Renewable Energy & Hydroelectric Works

8th semester, School of Civil Engineering

2nd semester, Master's Programme "Water Resources Science & Technology"

Energy policy issues, hybrid renewable energy systems and beyond

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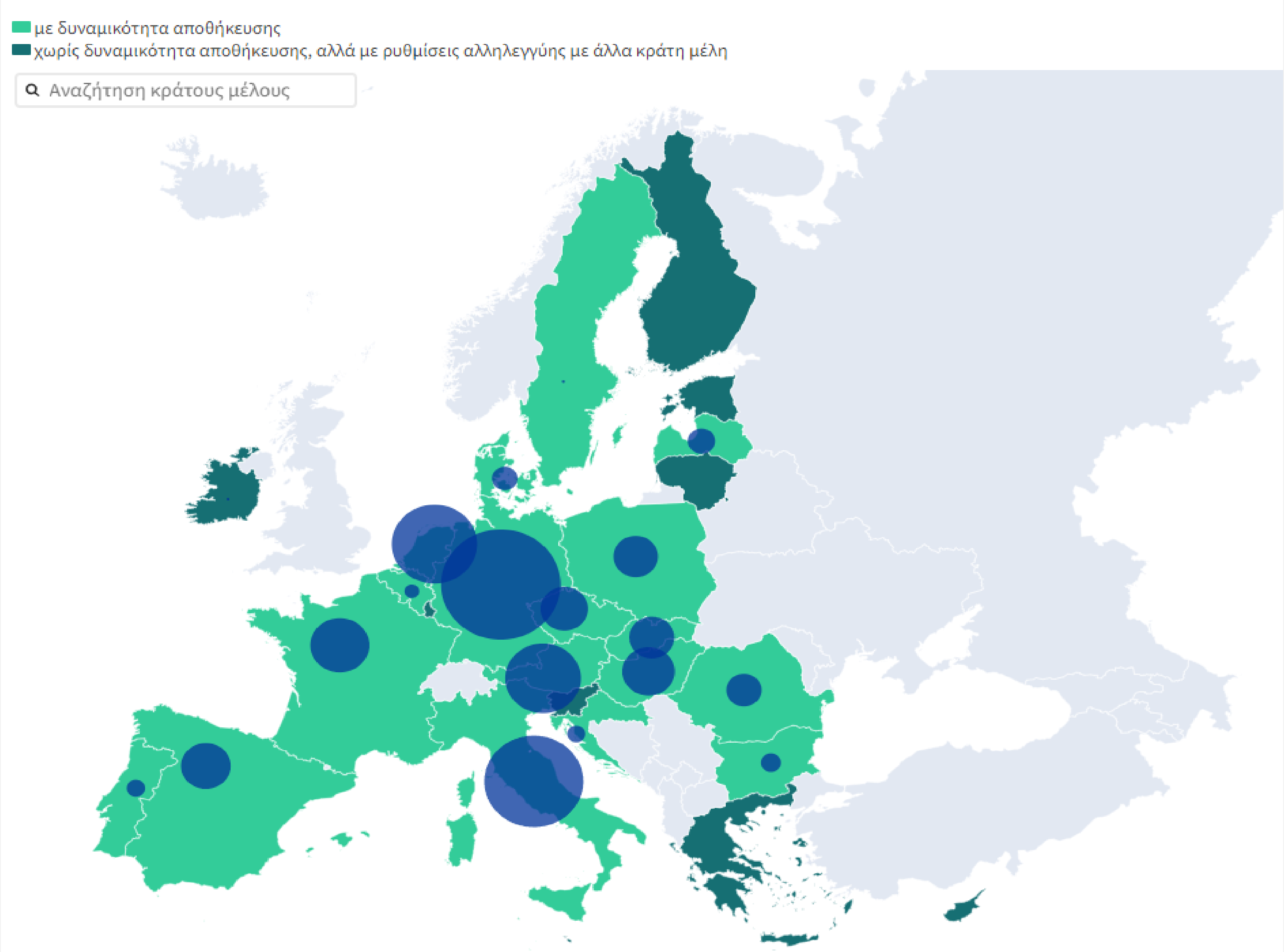
EU’s main energy policy objectives

- The EU's energy policy is based on the principles of decarbonisation, competitiveness, security of supply and sustainability.
- Major targets with respect to energy:
  - creating an internal energy market
  - improving energy efficiency
  - weaning off carbon energy forms
  - strengthening competitiveness



