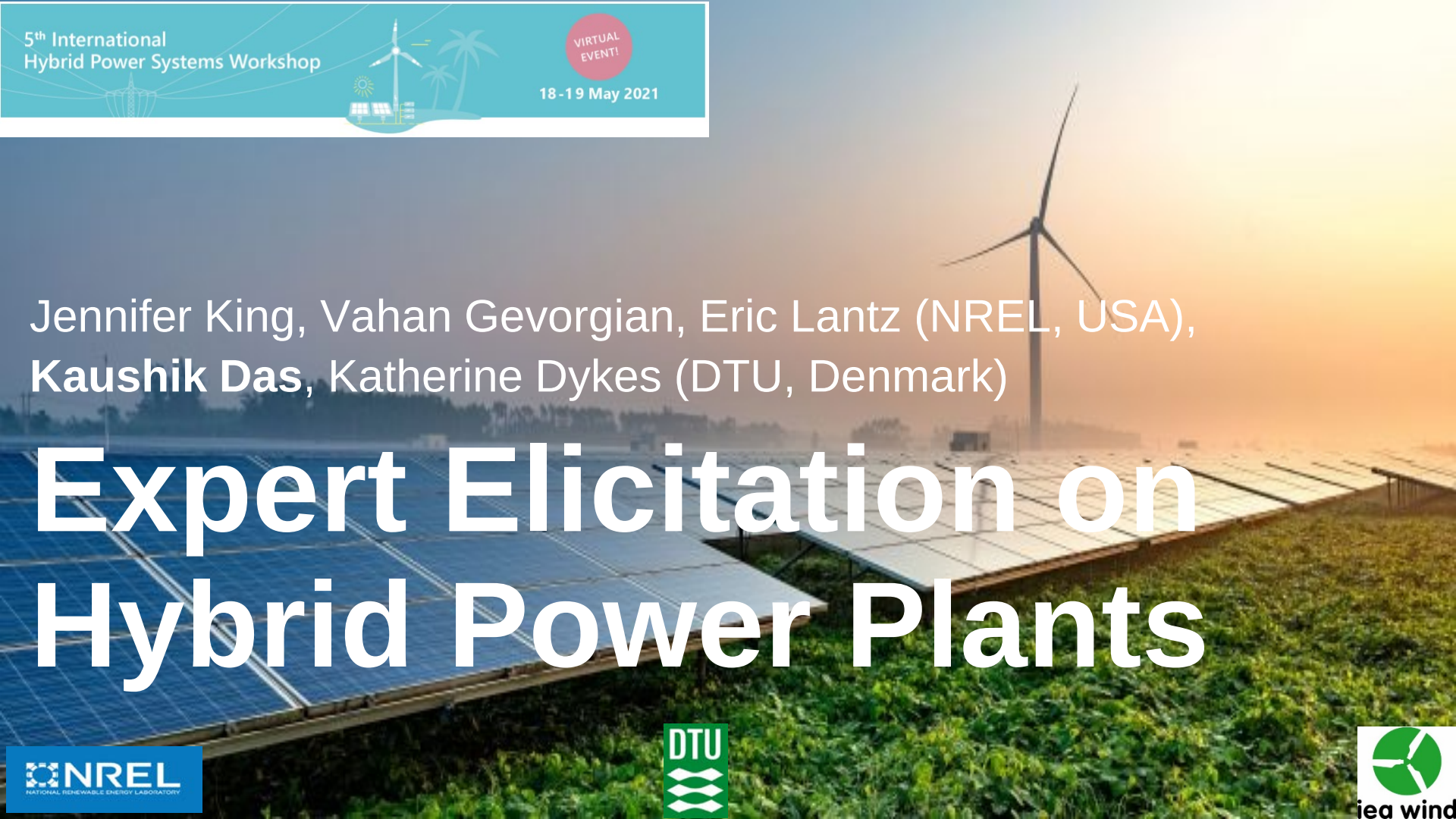

DTU



Jennifer King, Vahan Gevorgian, Eric Lantz (NREL, USA),
Kaushik Das, Katherine Dykes (DTU, Denmark)

Expert Elicitation on Hybrid Power Plants

NREL NATIONAL RENEWABLE ENERGY LABORATORY

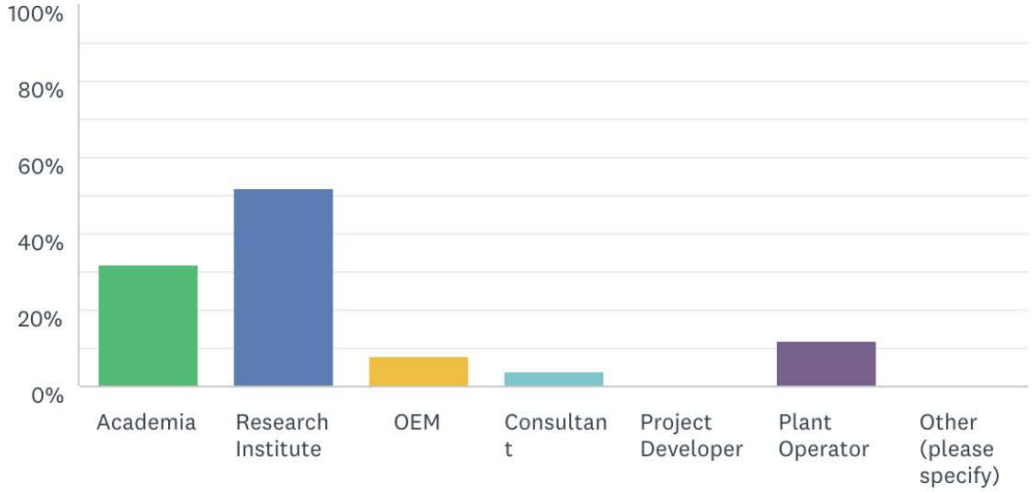
DTU

iea wind

Expert Survey

Survey Participants

- Belgium
- Canada
- Switzerland
- Germany
- Denmark
- Spain
- Finland
- France
- Ireland
- Japan
- Netherlands
- Norway
- Sweden
- United Kingdom
- United States

