Renewable Hybrid Power Plants

EXPLORING THE BENEFITS AND MARKET OPPORTUNITIES

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EXECUTIVE SUMMARY

This paper explores the benefits and market opportunities for Hybrid Power Plants (HPPs). As the share of variable renewable energy in power grids increases, a discussion on the potential advantages of HPPs, comprising wind or other renewables, with or without storage, has been evolving.

Currently, the number of such HPPs under development or already operating in Europe is very limited. Their business case is still under development or evaluation. The foreseen advantages of wind-solar HPPs seem however promising. These relate to cost effective integration of variable renewable energy sources (RES) in the system which is primordial in view of the EU decarbonisation target for 2050. Besides, the revolving digitalisation of the power system is expected to unleash the full potential of hybrid cases.

As various governments roll out their plans on RES system integration and electricity market reforms, and industry players develop various designs and control configurations, it becomes relevant to clearly establish HPPs in the regulatory framework, starting with the respective definitions. Based on the assessment of various HPP projects globally and the regulatory framework, HPP-wise, in selected countries, WindEurope has identified a number of common challenges and presents a set of policy recommendations.

- **HPPs offer several benefits**. The most important ones include optimised network use, higher yearly capacity factor, more stable power output, eased fulfilment of system-, site- and owner-specific power demand, more dispatchable generation, reduced infrastructure investment costs, reduced electricity balancing costs;
- A **clear regulatory framework**, starting with the **definition of the HPPs** needs to be established. WindEurope identifies 2 types of wind-solar HPPS in function of the common integration and operation of the different generating modules; (A) Wind and solar sharing the same substation and coupling point to the grid and (B) PV panels integrated with the wind turbines;
- To **facilitate the deployment** of HPPs, policy makers should initially **create a level playing field for them**, **by standardising grid connection requirements, metering and renewable energy traceability procedures** in such projects;
- **HPP developers must be able to install total renewable power capacity higher than the existing or agreed grid connection capacity**, even though a part of the produced energy might be curtailed when instantaneous generation exceeds the grid connection capacity. This is the only way to take full advantage of HPPs;
- In case storage is integrated in HPPs**,** the regulatory framework should set **clear criteria on the monitoring practices for tracing energy flows between the storage device and the grid.** Moreover, **double taxation and double grid charges must be avoided**; and
- In existing power plants under hybridisation, **developers should not have to re-apply for grid connection compliance as long as the power that the HPP exports to the grid does not exceed the approved capacity of the grid connection.**
- **European Research and Innovation (R&I) funding should address technical challenges** to the development and scaling-up of HPPs

1 BUILDING KNOWLEDGE

This paper explores the benefits and market opportunities for Hybrid Power Plants (HPPs). As the share of variable renewable energy in power grids increases, a discussion on the potential advantages of HPPs, comprising wind and other renewables, with or without storage, has been evolving.

Currently, the number of such HPPs under development or already operating is very limited. Their business case is still under development or evaluation. The foreseen advantages of HPPs seem however promising. These relate to cost effective integration of variable renewable energy sources (RES) in the system which is primordial in view of the EU decarbonisation target for 2050. Besides, the revolving digitalisation of the power system is expected to unleash the full potential of hybrid cases.

WindEurope explores this new promising opportunity, creates awareness and builds knowledge around HPPs. This paper assesses existing HPPs globally. Based on the assessment of these projects, developed under different conditions with different purposes, WindEurope has identified a number of common drivers and challenges and presents a set of policy recommendations that could unlock the potential of HPPs.

1.1 THE MOTIVATION BEHIND HYBRID POWER PLANTS

HPPs can present numerous benefits when compared to pure wind or other renewable power plants, or pure storage plants (**Figure 1)**:

- The possibility to **optimise the use of the network** by installing more capacity than the authorised one in the connection agreement, what it is translated into grid development savings, maximising the use of the existing network and solving the bottleneck problem in many areas or countries where new grid deployments are not allowed. Although the installed capacity at the connection point increases, the maximum evacuation capacity remains the same, so the impact on the network is limited;

- When wind and solar resources are complementing (e.g. negatively correlated) at the site (**Figure 2**) → **higher yearly capacity factor, more stable power output over time** with less ramping issues and instantaneous peaks than pure wind or solar plants → the possibility for partially scheduled power dispatch → **eased fulfilment of system- , site- and owner-specific power production requirements** (e.g. load following production, flatter power generation profile over day / season / year);

- Even when wind and solar resources are not correlated, **HPPs can be advantageous in terms of dispatching power in the market**. For example, if electricity market prices are negatively correlated to wind power (due to high share of wind), the HPP can potentially earn revenue from the market, when prices are high, thanks to the solar resource;

- One single grid connection point needs to be set up in most cases → **reduced infrastructure investment costs** thus reduced overall project or grid investment costs and in certain frameworks, reduced subsequent network use tariffs paid by grid end-users;

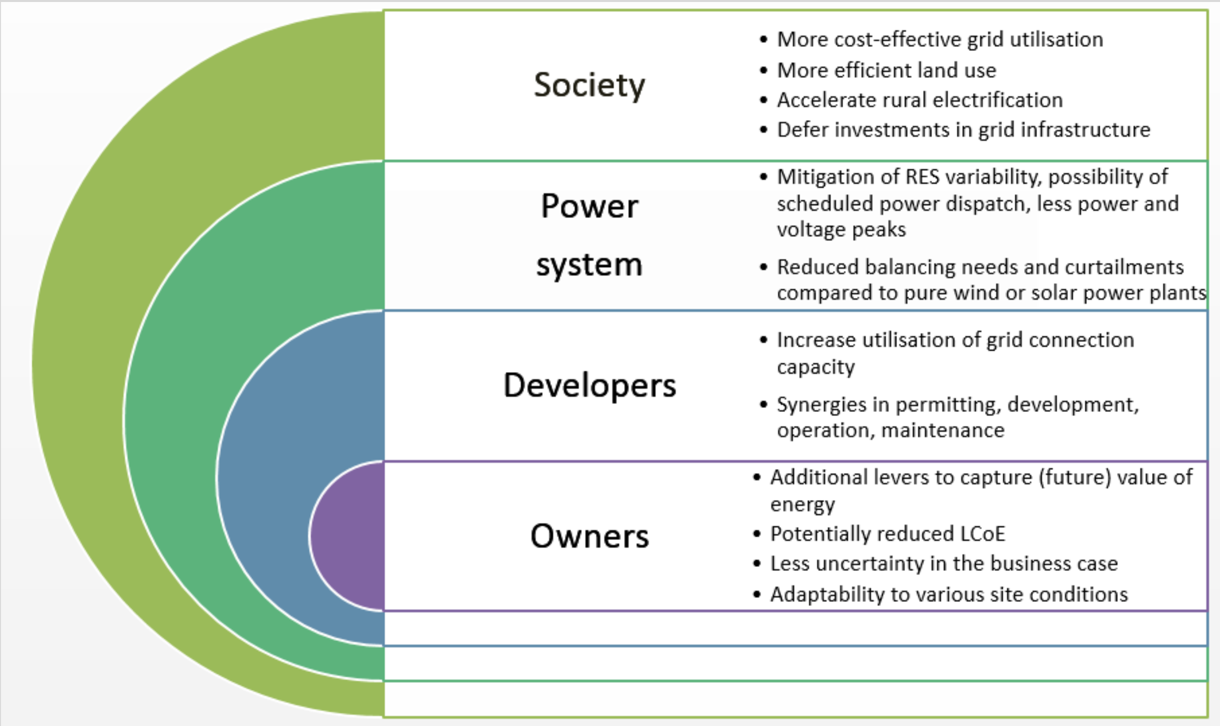
- Resources can be further complemented by, thanks to the co-existence of generation units and digital technologies. This makes HPPS a good partner to the grid in terms of flexibility but also resilience when storage is included → **reduced balancing costs and less renewable energy sources' (RES) curtailment.** The latter can be of great cost in those countries where reimbursement for curtailed energy is still granted;