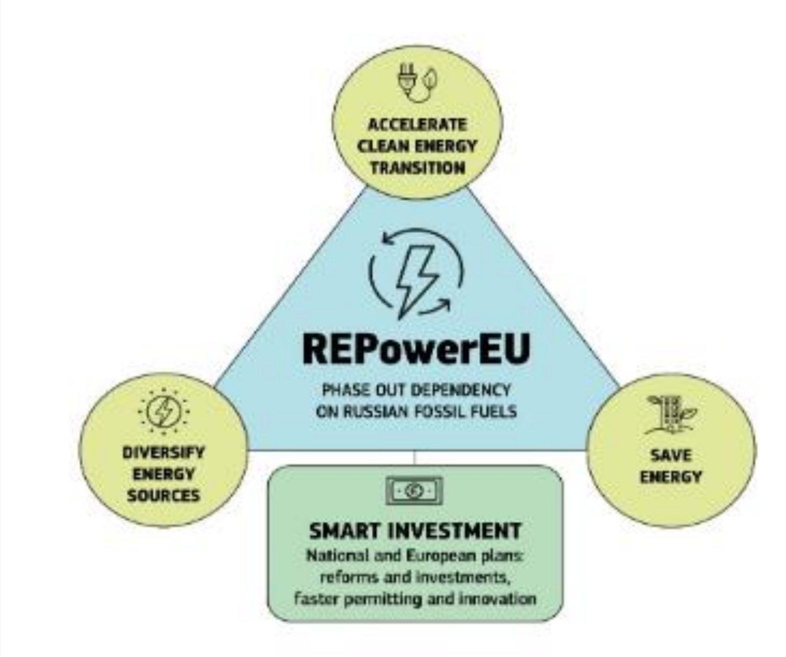
Liberalization of the energy market

- Directive 1996/92/EC:
  - Opening of the production sector to competition;
  - Provision for the appointment of a transmission and distribution system operator;
  - Priority integration of RES into the grid.
- Directive 2003/54/EC:
  - Focus on the liberalization of vertically integrated companies;
  - Establishment of national regulatory authorities with a minimum level of competence.
- Directive 2009/72/EC:
  - New responsibilities of NRA - institutional autonomy;
  - Complete separation of generation, supply, and transmission;
  - Cross-border cooperation of operators.
- Directive 2019/944:
  - Prosumers, energy communities, smart meters;
  - Electromobility;
  - Definition of the energy market.

Re-Power EU Plan

Development of photovoltaic energy, specifically, the strategy aims to connect over 320 GW of solar photovoltaic installations by 2025, and nearly 600 GW by 2030 (with an obligation to install photovoltaic panels on certain buildings).

Increase of the EU's renewable energy target for 2030 from the current 40% to 45%.



Additional investments of 210 billion € by 2027 to phase out Russian fossil fuel imports, which cost European taxpayers nearly 100 billion € annually.

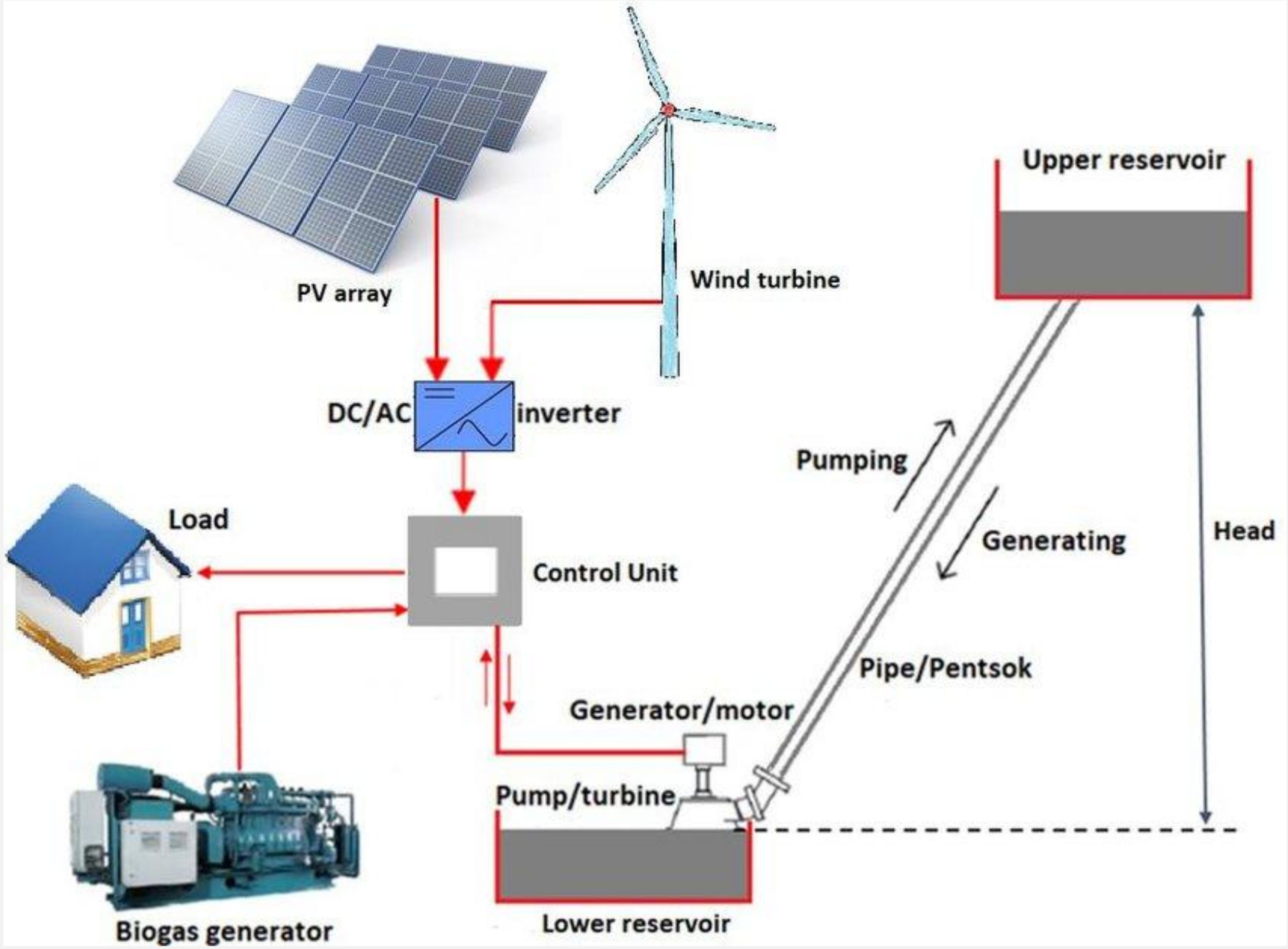
Increase of the total renewable energy production capacity by RES to 1236 GW by 2030, compared to the projected 1067 GW (as envisaged in the fit for 55 plan).

