Innovation, Sustainability and New Regulatory Approaches to Hybrid Power Systems

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- Characteristics of HPSs
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- Barriers to HPSs' development
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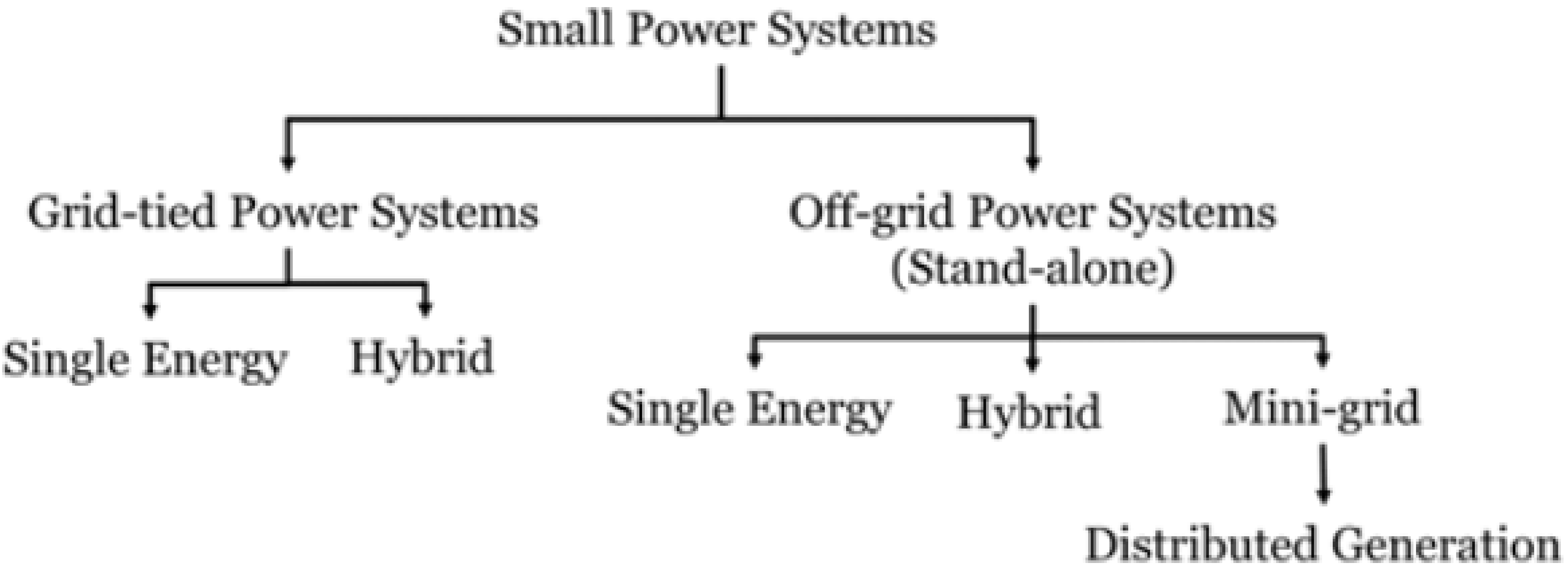
Definition of a HPS

- A hybrid system uses jointly more than one energy source to produce electricity
- The availability of local energy resources determines the mix (and the cost of production)
- A hybrid system is feasible when technical complementarity exists among various alternative energy sources
  - Use an energy source in case of failure of the alternative source or use one source when conditions don’t allow the other to work
- The mix of energy sources varies:
  - wind-photovoltaic (with energy storage)
  - hydro-diesel (with or without energy storage)
  - Etc..

