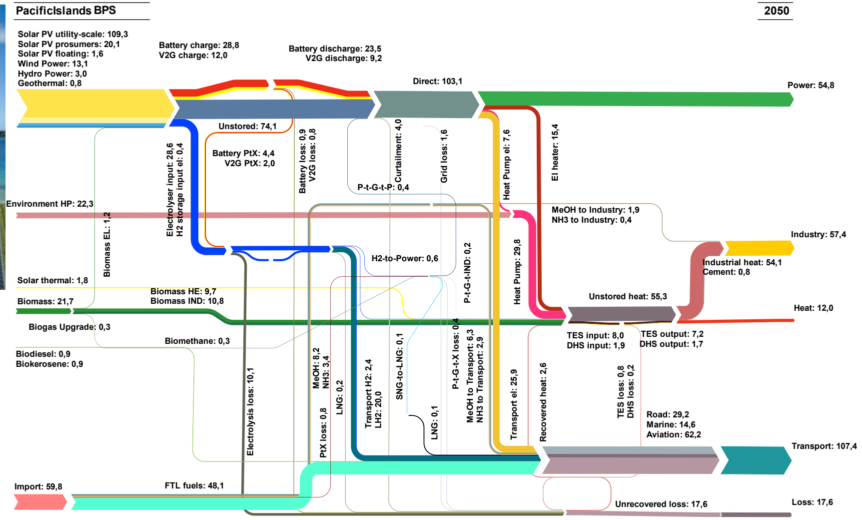

TRANSITION TOWARDS 100% RENEWABLE ENERGY IN THE PACIFIC

Christian Breyer [1], Gabriel Lopez [1], Mai ElSayed [1], Maxi-Ann Campbell [1], Akash J. Handique [2], Rebecca Peer [2], Jannik Haas [2]

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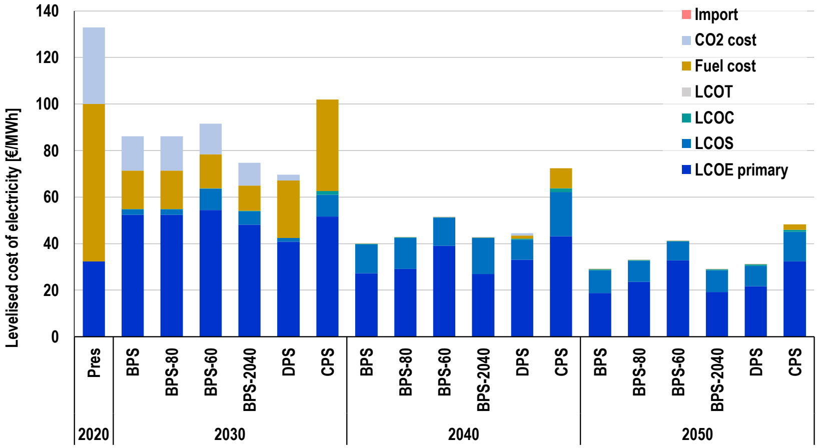
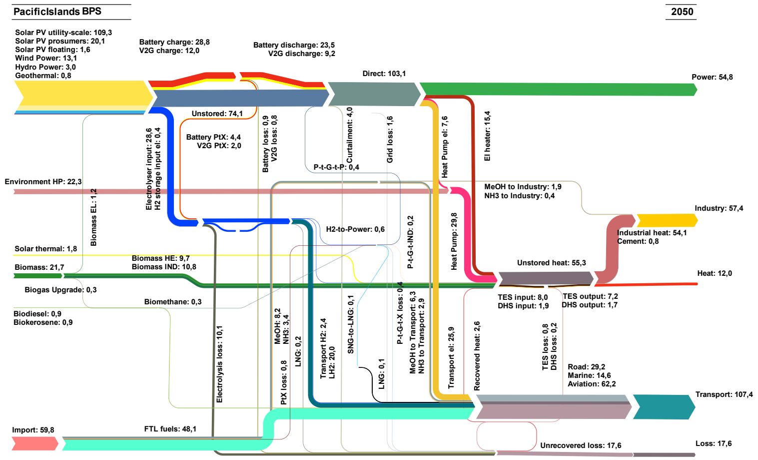
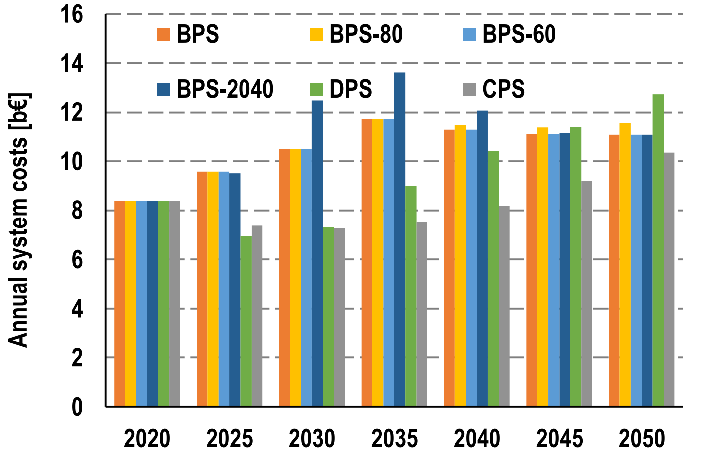
Pacific Islands are rich in renewable energy opportunities