Actions in Greece

- **National Energy and Climate Plan (NECP) 2030**:
  - Share of renewable energy sources in gross final energy consumption to increase to at least 35%;
  - Share of RES in gross final electricity consumption to increase to at least 60%;
  - Complete phase-out of lignite units;
  - Increased reliance on natural gas.
- **Roadmap 2050**:
  - Interventions to improve energy efficiency
  - Large-scale implementation of circular economy principles
  - Electrification across all sectors and applications, including transportation
  - Reduction of car usage
  - Development of chemical storage of electrical energy via hydrogen
  - Implementation of carbon capture, utilization, and storage (CCUS)

Hybrid renewable energy systems

- Mixing of at least one RES power plant (non-guaranteed power production), storage power plants and back-up generators (e.g., thermal) to ensure **energy autonomy**.
- Utilization of surplus energy production by RES, which would be necessarily rejected (thus resulting in small CFs).
- Relatively small remaining deficits to be fulfilled by conventional (i.e., thermal) units.
- Combination with “smart" technologies for power saving (networks, devices, meters) and electricity demand management measures (financial, legal).
- **Decentralized** solution, ideal for remote, non-interconnected areas (e.g., islands) and Small Energy Communities.



Renewables vs. conventional thermal units

Shortcomings of Renewables

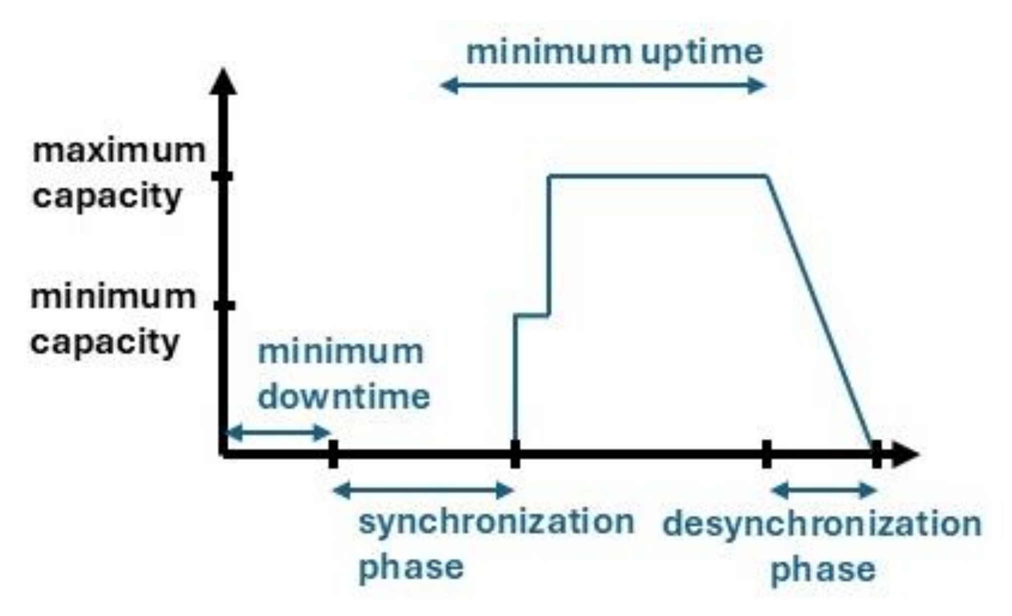
- Electricity production must always be synchronized with grid demand
- Solar and wind power is intermittent and stochastic — dependent on weather and daylight – thus creating unpredictable supply gaps
- Output power can drop to zero during calm nights or cloudy calm days (*Dunkelflaute*)

The Role of Thermal Units

- Operate independently of weather — dispatchable on demand
- Provide a reliable baseline to cover deficits from renewables
- Ensure continuous supply security regardless of conditions
- Act as a mandatory complement in any renewable-heavy energy mix

