Western Norway
University of
Applied Sciences

Optimized renewable energy supply for a sustainable Recircuating Aquaculture System (RAS)

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PhD programme in Computer Science.

The project and work packages

Mass balance and energy optimisation in recirculating aquaculture systems (RAS) with special focus on diurnal variations in water quality (RAS-EN)

WP1: Diurnal variations in mass and energy flows with respect to water quality parameters.

WP2: Optimised renewable energy supply for a sustainable RAS.

WP3: Sludge and sustainable energy.

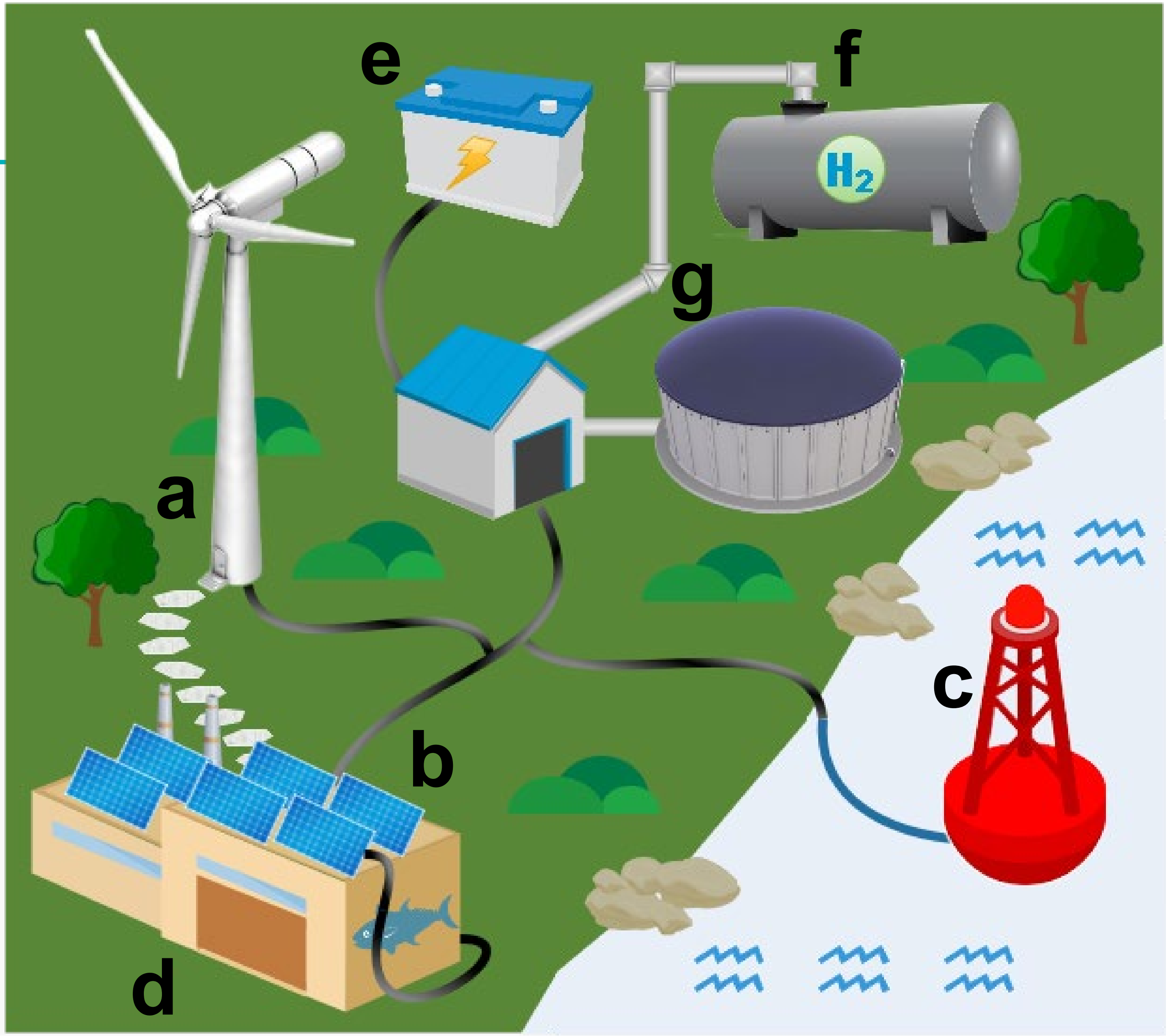
- Leila (ISKB) **WP1** and **WP3**
- Gerard (IMM) **WP2** and **WP3**

WP2 supervisors:

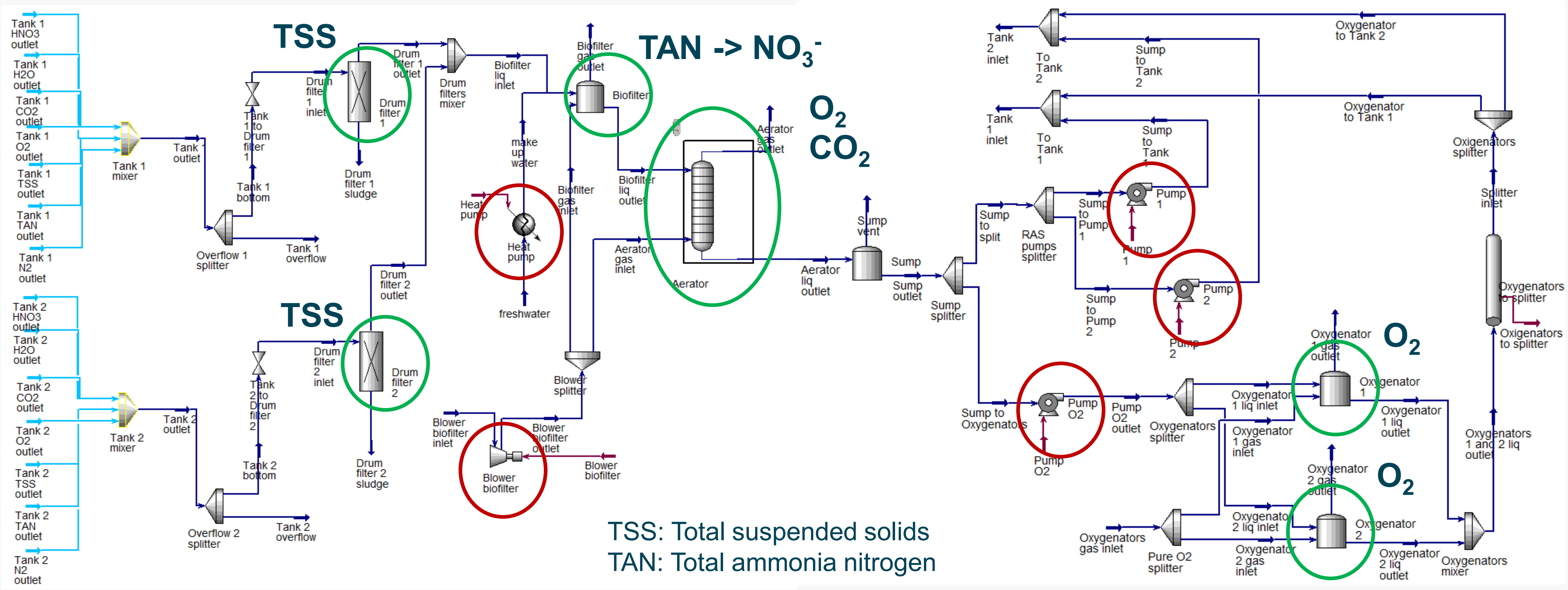
- Norbert Lümmen (IMM) / David Lande-Sudall (IMM) / Kjell Eivind Frøysa (IDER)

The energy system

- Model and simulate an energy system with **wind (a)**, **solar (b)** and **wave (c)** energy harvesting.
- Supply the energy demand of a **RAS (d)**.
- Use **batteries (e), hydrogen (f)** and **biogas (g)** to store energy and balance the grid.



RAS in AspenHYSYS



TSS: Total suspended solids
TAN: Total ammonia nitrogen

Ayuso Virgili et al., *Aquacultural Engineering* 101, 102330 (2023)

RAS energy demand

a) Constant water flow

Oxygen cones pump adjusted to oxygen need.

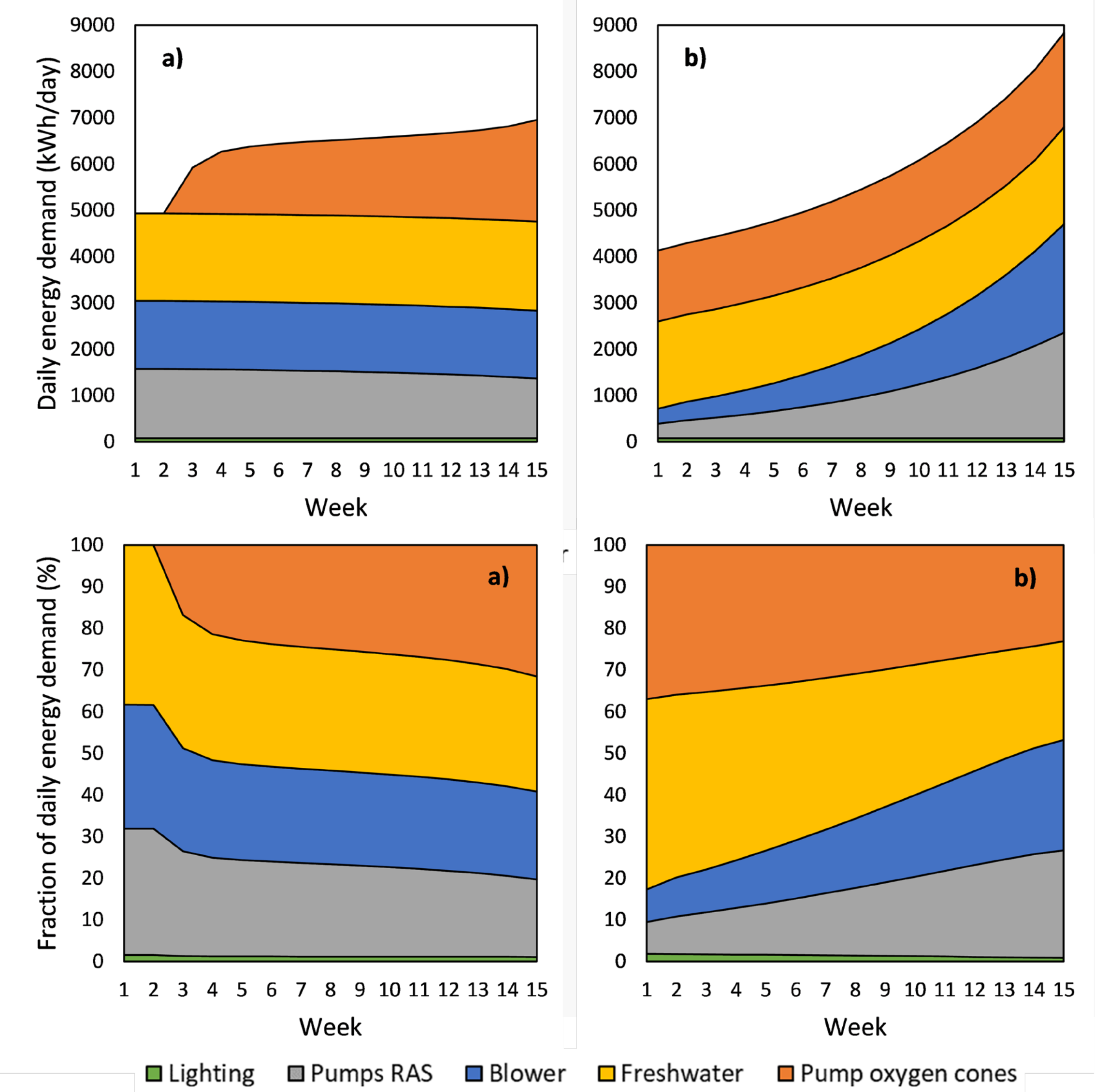
205 kW – 290 kW (weeks 1 to 15)

a) Adjusted water flow

Blower and RAS pumps have much reduced demand at the start.