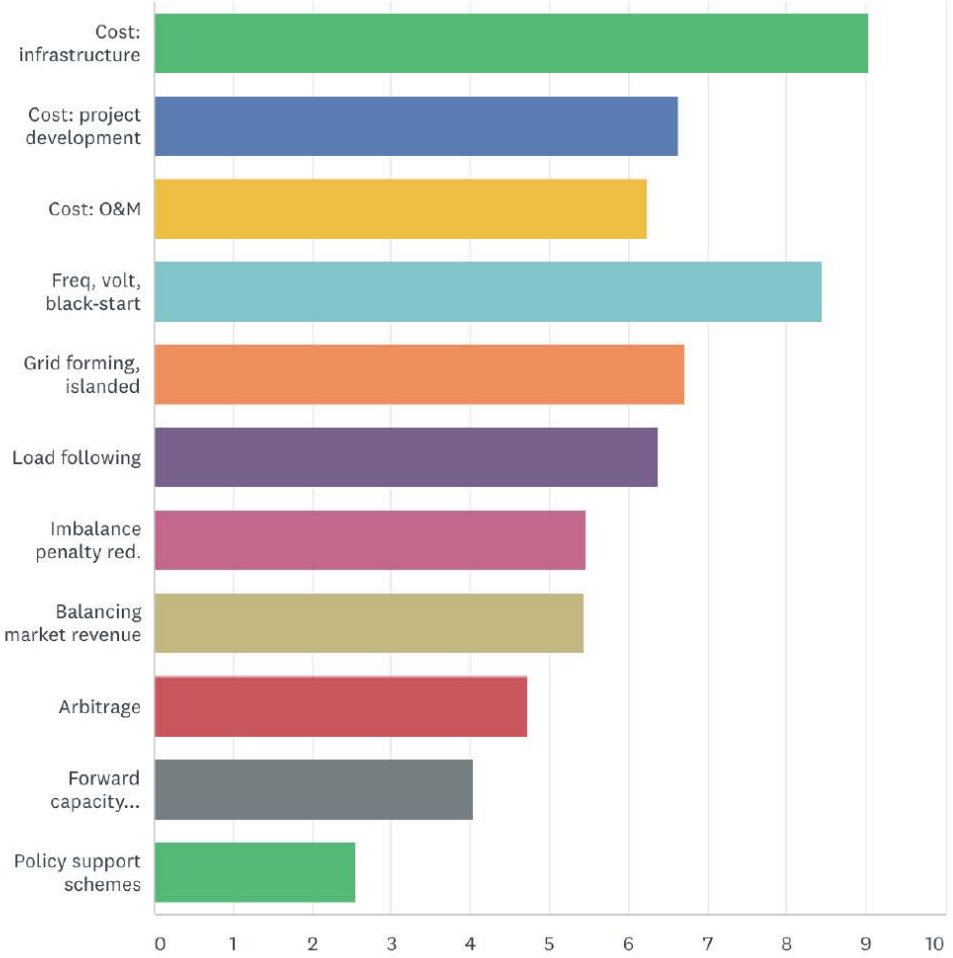



Colocation
Forecasting
Realtime
reduction
synergies
Technology
Optimization
Grid
Increase
sizing
Increased
Power
Hybrid
Storage
System
Cost
Solar
services
plant
Energy
Ancillary
modeling
Wind
Renewable
control
Dispatchability
Complementary
Simulation
stability
Systems
Battery
Arbitrage
Complementarity
demandproduction
Reliability
compared
Variability
Intelligent
Fossilfree
cocontrol
Offgrid
ORE
interconnection
demonstration
floating
resources
microgrids
Compliance
rates
predictions
Stochastic
capacity
electronics
analysis
ramp
Risk
Policy
plants
sources
Reduced
Aggregation
Operational
costs
Creating
Efficiency
hydro
LCOE
supporting
Ramping
microgrid
generation
development
Pumped
results
Shared
markets
intermittency
Survey
utilization
frameworks
flexibility
standards
Onshore
Coordination
hardwareintheloop
Futuristic
scheduling
Customizable
Operation
Complexity
Colocated

Objectives of HPP

- Rank based on importance of HPP being able to achieve the following

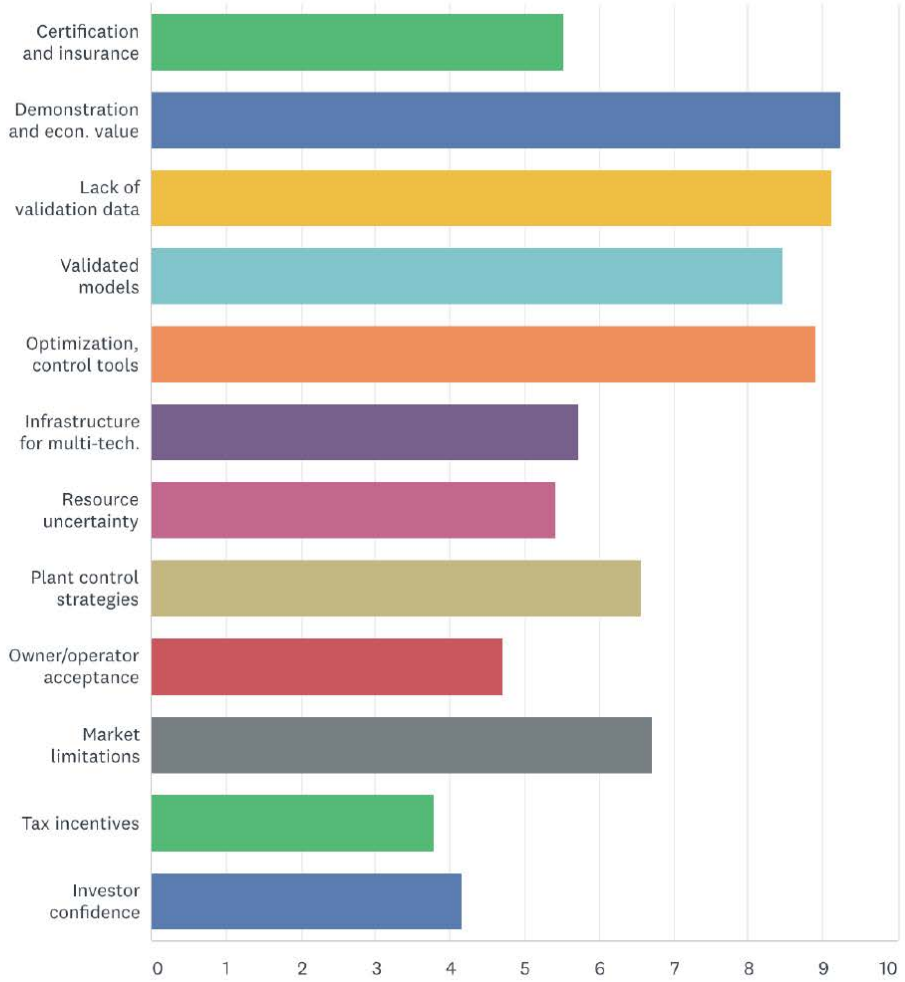
- Top responses:
  - Cost reduction: infrastructure
  - Grid services (freq support)



Main Barriers for HPP

- Rank 1 through 10
- Weighted average

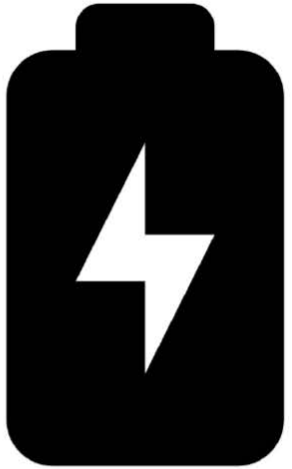
- Top responses:
  - Demonstration of economic value
  - Lack of validation/verification data
  - Optimization and control tools