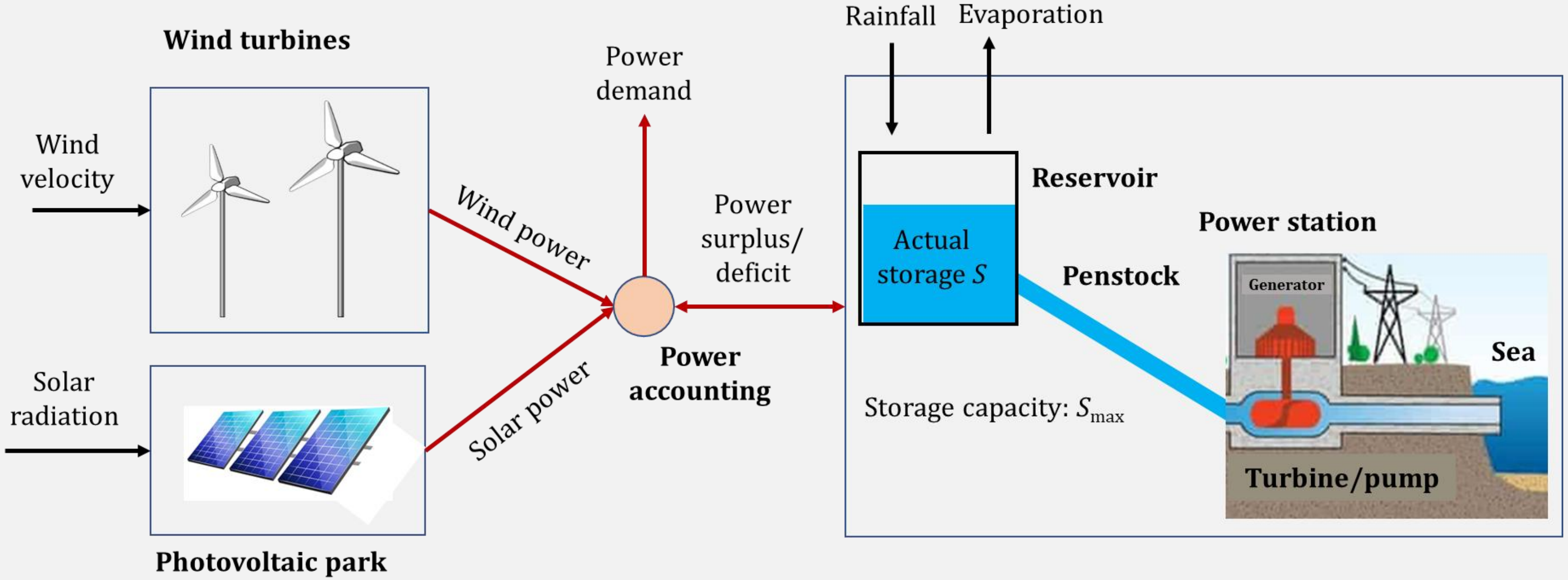
The operation of thermal units in a nutshell

- ☐ **Synchronization time**: Before injecting power, the unit must reach its technical minimum. During this ramp-up, energy output is zero.
- ☐ **Minimum uptime**: Once activated, a thermal unit must remain online for a defined minimum period — it cannot be switched off immediately
- ☐ **Desynchronization time**: Exiting the system requires a gradual ramp-down from technical minimum to zero — an orderly shutdown phase
- ☐ **Minimum downtime**: After deactivation, the unit must remain idle for a mandatory rest period before it restarts.
- ☐ **Ramp rates**: Load adjustments between technical minimum and maximum are constrained by how fast power output can change per time step.
- ☐ **Technical min/max:** Operation is only possible within a defined power band — below minimum, the unit is off; above maximum, it cannot go.



(Nearly) real-world example: The case of Sifnos island

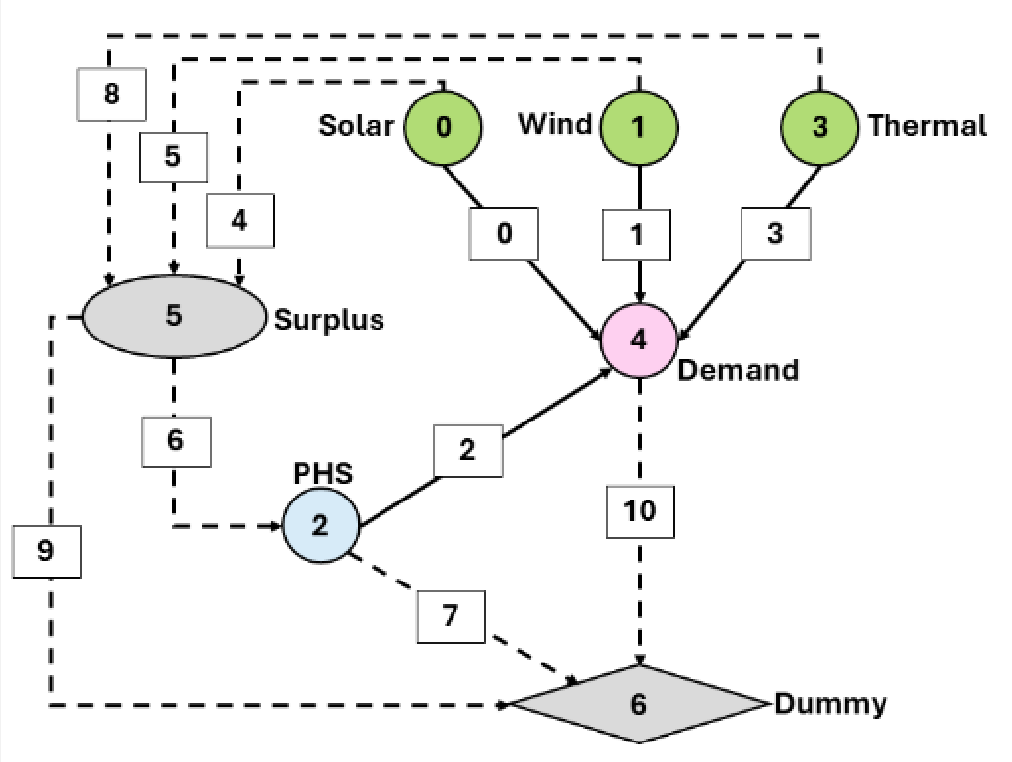
- Permanent population 2800 residents, estimated number of tourists up to 100 000 people.
- Annual demand 17.3 GWh (hourly peak 5.4 MW), mainly covered by a 9.0 MW oil power plant.
- Configuration of a HRES fostering the significant solar and aeolic potential of the island (installation of 6000 PV panels and four commercial wind turbines) and regulating energy surpluses and deficits through a seawater pumped hydropower storage unit.