Peak demand in b) is higher than a) justified to maintain water quality.

172 kW – 369 kW (weeks 1 to 15)



Ayuso Virgili et al., *Aquacultural Engineering* 101, 102330 (2023)

Overview of energy harvesting system

		Power capacity range
Wind turbine		0 – 2 MW
Photovoltaic panels	Configuration S	0 – 848 kW
	Configuration EW	0 – 920 kW
Wave energy converter	M4-132	-

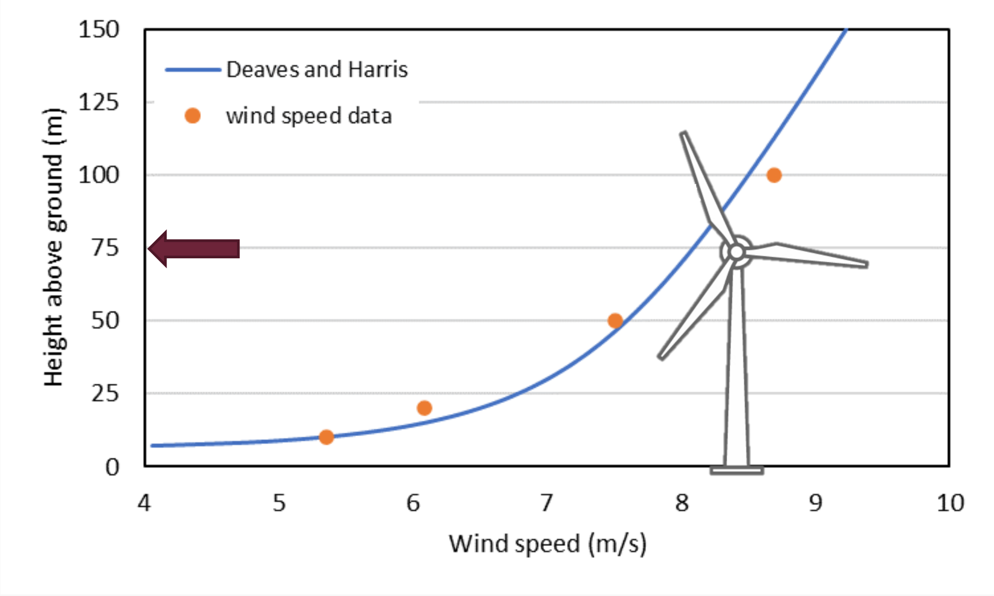
- Hourly data for wind speed, solar irradiation and ocean conditions is gathered between 2012 and 2021.
- Models for scalable wind and solar energy harvest devices are ready.
- Preliminary results are generated for three WEC sizes.

Wind speed profile

› 7 hourly wind speed datapoints at different heights (in m):
10, 20, 50, 100, 250, 500 and 750.

› Deaves and Harris model for fitting wind speed profile to data between 2012 and 2021.

› Interpolated wind speed at wind turbine hub height.



Parameter	Description	Value
z_d	Zero-plane displacement	6 m
z_0	Surface roughness	0.013 m
κ	Von Kármán constant	0.41
h	Atmospheric boundary layer height	300 m
$A_{swept,rated}$	Vestas 90-2.0 MW swept area	6362 m^2
v_{rated}	Vestas 90-2.0 MW rated wind speed	11.5 m/s
$P_{rated,WT}$	Vestas 90-2.0 MW power rating	2 MW
v_{cut-in}	Vestas 90-2.0 MW cut-in wind speed	4 m/s
$v_{cut-out}$	Vestas 90-2.0 MW cut-out wind speed	25 m/s
$v_{re-cut-in}$	Vestas 90-2.0 MW re-cut-in wind speed	23 m/s
ρ_{air}	Air density	1.2 kg/m^3

