Journal of Renewable and Sustainable Energy | PERSPECTIVE | scitation.org/journal/rse

Principles to adapt financing mechanisms for fully integrated hybrid energy systems

Cite as: J. Renewable Sustainable Energy **14**, 052301 (2022); doi: 10.1063/5.0118251
Submitted: 4 August 2022 · Accepted: 25 August 2022 ·
Published Online: 27 September 2022

View Online Export Citation CrossMark

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Note: This paper is part of the special issue on Hybrid Renewable Energy Systems.
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ABSTRACT

As the electricity sector evolves, and as all energy types (thermal, electric, chemical, etc.) become more coupled, there has been increased interest to develop and deploy hybrid energy systems (HES). This work focuses on fully integrated HES, where there are multiple energy sources and multiple energy products, often coupled through a storage buffer. A significant amount of the available literature on this work describes technology pathways for fully integrated HES; however, it is unclear how financial institutions should treat these systems. Fully integrated HES represent an increase in complexity from their stand-alone counterparts, but they also potentially mitigate financial risk and provide value to the energy system, which has not yet been accounted for in financing mechanisms that could help to enable such systems. This paper provides some examples of fully integrated HES and proposes principles to help adapt financing to adequately capture the value of such systems.

INTRODUCTION

The last two decades have seen a significant upswing in public and private sector interest in hybrid energy systems (HES), resulting in both increased research and deployment of HES. There appear to be several trends that have contributed to this. As local and global energy systems (e.g., electricity, chemicals, and thermal energy) become more integrated, systems that can produce multiple energy services or products have become more attractive from an engineering and economic perspective. The growing economic appeal reflects both recent and expected increases in the value of flexible electricity supply (within a single market segment) as well as the expectation of emerging markets to facilitate a transition to a decarbonized and sustainable energy system (e.g., capturing value streams across multiple market segments such as electricity and heat or hydrogen).

The goal of this paper is to suggest how targeted financing mechanisms (or the method that an entity receives funding) could account for the physical and economic efficiencies associated with HES. This paper seeks to address the class of technologies that is often referred to as fully integrated HES, which represents a relatively broad definition among those presented in the literature (Murphy and Mills, 2021; Murphy, 2021; Arent *et al.*, 2020; Ahlstrom *et al.*, 2021; Bragg-Sitton *et al.*, 2020). Common characteristics of fully integrated HES include multiple energy generation technologies, energy storage, and the ability to produce multiple energy products or services. Very often, fully integrated HES are colocated to share infrastructure or to reduce on-site energy losses vs their same components in a stand-alone configuration. To demonstrate the broad category that is HES or fully integrated HES, Fig. 1 shows different technologies and configurations that have been deployed or proposed.

EXAMPLES OF FULLY INTEGRATED HES PHYSICAL AND ECONOMIC BENEFITS

One of the most successful examples of a fully integrated HES (based on deployed and proposed capacity) is the coupling or integration of photovoltaic (PV) and battery energy storage system (BESS) technologies (Wiser *et al.*, 2020; Bolinger *et al.*, 2021). PV+BESS make an excellent case study because these systems have been deployed in multiple HES architectures that vary in terms of their physical coupling, performance characteristics, and flexibility, all of which should inform financing risk, rates, and mechanisms. Compared to separate

