operate, and—to a limited extent—develop income-producing real estate property. Hold significant potential for application to renewable electricity, but require definitive tax rulings from the IRS or legislative changes.
Yieldcos	A dividend distributing publicly listed company, yieldcos combine different operational assets that have predictable cash flows. These structures are already common in the market.
Green Bonds	Standard (or ‘plain vanilla’) bonds applied to environmentally-friendly projects.
Green Banks	A model that leverages a set amount of public monies to attract greater sums from the private sector.
Institutional investors	Corporations or other legal entities that ultimately serve as financial intermediaries between individuals and investment markets. Examples include pension funds, insurance companies, sovereign wealth funds, and university endowments.
Corporate PPAs	Contracts inked by corporates with renewable generators to provide renewable energy generation. An example would be Google procuring power for a data centre.
Crowdfunding	Websites that allow the public to fund causes or businesses.
Community energy	Non-profit generators, such as communities.

Table 5
Solar asset-backed security characteristics of two leading US markets (Source: Bloomberg New Energy Finance [8]).

Issuer	SolarCity				Sunrun
Deal	2013	2014–1	2014–2	2015–1	2015–1
Amount raised	54.4m	70.2m	201.5m	123.5m	111.0m
Tenor(1,2)	7.05y	6.60y	6.89y	6.04y	7.07y
Spread(1,3)	265bps	230bps	180bps	230bps	230bps
Coupon(1)	4.80%	4.59%	4.02%	4.18%	4.40%
PV systems	5033	6596	15,915	16,400	7893
Total capacity	44 MW	47 MW	118 MW	108 MW	50 MW
Residential portion	71%	87%	86%	100%	100%
Overcollateralisation	38%	34%	27%	32%	24%
Tranches	Single	Single	Senior/Sub	Senior/Sub	Senior/Sub
Rating(4)	BBB+	BBB+	BBB+/BB	A/BBB	A/BBB
Tax equity structure	Sale-leaseback	Sale-leaseback	Inverted lease	Partnership-flip	Inverted lease
Underwriter(5)	Credit Suisse	Credit Suisse	Credit Suisse	CS, BAML	Credit Suisse

Source: Bloomberg New Energy Finance, Bloomberg First Word, company filings Notes: (1) Tenor, spread and coupon correspond to the senior tranche of each securitisation. (2) Tenor is the weighted-average life for the senior tranche of each securitisation. (3) Spread is the basis point spread (bps) over the 7-year interest rate swap. (4) S&P rating for SolarCity 2013, 2014-1 and 2014-2; KBRA rating for Sunrun 2015-1 and SolarCity 2015-1 ABS. (5) ‘CS’ and ‘BAML’ refer to Credit Suisse and Bank of America Merrill Lynch, respectively.

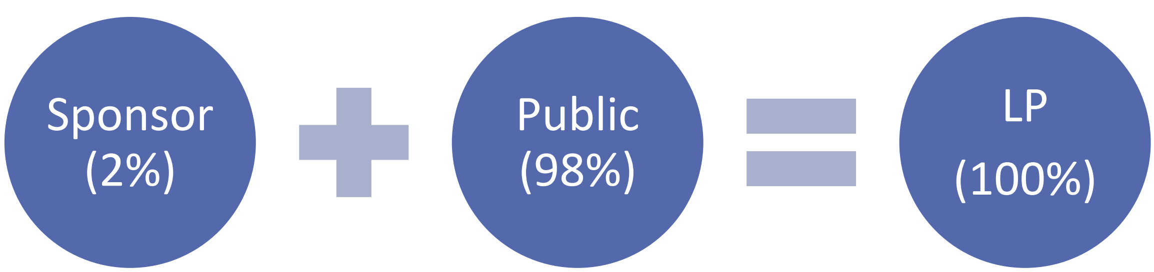

Fig. 8. Ownership composition of an MLP (Source: Adapted by the authors from Ref. [26]).

mortgage REITs for the housing sector, while more specialized types that focus on sectors like hospitality or storage can also be found. REITs have been in use since 1960, primarily as a method of aggregating illiquid real estate equity and debt investments into real estate securities available to the capital markets that can distribute revenues back to investors [59]. They are accessed by many different investors, and are prized for their liquidity and ***price discovery*** (meaning that the market determines their share value on an ongoing basis).

Like MLPs, a REIT relies on a tax-advantaged “pass through” to shareholders from the parent company's real estate revenues, thereby constraining the amount that can be reinvested into company operations (but allowing income to be taxed only once at the shareholder level). 3 key criteria must be met to maintain this pass through: at least 75% of gross income must come from rent or interest payments, at least 95% of income must be from passive sources (real property rent, interest, dividends), and – of particular relevance to renewable electricity – at least 75% of assets held must be “real property” [59]). In the United States, IRS rulings on the term “real property” will be required for REITs to be applied to renewable electricity (which the agency has proven reluctant to offer). Legislative changes could also help.