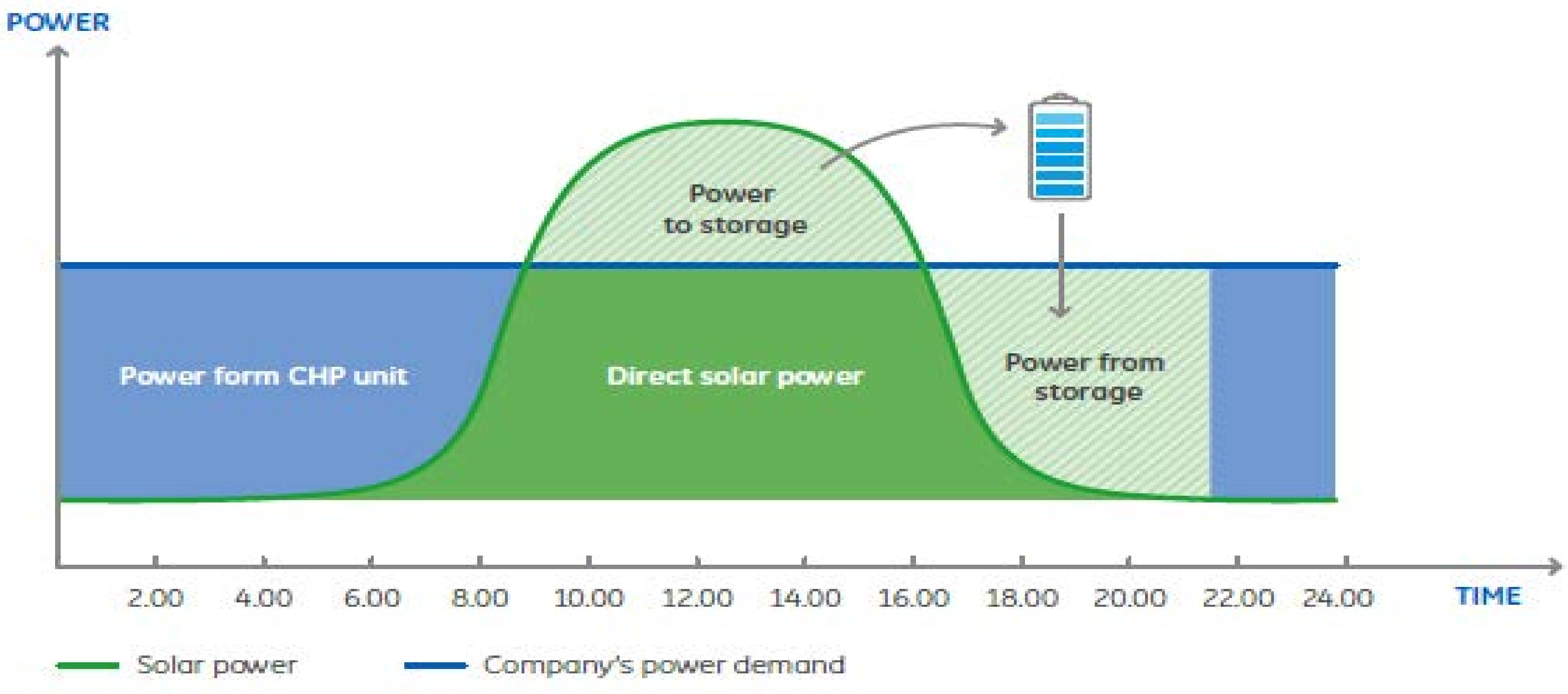
On- Off-grid HPSs

- Small power systems may be on-grid or off-grid, single- or hybrid-energy or organized in mini-grids.