Expansion of renewable electricity can reduce electricity generation costs (slide 17)

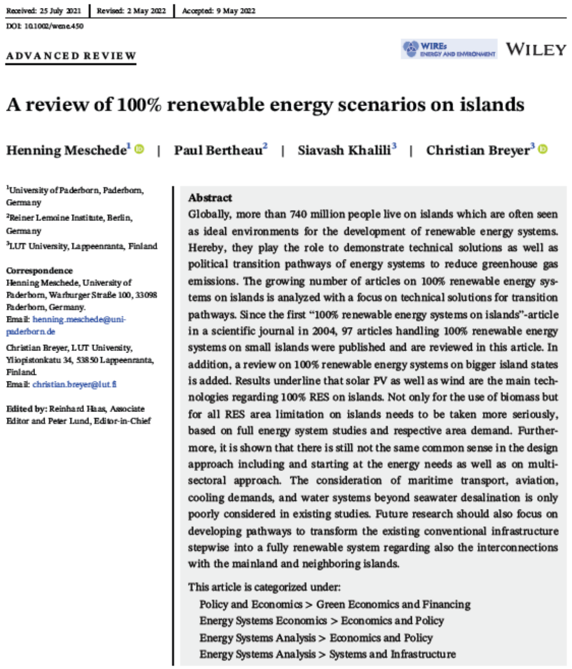


Opportunity to reduce/ eliminate fossil fuel imports (slide 19)



Accelerated (2040) net-zero transition with similar costs as 2050 net-zero target (BPS vs CPS) (slide 17)