4.2.2. Yieldcos

Urdanick [96] has noted that yieldcos can sometimes be described as “synthetic MLPs”. A dividend-distributing, publicly-listed company, yieldcos combine different operational assets (with predictable cash flows) into a single vehicle. The operational assets within a yieldco are often dropped down from a well-capitalized parent – typically a utility such as NRG Energy or Florida Power & Light – that benefits from the cash received to re-invest in the parent company's operations [66]. Indeed, this parent company can act as a sort of funnel, with assets still under development held in the parent's structures until the construction or post-construction period has elapsed and an asset has been suitably "de-risked" for downloading into the yieldco [59].

With an ability to access public markets, a generally lower risk profile, and the potential to broaden attractiveness to investors through integration with the fossil fuel assets of the parent company, yieldcos distribute their relatively stable cash flows by offering yearly or quarterly distributions to investors in the form of ***cash available for distribution*** (CAFD). A generalized CAFD calculation, adapted from Urdanick [96]; is presented below:

$$CAFD = QE - (I\&TP + M\&CE + \mathrm{PP}) - \mathrm{R} \tag{7}$$

where:

QE = Quarterly Earnings
$I\&TP$ = Interest & Tax Paid
$M\&CE$ = Maintenance & Capital Expenditures
PP = Principal Payments on Existing Debt
R = Reserves for prudent conduct of business

It should be noted here that this cash distribution structure differs slightly from the MLP or REIT in that any earnings of the yieldco are taxable. However, through clever usage of depreciation and loss carryforwards, a yieldco can avoid taxation at the corporate/entity level, as well as – in some cases - at the investor level (further description of the nuances around this can be found in Martin [59]).

It is important to note that yieldcos do not significantly reduce financing costs for new renewables projects [68]. A number of reasons explain this shortcoming, including the presence of high costs and fees when a yieldco is launched and the fact that investors tend to price yieldcos closer to equity rather than debt as a result of the inclusion of a premium in the publicly traded stock price for anticipated future equity appreciation [68]. As a result, yieldcos have recently fallen short of expectations and, in the discussions we undertook to shape this review, one of our respondents called for re-imagining a Yieldco 2.0, given that impactful public market vehicles must ultimately reduce the cost of capital.

4.3. Green Bonds

Bonds, also known as fixed income investments, are long-term instruments used to allow for the extension of debt from creditors to borrowers. Green bonds are used for environmentally sustainable projects (including renewable electricity). No compulsory standards currently exist for Green Bonds, making the term subject to some interpretation. The ***International Capital Market Association*** (ICMA), an international self-regulatory financial organization, has formulated voluntary ***Green Bond Principles*** (GBP). The Principles emphasize transparency and disclosure [36] by following 4 key principles:

i) Reporting on the use of proceeds;
ii) Having a clear process for project evaluation and selection;
iii) Ensuring traceability of proceeds within the issuer; and
iv) Reporting of annual proceeds.

4.3.1. Supranational and sovereign green bonds

At the macro-scale, large "green bond" offerings are becoming increasingly common. Supranational organizations such as the Washington, D.C. – based World Bank (which focuses primarily on developing countries) have been at the forefront of this movement [107]. Clapp et al. [15] observed that demand for many offerings exceeds supply, and strong interest has been expressed by both investors with socially and/or environmentally responsible investment preferences and mainstream investors that are focused on the yield of their investments. Such popularity suggests that a Treasury-directed green bond – that is, a bond offered by the U.S. government – is an intriguing opportunity. To date, however, there has been little movement on this front.

4.3.2. Innovative corporate bonds

Innovation can be a nebulous concept, but for bonds, we take it to be those bond offerings that go beyond the routine conventional corporate bonds of Vestas, First Solar, and other renewable electricity companies. These start with businesses that do not include electricity generation among core business functions but offer bonds earmarked for financing their own renewable electricity initiatives. This opens up a pair of increasingly important segments in the renewable electricity; specifically, commercial and industrial customers, many of whom are well-positioned to act as alternative procurers for renewable electricity supply.[29]

4.3.3. State and municipal bonds

Municipal bonds are another avenue for funneling capital into the renewable electricity space. The $3 trillion dollar U.S. municipal bond market has traditionally funded community infrastructure (roads, sewers, and buildings), and this history can serve as the foundation for extension of debt to renewable electricity projects [62]. Numerous schemes – taxable and tax-exempt – are currently in operation.[30] One scalable opportunity for distributed generation can be found in ***Property Assessed Clean Energy*** (PACE) financing. Under this scheme (which has been found in other iterations, such as land-secured financing districts), municipalities would initiate a bond issuance whose revenue stream is backed by a municipality's ability to charge property taxes [1]. Building owners, in turn, repay their upfront loan for a renewable electricity installation (or energy efficiency and/or water conservation measures) through their annual property tax assessments, with a PACE assessment being a debt of property (meaning that the debt is tied to the property itself as opposed to the potentially changeable tenant – [97]).

4.4. Green banks

Green banks work to close financing gaps and bring down the

[29] Apple Inc., one of the most valuable companies in the world, recently undertook one such offering for $1.5 billion [103]. This green bond will allow Apple to undertake company-wide renewable electricity initiatives, such as for electricity supply for data centers, and could allow for the avoidance of purchasing electricity from other suppliers. Through an adherence to the aforementioned GBP, the company's plans to allocate the proceeds towards "expenditures related to new and ongoing renewable energy projects, such as solar and wind projects, or associated energy storage solutions", as well as other initiatives such as material and energy efficiency [2].