Source: Baring-Gould, 2009, p.4

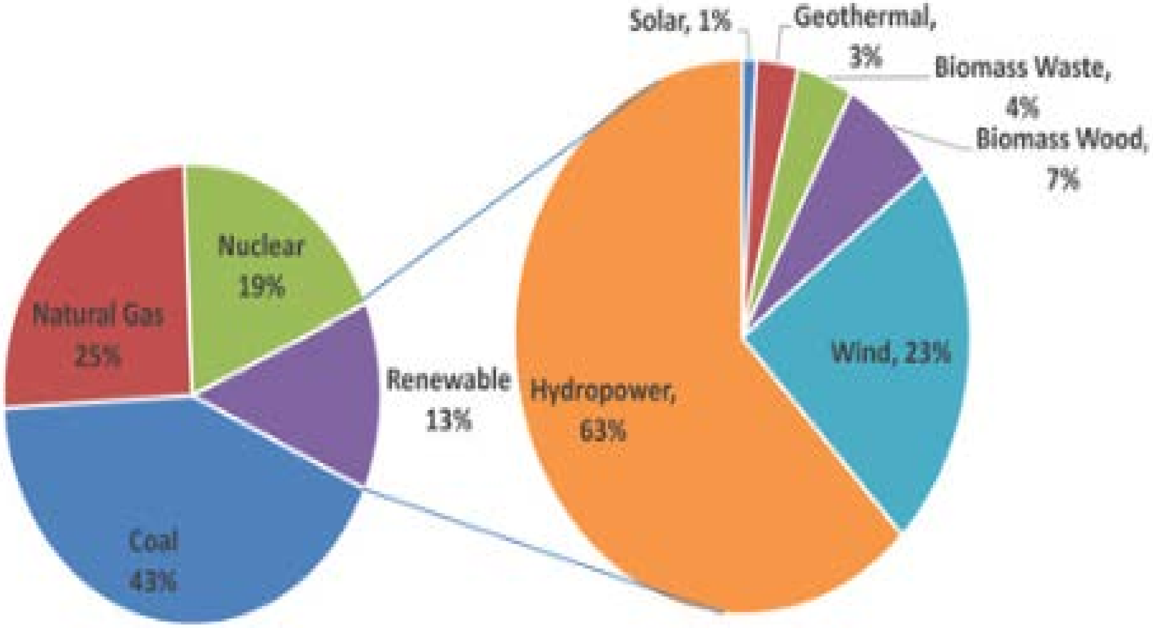
Markets and Technology: The idea behind HPSs



Source: ge.com/de p. 3

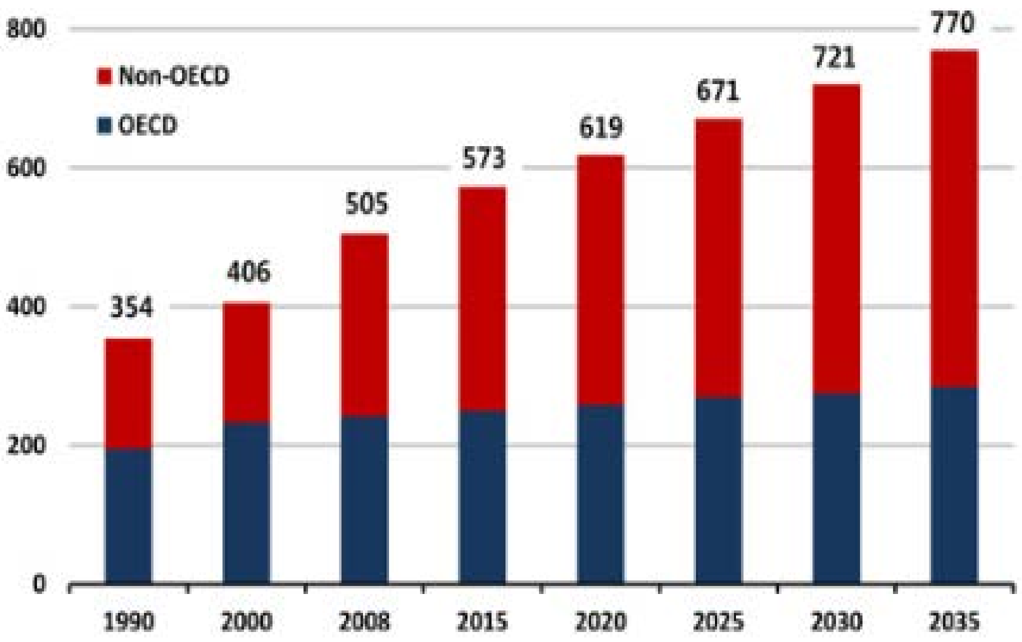
Energy sources determine technology mix in HPSs

Technological mixes



Energy sources in the US

Market



World energy consumption, 1990-2035 (quadrillion Btu)