- In certain HPP configurations (see paragraph 1.2.1), **land is more efficiently used** since installed capacity and energy output per square meter of used land increases;

- HPPs can ease the **acceleration of rural electrification,** given that they can partially provide scheduled power dispatch to satisfy load demand in areas where the power grid is too weak to provide reliable power supply. In such cases, HPPs can **defer investments in grid infrastructure;** and

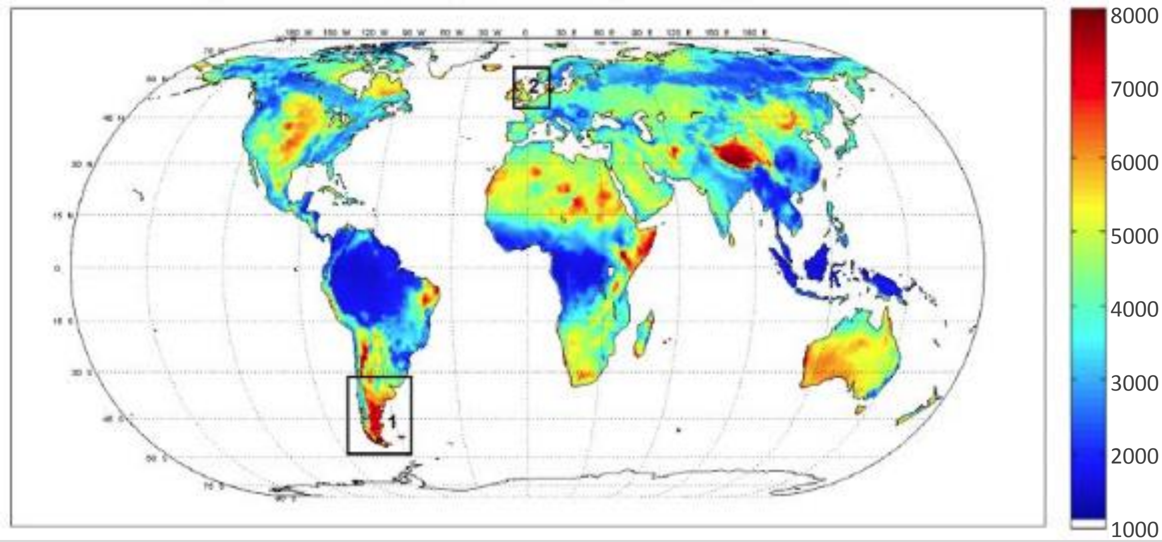
- **Developers can harvest synergies within the development and permitting process** as well as for the operation and maintenance of the plants → development, capital and operation expenses reduction (DEVEX & CAPEX & OPEX).

Figure 1 Foreseen benefits of wind-solar HPPs



Source: WindEurope

Figure 2 World's hybrid PV-Wind power plant Full Load hours' map



Source: Fasihi, Bogdanov & Breyer [1]

1.2 DEFINITIONS

Certain countries (e.g. India) have already shown support for hybrid projects by setting up hybrid-specific auctions or by clearly establishing criteria for them in their legislative framework or in RES tenders[2]. As various governments roll out their plans on system integration of renewable energy sources (RES) and electricity market reforms, and industry players develop various designs and control configurations, it becomes relevant to create a clear regulatory framework, starting with the definition of the HPPs. This paper proposes the following scope and definitions.

The term HPP refers to a *power-generating facility*[3] *that converts primary energy into electrical energy and which consists of more than one power-generating modules*[4] *connected to a network at one connection point*[5]. These might also include different forms of energy storage. Moreover, it is usual to find systems that combine renewable sources (wind, solar, hydro) with fossil fuels (e.g. diesel generators). **For the scope of this paper, HPP only refers to variable renewable-based systems (with a focus on wind and solar), with or without storage technologies.**

[1] Fasihi, Bogdanov, Breyer, "Techno-Economic assessment of Power-to-Liquids (PtL) fuels production and global trading based on hybrid PV-wind power plants", Energy Procedia, Vol. 99, 2016, p. 243-268, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2016.10.115. The numbers refer to the place of RE-diesel production (1) and diesel demand (2)

[2] Government of India, Ministry of New & Renewable Energy, Wind Energy Division, "National Wind-Solar Hybrid Policy","Amendment in National Wind-Solar Hybrid Policy - Reg", 2018/ Hellenic Regulatory Authority for Energy, "Tender 230/19", 2019

[3,4] 'power-generating module' means either a synchronous power-generating module or a power park module and 'power-generating facility' means a facility that converts primary energy into electrical energy and which consists of one or more power-generating modules connected to a network at one or more connection points. Both are defined in Regulation 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators.

[5] Consequently, hybrid power plants must not be confused with hybrid power systems such as the interconnectors of an offshore wind farm to two different power systems or markets

Regarding solar, the focus is on photovoltaic (PV) technology. Regarding storage, the scope is narrowed down to Electrical Energy Storage (EES) as defined by the IEC 62933-1 standard[6] "*Installation able to absorb electrical energy, to store it for a certain amount of time and to release electrical energy during which energy conversion processes may be included*"[7]. Without making this differentiation, it wouldn't be possible to identify common benefits, drivers and policy recommendations reflecting the whole set of assessed projects[8].

There are a number of different HPP configurations depending on the grid connection, park layout, control strategy and main functionalities. Each type of HPP presents a different cost structure and particular benefits that will determine the market viability of the project.

WindEurope identifies 2 types of HPPS in function of the common integration and operation of the different generating modules and 3 types of HPPs in function of storage integration and operation in the HPP. In terms of functionalities, WindEurope identifies 6 categories overall but most HPPs are designed to serve a combination of those rather than one or two. Other interesting parameters to observe are the total capacity of the plants and the capacity shares of different technologies.