[30] In 2013, the state of Massachusetts launched a $100 million dollar issuance that represented the first state or local government Green Bond issuance. The State's Green Bonds Investor Impact Report called it a replicable success, as the offering was oversubscribed by 30% and received a bond rating (AA+, Aa1, AA+, depending on the rating agency) that matched the state's other general obligation bonds [87]. 2014 and 2015 saw substantial follow-up, with $10.5 billion USD being issued in 2015 as the U.S. surpassed supranational institutions such as the World Bank to become the largest single country source of green bond issuance in the world [16].

cost of capital - largely by taking advantage of the low-cost borrowing and risk-taking capabilities of governments [51]. The approach to a Green Bank can be tailored to the context of the region in which the Bank's mandate is concentrated. There is no uniform solution, and the banks in operation reflect this flexibility. For example, U.S.-based Green Banks are located in states (such as New York), with one smaller-scale regions in the form of a county (Montgomery County in Maryland – [69]). While models exist for the federal government (e.g. the (recently privatized) UK Green Investment Bank, the Japanese Green Fund, and the Australia Clean Energy Finance Center are national analogues - [80]), as of the date of writing no entity exists at the U.S. federal level.

The Green Bank model is intended to inspire investor confidence with public sector efforts that are specifically designed to be additive and inexpensive.[31] As such, it is a politically viable appeal to both the fiscally-minded and environmentally-oriented. To reach their goals, Green Banks can deploy a variety of different mechanisms. So far, credit enhancements, guarantees, and risk transfer have been some of the most favoured options. Some examples of potential Green Bank tools are provided in Table 6:

Table 6
Examples of Green Bank tools (Source: Adapted by the authors from Ref. [51]).

Loan loss reserves	A risk management arrangement that involves the repayment (by a Green Bank to the private sector) of a certain percentage of a loan in the event of a default.
Subordinated debt	A risk management tool that involves the bank taking a loss before the private sector financiers in the event of a default, thereby "subordinating" their creditor claim to assets in the event of a loss.
Residential products	Programs (such as CT Solar Lease in the American state of Connecticut) that use the Bank's tools to support renewable electricity deployment in residential settings.
Warehousing	A process that involves the aggregation of numerous loans into more readily investable "pools" of capital that possess more appeal for investors.
Technology Guarantees	A form of credit enhancement that involves facilitating the extension of credit to renewable electricity technologies that are incapable of attracting private finance on their own, perhaps owing to a limited operational history.
Creation of specialized funds	Allows for the introduction of new funds tailored to the specific needs of investors (e.g. tax equity funds).

4.5. Ramping up institutional investor involvement

Cost-of-capital considerations are central to renewable electricity, and tapping into the vast capital stores of institutional investors will be essential. But while institutional investors have a key role to play, barriers to their involvement are very real. Kaminker & Stewart [44] identified several barriers to institutional investment: problems with infrastructure investments more generally, renewable electricity-specific issues, and a lack of appropriate investment vehicles.

The first problem begins with general infrastructure investment. Institutional investors operate on a ***total portfolio approach*** that emphasizes diversification. Direct allocations to infrastructure are less than 1% of current portfolios [70], as infrastructure is simply a part of a broader institutional mindset that tends to look at how an asset behaves (as opposed to the asset itself) in an effort to ensure asset-liability matching and optimal returns. Moreover, institutional investors must adhere to the ***prudent person standard***. This is a notion of ***fiduciary responsibility*** which holds that trustees of the fund must assemble their portfolio in the model of a 'prudent' investor. This emphasis on diversification and liquidity often limits the investments that institutional investors can make in renewable electricity projects.

Institutional investors are also concerned about the attributes of renewable electricity in particular. Investors may be required to pick between holding transmission and generation assets due to regulatory concerns. In addition, it is sometimes believed that the anticipated yields associated with renewable electricity are not commensurate with expected risks.

The final issue pertains to a lack of acceptable investment vehicles. For example, institutional investors need liquid markets with strong ratings, but these have proven elusive. REITs, MLPs, and other options discussed in this paper hold some potential, yet their integration has been hamstrung by legislative and tax policy barriers. Yieldcos were believed to hold the solution, but uptake has not been as sustained as the market had originally anticipated. Other issues pose a threat to viability. For example, Nelson [68] finds that financial regulations around solvency and accounting standards favour short-term holdings over longer-term plays like renewable electricity.

So what can be done to address these issues? Researchers from the OECD [70] found that financial de-risking (e.g. debt subordination, wherein particular lender types are repaid before others) and credit enhancement (e.g. wherein the creditworthiness of bonds is enhanced by a third party) tools are useful for bringing in institutional players and assuaging concerns around technology risk. Increasing co-investment, perhaps through partnerships with infrastructure funds or private equity firms, would also help better apportion risk. Non-financial drivers (e.g. ***socially responsible investing***) may grow to play an increasingly significant role, even as risk-adjusted returns remain the core priority for the majority of investors.