	1	2	3	4	5	6	7	8	9	10
Imbalance penalty red.	0.00% 0	8.33% 2	4.17% 1	4.17% 1	4.17% 1	8.33% 2	41.67% 10	20.83% 5	4.17% 1	4.17% 1
Balancing market revenue	0.00% 0	4.00% 1	12.00% 3	16.00% 4	8.00% 2	0.00% 0	4.00% 1	28.00% 7	24.00% 6	4.00% 1
Forward capacity markets	0.00% 0	0.00% 0	4.00% 1	4.00% 1	12.00% 3	12.00% 3	8.00% 2	12.00% 3	0.00% 0	44.00% 11
Cost: project development	4.17% 1	12.50% 3	12.50% 3	8.33% 2	12.50% 3	16.67% 4	0.00% 0	25.00% 6	8.33% 2	0.00% 0
Grid forming, islanded	4.00% 1	16.00% 4	12.00% 3	4.00% 1	12.00% 3	32.00% 8	4.00% 1	0.00% 0	4.00% 1	8.00% 2
Arbitrage	4.00% 1	12.00% 3	0.00% 0	0.00% 0	8.00% 2	8.00% 2	16.00% 4	4.00% 1	28.00% 7	4.00% 1
Policy support schemes	4.00% 1	4.00% 1	0.00% 0	4.00% 1	4.00% 1	0.00% 0	4.00% 1	0.00% 0	4.00% 1	4.00% 1
Cost: O&M	8.00% 2	4.00% 1	16.00% 4	8.00% 2	12.00% 3	12.00% 3	8.00% 2	8.00% 2	12.00% 3	12.00% 3
Load following	8.33% 2	8.33% 2	16.67% 4	8.33% 2	12.50% 3	8.33% 2	8.33% 2	0.00% 0	8.33% 2	20.83% 5
Freq, volt, black-start	29.17% 7	16.67% 4	12.50% 3	12.50% 3	16.67% 4	0.00% 0	0.00% 0	0.00% 0	8.33% 2	0.00% 0
Cost: infrastructure	37.50% 9	12.50% 3	8.33% 2	29.17% 7	0.00% 0	0.00% 0	8.33% 2	4.17% 1	0.00% 0	0.00% 0

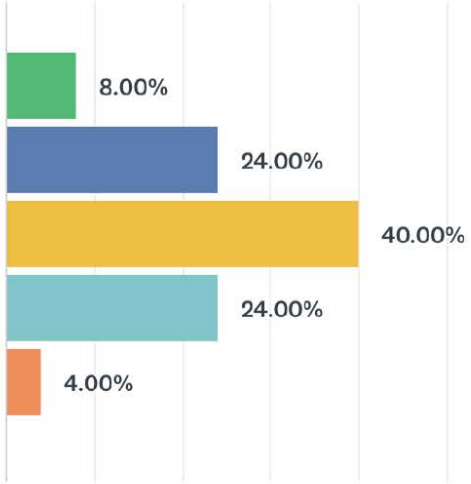
Most Promising Storage Technologies

- Lithium-ion
- Lead acid
- Flow battery
- Site-dependent
- Hydrogen
- Green Methane
- Fly-wheel
- CAES
- Redox flow
- Fuel cell
- Super capacitors
- Compressed air
- Heat storage
- Carnot batteries
- Pumped hydro storage
- Ultracapacitors



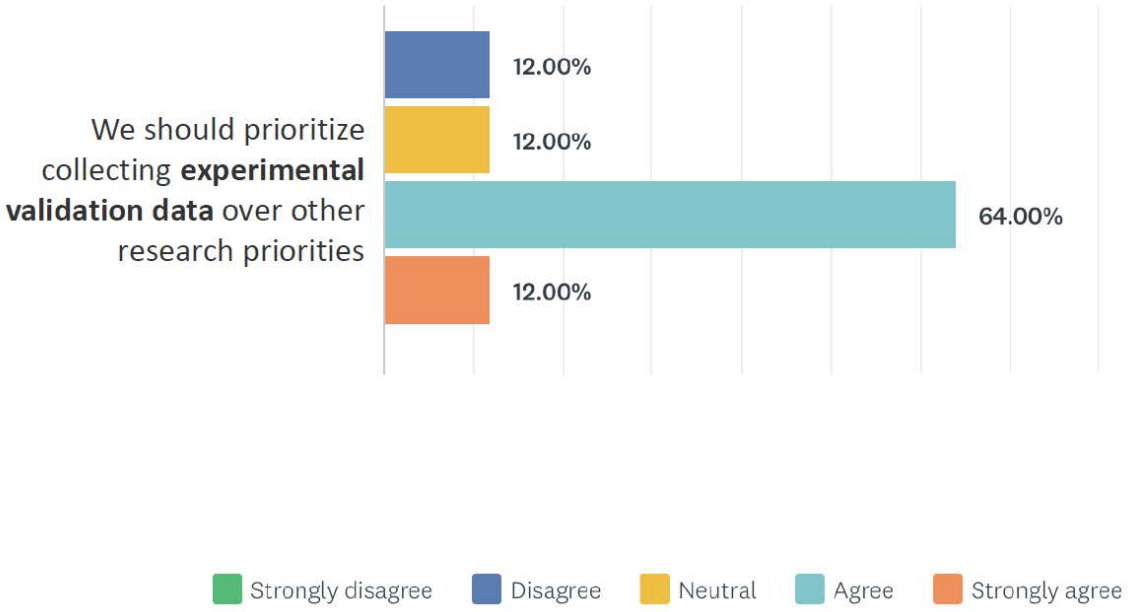
Current State of Hybrid Power Plants

Existing **experimental methods** are sufficient for testing and developing viable hybrid power plants.