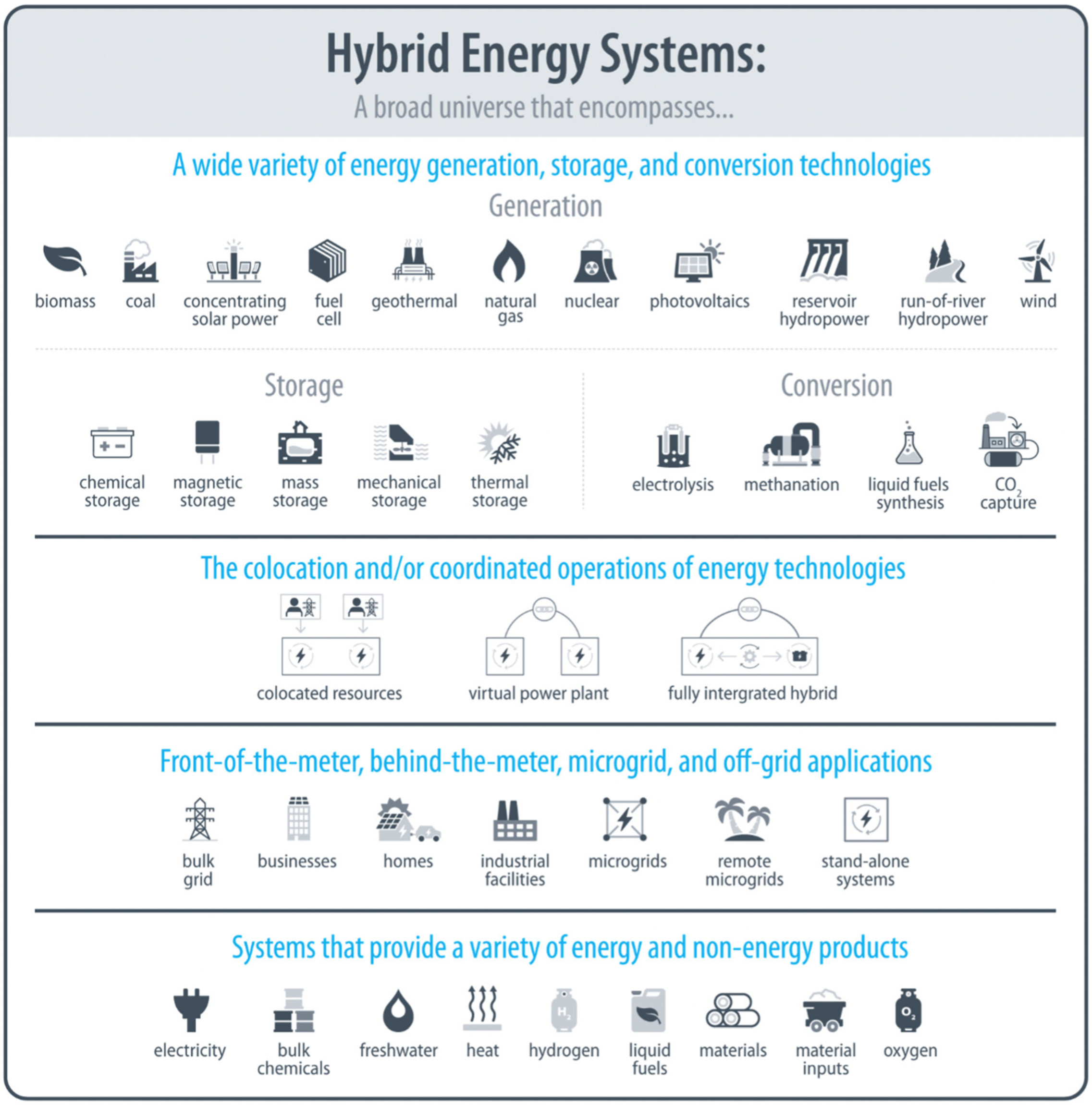

FIG. 1. HES: A broad category (Murphy and Mills, 2021). Reprinted with permission from Murphy and Mills, "Hybrid energy systems: Opportunities for coordinated research," Report No. DOE/GO-102021-5447 (National Renewable Energy Laboratory, Golden, CO, 2021).

projects, the hybridization of PV and BESS allows the combined plant to provide the full suite of services that each individual component could provide. Additionally, having multiple energy products (even if they are all in the electricity market) de-risks the overall plant profitability—if prices drop in one product category (e.g., energy services), the plant can choose to sell into another (e.g., capacity or ancillary services). For the architecture in which the BESS is located behind a shared inverter through direct current (DC) referred to as "DC coupling," plant profitability can be further de-risked through the increased modularity or the ability to upgrade individual components (PV or BESS) behind the point of interconnection—without modifying the interconnection agreement—to maximize the plant's contributions to the highest-value services as the mix of generation resources and electricity services evolves over time. A PV+BESS system can be either or alternating current (AC) or DC coupled. AC coupled BESS means that all batteries are at a central location and have their own inverters which not only lower round trip efficiency from the solar cells but also lower site complexity. DC coupled BESS means that batteries are distributed behind the inverter resulting not only in higher overall PV to BESS round trip efficiency but also higher site complexity. AC or DC coupling must be balanced based on benefits and risks that include, for the DC coupling, increased complexity, a single point of failure for both the PV and BESS, enhanced efficiency, synergies (e.g., capturing and using energy that would otherwise be lost by the inverter), and greater ease with which one can prove eligibility for federal incentives (Elgqvist *et al.*, 2018; Audap, 2018).