Source: Zisos, A., G.-K. Sakki, and A. Efstratiadis, Mixing renewable energy with pumped hydropower storage: Design optimization under uncertainty and other challenges, *Sustainability*, 15(18), 13313, doi:10.3390/su151813313, 2023.

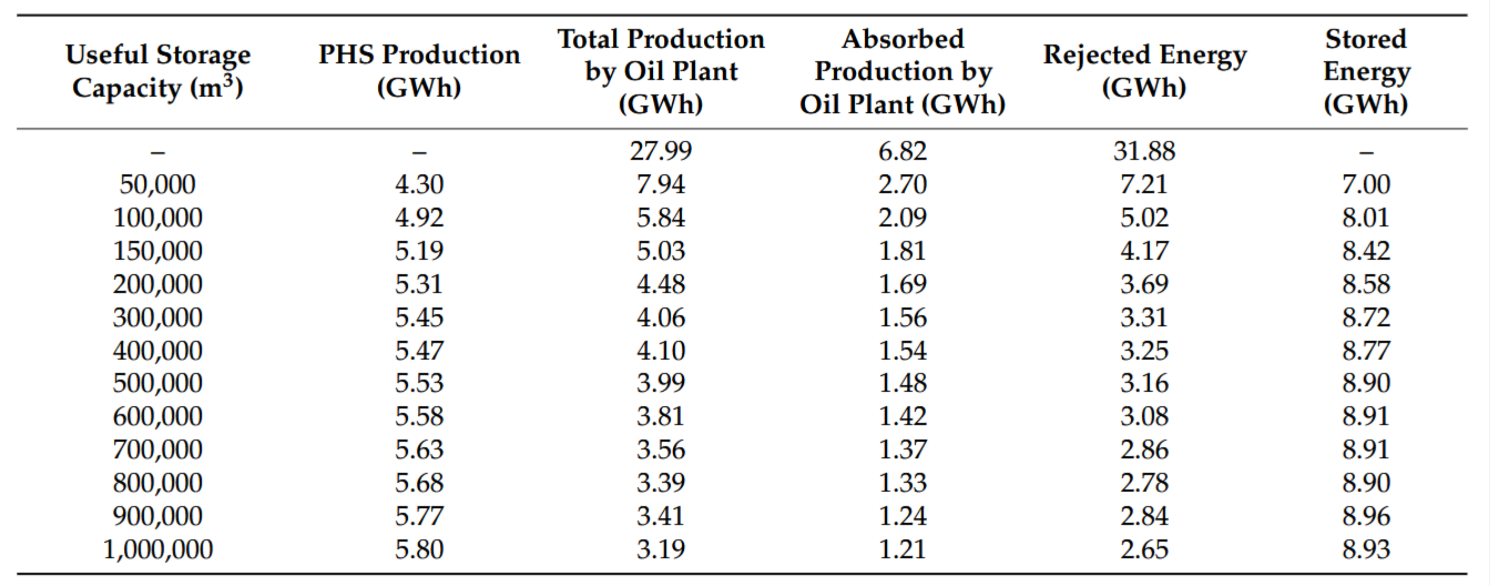
Computational framework

- Input time series: Hourly meteorological drivers (wind velocity, solar radiation, temperature) and electricity demand data for a 20-year period
- Simulation context relying upon the graph theory and the network linear programming problem, implemented within the *Enerflow* software.
- Performance metrics:
  - System's reliability (1 – frequency of power deficits);
  - Frequency of thermal unit operation;
  - Mean annual rejected energy;
  - Mean annual energy production by the thermal unit.
- Cost function, accounting for the total capital expenses of the upper reservoir, the mean annual operational cost of the thermal unit, and the cost of power rejections.