1.2.1 CONNECTION AND OPERATION CONFIGURATION

RES integration in HPPs

Until today, WindEurope has identified two configurations. The first is the mostly developed one, while the second is an alternative version where solar converters can be eliminated in certain cases (**Figure 3**). **Table 1** outlines the principal advantages and disadvantages per configuration type.

In general, both types of HPP configurations are able to maximise the use of the grid connection point, by increasing the capacity factor of the installation, reducing CAPEX and permitting timing, and thus to defer investments for grid reinforcement.

A. Wind and solar sharing the same substation and coupling point to the grid

Wind and solar share the same grid connection and substation, leading to savings in CAPEX and permitting times, compared to developing separate wind or solar plants. Also, the overall development, including resource assessment and site conditioning as well as the regular operation and maintenance costs will be lower (compared to wind and solar plants located separately) given that both plants are located in a single site or at least in close proximity. In some cases, additional PV capacity could be located out of the wind farm limits in other to optimise the PV output but they would still share the grid interconnection point.

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[6] IEC, "IEC 62933-1:2018 Electrical energy storage (EES) systems," 2018

[7] In certain systems, only a part of the storage capacity is reserved for storing and releasing electrical energy. The rest of the capacity might be reserved for storing electrical energy, converting it to a different energy form and then using it in non-electrical applications. In such cases, the analysis and policy recommendations of this paper consider only the capacity that is reserved for storing and releasing electrical energy. This is not the case with the WindEurope database which includes information for the entire storage system and for projects with energy storage other than electrical.

[8] There are instances when HPPs may make use of existing Pumped Storage technology (PSP). As there are critical topography requirements for PSP one expects to see less PSP bundling with HPPs than HPPs with integrated ESS.

The HPP controller guarantees network code compliance, for the entire plant, at the point of interconnection, and simplifies its operation and maintenance. When “hybridising” existing assets, only new generating modules have to comply with the new network codes, not the existing one. Thus a coordinated control is necessary, fulfilling the different requirements per module.

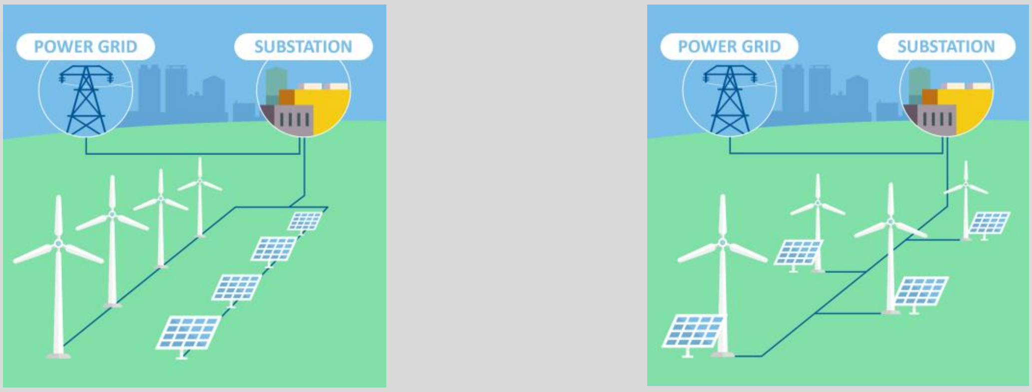
B. PV panels integrated with the wind turbines

The advantage of this solution is that the solar inverters can be eliminated when full-scale conversion is deployed in the wind turbine[9], with potentially important cost savings. This configuration offers the same advantages as the first one but with some specificities. The combination of the technologies allows a more efficient utilisation of the converter. Converters usually have a better efficiency in high-full load operation compared to partial load operation. Thus having PV generation available in times of partial wind generation may increase the efficiency of the converter.

In such configurations, the Annual Energy Production (AEP) per m^2 of the wind farm increases. However, shading of the PV panels by the blades and the tower can impose a disadvantage and may neutralize the overall AEP increase over the term of the project. A solution could be installing PV panels in less shadowed areas around the turbine or further apart from the turbines. However, the latter would increase cabling cost, potentially significant in certain countries, and induce line losses, active and reactive power-wise. Maximum Power Point Tracking (MPPT) techniques are necessary to maximise power extraction under all conditions.

This configuration is not suitable when “hybridising” an existing wind farm due to space constraints for PV integration and capacity limitation given the existing wind turbine power evacuation gear. Moreover, the provision of ancillary services can be limited compared to the first configuration, as the solar inverters are not interfaced with the grid.

Figure 3 Types of HPPS in terms of integration and operation of different generating modules



Same substation and grid connection | **PV panels integrated with the turbines**

Source: WindEurope

TABLE 1 Types of HPPS in terms of integration and operation of different generating modules

	Same substation and grid connection	PV panels integrated with the turbines

9 Petersen, L., Hesselbaek, B., Martinez, A., M. Borsotti-Andruszkiewicz, R. , C. Tarnowski, G. , Steggel, N., Osmond, D., Vestas Power Plant Solutions Integrating Wind, Solar PV and Energy Storage, 3rd International Hybrid Power Plants Workshop, 2018.

<table>
<tr><td rowspan="2">√</td><td colspan="2">- Reduced CAPEX and permitting time thanks to one single grid connection point and substation
- Maximised utilisation of the grid connection capacity
- Easier to optimise the sizing of the substation in function of the most possible range of power output, but necessary to carefully consider curtailment
- Adaptability of HPP towards owner business case to various site conditions
- Joint project development and O&M services</td></tr>
<tr><td>- Simpler and more flexible configuration to develop and size, especially when storage is integrated</td><td>- The solar inverters can be eliminated
- Wind turbines evacuation capacity can be utilized for solar power</td></tr>
<tr><td rowspan="2">X</td><td colspan="2">- Connection and metering processes quite new to authorities, not yet standardised and streamlined</td></tr>
<tr><td></td><td>- Potential shading of PV panels from the blades.
- PV capacity is limited by the turbines' power export capacity and by space
- Provision of ancillary services somewhat limited because the solar inverters are not interfaced with the grid</td></tr>
</table>

Storage integration in HPPs

When storage is included, WindEurope identifies three types of HPPs in function of ESS integration and operation in the HPP:

A. ESS as a supplementary component

The storage module is linked to at least one of the generating modules and cannot be independently controlled. In this case, storage is only used as a supportive element to the generating modules. Practically, the ESS is commanded by the individual control system of the generating module.

B. ESS as an independently operated component

The storage module is operated independently from the generating modules. In this case, storage can be used either to support the operation of the generating module or to provide ancillary services to the grid (by storing energy from the grid or directly supplying stored energy to the grid). Practically, the ESS can be directly commanded by the HPP controller.