THE ROLE OF FINANCING IN ENERGY SYSTEMS

Financing has often played a key role in the buildout of energy systems (Zweifel, 2017). Many energy systems, such as transmission infrastructure and nuclear reactors, are long-lived assets with a steady rate of return. For example, vertically integrated utilities can make a steady return on investment, partly due to their access to low-cost financing, which reflects their low risk especially for being a regulated monopoly (Zweifel, 2017).

Property assessed clean energy

The property assessed clean energy (PACE) model is one example of how financing can encourage the deployment of energy assets. Energy-efficiency measures for residential and commercial customers (e.g., improved insulation; replacing doors and windows; and upgrading heating, ventilating, and air-conditioning systems) can be capital-intensive projects (Harris *et al.*, 2016). The PACE model asserts that adopting energy-efficiency technologies should lower energy bills for a customer. This lower energy bill should allow the customer to help repay any energy financing that was used to secure the energy-efficiency measure. The PACE model suggests that the financing should account for energy bill reductions when estimating a customer's ability to successfully repay a loan, resulting in a lower financing cost to help encourage customer adoption of energy-efficiency and clean energy (Explore Financing Options, 2022). Similar assumptions have been made for programs such as "on-bill" financing or "Energy as a Service." Figure 2 shows a flow chart of some financing mechanisms available for energy-efficiency and renewable energy investments.

Similar to the PACE model, this paper suggests that there are physical and economic aspects of HES that should be accounted for in their financing costs. To that end, following are three suggested principles that can be used to adjust the financing costs of fully integrated HES while incorporating HES-specific characteristics. These financing suggestions could apply to new (green field) or existing assets seeking to hybridize. The ideas presented here are still nascent and should be further explored to find actionable approaches to HES financing.

Principle 1: Adaptable metrics

Because fully integrated HES can include many technologies, there is likely no single metric that could be used to compare the advantages of one fully integrated HES vs another. In the past, levelized cost of energy (LCOE) or levelized cost of heat (LCOH) and net present value (NPV) have been used to compare energy assets (Ray, 2020; Birol, 2019). Though useful, LCOE, LCOH, and NPV do not include temporal and spatial energy availability, reliability, or resilience of diverse energy sources. Some examples of additional or alternative metrics to overcome the shortcomings of LCOE, LCOH, or NPV could include reduced infrastructure costs to the utility to serve fully integrated HES capacity (perhaps on a $/kW capacity basis), energy-efficiency gains (energy needed to provide the same service provided by an HES vs a stand-alone system), environmental benefits (such as emissions' reductions where relevant to financial incentives or reduced feedstock needed for the HES to provide the same service), and net economic benefits for the energy system. Resilience metrics could include change to loss of energy expected (LOEE) or reduction in cumulative customer-hours of outages if the HES were to be built (Vugrin *et al.*, 2017). This list is not meant to be all-inclusive, but it suggests that metrics to account for the benefits of fully integrated HES installations should be adaptable to the specific technologies used to better inform real financing costs. These financing metrics could first be adopted by government entities, utilities, or financing institutions (Birol, 2019).

Principle 2: Risk reduction

Fully integrated HES often generate multiple energy services or products, are highly modular and scalable, and often provide multiple