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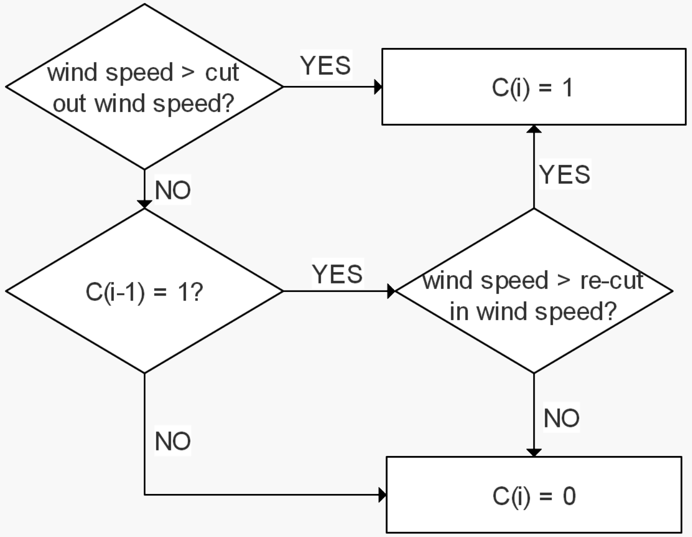
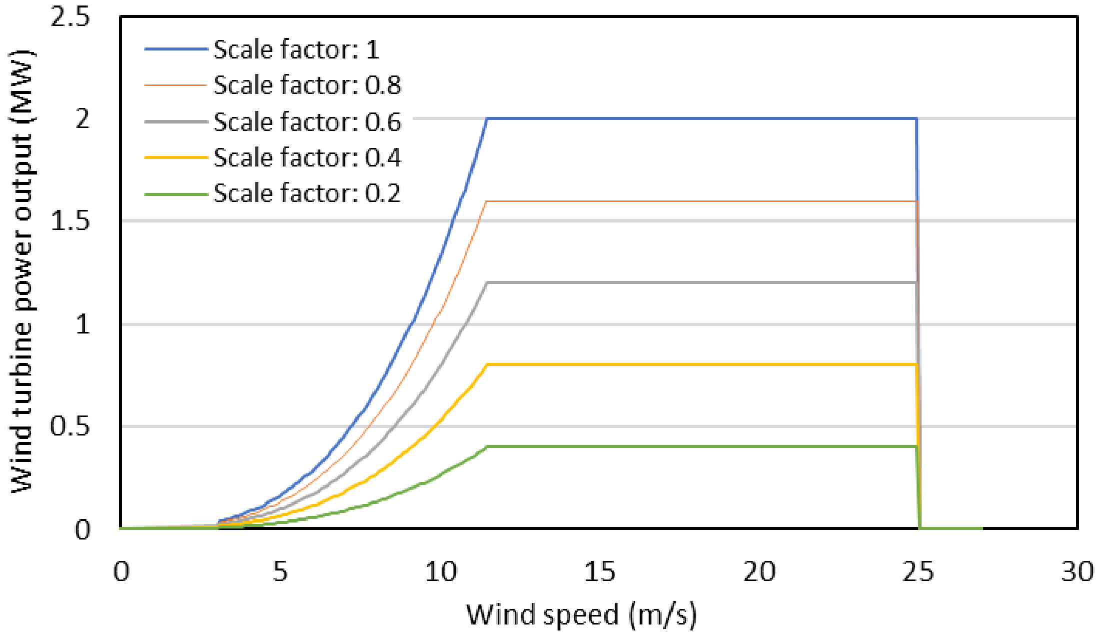
Power curves

- Wind turbine dimensions are adjusted to create power curves at different scale levels.
- Wind power capacity is simulated between **0 and 2 MW**.





$$P_{WT}(t) = \begin{cases} 0 & v(t, z_{hub}) < v_{cut-in} \\ A_{swept}\,\rho_{air}\,v(t, z_{hub})^3\,\eta_{WT}/2 & v_{cut-in} \le v(t, z_{hub}) \le v_{rated} \\ P_{rated,WT} & v_{rated} \le v(t, z_{hub}) \le v_{re-cut-in} \\ P_{rated,WT} & v_{re-cut-in} \le v(t, z_{hub}) \le v_{cut\ out} \cap C(t) = 0 \\ 0 & v_{re-cut-in} \le v(t, z_{hub}) \le v_{cut-out} \cap C(t) = 1 \\ 0 & v_{cut-out} < v(t, z_{hub}) \end{cases}$$

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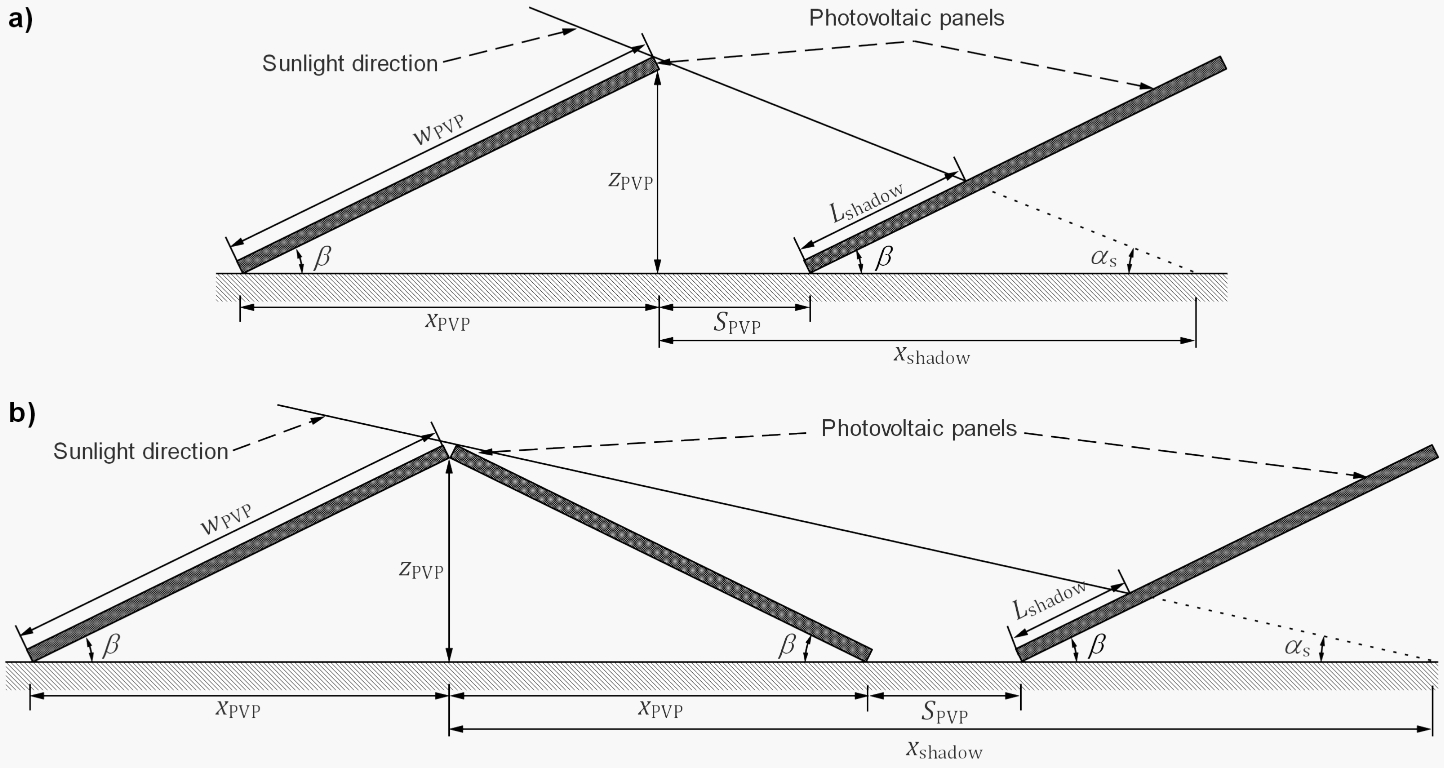
Photovoltaic panel configurations