C. ESS mixed case

In this case a share of the storage capacity is reserved (and should be registered) as a supplementary component enabled only when the generating module, to which it is linked, operates. The remaining part of storage capacity is reserved (and should be registered) as an independent component directly interacting with the grid (for instance, providing frequency containment reserve to the TSO). In this case, only the ESS is partly commanded by the HPP controller and partly commanded by the individual generating module's controller.

1.2.2 FUNCTIONALITIES AND SERVICES TO DEPLOY

HPPs can serve a set of different functionalities. WindEurope identifies the following ones:

- *Enhanced and flatter power output*: make power generation profile flatter over time compared to a pure wind or solar installation, ease control of the ramp rate (MW/min) to eliminate rapid voltage and power fluctuations in the electrical grid, make power dispatch more schedulable . This is particularly relevant when connecting to weak grids (e.g. long-radial distribution grids, far from the transformers to the transmission grid).
- *Increase capacity factor:* higher utilisation of the converter, transformer and connection capacity (higher number of full-load hours) compared to a pure wind or solar installation through negative correlation of wind and solar resources
- *Weak power grid*: to provide more schedulable power dispatch, contributing to satisfy load demand in an area where the power grid is too weak to provide reliable power supply. This functionality addresses power supply in remote or isolated areas including islands or even cases where load demand increased much further than estimations during the initial grid sizing (e.g. HPP serving a facility, for instance a production unit, a warehouse or a data centre, built in an originally residential area) and can also help to defer grid investments
- *Balancing*: offering services[10] to the TSO to ensure, in a continuous way, the maintenance of system frequency within a predefined stability range
- *Day-Ahead Forecast Deviation Settlement*: to reduce and “buffer” deviations from committed day-ahead forecasts; as such reducing penalties associated with day-ahead forecasts
- *Other ancillary services*: to provide reactive power control, black start when storage is integrated, , voltage control services, to the respective System Operator

Along with the increasing share of variable RES in the power grid, the functionalities of HPPs are expected to multiply for serving different flexibility and resilience needs of the system. Most HPPs are built to serve more than one functionality, multiplying in this way their revenue streams.

2 CREATING AWARENESS

2.1 DATABASE OF GLOBAL HPPS

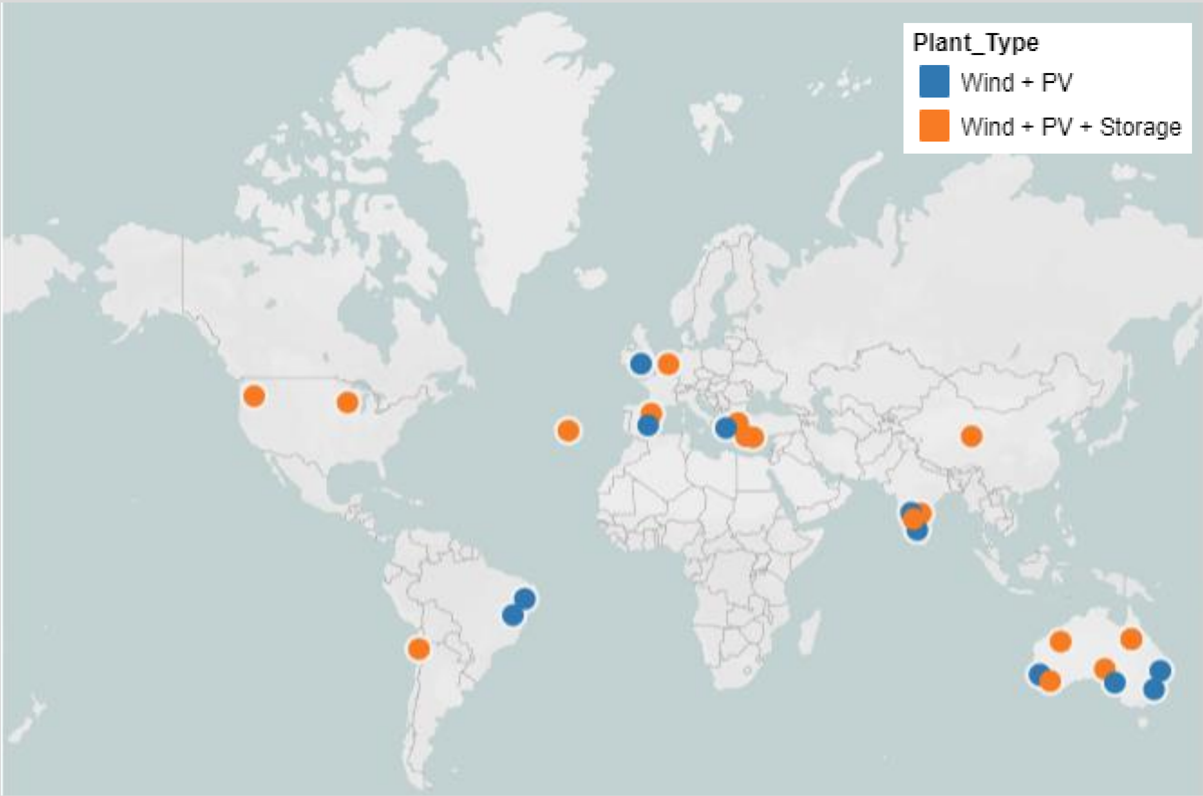
In 2017, WindEurope developed and made publicly available a database of co-located power plants with wind and storage technologies[11]. For creating awareness and building knowledge around HPPs, WindEurope complemented this database with HPPs including wind and solar, with or without storage. The scope of the database is larger than the one of this paper. It considers all kinds of energy storage including installations that store electrical energy from a RES plant and then convert and release it in a

[10] The European Commission, “Commission Regultation (EU) 2017/2195 establishing a guideline on electricity balancing”, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32017R2195

[11] WindEurope, “WindEurope’s online database of co-located projects,” 2017. [Online]. Available: https://windeurope.org/about-wind/database-for-wind-and-storage-colocated-projects/

different energy form (e.g. hydrogen) and all kinds of renewable-based generation. One screenshot of the database is presented in the following figures. **Figure 4** illustrates the global map with HPP locations and types.