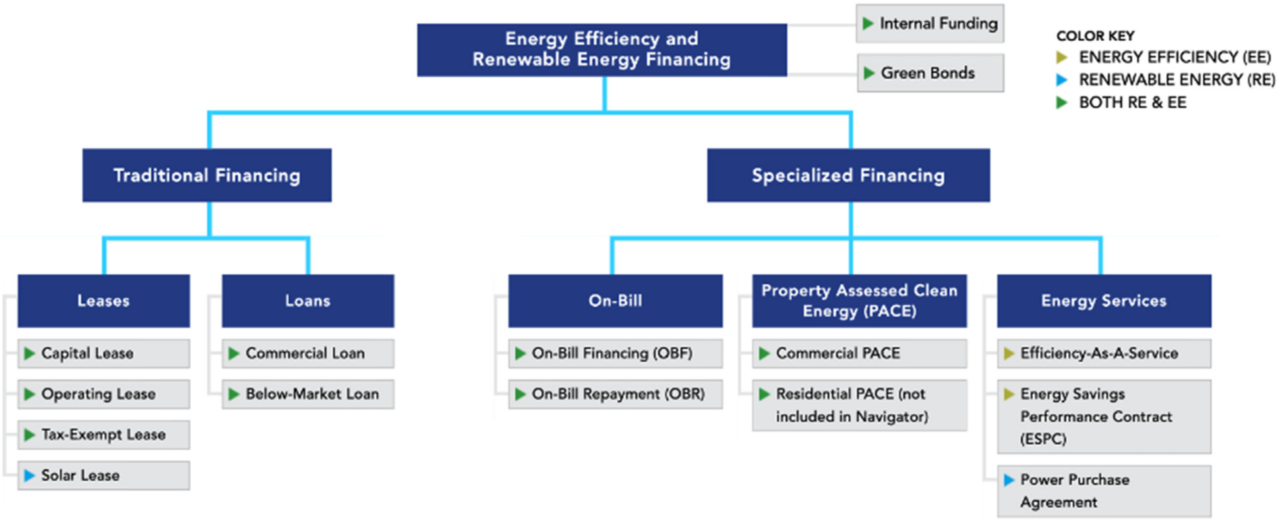

FIG. 2. HES: financing opportunities for renewable energy and energy-efficiency techniques. Reprinted with permission from Explore Financing Options, see https://betterbuildingssolutioncenter.energy.gov/financing-navigator/explore for "Better Buildings 2022."

services within a single market (such as electricity) or multiple products (such as electricity and hydrogen). Because multiple energy products often require increased infrastructure investment, having multiple energy products does not reduce the risk of price volatility to zero. However, for example, during periods of low wholesale electricity prices, a nuclear reactor coupled to a hydrogen electrolyzer could divert energy from electricity generation (where it might not be profitable) to hydrogen production (where prices might be more stable) (Frick *et al.*, 2019). Once the electrolyzer is built, to be profitable, its capacity factor cannot be zero, but the ability to shift between energy products on short timescales could reduce the facility's vulnerability to short-term price volatility, and the risk of reduced income due to price voltatility should reduce the financing cost. Fully integrated HES could also reduce financial risks by spreading ownership across multiple companies with diverse needs for electricity, heat, hydrogen, or other energy products, as in the shared ownership of Olkiluoto Unit 3 by six utilities and energy consumers in Finland under the "Mankala" system (Nuclear Energy Agency and OECD, 2015). Alongside financial risk, hybridization can mitigate policy risk, or the risk that a new policy will affect operations of a facility. If a hypothetical US national decarbonization policy was released, hybrid systems might reduce the risk that an emitting resource would become a stranded asset through reducing or capturing carbon emissions (i.e., natural gas and hydrogen production with carbon capture).

Principle 3: First-of-a-kind de-risking

Some fully integrated HES include first-of-a-kind technologies. These can include carbon capture installations, novel electrolyzer designs, fuel cells, and novel nuclear reactor types among others. Many potential private lenders (such as banks) are unwilling to take on the early mover or first-of-a-kind facilities even when these facilities play an important role in demonstrating the feasibility of new energy technologies. By pairing first-of-a-kind facilities with more established technologies, such as thermal energy storage or traditional fossil backup systems, fully integrated HES can reduce the financial risk to the facility overall and enable financing.

CONCLUDING PERSPECTIVES

HES and fully integrated HES are being proposed, researched, developed, and deployed at an astounding rate. Additionally, the added emphasis on clean energy along with traditional values of reliable and affordable energy creates a new opportunity to rethink how and where energy is used, transported, and consumed. Among the many opportunities is the hybridization of energy systems that can reduce energy losses, increase plant profitability, reduce risk, and allow for more localized control and use of energy sources in a decentralized configuration. History has shown that financing plays a key role in energy projects, and there are opportunities to reduce the cost of financing by accounting and value HES properties. Presented here are several principles meant to suggest new ways that financing do this. Future work and analysis could model the proposed financing mechanisms as well as others to better demonstrate the enabling role of financing in fully integrated HES deployment.

AUTHOR DECLARATIONS

Conflict of Interest

The authors have no conflicts to disclose.

Author Contributions

Jordan Cox: Conceptualization (equal); Investigation (equal); Writing – original draft (equal); Writing – review & editing (equal). **Caitlin Murphy:** Conceptualization (equal); Writing – original draft (supporting). **Andrew Foss:** Conceptualization (equal); Writing – original draft (supporting).

DATA AVAILABILITY

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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