4.6. Other innovations covered in the literature

Increasingly, corporations are getting involved through voluntary ***corporate PPAs***. A recent survey by PricewaterhouseCoopers of US companies investing in solar found that the most common reason for investing in renewables was to reduce the company's greenhouse gas emissions and meet sustainability targets [75]. Encouragingly for the trend's long-term sustainability, over 75% also identified the strong returns available in the renewable energy sector as a driver.

Mechanisms that harness technological means to democratize the spread of renewable electricity finance are a relatively recent transition, and they represent a useful method to access smaller retail investors. ***Crowdfunding*** models, which can be adapted to a range of project sizes [48], possess advantages beyond their obvious ability to tap smaller contribution amounts from retail investors, as noted in a Deloitte report by Motyka et al. [66]: "[crowdfunds] do not require the extensive underwriting and filing processes of a typical public offering, and they provide a simplified,

[31] For example, in the case of Connecticut, Leonard [51] contends that a ratio of 10:1 is achievable (i.e., 10 units of private capital invested for every 1 unit of public capital expended).

automated due diligence process…". ***Community energy*** projects, such as ***non-profit co-operatives***[32], are also available. Recent U.S. tax rulings make further ownership of community-owned solar systems even more accessible going forward [50].

5. Government involvement?

A preference for private property and capitalistic endeavor permeates the U.S. political and economic systems. Accordingly, this paper has mostly focused on large-scale private schemes, even though we have discussed distributed solar generation (which has the potential to be securitized into large transactions). Of course, the required investment levels could be readily absorbed by ramping up government direct investment. For example, government procurement of new renewable electricity, such as for publicly owned buildings, would be a relatively straight-forward method to increase overall capital allocation to the sector.

In 2015, US Gross Domestic Product (GDP) grew 2.4% to nearly $18 trillion [39]. Nearly a third of this amount was directly related to government expenditures ($5.65 trillion – [71]). Single states (such as California) maintain government-related GDPs similar to entire countries, making individual state decisions important as well. Indeed, state-level governments are getting involved, such as in New York's push to develop various funds and technology catalyzers [73].

All levels of government could do more. At the federal level, efforts backed by the full credit of the United States government need not be excessively burdensome. If federal debt were required to support renewable installations, the U.S. government benefits from extremely low borrowing costs; as of the date of original writing, 20-year Treasury yields are currently around 1.7% [98]. A Keynesian stimulus involving moderate additions to existing deficits (akin to the promise of investing $20 billion over 10 years by neighbouring Canada's newly elected Prime Minister Justin Trudeau – [52]) that would allow renewable electricity infrastructure to be prioritized for government investment would be a fiscally prudent pursuit.

Another excellent starting point would be to simply remove fossil fuel energy subsidies[33] and re-allocate these dollars to renewable electricity deployment or innovation. Other options include changes to tax laws (especially the closing of tax loopholes or charging carbon taxes) or fiscal measures (such as tax increases and/or the use of government debt).[34] Harrison [30] argues that many of the key tax subsidies for fossil fuels should be amended to include renewable electricity, with an especially intriguing option being subsidies that encourage the installation of renewable electricity in difficult environments (similar to upstream exploration incentives for the oil and gas industry).

6. Conclusion

This article has sought to introduce private renewable electricity financing, as practiced in the United States, to the non-specialist by reviewing a range of financing and policy drivers, as well as some of the most important potential opportunities on the horizon. The renewable energy sector continues to evolve, pushed forward by the same combination of policy, technology, and economics that has defined other energy transitions. Future research will face a new normal; for example, demand for electricity storage technologies may explode (with concurrent increases in demand for private finance), while regulators may curtail the growth of distributed electricity generation business models [66]. Natural gas prices may stay low, potentially inhibiting renewables growth, or they may rise (making renewable generators the clear low-cost option). In the absence of coordinated planning and funding by relevant energy agencies, it will be necessary for flexible financial innovation to help in meeting potential volatility.

A number of changes should be implemented to ensure that the positive momentum for private renewables finance in the United States is maintained. Over the course of preparing this review, we engaged with numerous industry and academic experts, who not only provided additional considerations for the many sections of this paper, but also proferred recommendations for change. In particular, they emphasized the following:

1) There is no shortage of demand for capital – this represents an opportunity for less conventional players to get involved in the space, as is already happening in the corporate PPA market. This incessant demand in the face of limited supply calls for more innovation in the capital markets than has been seen to date.
2) Simplicity may be key, as respondents in our discussions routinely emphasized the importance of streamlining information flow (a good heuristic being "the easier the deal, the lower the cost of capital").
3) Uncertainty disturbs the growing renewable sector financing opportunities (especially retroactive changes, such as the recent changes in net metering rules in Nevada), given that they occur in an era that already maintains legal risk [90] and unpredictability around additions to the generation fleet.
4) Tracking performance-related data (such as degradation, soiling, and operational issues for solar photovoltaics) is essential to easing lender or tax equity concerns

Non-financial research can help here. Policy specialists need to work in concert with economists to ensure that policies are not susceptible to the start-stop mentality that, all too often, has defined the renewable electricity space in the US. Minimizing unintended consequences can help; policy designers in other spheres (economic competition, financial regulation, environmental planning) should ensure that their proposed solutions do not impede renewable electricity financing viability. System planners need to enhance the current system of planning and coordination. Engineers and other technical researchers have a special role to play; for example, Stadelmann et al. [86] draw attention to the importance of continuing to develop dependable and long-term solar irradiation databases for concentrated solar thermal power plants.