Figure 4 A screenshot of the WindEurope database of HPPs[12]



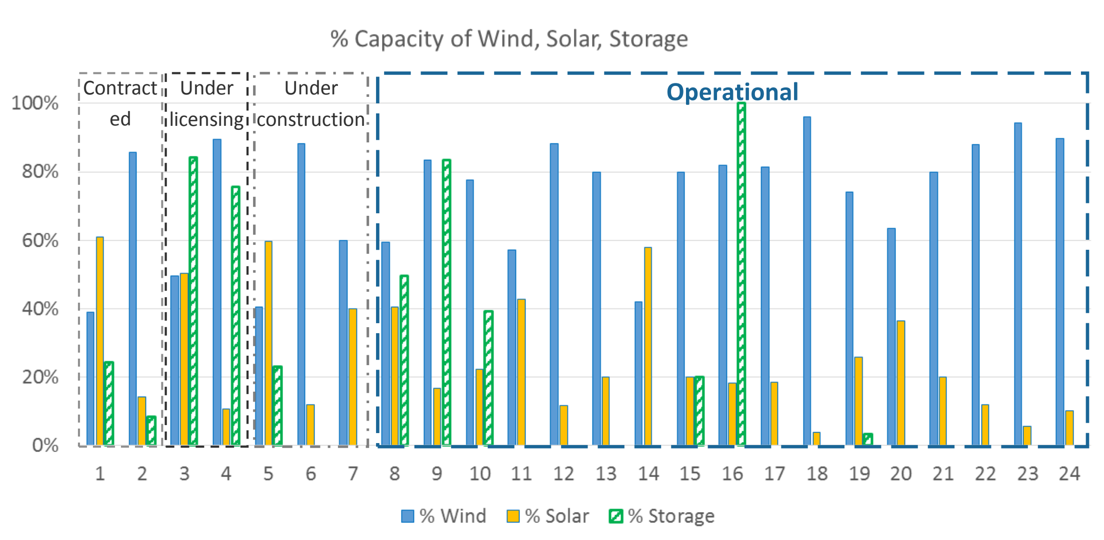
Source: WindEurope

2.1.1 TOTAL CAPACITY AND CAPACITY SHARE OF TECHNOLOGIES

The capacity share of the different technologies under a HPP vary in function of the developer's needs, the local conditions and the planned functionalities. The optimal sizing would maximise the use of the converter and substation capacity, increasing the plant capacity factors, while minimising energy curtailments. **Figure 5** presents the capacity share of wind, solar and storage technologies in twenty-four existing and under development HPPs. The total capacity is computed as the sum of nominal wind and solar output capacities. The wind-solar ratio is quite variable and heavily depends on where the HPP is built and how rich the individual resources are; in a country with significantly richer wind resource one may see more wind capacity in HPPs than in regions where solar is the richer resource.

[12] WindEurope, "WindEurope's online database of co-located projects," 2017. [Online]. Available: https://windeurope.org/about-wind/database-for-wind-and-storage-colocated-projects/

Figure 5 Capacity share of wind, solar and storage in twenty-four existing and under development HPPs



Source: WindEurope

2.2 OVERVIEW OF EXISTING HPPS

The following paragraphs outline some projects from pioneer HPP developers, mentioning the main functionality that initially drove their development. Thanks to the adaptability of HPPs to different revenue streams, most of these plants may serve a combination of functionalities to fulfil their business case in evolving market conditions.

- *Enhanced and flatter power output*

Cynog Park, United Kingdom

Vattenfall

Wind (MW)	PV (MWp)	Storage (MW/ MWh)	Main function	Status
3.6	4.95	0	Enhanced and flatter power output	Operating

% Total capacity: 47% wind | 53% PV

Description:
The Cynog Park is Vattenfall's first solar PV and wind HPP developed as a strategic project for gaining experience. In this pilot project, a solar PV farm of 4.95MWp has been installed, in 2016, in the 3.6 MVA onshore Cynog wind farm, built in South West Wales since 2001. The HPP has a grid connection capacity of 4.1MVA (co-location type A).

Wind + PV

Haringvliet, The Netherlands

Vattenfall

Wind (MW)	PV (MW)	Storage (MW/ MWh)	Main function	Status
21	31	12/ 12	Enhanced and flatter power output, Balancing	Construction to start in 2019

% Total capacity

40% wind | 60% PV | 23% storage

Description:
The objective of the developer is to combine the three technologies, since early development, to stay competitive in the future. The permitting and the Dutch Renewable Energy Grant Scheme (SDE+) have been secured for the plant since 2017. The construction will start in 2019 and the plant is expected to be commissioned in 2020. Revenue streams: participation in the wholesale electricity market and Guarantees of Origin (GoO), Frequency Containment Reserve services and time shifting services.

Wind + PV + Storage

Kavithal solar-wind project, India

Hero Future Energies & Siemens Gamesa

Wind (MW)	PV (MW)	Storage (MW/ MWh)	Main function	Status
50	28.8	0	Enhanced and flatter power output	Operating

% Total capacity

63% wind | 37% PV

Description:
The primary aim of this project is to address grid-integration concerns around variable power coming from renewable energy.

Wind + PV

Kennedy Energy Park, Australia

WindLab & Eurus Energy

Wind (MW)	PV (MW)	Storage (MW/ MWh)	Main function	Status
43	15	2/ 4	Enhanced and flatter power output, weak power grids	Operating

% Total capacity

74% wind | 26% PV | 3% storage

Through the complimentary combination of wind and solar energy at the project site, Kennedy Energy Park can deliver a more constant and demand-driven energy production while improving the effective utilization of the grid network. The hybrid power plant controller also eases the fulfilment of complex grid requirements through additional stabilization capabilities compared to traditional wind turbine plants. These include additional functionalities regarding Active and Reactive Power Control, Power Factor Control, Voltage Control and Frequency Control and Fast Frequency Control.

Wind + PV + Storage

- *Higher capacity factor*

Minnesota Community Site, United States of America

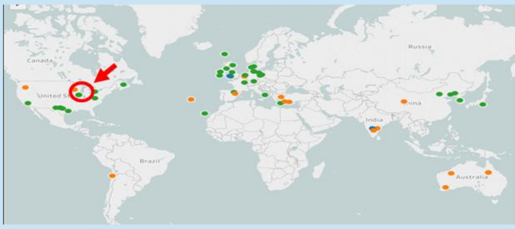
Juhl Energy

Wind (MW)	PV (MW)	Storage (MW/ MWh)	Main function	Status
5	0.5	0	Higher capacity factor	Operating

% Total capacity: 90% wind | 10 % PV

The project has been developed for a local municipality. The installed system is a GE WiSE system with one 2.0-116 wind turbine and 500kWp of solar (configuration type B, see paragraph 1.2.1). The system has been installed in December 2018 and is currently being commissioned.

Wind + PV



- *Weak power grids*

Ollagüe microgrid, Colorado

Enel Green Power

Wind (MW)	PV (MW)	Storage (MW/ MWh)	Main function	Status
0.3	0.205	0.3/ 0.8	Weak power grids	Operating

% Total capacity: 59% wind | 41% PV | 59% storage

Description:
Microgrid in a very isolated area of the country not covered by the national electric grid. The site comprises wind, PV, Lithium-ion batteries and a diesel generator. It is able to provide 24 hours of continuous supply of energy and guarantee important energy and economic savings when compared to the use of a diesel generator alone.