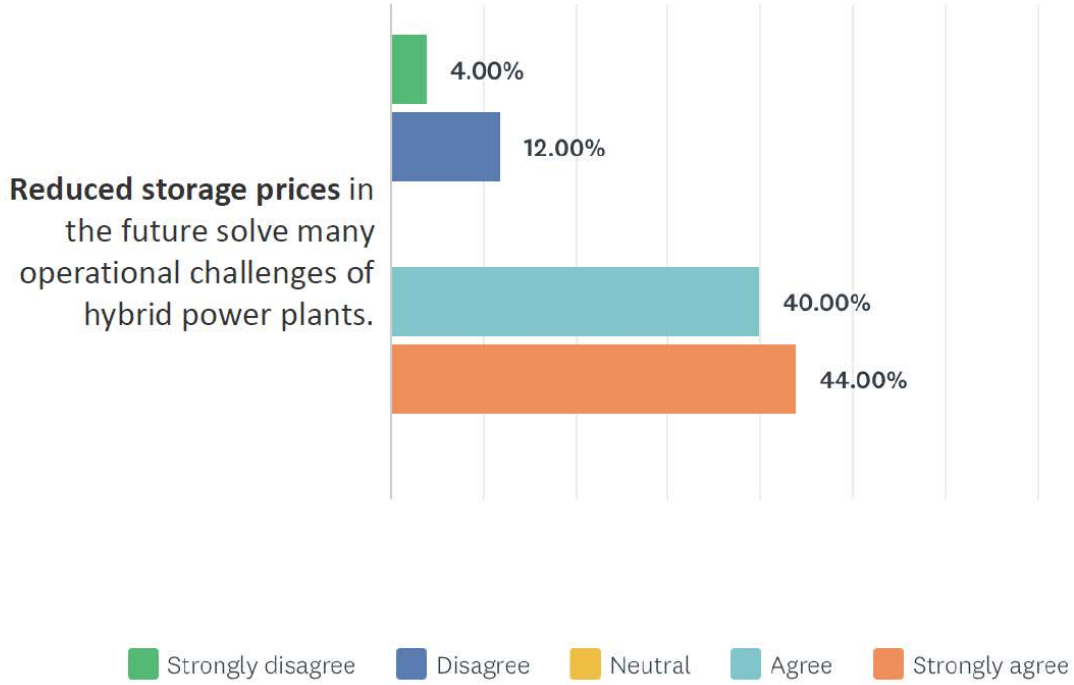


Strongly disagree | Disagree | Neutral | Agree | Strongly agree

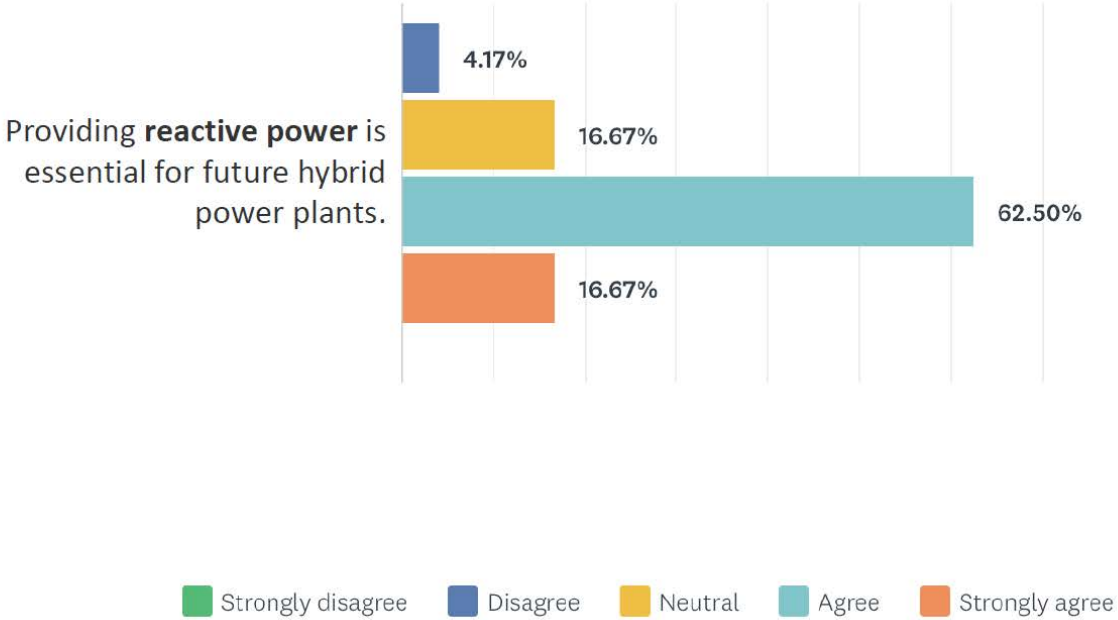
Experiments and Validation



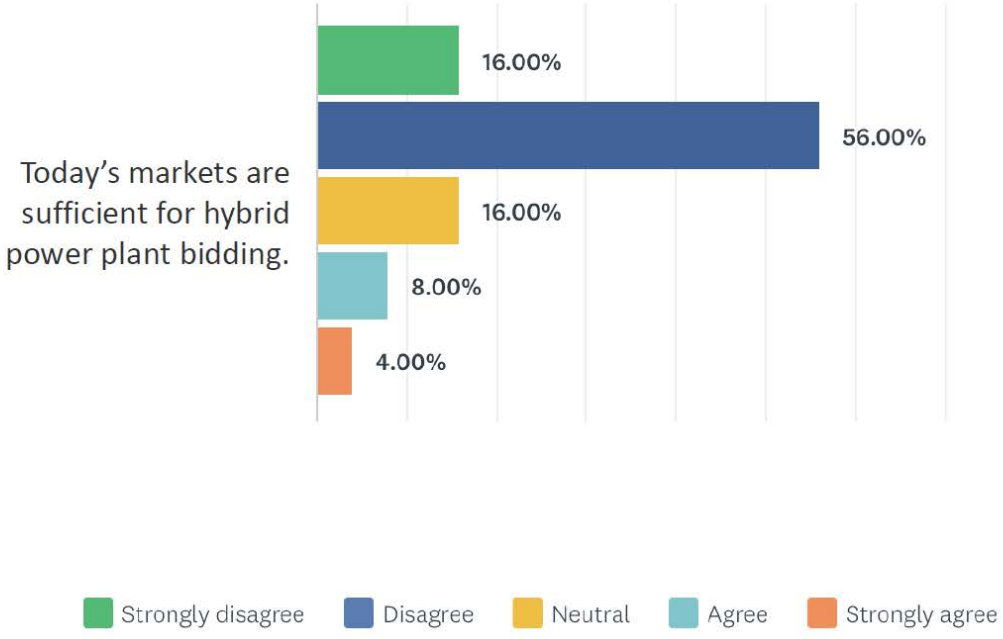
Storage


Reduced storage prices in the future solve many operational challenges of hybrid power plants.
4.00%
12.00%
40.00%
44.00%
Strongly disagree
Disagree
Neutral
Agree
Strongly agree