Source: Bhandari et al. 2014, p.99

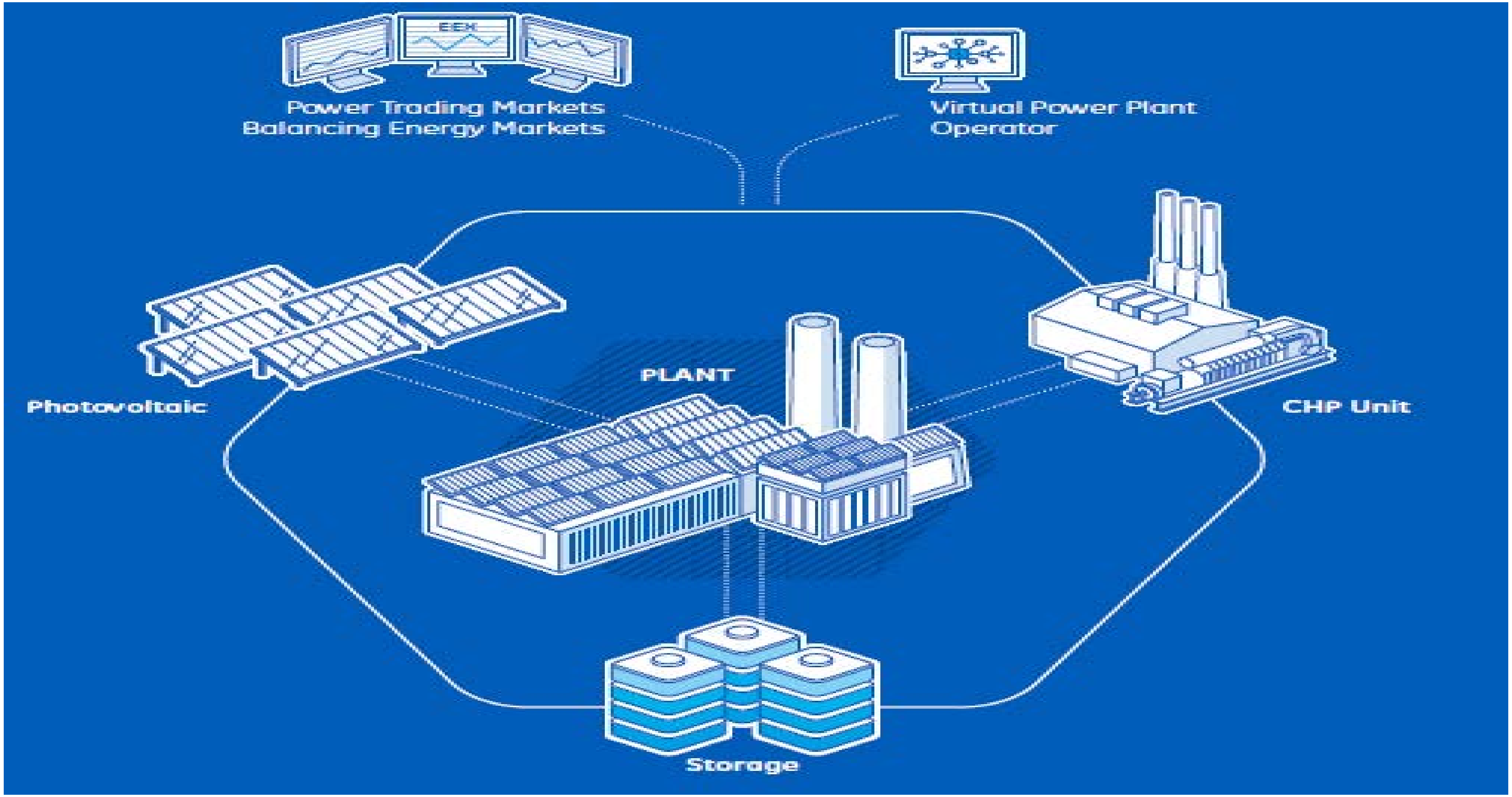
Usefulness of HPSs

- HPSs may be used to produce electricity and satisfy demand
  - for small isolated networks
  - for specific applications (such as water pumping, battery charges)
  - for supplying to small, dispersed and rural communities
  - for desalinization
- HPSs vary in size (between 10 kW and 200 kW)
- HPSs may be tailored made but their cost is quite high
- Certain technologies are used less commonly in the construction of HPSs due to their particular features (reliability, for instance)
- Due to reliability concerns, the first HPS installed was a Wind-diesel hybrid system in New Mexico, USA, in 1977.