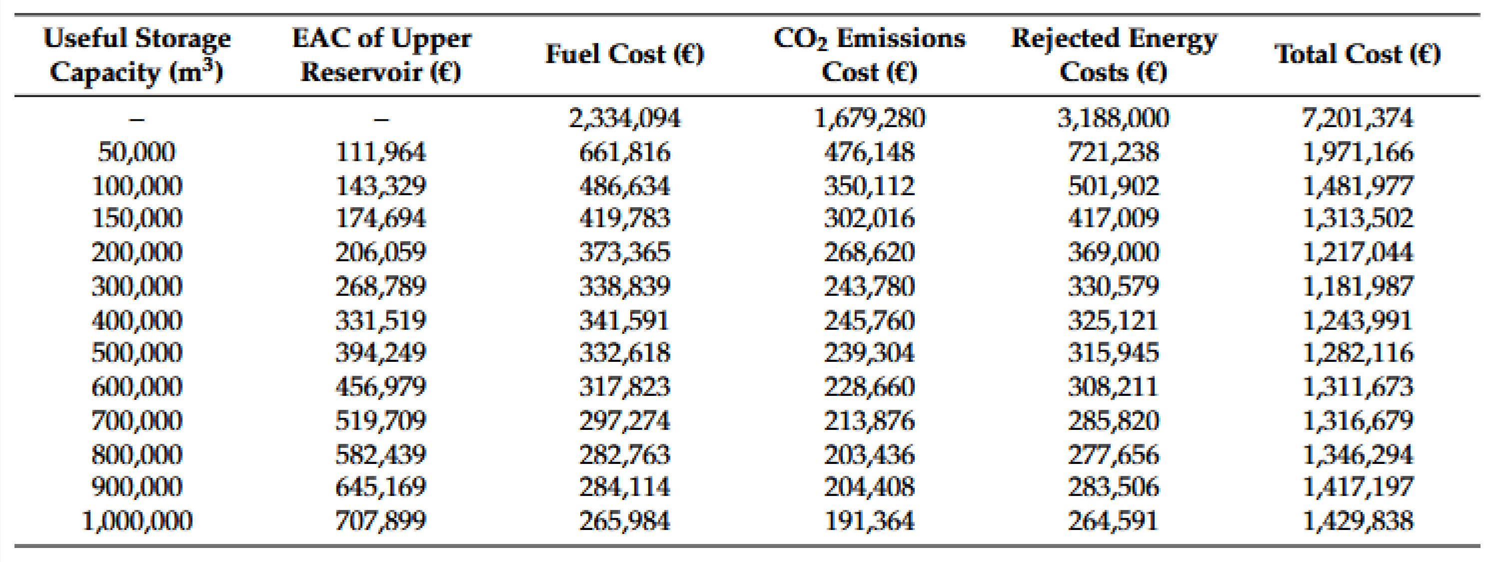


Source: Kolioukou, A., A. Zisos, and A. Efstratiadis, Effective planning and management of hybrid renewable energy systems through graph theory, *Energies*, 19 (5), 1381, doi:10.3390/en19051381, 2026.

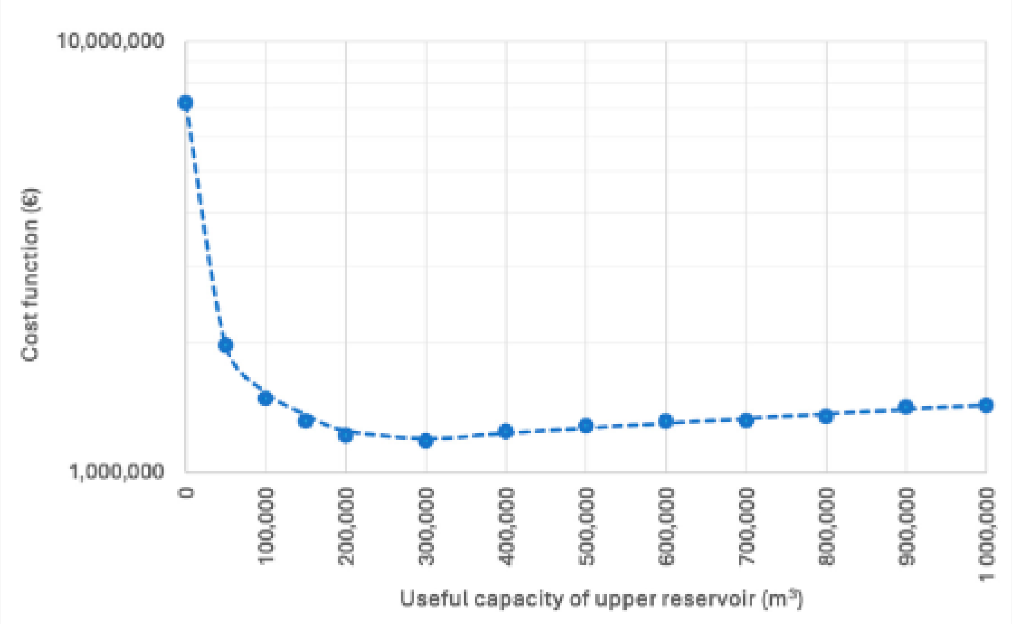
Investigation of different upper reservoir storage capacity options



Useful Storage Capacity (m^3)	PHS Production (GWh)	Total Production by Oil Plant (GWh)	Absorbed Production by Oil Plant (GWh)	Rejected Energy (GWh)	Stored Energy (GWh)
–	–	27.99	6.82	31.88	–
50,000	4.30	7.94	2.70	7.21	7.00
100,000	4.92	5.84	2.09	5.02	8.01
150,000	5.19	5.03	1.81	4.17	8.42
200,000	5.31	4.48	1.69	3.69	8.58
300,000	5.45	4.06	1.56	3.31	8.72
400,000	5.47	4.10	1.54	3.25	8.77
500,000	5.53	3.99	1.48	3.16	8.90
600,000	5.58	3.81	1.42	3.08	8.91
700,000	5.63	3.56	1.37	2.86	8.91
800,000	5.68	3.39	1.33	2.78	8.90
900,000	5.77	3.41	1.24	2.84	8.96
1,000,000	5.80	3.19	1.21	2.65	8.93