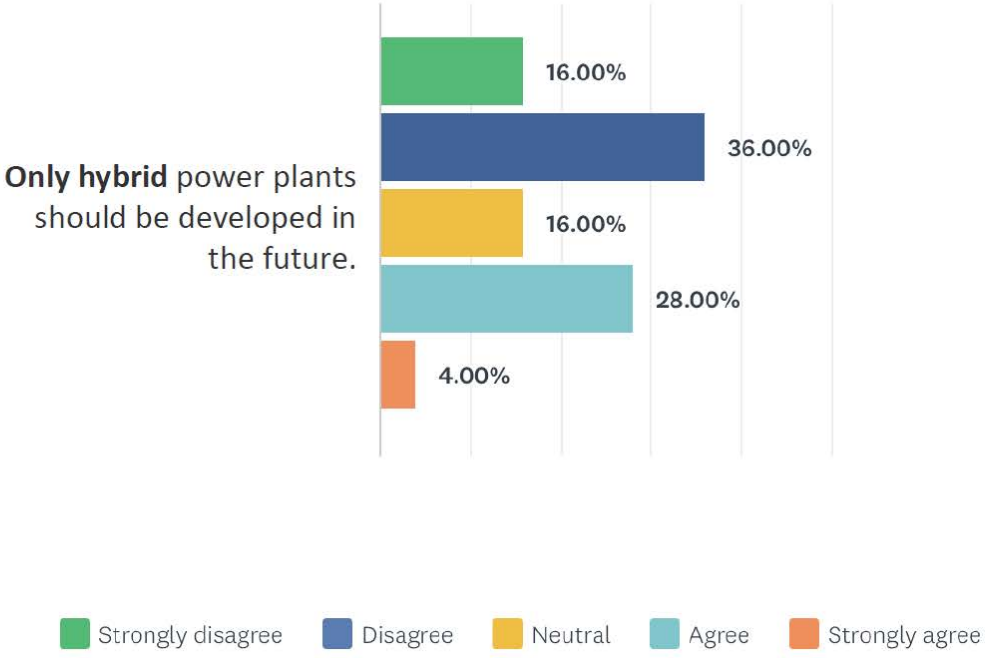
Reactive Power



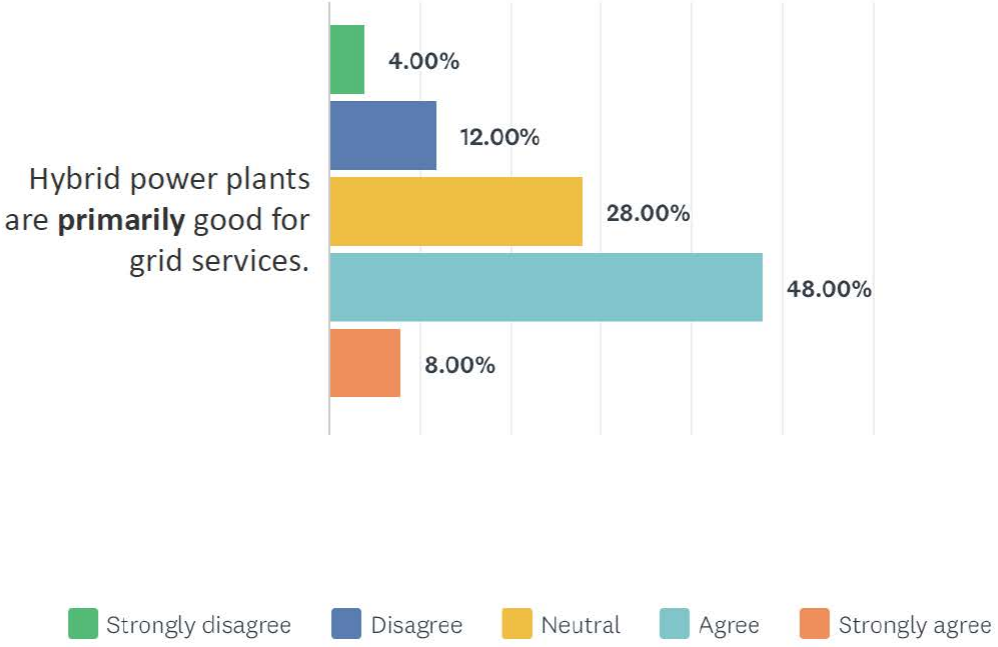
Market Design



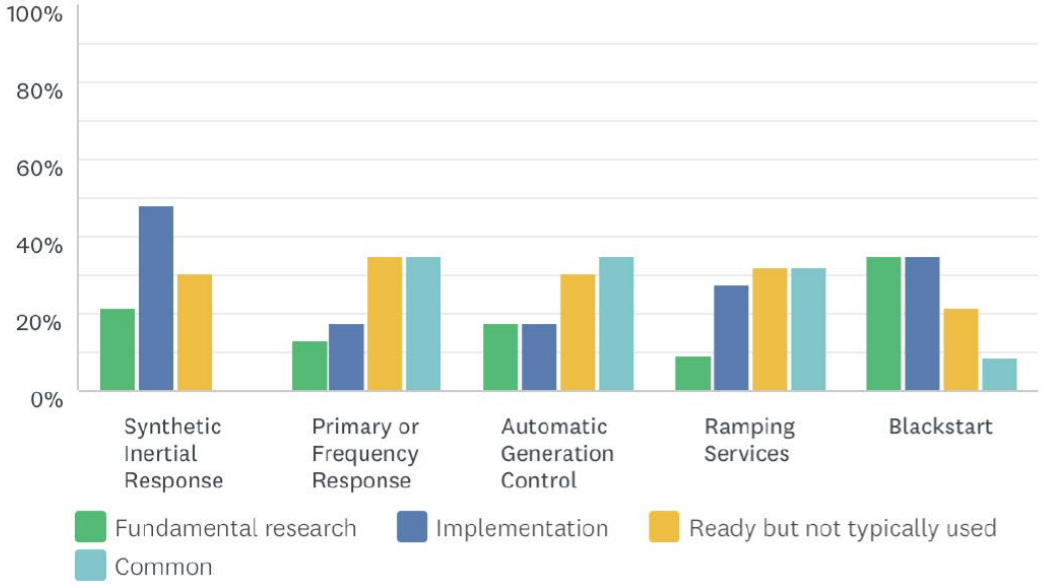
Hybrid versus Single Technology Plants



Ancillary Services



Grid Services



Danish Hybrid Wind Power Plant Forum (https://hybrid-vindenergi.dtu.dk/)

Others

- Wind turbine load and control and lifetime
- Storage lifetime assessment and control
- Wind farms wakes and control
- Grid interaction and stability assessment
- Offshore applications

Integration to Energy Systems

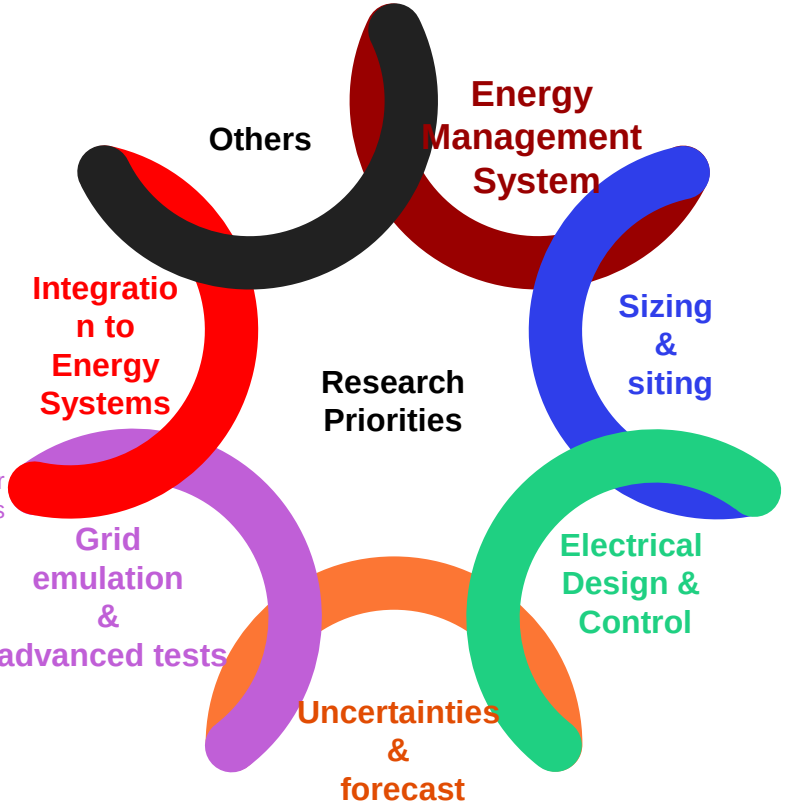
- Co-operation with other energy sectors
- Power2X
- Co-ordinated Control
- Load Balancing