a) Configuration S

b) Configuration EW

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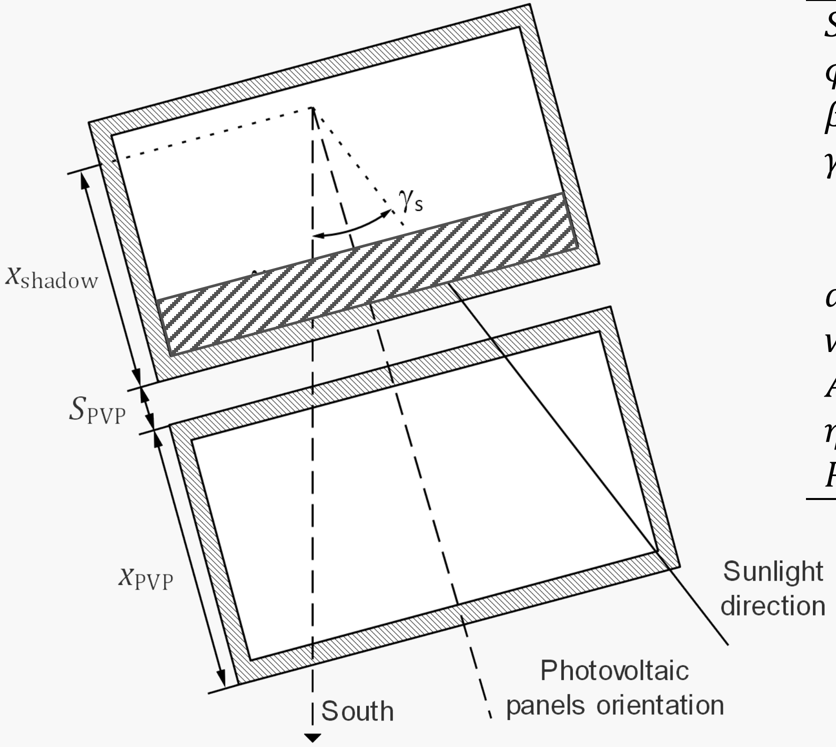
Shade modelling

- PV panel shaded fraction is calculated from the shadow length on the PV panel surface longitudinal to its orientation.



Parameter	Description	Value
s_{PVP}	Separation between photovoltaic panel rows	0.25 m
ϕ	Latitude	1.043 rad (59.77°)
β	Photovoltaic panel tilt angle	0.262 rad (15°)
γ_{PVP}	Photovoltaic panels azimuth angle with reference due south	S: -0.113 rad (-6.5°)
		E: -1.68 rad (-96.5°)
		W: 1.46 rad (83.5°)
α	Ground albedo	0.2
w_{PVP}	Photovoltaic panel width	1.016 m
A_{PVP}	Photovoltaic panel surface area	1.73 m^2
η_{PVP}	Photovoltaic panel efficiency	0.22
$P_{rated,PVP}$	Photovoltaic panel power rating	380 W

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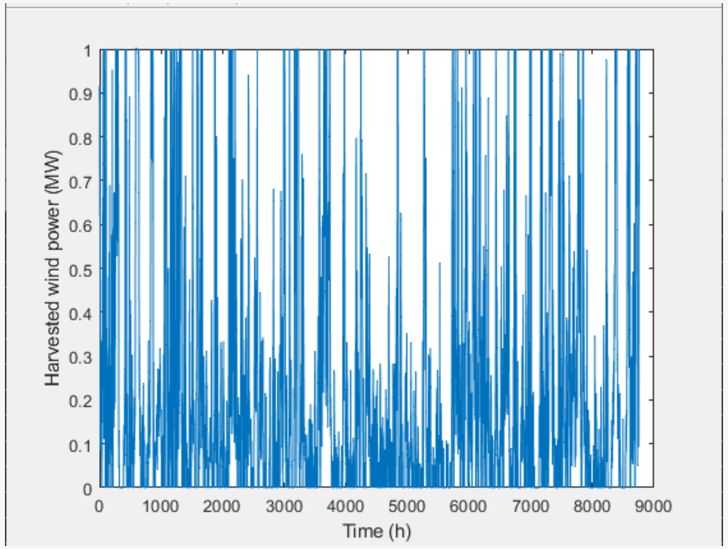
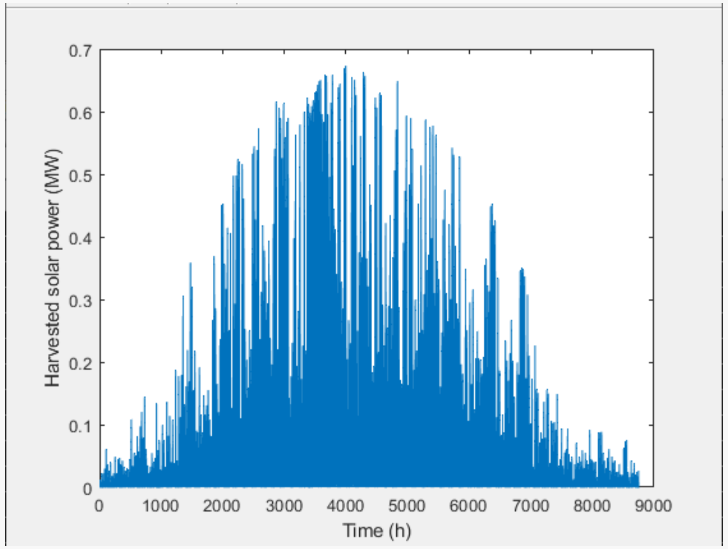
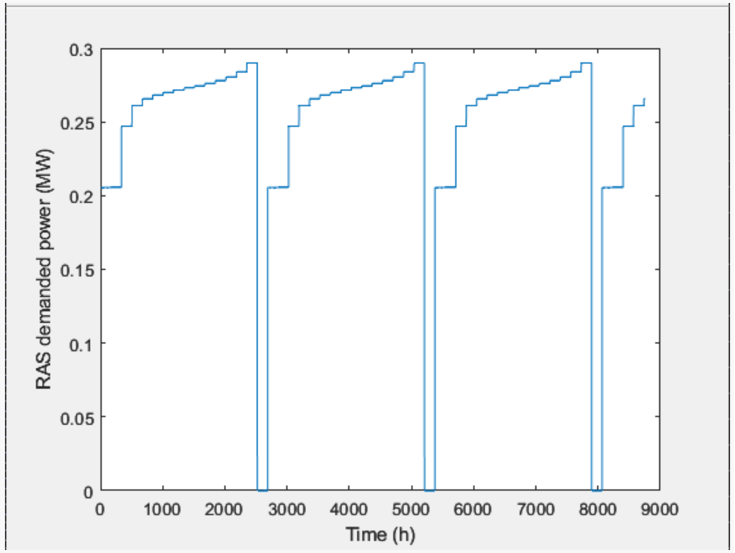
Definition of a hybrid renewable energy system