100% Renewable Energy on Pacific Islands



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ADVANCED REVIEW

WIREs ENERGY AND ENVIRONMENT WILEY

A review of 100% renewable energy scenarios on islands

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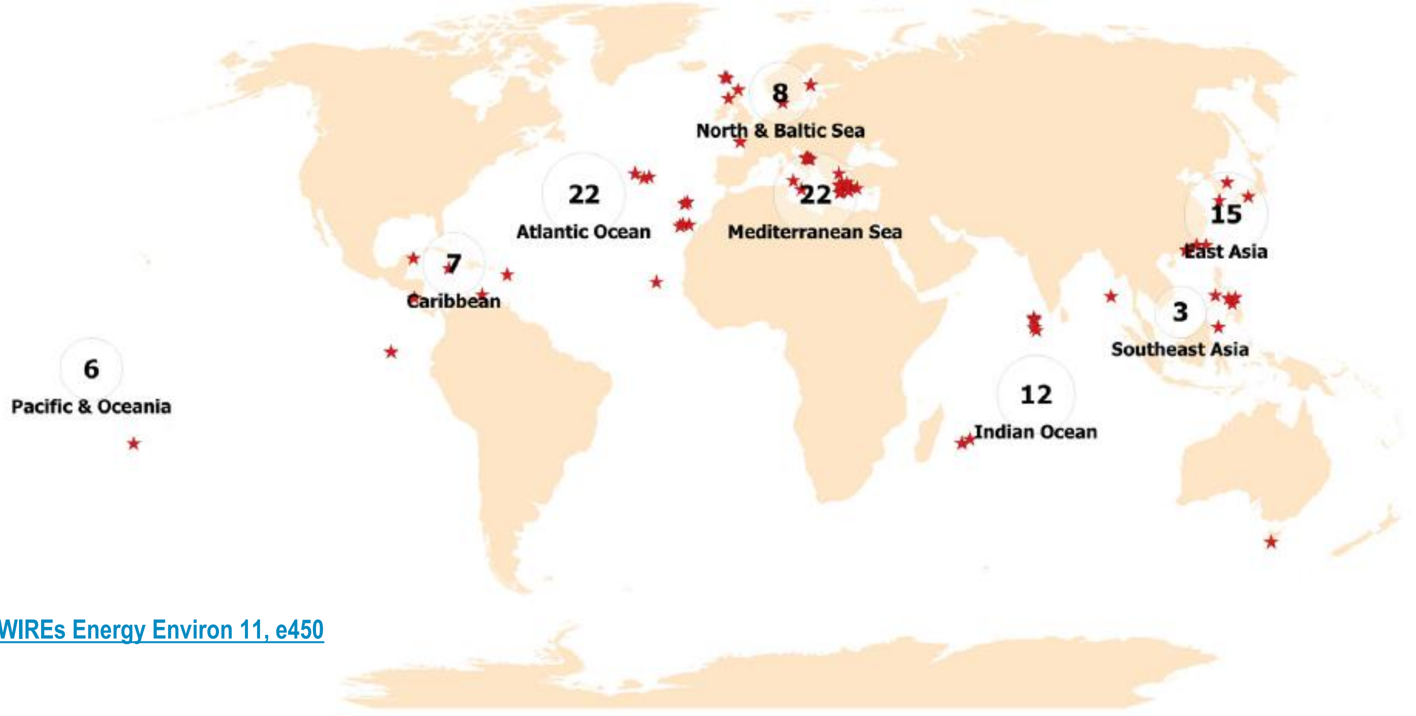
Edited by: Reinhard Haas, Associate Editor and Peter Lund, Editor-in-Chief

Abstract

Globally, more than 740 million people live on islands which are often seen as ideal environments for the development of renewable energy systems. Hereby, they play the role to demonstrate technical solutions as well as political transition pathways of energy systems to reduce greenhouse gas emissions. The growing number of articles on 100% renewable energy systems on islands is analyzed with a focus on technical solutions for transition pathways. Since the first "100% renewable energy systems on islands"-article in a scientific journal in 2004, 97 articles handling 100% renewable energy systems on small islands were published and are reviewed in this article. In addition, a review on 100% renewable energy systems on bigger island states is added. Results underline that solar PV as well as wind are the main technologies regarding 100% RES on islands. Not only for the use of biomass but for all RES area limitation on islands needs to be taken more seriously, based on full energy system studies and respective area demand. Furthermore, it is shown that there is still not the same common sense in the design approach including and starting at the energy needs as well as on multi-sectoral approach. The consideration of maritime transport, aviation, cooling demands, and water systems beyond seawater desalination is only poorly considered in existing studies. Future research should also focus on developing pathways to transform the existing conventional infrastructure stepwise into a fully renewable system regarding also the interconnections with the mainland and neighboring islands.

This article is categorized under:
Policy and Economics > Green Economics and Financing
Energy Systems Economics > Economics and Policy
Energy Systems Analysis > Economics and Policy
Energy Systems Analysis > Systems and Infrastructure



source:
Meschede et al., 2022. WIREs Energy Environ 11, e450

Key Insights

- Pacific islands not well researched in 100% RE systems literature
  - 16 articles in total (6 in Meschede et al.): Samoa, Fiji, Galapagos (4x), Hawaii (6x), Ecuadorian island, Australian islands (3x)
  - Studies for Pacific tend to focus on larger islands: Japan, the Philippines, Indonesia, Australia, New Zealand, Hawaii
  - Pacific Island full sector energy transition for small islands remains a significant research gap