Successful HPSs and Market Size

- The success of HPSs depends on two factors
  - the reliability/efficiency of the system
  - the costs of generating energy
- Customers value highly both attributes (demand for electricity is rather inelastic)
- Investors returns depend on these attributes
- The worldwide market for HPSs is growing quite fast
  - According to Reuters, the CAGR rate is expected to be around 5.7% in the next five years (or 8.34% according to *Zion Market Research*)
  - By 2023, it is expected to reach a market value of 58 000 million US$ from 41 600 $ in 2017 (https://www.reuters.com/brandfeatures/venture-capital/article?id=59087).

A Typical HPS



Source: ge.com/de, 2018, p. 3

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Characteristics of HPSs

Technological

- **Flexibility:**
  - Optimal sizing of system component represents an important part of a HPS (higher flexibility in the optimization of the Hybrid Renewable Energy System (HRES))
- **Constraints**:
  - lack of infrastructure
  - location of communities
  - shipment restrictions, etc.,
- These constraints impose significant limitations in choosing RSE (wind turbines, etc.).

Market

- **Growth potential**:
  - Desire for electrification is growing (isolated, dispersed, rural areas)
  - Environmental awareness is gaining more ground
- **Constraints**:
  - Country regulations and institutional frameworks may expand/restrict HPSs expansion
  - Current regulatory models either ignore and/or lack the instruments to incentivize the deployment of HPSs at a faster rate
  - Market size is limited (relatively poor customers).

Market risks and risks associated with the optimal design of an efficient HPS are high.

Disruptive technologies and risks

- Disruptive technologies are the ones braking market rules/norms and the traditional business models (Watls.com)
- Markets become riskier and investors require higher returns

Source: Christensen et al. 2015

Disruptive technologies and the HPSs

- The mix of more than two technologies opens up new markets while disrupting the incumbents' business model based on single energy source
- But when market characteristics are not favorable (rural and/or dispersed and rather poor populations, chiefly in developing countries), HPSs may be unsustainable
- In that context, HPSs' bankability is getting weaker and their deployment and sustainability is at risk
- Financial models which do not fully account for risks jeopardize the full potential of HPSs.
- The new concept of decoupled net present value (DNPV) is more appropriate to evaluate all the risks associated with the HPSs and determine their long term profitability.

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Risks in HPSs

- Renewables are cost competitive to diesel or other fossil plants and the mix of RE (wind turbines, etc.) and diesel generators reduce
  - fuel consumption
  - GHG emissions and
  - electricity production cost
- Despite of these advantages, high risks still remain:
  - high capital and O&M costs (combination of RE (wind turbines, etc.) to diesel needs regulators and controllers to provide reactive power, for instance),
  - investment risks associated with weather, remoteness, transportation, icing effect on wind turbines (in Northern areas, etc.).

Mitigating Risks in HPSs

- The presence of these risks make investment in off-grid renewable energy (RE) projects unprofitable
- Derisking the business environment contributes to the realization of investments in HPSs in remote, isolated communities
- Regulators and policy makers need to adopt derisking policies
- New tools may be developed to better take into account these risks and mitigate them more appropriately (See DNPV later).

Specific risk associated with the HPSs

- The risks are multiple:
  - Technological
    - HPSs are technologically more complex due to the combination of two or more energy sources
  - institutional/regulatory
  - financial
  - socio-economic related to uncertainties about the market and customers’ ability to pay
    - lack of sufficient data with respect to both load curves and meteorological characteristics make the design of HPS and their financial evaluation complex.

Risk and risk allocation in HPSs

- Risk allocation is an important aspect of any investment project
- Risk allocation is important for the design of an HPS project and critical to its financing and eventually to its realization (accept/reject decision)
- The various methodologies used to evaluate HPSs differ significantly in the way they value risk and risk allocation.

Methodologies for evaluating HPSs – the DNPV

- The NPC or the life-cycle cost:
- The NPV and the IRR:
- The LCE (levelized cost of energy):
- LCC or Life-cycle cost:
- The ACC (annualized cost of the system):
- The PBP (payback period):
- The DNPV rule:

- A single discount rate is used adjusted for risk

- The risk-free rate is used to discount Each individual risk is evaluated and a price (cost) is calculated
- The cost of each risk is added to total costs and discounted by the risk-free rate.