Wind + PV + Storage

Tilos Hybrid plant, Greece

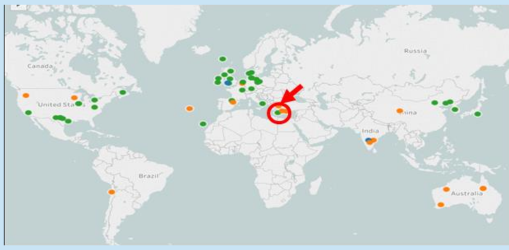
H2020 Research Consortium

Wind (MW)	PV (MW)	Storage (MW/ MWh)	Main function	Status
0.8	0.16	0.8/ 2.4	Weak power grids	Operating

% Total capacity: 83% wind | 17% PV | 83% storage

Description:
Tilos meets its energy demand with electricity from neighboring island Kos, via an undersea cable, which is however vulnerable to faults, especially when seas are rough. The new microgrid will supply 70% of the island's energy demand, ensuring **self-sufficiency**, **lower prices, greater stability** and a **smaller ecological footprint**. Surplus energy will be used to charge electric vehicles for local transport.

Wind + PV + Storage



Graciosa, Portugal

Younicos

Wind (MW)	PV (MW)	Storage (MW/ MWh)	Main function	Status
4.5	1	6/ 3.2	Weak power grids	Operating

% Total capacity

81% wind | 19% PV | 100% storage

Description:
The system combines software with a 6 MW/ 3.2MWh battery storage system, a 4.5 MW wind park and a 1 MWp photovoltaic power plant. The new, hybrid power system on Graciosa can immediately use up to 100 percent sun and wind power. The diesel generators will only be needed for back-up in weeks with very poor weather conditions. This means it could cover an annual average of up to 70 percent of the island's power demand with renewables.

Wind + PV + Storage

La Muela, Spain

Siemens Gamesa Renewable Energy

Wind (MW)	PV (MW)	Storage (MW/ MWh)	Main function	Status
0.85	0.245	0.4/ 0.5	Weak power grids	Operating

% Total capacity

78% wind | 22% PV | 37% storage

Description:
This offgrid prototype aims at generating offgrid power that minimises diesel consumption. The site also comprises 222-kilowatt diesel gensets.

Wind + PV + Storage

3 POLICY CONTEXT AND CHALLENGES

3.1 POLICY CONTEXT IN DIFFERENT COUNTRIES

HPPs being a new development, there are currently only few hybrid-specific policy schemes. India, aiming at an expansion of wind and solar shares but also targeting an efficient utilisation of the transmission grid, has taken the lead and introduced hybrid-specific auctions. HPPs are emerging in Australia, triggered by stricter grid requirements. Brazil is currently considering hybrid solutions to relieve the reliance on diesel generators in the isolated grid of Roraima. Furthermore, Brazil entitles wind-solar HPPS to participate in national energy auctions, under the PLS 107/2017 bill[13].

In most European countries, wind-solar HPPs are generally not treated differently, in terms of legal requirements, than other generation technologies. Often treated as pure wind or solar plants or as co-located RES/storage projects, HPPs are not fully rewarded for their particular societal and system integration benefits. However, such benefits may be considerable in cases with fully complementary wind-solar resources. **Figure 6** outlines the policy context with regard to HPPs, globally in different countries.

[13] Brazil's Senate Committee for Environment, Projeto de Lei do Senado n° 107, de 2017

Not considering the specific challenges of HPP development and treating such plants as pure solar or wind power plants induces costs and uncertainty, as it will be explained in the following paragraphs. Such challenges are often common between existing RES plants under "hybridisation" and new HPPs developed from the start. Nevertheless, in several countries "hybridising" an existing power plant can become very complex, costly and time consuming. Overall, **today most countries do not provide a level playing field for HPPs comparing to other power plants.** The limited policy experience shows however that the motivation for introducing hybrid policies varies in function of system needs. Most likely, there will be thus no policy design blueprint for hybrid solutions.

Figure 6 Policy context with regard to HPPs in different countries

Australia

- New revenue opportunities for batteries were to be introduced (an emission obligation and a reliability obligation) with the *National Energy Guarantee (NEG)* . Although the NEG has been recently abandoned by the federal government, the states continue to work on its reliability component.
- Settlement period for the electricity spot price to change from 30 minutes to 5 minutes (a plus for fast-acting batteries)

Denmark

- Today not allowed for existing older wind turbines/solar plants to become HPP
- Technology-neutral tenders for RES plants

Germany

- Innovation tenders for combined projects providing additional "system benefits". No certainty whether this measure will be implemented.
- New electricity storage (connected 2026) is exempted from grid charges for electricity stored by the grid for 20 years

Greece

- HPPs established in the current regulatory framework. Minimum guaranteed power supply is a prerequisite for permitting. The last RES tender clearly invites HPPs for participation
- In case of storage, the annual grid energy stored by the HPP must not exceed 30% of the required energy for fully charging the storage device
- The ratio of total RES capacity to storage capacity in the HPP should not exceed 1.2

Ireland

- The Department of Communications, Climate Action and Environment (DCCAE) requests tenders for the provision of economic and policy advice to support the design and implementation of the new renewable electricity support scheme (RESS). The request specifically asks for support on the facilitation of hybrid projects under the RESS including hybrid solar, wind and storage technologies

India

- National wind-solar HPP policy since 2017. The policy has been recently updated to cover various storage technologies.
- Very friendly framework for hybridising existing power plants in terms of grid connection capacity and sub-station increased utilisation/ upgrade
- In case of storage → minimum firm power output as bidding factor
- Standards (metering etc.) to be developed for HPPs

Poland

- HPPs have been established in the current regulatory framework

Spain

- Wind-solar HPPs have not yet been established in the currently approved framework (only in a separate draft bill) but no permission to install more capacity than the maximum initially agreed one (so no possibility to hybridise an existing power plant)
- No regulatory framework for medium-scale and large-scale storage systems

Source: WindEurope

3.2 CHALLENGES AND POLICY RECOMMENDATIONS

3.2.1 SIZING THE PLANT

Based on the feedback from first developments, **maximising the utilisation of grid connection capacity is primordial.** To this end, the choice of the specific site to install a plant needs significant attention. Wind and solar resources need to be as much complementary as expected by the use case of the plant (e.g. negatively correlated to increase capacity factor). This allows optimally sizing the plant's equipment, maximizing the utilisation of the grid connection capacity and reducing power curtailment while considering business case driver from the customer. For example, curtailment estimation studies need to be deployed on 10-min or 15-min basis to be reliable for decision making. Picking the right sites is a major factor in HPP design because it will result in both CAPEX and OPEX reduction. Adapting the output of a plant to foreseen remuneration will also increase its value, for example in a Power Purchase Agreement (PPA).

Investing on high quality forecasting of energy production is also very important. The complementarity of different RES can mitigate the variability of the power output potentially leading to lower imbalance costs.