- Hourly harvested and demanded energy (MWh/h)







- Wind (1 MW) Solar S (0.75 MW) RAS demand

- Example of a power capacity signature for a hybrid system simulated for 1 year.
- Defined as 1 / 0.75 / 0 (*wind* / *solar* / *wave*) power capacities.

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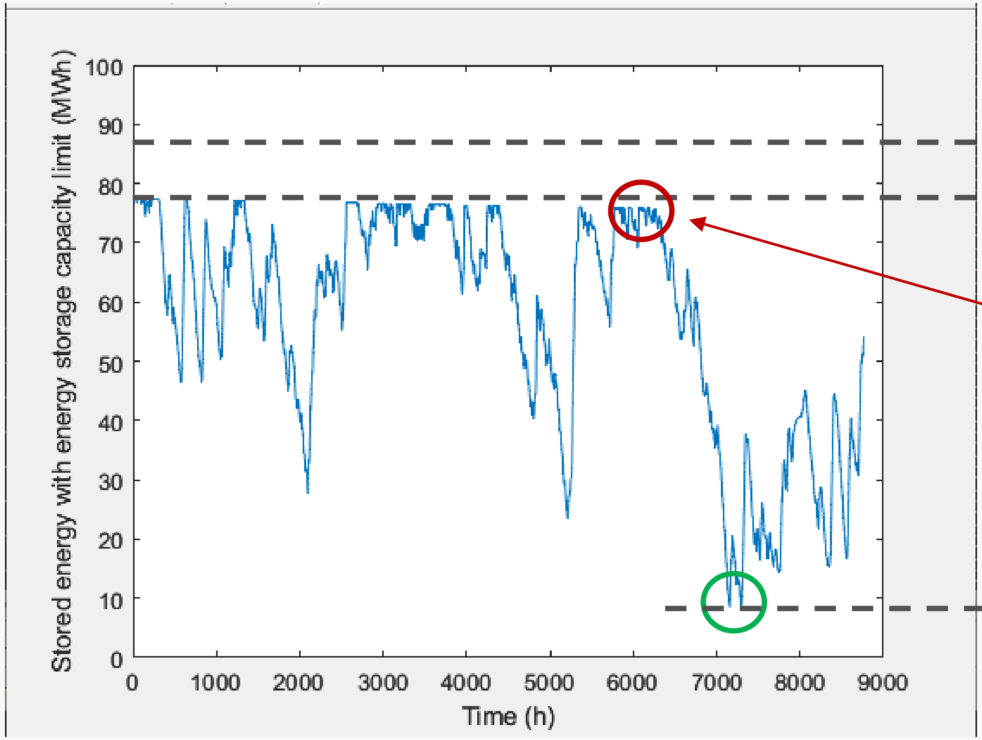
Minimum necessary energy storage capacity

- Simulate the hybrid energy system to calculate the energy storage surplus or deficit, then adjust the installed battery capacity accordingly on the next iteration.
- Find the minimum necessary energy storage that still ensures energy supply to the RAS.



86 MWh (Installed battery capacity)
78 MWh (maximum 90% of SoC)

Reduction in maximum battery capacity due to capacity fade from ageing and cycling.