Overall, interdisciplinary mindsets will be essential to solving these challenges, as finance is only one piece of the broader puzzle. These matters take on a special urgency when considering anthropogenic climate change and the collective duty to address our most pressing environmental challenges.

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[32] In the nearby Canadian Province of Ontario, SolarShare has over 1000 members (including one of the authors) investing in large-scale solar energy installations through short and long maturity Solar Bonds [85].

[33] These domestic subsidies are conservatively estimated by the U.S. Department of the Treasury [99] at $4.7 billion, or approximately 1% of the International Energy Agency's [38] global estimate of $490 billion.

[34] The Congressional Research Services has exhaustively compiled a list of energy tax policies in the United States, found in Ref. [83].

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References

[1] Ameli N, Kammen DM. Clean energy deployment: addressing financing cost. Environ Res Lett 2012;7(3):034008.

[2] Apple Inc. Preliminary prospectus supplement. Retrieved from. 2016, February 16. http://investor.apple.com/secfiling.cfm?filingid=1193125-16-463982&cik=320193#D60003D424B2_HTM_SUPPROM60003_7.

[3] Auerbach N. The future of clean energy finance. NYU Environ Law J 2013;20:363.

[4] Auerbach NZ. Testimony of Neil Z. Auerbach, managing partner of Hudson clean energy partners, before the committee on ways and means, United States House, september 22, 2011, on "energy tax policy and tax reform". Retrieved from. 2011. http://waysandmeans.house.gov/UploadedFiles/Auerbachtestimony922.pdf.

[5] Berger J. Current issues in holdco loans. Retrieved from. 2014. http://www.chadbourne.com/Current-Issues-in-Holdco-Loans_projectfinance.

[6] Bloomberg New Energy Finance. Sustainable energy in America factbook. Retrieved from. 2017. https://data.bloomberglp.com/bnef/sites/14/2017/02/BCSE-BNEF-2017-Sustainable-Energy-in-America-Factbook.pdf.

[7] Bloomberg New Energy Finance. New energy outlook. Retrieved from. 2016. http://www.bloomberg.com/company/new-energy-outlook/#form.

[8] Bloomberg New Energy Finance. H2 2015 green bonds market outlook. 2015.

[9] Board of Governors of the Federal Reserve System. Community reinvestment act. Retrieved from. 2014, February 11. https://www.federalreserve.gov/consumerscommunities/cra_about.htm.

[10] Bolinger M, Wiser R, Cory K, James T. PTC, ITC, or cash grant? An analysis of the choice facing renewable power projects in the United States. Retrieved from. 2009. http://www.nrel.gov/docs/fy09osti/45359.pdf.

[11] Brandt T, Grant T, Cornfield J. The solar securitization opportunity. Retrieved from. 2016. http://www.marathon-cap.com/docs/default-source/white-papers/the-solar-securitization-opportunity-march-2016.pdf?sfvrsn=2.

[12] Business Council on Sustainable Energy. Sustainable energy in America factbook. Retrieved from. 2017, February 8. https://about.bnef.com/blog/sustainable-energy-america-2017-factbook/.

[13] Business Council on Sustainable Energy. Sustainable energy in America factbook. Retrieved from. 2016. http://www.bcse.org/sustainableenergyfactbook/#.

[14] CERES. Investing in the clean trillion: closing the clean energy investment gap. Retrieved April 17, 2016, from. 2010. http://www.ceres.org/resources/reports/investing-in-the-clean-trillion-closing-the-clean-energy-investment-gap/view.

[15] Clapp CS, Alfsen KH, Torvanger A, Lund HF. Influence of climate science on financial decisions. Nat Clim Change 2015;5(2):84–5.

[16] Climate Bonds Initiative. 2015 green bond market roundup. Retrieved from. 2015. http://www.climatebonds.net/files/files/2015%20GB%20Market%20Roundup%2003A.pdf.

[17] Collins M. Wealthy families unite at White House for clean-tech push. Retrieved from. 2015, June 16. http://www.bloomberg.com/news/articles/2015-06-16/wealthy-families-unite-at-white-house-for-clean-tech-push.

[18] Coons, C. (n.d.). The Master Limited Partnerships Parity Act. Retrieved from http://www.coons.senate.gov/issues/master-limited-partnerships-parity-act.

[19] Crooks E. Swanson's Law provides green ray of sunshine for PV. Retrieved from. 2016, January 17. http://www.ft.com/intl/cms/s/0/d9f9f1b4-a3f0-11e5-873f-68411a84f346.html#axzz463yolzMl.

[20] Doom J. U.S. expects $5 billion from program that funded Solyndra. Retrieved from. 2014, November 12. http://www.bloomberg.com/news/articles/2014-11-12/u-s-expects-5-billion-from-program-that-funded-solyndra.

[21] Doom J. Shaw joins KKR buying cleaner energy rivals won't touch: Energy. Retrieved from. 2014, February 18. http://www.bloomberg.com/news/articles/2014-02-18/shaw-joins-kkr-buying-cleaner-energy-rivals-won-t-touch-energy.