Grid emulation & advanced tests

- Emulation of future converter dominated power systems using CGI and / or synchnonus condenser to emulate grid
- Development of new test methods / grid codes
- Validation of models

Uncertainties and forecast

- Variability for combined wind-solar-storage
- Market forecasts
- Hybrid power forecast
- Real time power simulation
- Assessment of flexibility & grid services



Energy Management System

- Optimal operation on markets: energy markets, grid service markets and capacity markets considering uncertainties, component lifetime

Sizing and siting

- Resource assessment
- Physical Design Optimization
- Selection / hybridization of storage technologies
- Optimal sizing of wind-solar-storage
- Hybridization of existing wind or solar plants

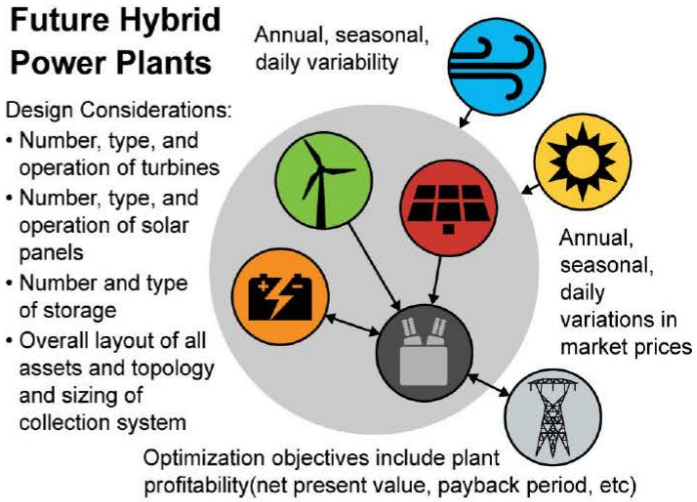
Electrical Design and Control

- Optimal electrical design – utilization of wind turbine DC links and inverter
- Use of electrical auxiliaries (supercapacitor, chopper, FACTS)
- Hierarchical control / Distributed control
- Grid services
- Blackstart capability

Goal of the Topical Expert Meeting

Overall: Accelerate the development and deployment of hybrid power plants

- What are our biggest roadblocks?
- **Topical Experts Meeting (TEM):** If this were to become an IEA Task
  - Determine areas of international collaboration
  - Determine the role of this task
- **Critical Areas:**
  - Benefits of hybrid power plants
  - Microgrids and control
  - Sizing/Optimization and Storage solutions



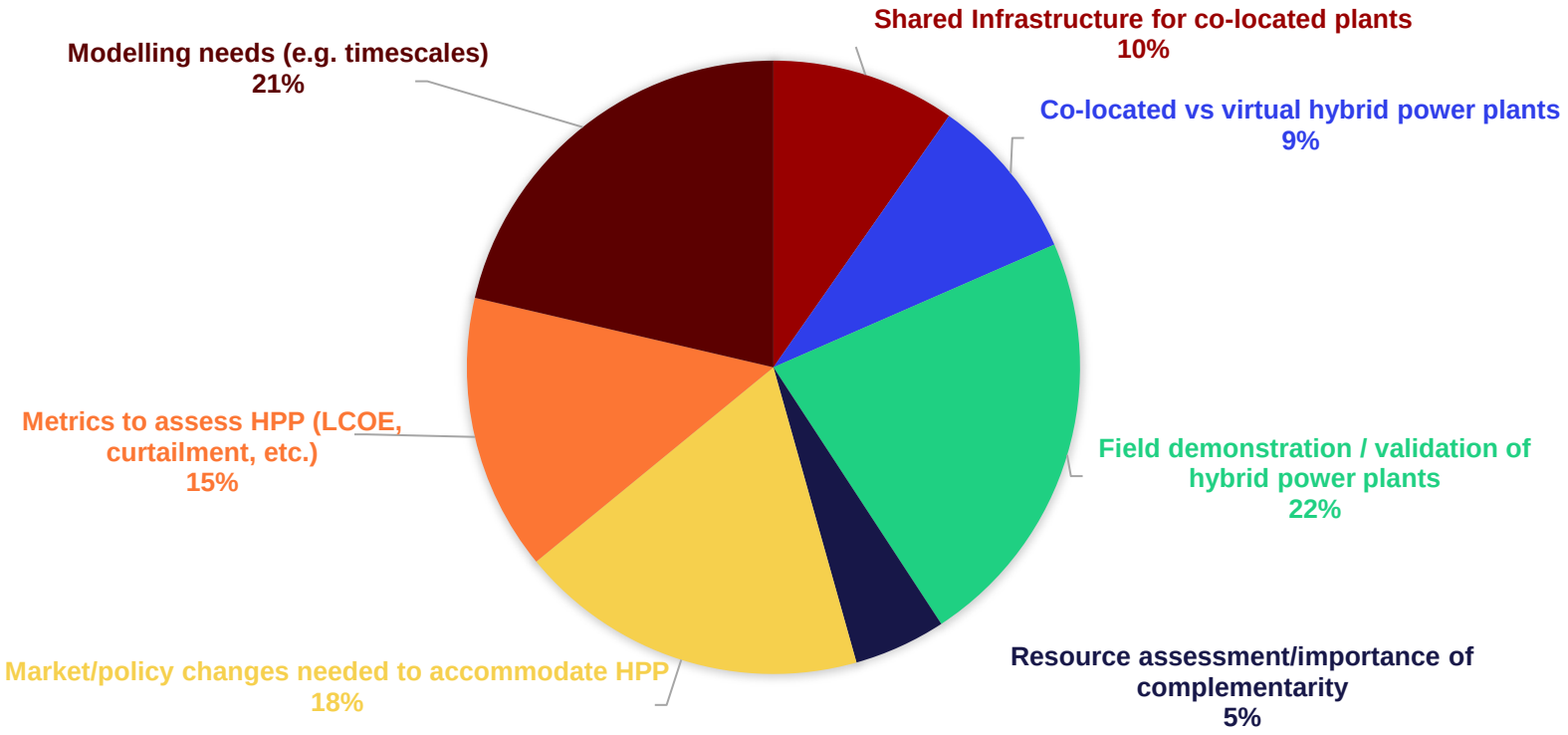
Hybrid Power Plants (HPP): Topical Experts Meeting

To realize accelerate the deployment of hybrid power plants, important work to be done, which requires active involvement of the stakeholders: OEM, developers, owner/operators, consultants and researchers