Optimal system design and profitability (I)

- The optimal equipment configuration is one of the main objectives for setting up a HPS
- It has to meet two key decisive parameters, one technical and another financial :
  - **technical**
    - the low or medium penetration level of RE (wind turbine, solar, etc.) and
  - **Financial**
    - the minimum Total Net Present Cost (NPC) and Return on Investment (ROI)
- Computer models (Homer, etc.) are used to evaluate design options for on-, off-grid power systems for remote, stand-alone and distributed generation applications.

Optimal system design and profitability (II)

- These programs use the traditional tools to evaluate the financial viability of a project
- However, these tools use a single discount factor and this may lead to a non optimal decision
- The newly developed DNPV criterion, by identifying, separating and pricing all risks and calculating them as a cost, leads to better financial decisions (Espinoza, Gentzoglanis, 2019).

Hooshangi, 2014

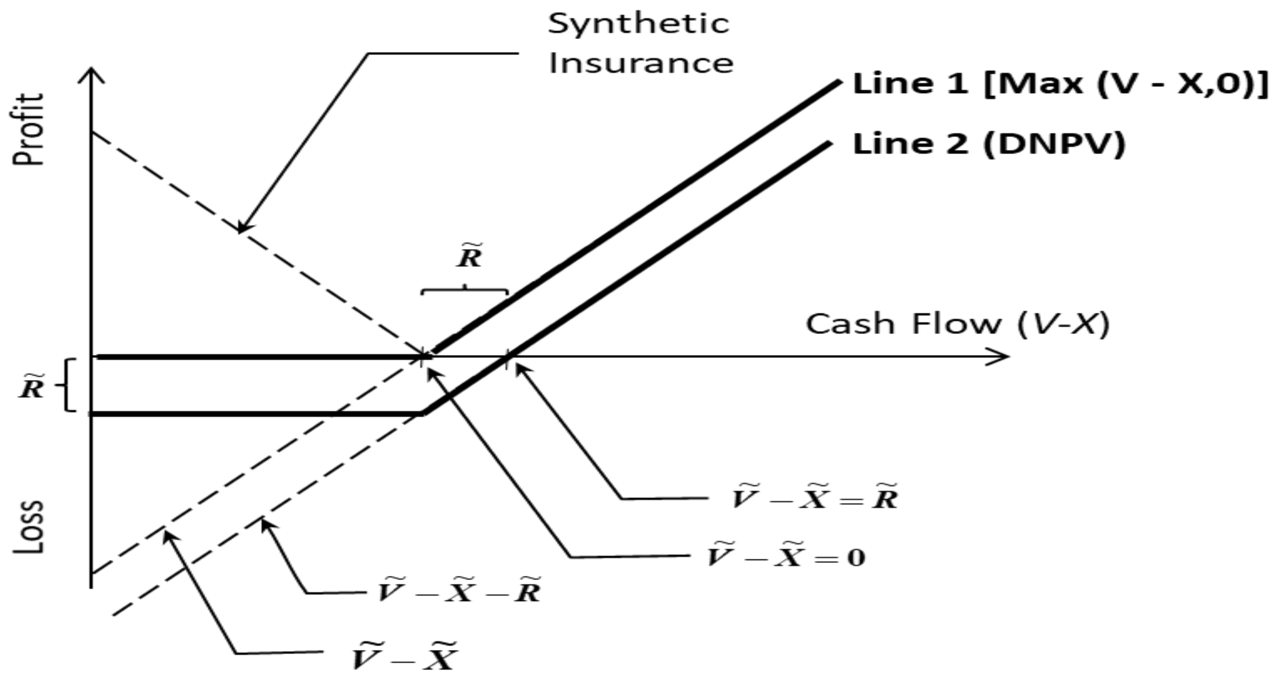
The DNPV formula for HPSs evaluation

- DNPV over a single period T is calculated as
    - the risk-adjusted revenue (i.e., expected revenues, $\tilde{V}$, minus the cost of revenue risk, $\tilde{R}_V$) minus the risk-adjusted expenditures (i.e., expected expenditures, X, minus the cost of expenditure risk, $\tilde{R}_X$) discounted at the risk-free rate (r) which can be a DDR

$$DPNV = \frac{(\tilde{V} - \tilde{R}_V) - (\tilde{X} + \tilde{R}_X)}{(1+r)^T} = \frac{(\tilde{V} - \tilde{X}) - \tilde{R}}{(1+r)^T}$$