Although the complementarity of wind and solar resources in a region is an important economic driver for developing HPPs, several national frameworks do not ease "hybridising" existing renewable power plants (e.g. Spain, Denmark). Indeed, in such cases, the developer cannot integrate more RES capacity in an existing plant than the initially settled in the connection agreement.

When an existing power plant under configuration type A (see paragraph 1.2.1) is to be "hybridised", technical requirements (network codes) should apply to each module composing a power-generating facility, as determined by Regulation (EU) 2016/631**:**

- Existing power-generating modules are not subject to the requirements of the Regulation.
- The requirements set out in Regulation (EU) 2016/631 shall apply to new power-generating modules.

Regulation (EU) 2016/631 (Art 2(6)) therefore already allows hybridisation to be economically viable, by just adding new power generating modules in existing power generation facilities. The existing module remains subject only to technical requirements valid at its time of commissioning, while new modules are subject to technical requirements determined by the last version of network codes. In this way, the existing installation is upgraded to provide better grid services thanks to new modules, without requiring large investments to re-permit the existing module. Otherwise, the hybridisation would not be viable.

In case an HPP of configuration type B is to be "hybridised", existing generating modules may also be subject to new network code requirements if the relevant system operator considers that the extent of upgrade or equipment replacement is such that a new connection agreement is required. The latter imposes a disadvantage to this solution, as the existing power electronics (converters, inverters…) are commonly shared by the existing and new modules. In such cases, local authorities must establish a formalised and standardised solution when upgrades come to a very large extend.

To make HPPs viable, when an existing power plant is to be hybridised, the developer must be able to exploit the full capacity of the existing grid connection. This means that **HPP developers must be able to integrate total RES capacity higher than the existing grid connection capacity**, even though a part of the produced energy might be curtailed when instantaneous generation exceeds grid connection capacity. Therefore, **developers should not have to re-apply for grid connection compliance as long as the power that the HPP exports to the grid does not exceed the approved capacity under the grid connection.** This is the only way to take full advantage of the complementarity of wind and solar resources and potential use of energy storage to mitigate the variability of wind and solar power generation, to ease fulfilments of power demand (e.g. scheduled power dispatch) and to encourage adaptability to shifting demand and supply patterns

A similar rule should apply to new HPPs. **Developers must be flexible to size and agree with the local authorities the grid connection capacity based on the optimised generation output of the HPP, driving a profitable business case for the project.**

Moreover*, to make HPPs economically viable*, when an existing power plant is to be hybridised, each module in the HPP should comply with network code requirements that were in place when the module was commissioned. Thus, the existing module should be subject to different requirements than the new module. In case of configuration type B, a formalised and standardised solution needs to be applied when upgrades come to a very large extend. Otherwise, the hybridisation project will not be viable due to costly and time consuming re-permitting of the existing module

3.2.2 PERMITTING AND DEVELOPMENT

Overall, HPP developers can harvest synergies within the development and permitting process as well as for the operation and maintenance of the plants.

In terms of permitting, the advantage of HPPs is that only a single grid connection needs to be set up or upgraded. However, given the limited number of projects, the permitting and connection procedures of HPPs are still quite new to most local authorities and system operators; this might induce some delays and complexities.

In terms of development complexities, a multi-disciplinary team is required with expertise on wind and solar generation technologies, storage devices and the interoperability between them[14]. The project management is also more complex compared to pure wind or solar plants as the developer needs to align different development schedules (e.g. wind permitting process is usually lengthier than solar). To manage such complexities, continuous adjustment of internal organisation and project steering are required. Finally, in some countries, solar PV systems cannot be installed on farm land (not the case for wind) which might limit co-location opportunities. At the same time, *Agrophotovoltaic* is becoming an established

[14] S. Hagemann, "Think Hybrid, Combine the Best of Two and Manage Complexity," in *WindEurope Working Group System Integration meeting*, 2019

practice to increase land efficiency, and further deployment of this type of solutions can increase HPP opportunities[15].

With regard to building permits, whilst often driven by local bodies (versus national governments), it is advised for larger HPPs to declare them as "national interest" to spur innovation and support the increased share of renewables in the system. At least, exceptions should be granted in current legislation, e.g. to allow for HPPs on farmland if and where PV plants are currently not permitted.

For the definition of different HPP configuration types, see paragraph 1.2.1

3.2.3 METERING

In general, **metering concepts are not standardized or formalised for HPPs but subject to bilateral negotiation and agreement with the relevant system operator or local authority**. To be eligible for direct financial support, a separate metering of the individual assets is most often required. This is especially the case when an existing power plant is "hybridised" and one of the existing RES plants has been receiving some sort of financial compensation. This is a challenge that may increase costs and administrative complexity.

Having one metering system installed at the grid connection point allows the measurement of the total project production or consumption but also a transparent metering of the individual technologies´ energy flows. Additional virtual metering points within the HPP could be set up[16]. Virtual metering could be more economically viable in certain cases, compared to numerous physical meters. In any case, **the developer should be able to design the metering system according to his business case as long as he can reliably trace energy flows according to local authorities' requirements.**

When Guarantees of Origin (GO) are required, the metering system must be able to trace the share of energy produced by the renewable energy technologies of the plant and the share of grid energy stored by the HPP and supplied later to the grid.

3.2.4 ADDING STORAGE

Apart from increasing metering requirements, adding a storage device in an existing HPP (or even pure wind or solar power plant) could endanger subsidy payments in certain cases (suspicion of "grey" power supplied by the plant rather than "green" power). Some national regulations treat this issue by applying a limit to the maximum amount of grid energy that can be stored by the HPPs and a maximum ratio of total RES capacity to storage capacity integrated in the plant (e.g. Greece, **Figure 6**). In this way, HPP developers are incentivized to prioritise RES share rather than storage share in a HPP.

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[15] Fraunhofer ISE, "Harvesting the Sun for Power and Produce – Agrophotovoltaics Increases the Land Use Efficiency by over 60 Percent," 2017. [Online]. Available: https://www.ise.fraunhofer.de/en/press-media/press-releases/2017/harvesting-the-sun-for-power-and-produce-agrophotovoltaics-increases-the-land-use-efficiency-by-over-60-percent.html.

[16] A virtual metering system uses process conditions to estimate flow rates instead of using a physical meter. Once calibrated with a physical flow, the virtual meter can then just use process conditions to make its estimates

Sizing of storage should be optimised for each project based on market design and opportunities, which are expected to align with system needs and social welfare, HPP design, curtailments reduction, costs and technical features. **Storage sizing should not be imposed or limited by regulation.**

Regarding grid energy to be stored by HPPs, no limits on stored energy should be established unless the HPP is under a support mechanism. Wholesale market prices shall incentivize the storage to charge when prices are low, thus ensuring that systematic charging helps the system. **A formally approved and transparent metering approach on national level (avoid having individual negotiations per System Operator region) can ensure RES traceability and power labelling** (so that green versus grey stored and exported power can be distinguished).