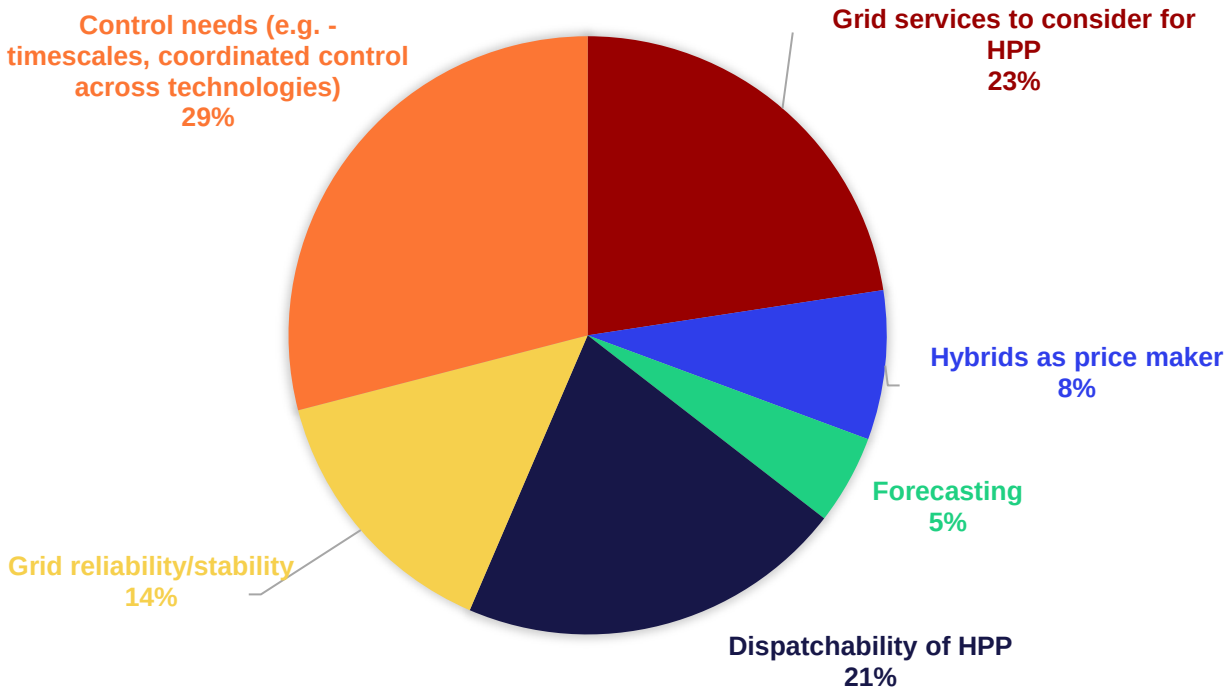
Organized a virtual Topical Experts Meeting (TEM) in August 2020 to begin the process

Approximately 80 participants over 3 days from 18 countries

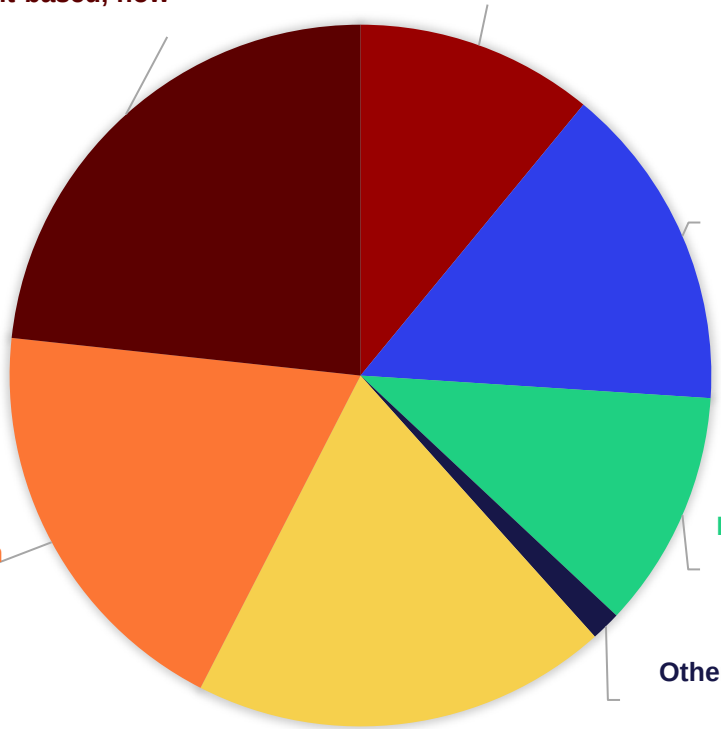
Important topics for IEA task collaboration



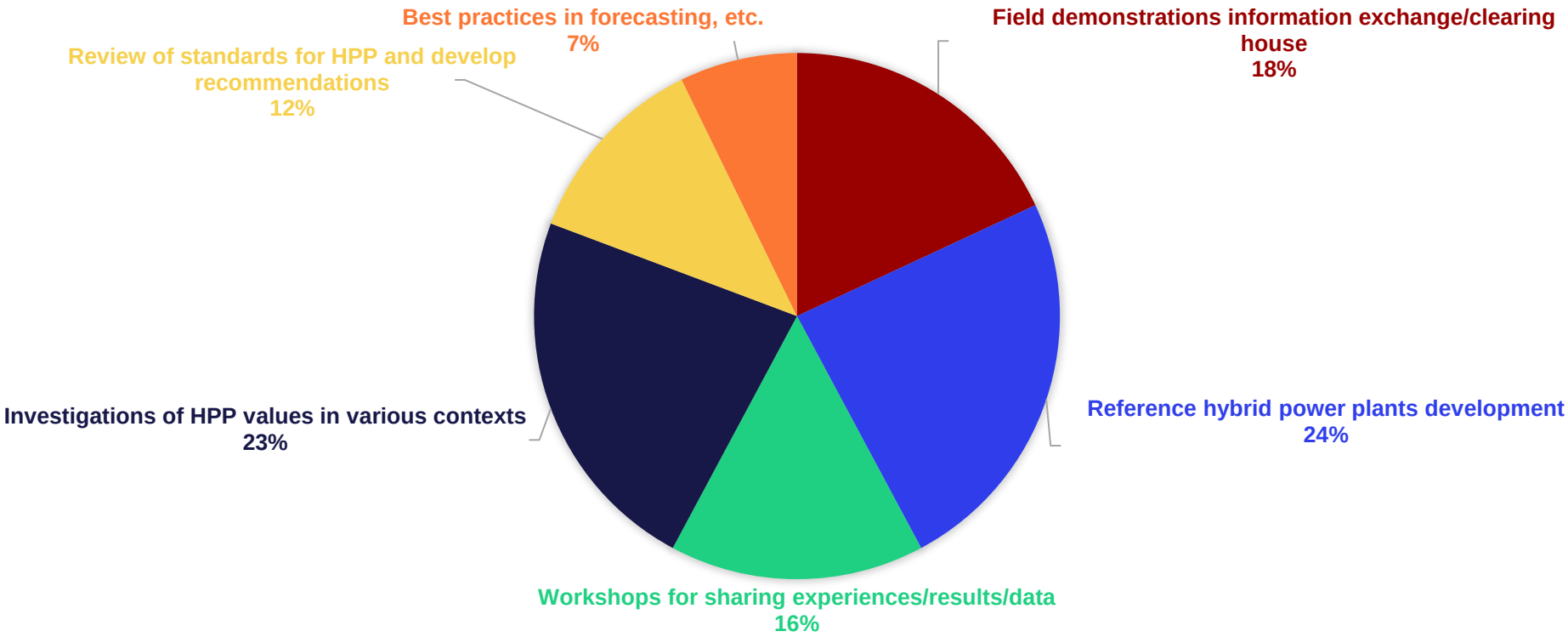
Important topics for IEA task collaboration