Source: Espinoza et al. (2019)

The DNPV criterion and investment decisions



Investing at any stage can be viewed as an option to be exercised if the present value of the expected future cash flows discounted at the risk-free rate is greater than, or equal to, the cost of risk ($\tilde{R}$)

Source: Espinoza et al. (2019)

Main characteristics of risk valuation methodologies

Methodology	Tool used	Discount factor	Risks	Advantages	Results
NPV	DCF	WACC	Single risk – project's beta Static model	Easy to understand Well-entrenched in business community	Over or under investment
DNPV	DCF	Risk-free rate	Multiple risks decoupled from cash flows	Less well-known – not widely applied yet	Eliminates bias leading to the right investment decision
Quantitative risk analysis	na	na	Multiple risks -probability distributions, Stochastic models	Sophisticated econometric techniques improves results	Better evaluation of risks
Monte Carlo Simulations	na	na	Multiple risks -probability distributions, Stochastic models	Easy to implement	Better evaluation of risks
The NPC or the life-cycle cost:	DCF	WACC	Single risk – project's beta Static model	Easy to understand Well-entrenched in business	Over or under investment

Regulation, sustainability and HPSs deployment

- In dynamic business environments, firms focus on most lucrative markets (urban and dense populated markets)
- Markets left unserved may be developed and served by disruptive firms
- Their sustainability depends on the existing regulatory framework
- The latter is rarely suitable for new entrants
- Long term sustainability of HPSs may be enhanced by the adoption of new regulations that reduce risks and provide incentives for their deployment.

Current regulatory models with respect to HPSs deployment

- There is no a single regulatory model
- The current regulatory models vary from the traditional COS to the RIIO model with a variety of PBR (varying according to the context and local market conditions)
- None of them treats explicitly the HPSs
- The RIIO model supports innovation and customer satisfaction but does not refer to HPSs
- The PBR models emphasize investment in infrastructure but they do not refer to HPSs
- Regulatory policies should support technological innovations sparkling from HPSs and favor unconventional solutions to the challenges the HPSs are facing
- A more streamlined regulation that reflects the needs of HPSs.

Global regulatory policies

Country	FIT	Net Metering	RPS	Grants and Subsidies	Permitting and Zoning	Certification
US	NI	I	I	I	I	I
UK	NI	I	I	I	I	I
Canada	I	I	NI	I	NI	I
Spain	I	NI	NI	I	NI	NI
Netherlands	I	NI	I	I	I	NI
Portugal	I	NI	I	I	NI	NI
China	I	NI	NI	I	NI	NI

NI = not implemented; I = Implemented

Regulatory barriers to the deployment of HPSs

- Unclear definitions of the market structure of the electricity industry (single vs multiple players)
- Unclear role of the independent power producers (IPPs)
- Unclear jurisdictional responsibilities in signing power purchasing agreements (PPA)
- Legacy tariff structures resulting in subsidies but incompatible with the development of HPSs
- Lack of explicit codes and standards allowing
  - the integration of RE
  - the connection to the grid (energy storage systems and other electronic power devices)
- New regulations allowing the introduction of new pricing schemes like FiT programs and/or RE production certificates would make the implementation of HPSs much easier.

Conclusions

- HPSs combine more than two technologies to provide electricity at lower cost than stand-alone projects and reduce GGE
- They are disruptive technologies with high risks
- Current regulatory models are not designed to promote the deployment of HPSs
- Financial tools are not designed to take into full account all the risks (expenditure risks, revenue risks, etc.) resulting in suboptimal design solutions and jeopardizing HPSs' sustainability
- New regulations should be designed to derisk HPSs' business environment
- The new evaluation tool, the DNPV, is more appropriate to HPSs valuation projects and should be used more extensively.

The End

Thank you for your attention