LUT Research on Islands

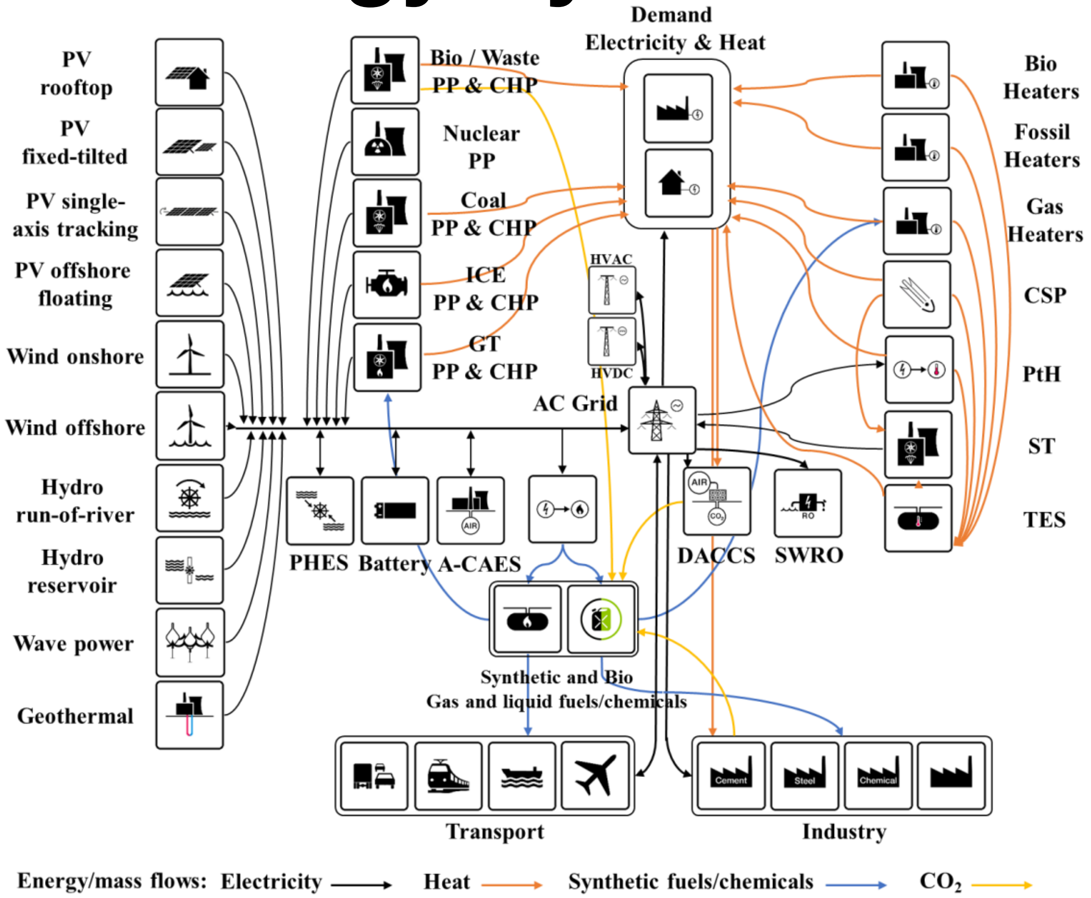
Small Islands

- Global Islands – Review 100% RE
- Global Islands – hybrid RE systems
- Åland ET – main options
- Åland ET – V2G
- Greenland ET – e-fuels export
- La Gomera ET – main options
- La Gomera ET – multi-years
- Maldives ET – offshore energy
- Maldives ET – OTEC
- Seychelles ET – EP-ALISON-LUT

Large Islands

- Global Islands – Review 100% RE
- Caribbean ET & Puerto Rico
- Hawaii ET – storage and PtX Economy
- Hawaii ET – ocean energy diversity
- Sri Lanka ET
- Philippines ET
- UK & Ireland ET – onshore vs offshore
- UK & Ireland ET – inter-annual storage
- Japan ET – transition options
- Japan ET – hierarchical modelling
- Japan ET – flexibility: smart charging, V2G, electrolysers
- Australia – carbon sinks and sustainable communities