8.6 MWh (minimum 10% of SoC)

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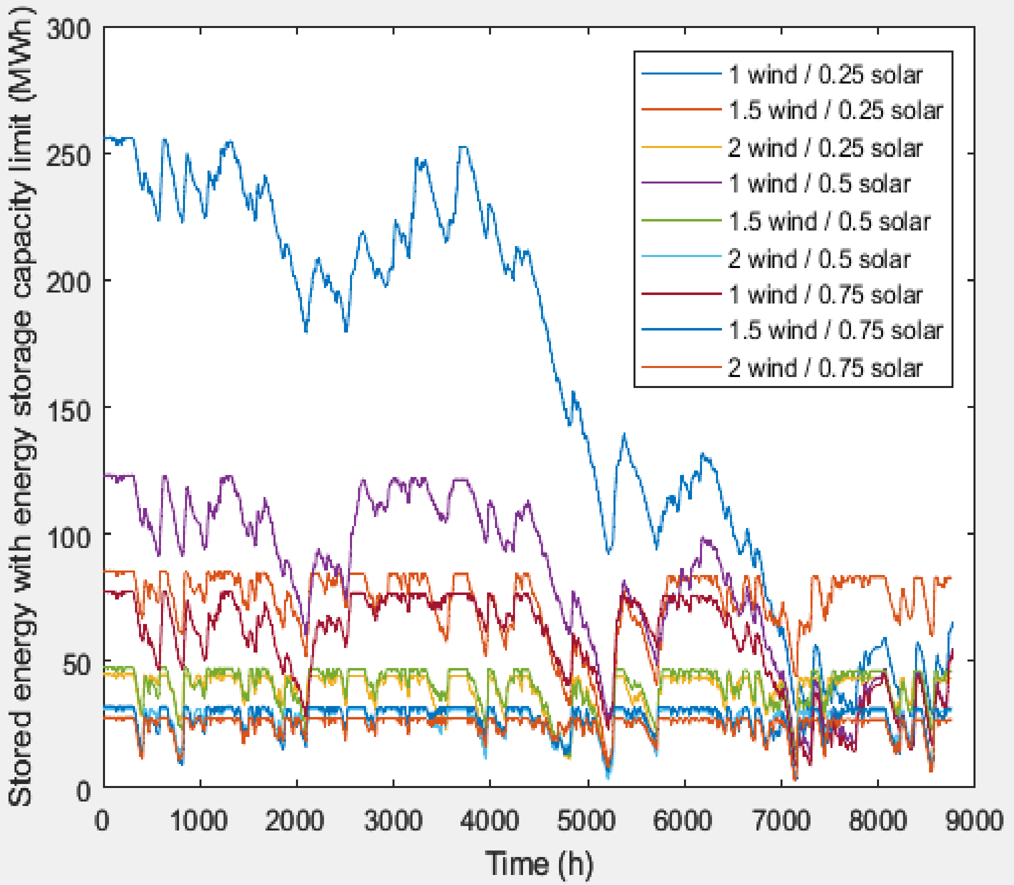
Sample results – no backup generator

- Simulated RES for 2012
- Combinations of:
  - Wind = 1 MW, 1.5 MW, 2 MW
  - Solar = 0.25 MW, 0.5 MW, 0.75 MW
- Battery SoC limits between 0.1 and 0.9
- No H_2 storage.
- Storage requirements for each case (MWh):

Wind\Solar	0.25 MW	0.5 MW	0.75 MW
1 MW	284	137	86
1.5 MW	95	53	35
2 MW	50	35	31



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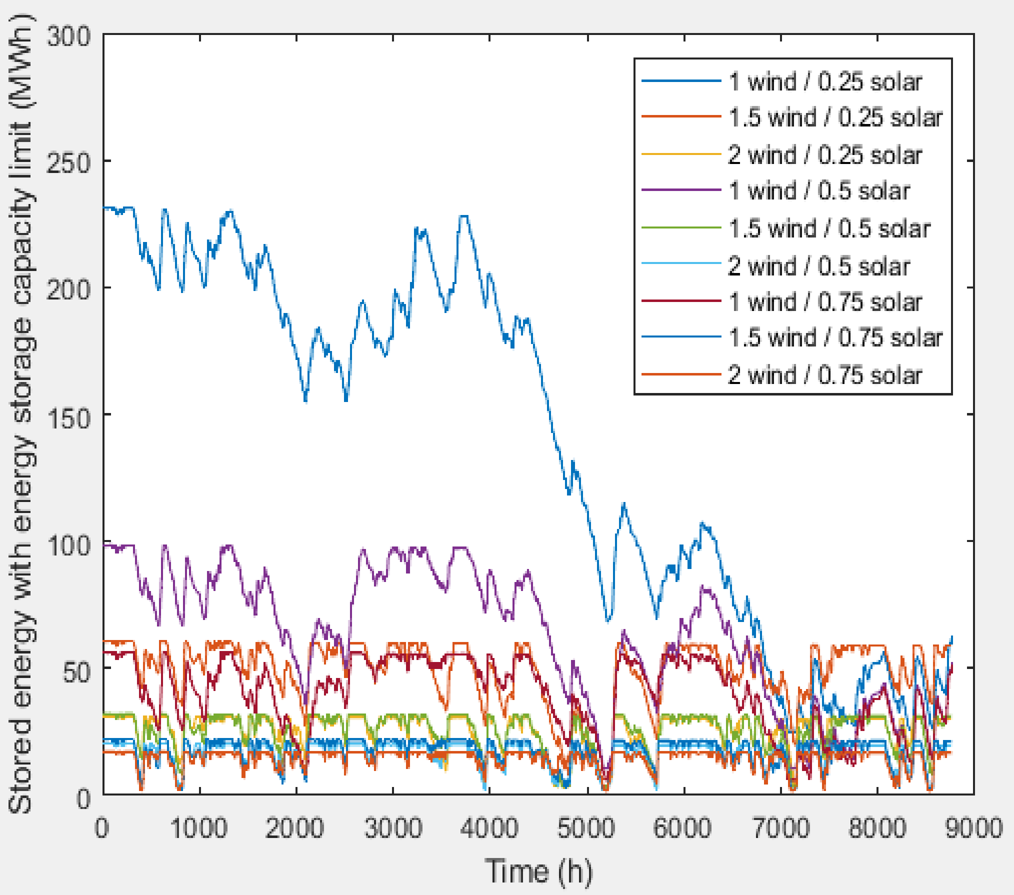
Sample results – 1% of yearly demand covered by backup

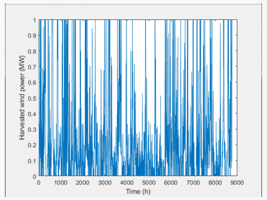
- Simulated RES for 2012
- Combinations of:
  - Wind = 1 MW, 1.5 MW, 2 MW
  - Solar = 0.25 MW, 0.5 MW, 0.75 MW
- Battery SoC limits between 0.1 and 0.9
- No H_2 storage.
- Storage requirements for each case (MWh):