[22] DSIRE. (n.d.) DSIRE. Retrieved from https://nccleantech.ncsu.edu/resource-center-2/dsire/.

[23] Energy Information Administration. Annual energy outlook 2017 with projections to 2050. Retrieved from. 2017, January 5. https://www.eia.gov/outlooks/aeo/pdf/0383(2017.

[24] Energy Information Administration. Electric power annual. Retrieved from. 2016, November 21. https://www.eia.gov/electricity/annual/html/epa_04_03.html.

[25] Farmer JD, Lafond F. How predictable is technological progress? Res Policy 2016;45:647–55.

[26] Fenn T. Master limited partnerships (MLPs): a general primer. Retrieved from. 2014. https://www.lw.com/admin/Upload/Documents/Latham-Master-Limited-Partnership-Primer-2014.pdf.

[27] Fink AC. Securitize me: stimulating renewable energy financing by embracing the capital markets. Univ N. H Law Rev 2014;12:109.

[28] Giddy I. The securitization process. Retrieved from. 2001. http://people.stern.nyu.edu/igiddy/ABS/absprocess.pdf.

[29] Global Wind Energy Council. Global wind statistics 2015. Retrieved from. 2016, February 10. http://www.gwec.net/wp-content/uploads/vip/GWEC-PRstats-2015_LR_corrected.pdf.

[30] Harrison B. Expanding the renewable energy industry through tax subsidies using the structure and rationale of traditional energy tax subsidies. U Mich JL Reform 2015;48:845.

[31] Harvey LDD. Global climate-oriented building energy use scenarios. Energy Policy 2014;67:473–87.

[32] Harvey LDD. Global climate-oriented transportation energy use scenarios. Energy Policy 2013;54:87–103.

[33] Harvey LDD. Energy and the new reality, volume 1: energy efficiency and the demand for energy services. London: Earthscan; 2010a. p. 614.

[34] Harvey LDD. Energy and the new reality, volume 2: carbon-free energy supply. London: Earthscan; 2010b. p. 565.

[35] Helms T, Salm S, Wustenhagen R. Investor-specific cost of capital and renewable energy investment decisions. In: Donovan C, editor. Renewable energy finance: powering the future. London: Imperial College Press; 2015. p. 77–101.

[36] International Capital Market Association. Green bond principles. Retrieved from. 2015. http://www.icmagroup.org/Regulatory-Policy-and-Market-Practice/green-bonds/green-bond-principles/.

[37] International Energy Agency. The power of transformation: wind, sun and the economics of flexible power systems. Retrieved from. 2016. https://www.iea.org/publications/freepublications/publication/The_power_of_Transformation.pdf.

[38] International Energy Agency. Medium-term renewable energy market report 2015. Retrieved from. 2015. www.iea.org/Textbase/npsum/MTrenew2015sum.pdf.

[39] International Monetary Fund. World economic outlook. Retrieved from. 2016, April. http://www.imf.org/external/pubs/ft/weo/2016/01/pdf/text.pdf.

[40] International Renewable Energy Agency. Renewable power generation costs in 2014. Retrieved from. 2015. http://www.irena.org/documentdownloads/publications/irena_re_power_costs_2014_report.pdf.

[41] Internal Revenue Service. (n.d.). Publication 946 – additional material. Retrieved from https://www.irs.gov/publications/p946/ar02.html#en_US_2013_publink1000107772.

[42] Jacobson MZ, Delucchi MA. Providing all global energy with wind, water, and solar power, Part I: technologies, energy resources, quantities and areas of infrastructure, and materials. Energy Policy 2011;39(3):1154–69.

[43] JP Morgan Asset Management. Sentimental journey: the long, winding road to a renewable energy future. 2016, June.

[44] Kaminker C, Stewart F. The role of institutional investors in financing clean energy. Retrieved from. 2012. http://www.oecd.org/environment/WP_23_TheRoleOfInstitutionalInvestorsInFinancingCleanEnergy.pdf.

[45] Kauffman R. Bringing down green financing costs: how a state-sponsored bank might be the key. Retrieved from. 2014. http://www.frbsf.org/community-development/files/cdir_vol10issue1-Bringing-Down-Green-Financing-Costs.pdf.

[46] Kim SE. Managing regulatory blindspots: a case study of leveraged loans. Yale J Regul 2015;32(1):89–120.

[47] Krupa J, Poudineh R. Financing renewable electricity in the resource-rich countries of the Middle East and North Africa. Retrieved from. 2017, February. https://www.oxfordenergy.org/wpcms/wp-content/uploads/2017/02/Financing-renewable-electricity-in-the-resource-rich-countries-of-the-Middle-East-and-North-Africa-A-review-EL-22.pdf.

[48] Lam PT, Law AO. Crowdfunding for renewable and sustainable energy projects: an exploratory case study approach. Renew Sustain Energy Rev 2016;60:11–20.

[49] Lazard. Levelized cost of energy analysis 9.0. Retrieved from. 2015, November 17. https://www.lazard.com/perspective/levelized-cost-of-energy-analysis-90/.