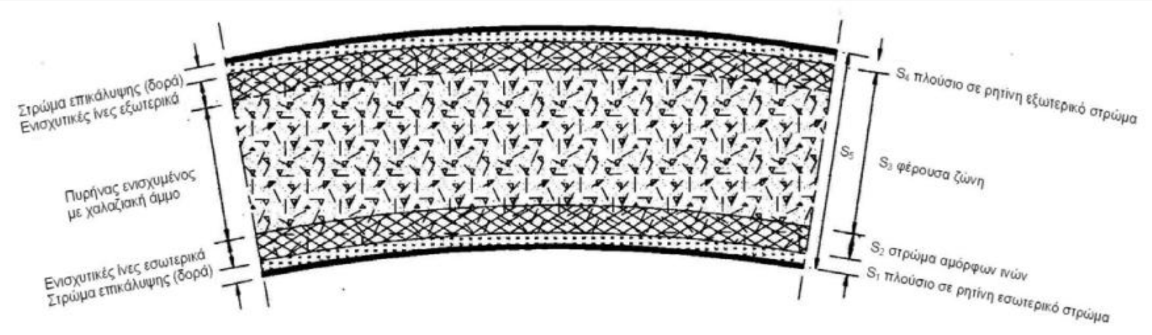


Useful Storage Capacity (m^3)	EAC of Upper Reservoir (€)	Fuel Cost (€)	CO_2 Emissions Cost (€)	Rejected Energy Costs (€)	Total Cost (€)
–	–	2,334,094	1,679,280	3,188,000	7,201,374
50,000	111,964	661,816	476,148	721,238	1,971,166
100,000	143,329	486,634	350,112	501,902	1,481,977
150,000	174,694	419,783	302,016	417,009	1,313,502
200,000	206,059	373,365	268,620	369,000	1,217,044
300,000	268,789	338,839	243,780	330,579	1,181,987
400,000	331,519	341,591	245,760	325,121	1,243,991
500,000	394,249	332,618	239,304	315,945	1,282,116
600,000	456,979	317,823	228,660	308,211	1,311,673
700,000	519,709	297,274	213,876	285,820	1,316,679
800,000	582,439	282,763	203,436	277,656	1,346,294
900,000	645,169	284,114	204,408	283,506	1,417,197
1,000,000	707,899	265,984	191,364	264,591	1,429,838



Addressing challenges introduced by seawater (1)

- Application of **GRP pipes** (glass fiber reinforced plastic):
  - Robust material, made of unsaturated polyester resins, glass fibers, and calcite sand
  - No special coating, priming or cathodic protection is required
  - Hydraulic characteristics remain virtually unchanged
  - Low friction due to their smooth inner surface
  - High resistance to ultraviolet radiation
  - Low maintenance cost and long service life



- **Waterproofing of the upper reservoir**:
  - Application of HDPE geomembranes;
  - High resistance to tensile stress, impact, tearing, and puncture;
  - Excellent resistance to environmental stress (ESCR) and chemical agents.

Addressing challenges introduced by seawater (2)

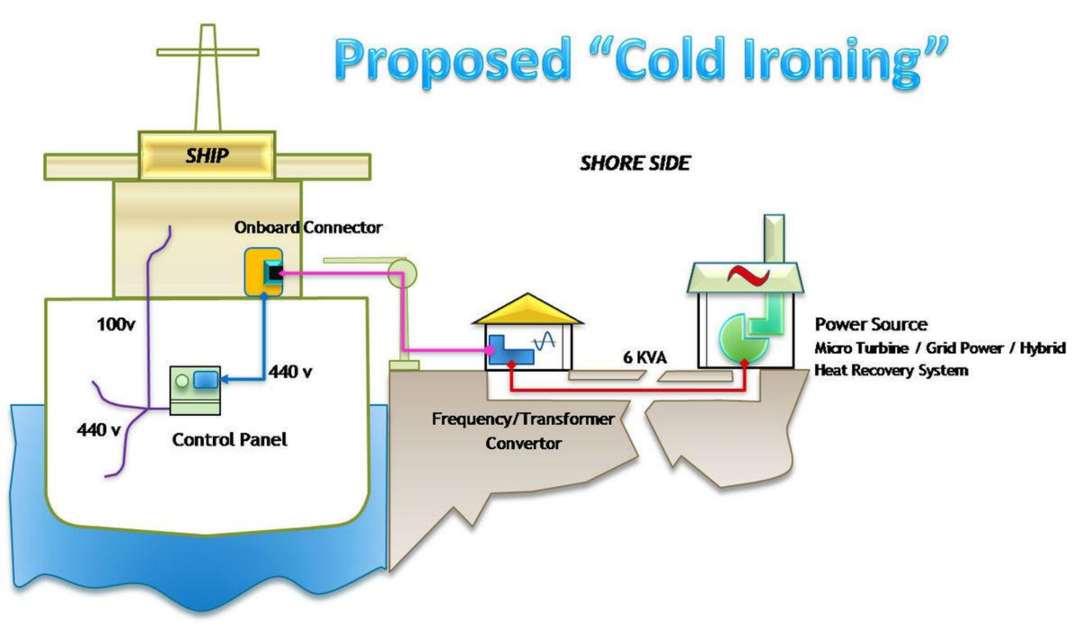
- Use of stainless steel for the **mechanical equipment**:
  - High resistance to corrosion from seawater
  - Steel alloys containing chromium, nickel, and molybdenum exhibit increased corrosion resistance
- Pitting Resistance Equivalent Number (PREN) → measure of corrosion resistance
- Minimum acceptable PREN value for seawater projects, according to Norwegian NORSOK standards: 40

			Nominal Composition (wt%)							
Type	UNS No.	Generic name	Fe	Cr	Ni	Mo	N	Cu	W	**PREN**
Austenitic	J92900	316	Bal	18	10	2	--	--	--	24
	J94651	CN3MN	Bal	20	24	6	0.20	--	--	43
	J93254	CK3MCuN	Bal	20	18	6	0.20	0.7	--	43
Duplex	J93372	Grade 1B*	Bal	25	5	2	0.14	--	--	34
	J92205	Grade 4A*	Bal	22	5.5	3	0.16	--	--	35
	J93380	Grade 6A*	Bal	25	8	3.5	0.25	0.7	0.7	41