Wind\Solar	0.25 MW	0.5 MW	0.75 MW
1 MW	257	110	63
1.5 MW	68	36	25
2 MW	35	23	19

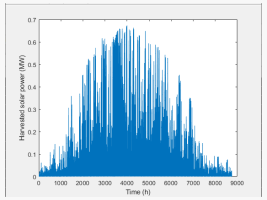


Creation of hybrid energy systems

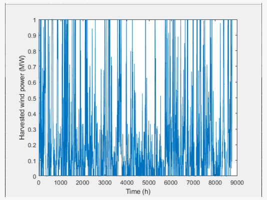
- Wind — Solar S
- 0.5 MW



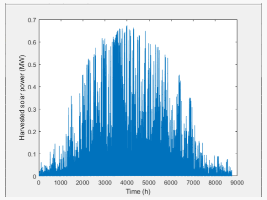
0.2 MW



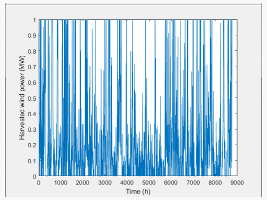
- 1 MW



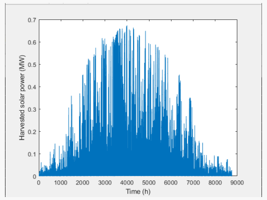
0.4 MW



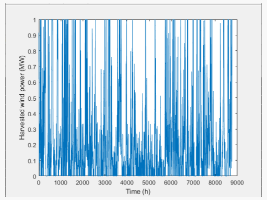
- 1.5 MW



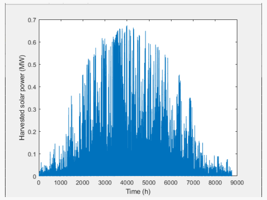
0.6 MW



- 2 MW



0.8 MW



Hybrids
(Wind / Solar S / Wave)

0.5 / 0.2 / 0
0.5 / 0.4 / 0
0.5 / 0.6 / 0
0.5 / 0.8 / 0
1 / 0.2 / 0
1 / 0.4 / 0
1 / 0.6 / 0
…

→ Compute minimum necessary energy storage capacity (MWh)

Plan going forward

- First step is to simulate combinations of power capacities of wind, solar and wave energy and find the minimum required energy storage.

- Repeat the simulations with different storage capacities of H_2 and a backup system. Study the effect of H_2 / backup capacities on the minimum required energy storage.

- Implement cost functions on all components to optimize the energy system:
  - wind, solar and wave power capacities.
  - battery and H_2 storage capacities.
  - fuel cell and electrolyzer power capacities

Contact

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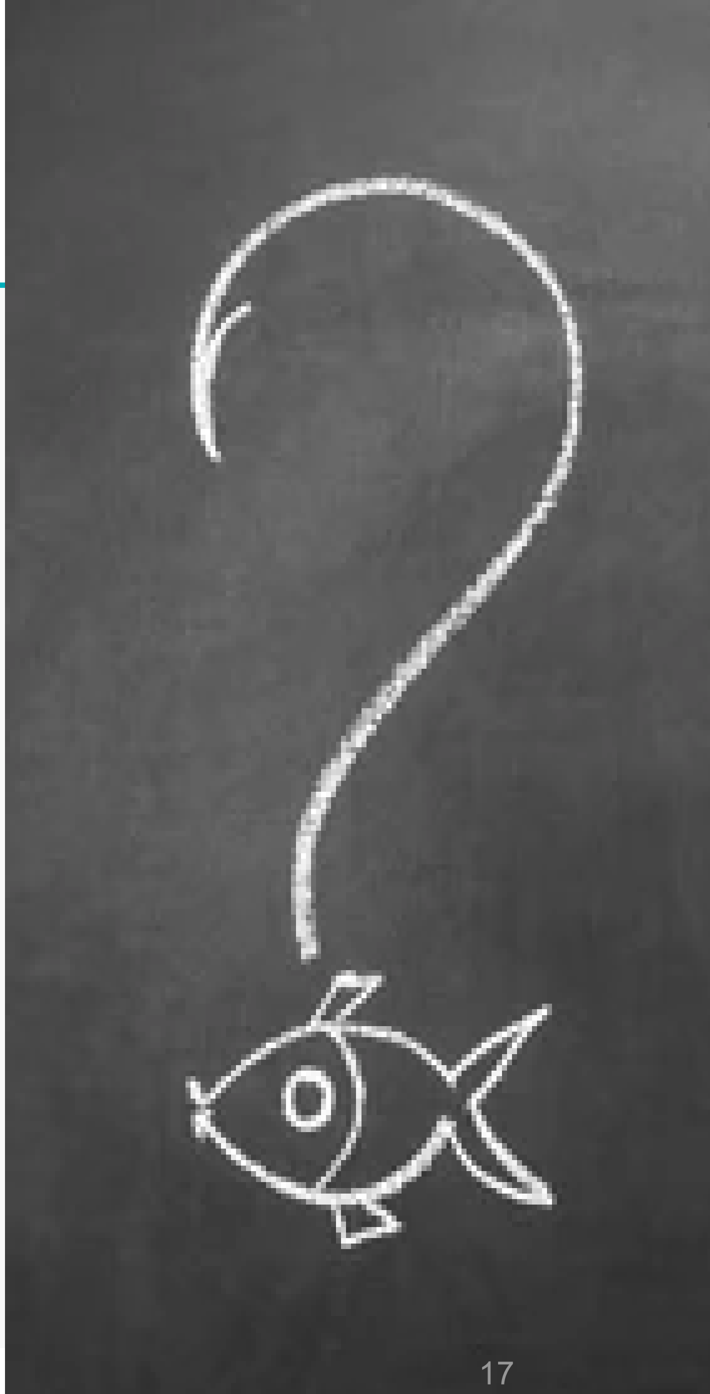
Thanks for listening!

Questions?



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