Other countries have recently decided an exemption from grid charges for new ESS when storing grid energy (connected before 2026) to boost the market uptake of electrical storage (e.g. Germany, see paragraph 3.1). This measure is useful when the main revenue stream of an HPP is generated by the storage device through participation in the balancing market or ancillary services. As one can see in **Figure 5**, storage is often integrated in HPPs, to smooth further the power output and to diversify its revenue streams through value-stacking. Policy makers should ensure that the respective integration and operation procedures do not become a burden for developers. **The amount of energy re-injected into the grid from an HPP with storage should have an equal treatment with respect to stand-alone batteries injecting power to the grid. Overall, double taxation and double grid charges, when storage is integrated, must be avoided.**

To tackle permitting and development issues, including metering and storage integration, countries need to establish HPPs in their national regulatory framework. **Procedures and requirements for HPPs must be standardised and formalised**. Given the intrinsic complexities in making different technologies interoperable, this step is primordial.

Streamlining metering procedures in HPP will drastically decrease administrative needs in cost and time. Moreover, it will relieve HPP developers of significant economic and regulatory uncertainty. Having one metering system installed at the grid access point with additional virtual metering points within the hybrid project, allows the measurement of the total project production or consumption but also a transparent metering of the individual technologies´ energy flows. In turn, this provides clarity to the developer on the expected revenues and thus stimulates the potential development of HPPs. Moreover, it reinforces the business case of the respective digital solutions and services.

In case storage is integrated in HPPs, **the regulatory framework should set clear criteria on the monitoring practices for tracing energy flows between the storage device and the grid**. Moreover, **double taxation and double grid charges must be avoided.**

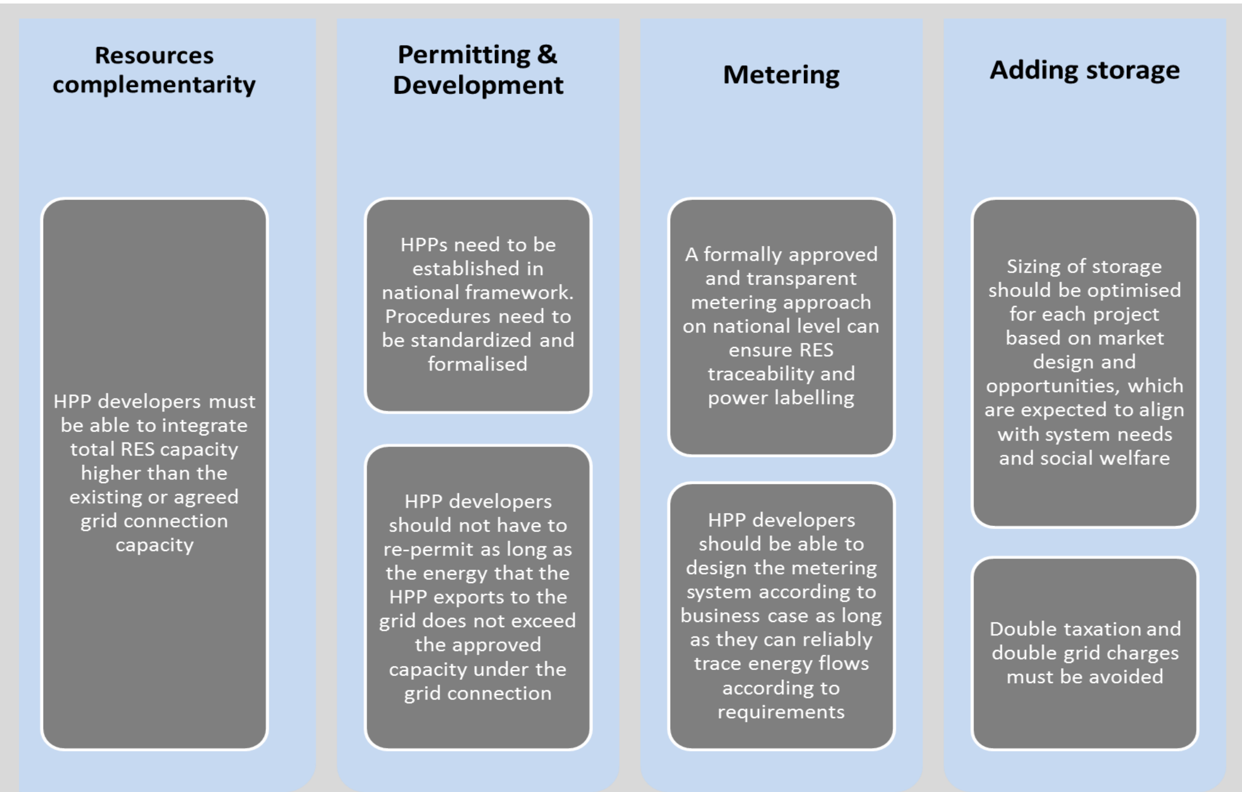
Sizing of storage should be optimised for each project based on market design and opportunities, which are expected to align with system needs and social welfare, HPP design, curtailments reduction, costs and technical features. Storage sizing should not be imposed or limited by regulation.

3.2.5 INVESTMENT FRAMEWORK

Given that the specific challenges of HPP development are generally not taken into account by policy makers, today developers encounter uncertainty which induces costs and reluctance to deploy more projects. To accelerate the deployment of wind-solar HPPs, support schemes will be required. In today´s RES support schemes, it is a challenge for HPPs to get support for the full concept. Their foreseen advantages are not rewarded in common technology-neutral RES auctions. For this reason, countries should create a level playing field for HPPs, by considering WindEurope's policy recommendations, summarized in **Figure 7**, to relieve investors from uncertainty and administrative costs.

HPPs should be allowed to provide different services at the same time, thus improving the profitability of the project thanks to service stacking. For instance, HPPs could deliver congestion management services and voltage support to Distribution System Operators (DSOs) while offering frequency reserves to Transmission System Operators (TSOs). When capacity markets are present, HPPs should be allowed to participate along with conventional power plants. In such case, another incremental revenue stream will arise for HPPs. **Market operators should remove all barriers to the participation of HPPs in ancillary service and capacity markets**. Products and pre-qualification processes need to evolve too in order to foster technology deployment.

Figure 7 Policy recommendations for creating a level playing field for HPPs



Source: WindEurope

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ANNEX I: ABBREVIATIONS

Table I Abbreviations

Abbreviation	Definition
AEP	Annual Energy Production
DSO	Distribution System Operator
GO	Guarantee of Origin
HPP	Hybrid Power Plant
PPA	Power Purchase Agreement
RES	Renewable Energy Source
TSO	Transmission System Operator