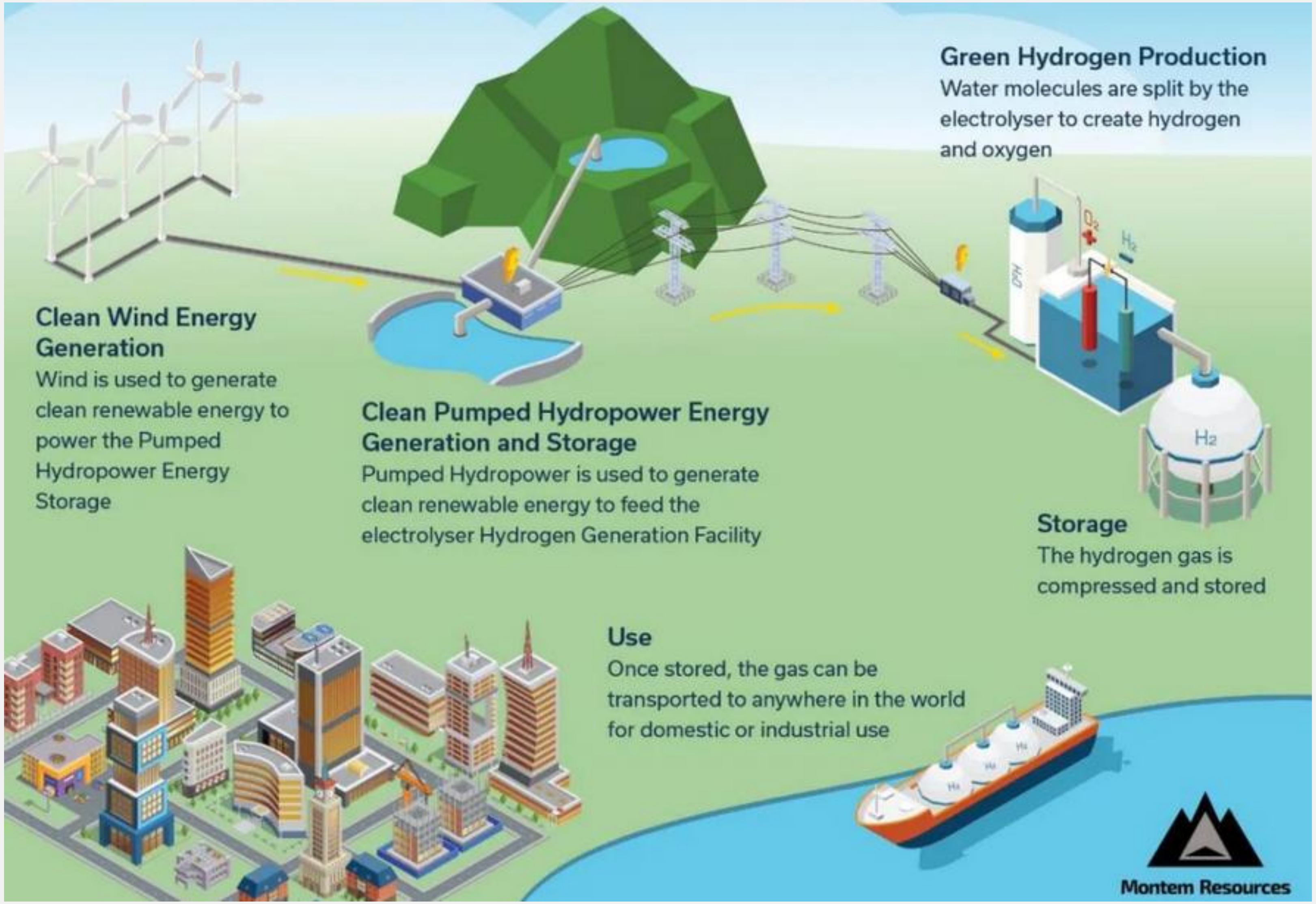
Bal = Balance; Grade designations in ASTM A995

Other forms of exploitation of electricity surpluses by renewables

- **Circularity solutions across the water industry**:
    - Water pumping and temporary storage to tanks
    - Desalination → drinking water production
    - Sewer mining
- Converting excess power into **primal energy sources**, also referred to as “**power-to-X**”:
    - Hydrogen production through electrolysis
    - Power-to-gas (methanation)
    - Thermal storage (power-to-heat)
- Electrification of **transportation domain**:
    - Charging of electric vehicles
    - “Cold ironing”: providing electrical power from the shore to ships at berth, allowing them to turn off their diesel-driven auxiliary engines



A look to the future: “Green energy project” Tent Mountain



Clean Wind Energy Generation

Wind is used to generate clean renewable energy to power the Pumped Hydropower Energy Storage

Clean Pumped Hydropower Energy Generation and Storage

Pumped Hydropower is used to generate clean renewable energy to feed the electrolyser Hydrogen Generation Facility

Green Hydrogen Production

Water molecules are split by the electrolyser to create hydrogen and oxygen

Storage

The hydrogen gas is compressed and stored

Use

Once stored, the gas can be transported to anywhere in the world for domestic or industrial use