[50] Lemay N, Wade A. IRS issues favorable PLR allowing an individual panel owner in an offsite, NetMetered community-shared solar project to claim the section 25D tax credit. Retrieved from. 2015, September 1. http://www.foleyhoag.com/publications/alerts-and-updates/2015/september/irs-issues-favorable-plr.

[51] Leonard WA. Clean is the new green: clean energy finance and deployment through green banks. Yale Law Policy Rev 2015;33(1):6.

[52] Liberal Party of Canada. An historic investment plan to strengthen the middle class, create jobs, and grow our economy. 2015, August. https://www.liberal.ca/files/2015/08/An-historic-investment-plan.pdf.

[53] Lowder T, Mendelsohn M. The potential of securitization in solar PV finance. Retrieved April 20, 2016, from. 2013. http://www.nrel.gov/docs/fy14osti/60230.pdf.

[54] Lutton J. Tax equity 101: structures. Retrieved April 17, 2016, from. 2013, March 8. https://woodlawnassociates.com/tax-equity-101/.

[56] Martin K. Cost of capital: 2016 outlook. Retrieved from. 2016. http://www.

chadbourne.com/cost-capital-2016-outlook_Feb2016.
[58] Martin K. Solar tax equity structures. Retrieved from. 2015, September. http://www.chadbourne.com/Solar_Tax_Equity_Structures_projectfinance.
[59] Martin K. Drive to reduce the cost of capital. Retrieved from. 2013, April. http://www.chadbourne.com/files/upload/Martin_Drive%20to%20Reduce%20the%20Cost%20of%20Capital_project_finance_april13.pdf.
[62] Milford L, Saha D, Muro M, Sanders R, Rittner T. Clean energy finance through the bond market: a new option for progress. Retrieved from. 2014, April. http://www.brookings.edu/~/media/research/files/reports/2014/04/clean%20energy%20bonds/cleanenergyfunds.pdf.
[63] Mills SJ, Taylor M. Project finance for renewable energy. Renew Energy 1994;5(1):700–8.
[64] Modigliani F, Miller MH. Corporate income taxes and the cost of capital: a correction. Am Econ Rev 1963;53(3):433–43.
[65] Mormann F, Reicher D. Smarter finance for cleaner energy: open up master limited partnerships (MLPs) and real estate investment trusts (REITs) to renewable energy investment. Retrieved from. 2012. https://www.brookings.edu/wp-content/uploads/2016/06/13-clean-energy-investment.pdf.
[66] Motyka, M., Boufrah, B., Sanborn, S., & Stevens, T. 2015. U.S. renewable M&A revs up: Renewable power enters the mainstream. Retrieved from http://www2.deloitte.com/us/en/pages/energy-and-resources/articles/us-renewable-manda-enters-mainstream.html.
[67] National Renewable Energy Laboratory. Analysis of project finance. Retrieved April 7, 2016, from. 2015, March 31. http://www.nrel.gov/analysis/key_activities_finance.html.
[68] Nelson D. The untapped potential of institutional investors. In: Donovan C, editor. Renewable energy finance: powering the future. London: Imperial College Press; 2015. p. 273–305.
[69] OECD. Green investment banks: policy perspectives. Retrieved from. 2015. http://www.oecd.org/environment/cc/Green-Investment-Banks-POLICY-PERSPECTIVES-web.pdf.
[70] OECD. Mapping channels to mobilise institutional investment in sustainable energy. Retrieved from. 2015. http://dx.doi.org/10.1787/9789264224582-en. https://www.oecd.org/g20/topics/energy-environment-green-growth/mapping-channels-to-mobilise-institutional-investment-in-sustainable-energy-9789264224582-en.htm.
[71] Office of Management and Budget. Historical tables. Retrieved April 17, 2016, from. 2016. https://www.whitehouse.gov/omb/budget/Historicals.
[72] Ondraczek J, Komendantova N, Patt A. WACC the dog: the effect of financing costs on the levelized cost of solar PV power. Renew Energy 2015;75:888–98.
[73] Ottinger RL, Bowie J. Innovative financing for renewable energy. Pace Environ Law Rev 2015;32:701.
[74] Potskowski B, Hunt C. The growing role for private equity. In: Donovan C, editor. Renewable energy finance: powering the future. London: Imperial College Press; 2015. p. 225–44.
[75] PricewaterhouseCoopers. Corporate renewable energy procurement survey insights. Retrieved from. 2016, June. http://www.pwc.com/us/en/corporate-sustainability-climate-change/publications/assets/pwc-corporate-renewable-energy-procurement-survey-insights.pdf.
[76] Randall T. Fossil fuels just lost the race against renewables. Retrieved April 5, 2016, from. 2015, April 14. Ren21 (Renewable Energy and Policy Network for the 21st Century). 2015. Renewables 2015 Global Status Report, http://www.bloomberg.com/news/articles/2015-04-14/fossil-fuels-just-lost-the-race-against-renewables.
[77] Riverstone Holdings LLC. Renewable energy. Retrieved from. 2016. http://riverstonellc.com/#!focus/renewable-energy.
[78] Russell R. ABCs of investing: alpha, beta and correlation. Retrieved from. 2014, July 15. http://www.forbes.com/sites/robrussell/2014/07/15/abcs-of-investing-for-experienced-investors/#3eacb134588d.