Important topics for IEA task collaboration



Important topics for IEA task collaboration



Results of TEM

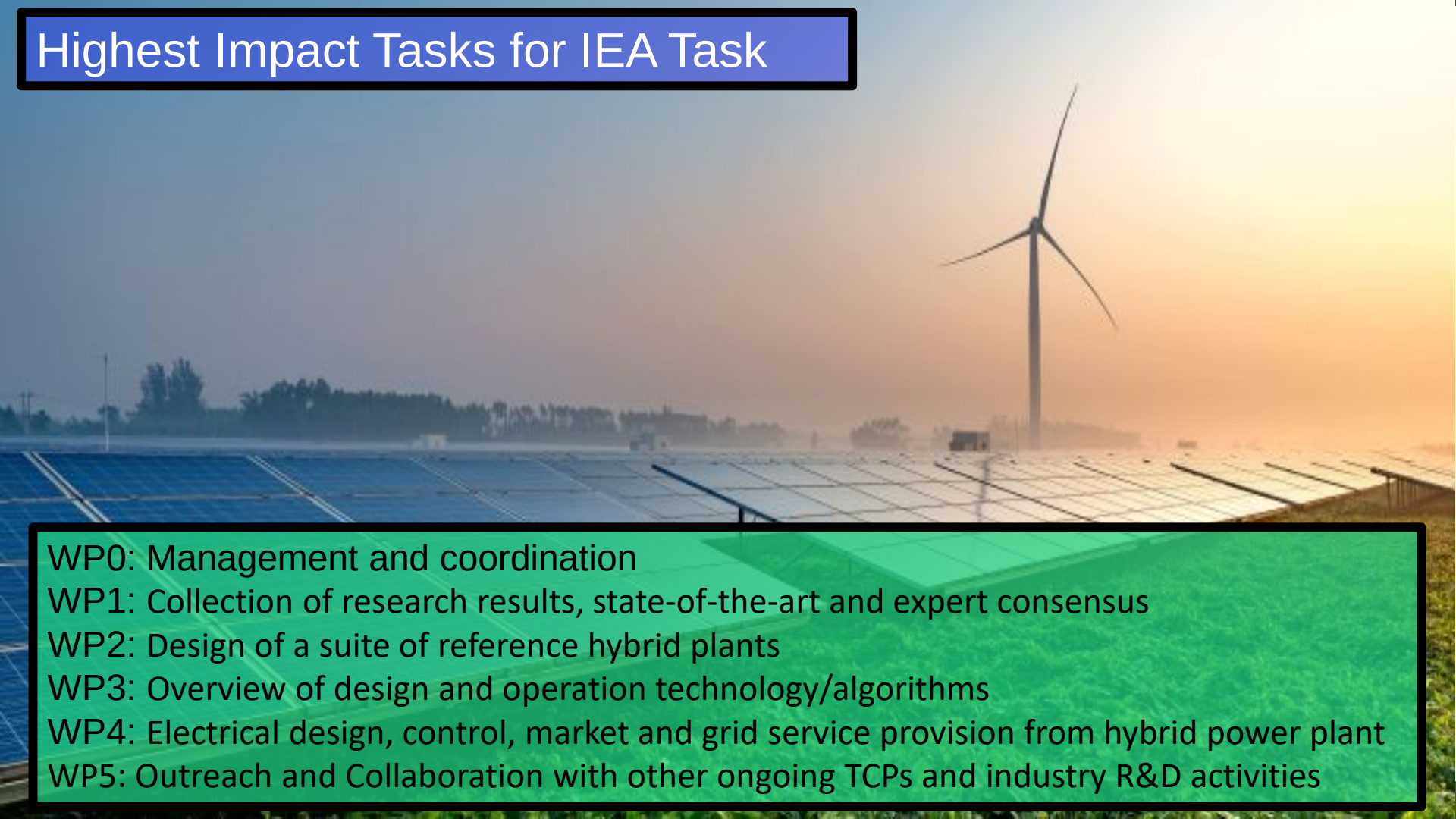
Question	Agree	Disagree
Only HPP should be developed in the future	40%	60%
Markets are sufficient for HPP participation	12%	72%
Providing grid services as an essential HPP capability	70%	30%
Prioritize experimental validation	76%	12%

Results from the TEM: Market Barriers

- Demonstration and economic value
- Lack of validation data
- Validated models
- Optimization, control, modeling tools

Basis for our work packages

Highest Impact Tasks for IEA Task



WP0: Management and coordination
WP1: Collection of research results, state-of-the-art and expert consensus
WP2: Design of a suite of reference hybrid plants
WP3: Overview of design and operation technology/algorithms
WP4: Electrical design, control, market and grid service provision from hybrid power plant
WP5: Outreach and Collaboration with other ongoing TCPs and industry R&D activities

Hybrid Power Plants: Moving Forward

Operating agents:

- Jennifer King, NREL (US)
- Kaushik Das, DTU (DK)

Expected budget:

- ~60.000 euro/year

Annual costs:

- 5.000 euro/year

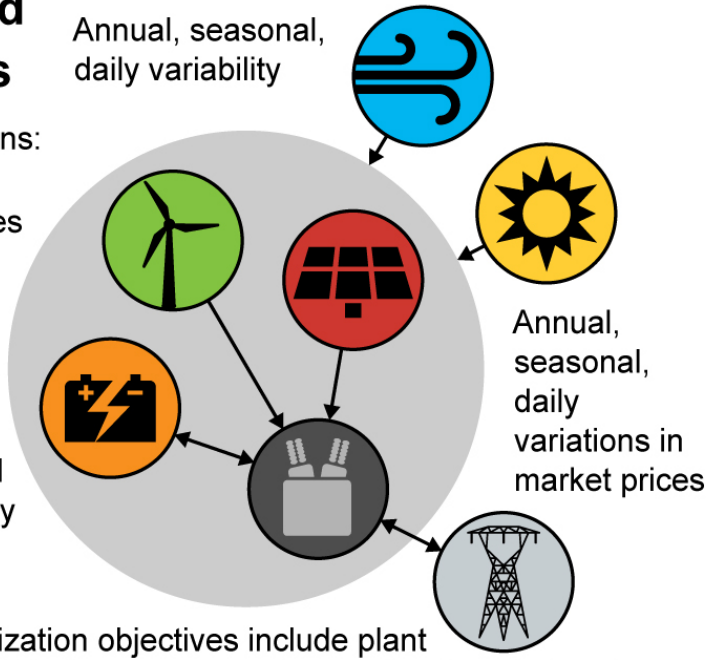
Duration:

- 4 years

Future Hybrid Power Plants

Design Considerations:

- Number, type, and operation of turbines
- Number, type, and operation of solar panels
- Number and type of storage
- Overall layout of all assets and topology and sizing of collection system



Optimization objectives include plant profitability(net present value, payback period, etc)

Thank You

- Contact - kdas@dtu.dk