[79] Sanzillo T, Chung Y, Buckley T. Making the case for Norwegian Sovereign Wealth Fund investment in renewable energy infrastructure. Retrieved from. 2017, February. http://ieefa.org/wp-content/uploads/2017/02/Making-the-Case-for-Investment-in-Renewable-Energy-Infrastructure_February-2017.pdf.
[80] Schub J. Green banks: growing clean energy markets by leveraging private investment with public financing. J Struct Finance 2015;21(3):26–35.
[82] Segal J. BlackRock retains crown as America's largest money manager. Retrieved April 5, 2016, from. 2015, July 14. http://www.institutionalinvestor.com/Article/3470561/BlackRock-Retains-Crown-as-Americas-Largest-Money-Manager.html#/.VwQwsaQrKUk.
[83] Sherlock MF, Stupak JM. Energy tax policy: issues in the 114th congress. Retrieved from. 2016, June 15. https://www.fas.org/sgp/crs/misc/R43206.pdf.
[84] Shrimali G. The impact of government policies on renewable energy investment. In: Donovan C, editor. Renewable energy finance: powering the future. London: Imperial College Press; 2015. p. 131–46.
[85] SolarShare. (n.d..). About us. Retrieved from http://www.solarbonds.ca/about/about-us.
[86] Stadelmann M, Frisari G, Boyd R, Feás J. The role of public finance in CSP: background and approach to measure its effectiveness. Retrieved from. 2014. https://climatepolicyinitiative.org/wp-content/uploads/2014/01/SGG-Brief-The-Role-of-Public-Finance-in-CSP-Background-and-Approach-to-Measure-its-Effectiveness.pdf.
[87] State of Massachusetts. MassGreenBonds. Retrieved from. 2014, August 20. http://www.massbondholder.com/sites/default/files/files/QE%20August%202014%20Green%20Report(1).pdf.
[88] Summers LH. The age of secular stagnation: what it is and what to do about it. Foreign Aff 2016;95:2.
[89] Tesla Motors Inc. Form 424B5. Retrieved from. 2013. http://files.shareholder.com/downloads/ABEA-4CW8X0/0x0xS1193125-13-226108/1318605/filing.pdf.
[90] The Economist. The supreme court puts the clean power plan on hold. Retrieved from. 2016, February 9. http://www.economist.com/blogs/democracyinamerica/2016/02/americas-battle-over-climate-change.
[92] Toson SJ. The master limited liability partnerships parity act: friend or foe. Pace Environ Law Rev 2015;32:285.
[93] United Nations Framework Convention on Climate Change. Decisions adopted by the conference of the parties. Retrieved from. 2016, January 29. http://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf.
[94] United States Congress. H.R. 2883 – master limited partnerships parity act. Retrieved from. 2015. https://www.congress.gov/bill/114th-congress/house-bill/2883.
[95] UNSD (United Nations Statistics Division). 2013 energy statistics yearbook. 2016.
[96] Urdanick M. A deeper look into yieldco structuring. Retrieved from. 2014. https://financere.nrel.gov/finance/content/deeper-look-yieldco-structuring.
[97] d. Property-assessed clean energy programs. Retrieved from http://energy.gov/eere/slsc/property-assessed-clean-energy-programs.
[98] U.S. Department of the Treasury. Daily Treasury yield curve rates. Retrieved from. 2016, July 10. https://www.treasury.gov/resource-center/data-chart-center/interest-rates/Pages/TextView.aspx?data=yield.
[99] U.S. Department of the Treasury. Progress report on fossil fuel subsidies. Retrieved from. 2014. https://www.treasury.gov/open/Documents/USA%20FFSR%20progress%20report%20to%20G20%202014%20Final.pdf.
[100] U.S. Energy Information Administration. Short-term energy outlook. Retrieved from. 2017, March 7. https://www.eia.gov/outlooks/steo/report/renew_co2.cfm.
[101] U.S. Energy Information Administration. Renewable generation capacity expected to account for most 2016 capacity additions. Retrieved from. 2017, January 10. https://www.eia.gov/todayinenergy/detail.php?id=29492.
[103] Volcovici V. Apple issues $1.5 billion in green bonds in first sale. Retrieved from. 2016, February 17. http://www.reuters.com/article/us-apple-greenbonds-idUSKCN0VQ2K2.
[105] Wirth H. Recent facts about photovoltaics in Germany. Retrieved from. 2015, December 25. https://www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/recent-facts-about-photovoltaics-in-germany.pdf.
[106] Wiser RH. Renewable energy finance and project ownership: the impact of alternative development structures on the cost of wind power. Energy Policy 1997;25(1):15–27.
[107] World Bank Green Bonds. (n.d.). Green bond issuances to date. Retrieved from http://treasury.worldbank.org/cmd/htm/GreenBondIssuancesToDate.html.
[108] Feldman DJ, Settle E. The piece is called: Master limited partnerships and real estate investment trusts: opportunities and potential complications for renewable energy. 2013. http://www.nrel.gov/docs/fy14osti/60413.pdf.