LUT Energy System Transition Model

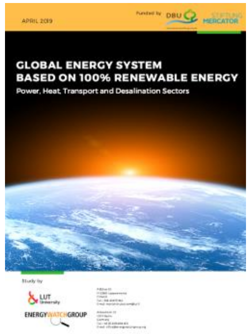


source:
Bogdanov, Breyer et al., 2021. Applied Energy, 283, 116273

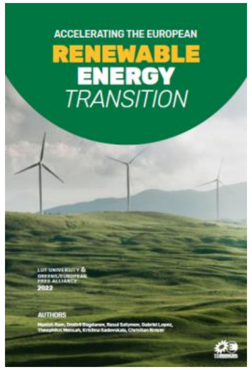
recent reports


100% Renewable Europe
How To Make Europe's Energy System Climate-Neutral Before 2050

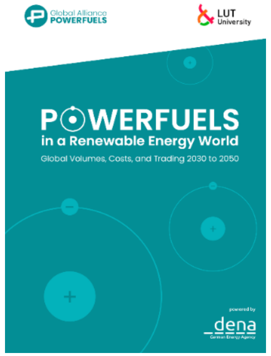
link to report


GLOBAL ENERGY SYSTEM BASED ON 100% RENEWABLE ENERGY
Power, Heat, Transport and Desalination Sectors

link to report


ACCELERATING THE EUROPEAN RENEWABLE ENERGY TRANSITION

link to report


POWERFUELS
in a Renewable Energy World
Global Volumes, Costs, and Trading 2030 to 2050

link to report

Key features:

- full hourly resolution, applied in global-local studies, comprising more than 150 technologies
- strong consideration of all kinds of Power-to-X (heat, fuels, chemicals, materials, freshwater, CO_2, CDR, forests)
- allows for e-fuel imports to replace fossil fuel imports

Scenarios Investigated

- BPS – Best Policy Scenario reaching net-zero emissions in all energy and industry sectors by 2050
- BPS-80 – same target as BPS, but with solar PV limited to 80% of all electricity generation
- BPS-60 – same target as BPS, but with solar PV limited to 60% of all electricity generation
- BPS-2040 – net-zero emissions for all energy and industry sectors by 2040
- DPS – delayed policy scenario, with some reduced integration of electric heating, heat pumps, and e-fuels/e-chemicals
- CPS – current policy scenario, largely targeting significant emissions reduction in the power sector, but limited electrification of heat, transport, and industry sectors

- Islands groups modelled

1	**PG**	Papua New Guinea
2	**US-HI**	Hawaii
3	**FJ**	Fiji
4	**FR-NC**	New Caledonia, Norfolk Island
5	**EI-GI**	Easter Island, Galapagos Islands
6	**US-GN**	Guam, N Mariana Islands
7	**SV**	Solomon Islands, Vanuatu
8	**FMP**	Fed. Stat. Micronesia, Marshall Islands, Palau
9	**OPIST**	American Samoa, Cook Islands, French Polynesia, Kiribati, Nauru, Niue, Pitcairn Islands, Samoa, Tokelau, Tonga, Tuvalu, Wallis and Futuna

Techno-Economic Assumptions: RE supply

Technologies	Parameter	Unit	2020	2025	2030	2035	2040	2045	2050
PV rooftop – residential	Capex	€/kW$_{el}$	1150	926	787	622	551	496	453
	Opex fix	€/(kW$_{el}$·a)	9.13	7.66	6.66	5.88	5.26	4.75	4.36
	Opex var	€/kWh$_{el}$	0	0	0	0	0	0	0
	Lifetime	Years	30	35	35	35	40	40	40
PV rooftop – commercial	Capex	€/kW$_{el}$	758	598	502	393	345	308	280
	Opex fix	€/(kW$_{el}$·a)	9.13	7.66	6.66	5.88	5.26	4.75	4.36
	Opex var	€/kWh$_{el}$	0	0	0	0	0	0	0
	Lifetime	Years	30	35	35	35	40	40	40
PV rooftop – industrial	Capex	€/kW$_{el}$	563	437	362	281	245	217	197
	Opex fix	€/(kW$_{el}$·a)	9.13	7.66	6.66	5.88	5.26	4.75	4.36
	Opex var	€/kWh$_{el}$	0	0	0	0	0	0	0
	Lifetime	Years	30	35	35	35	40	40	40
PV fixed tilted	Capex	€/kW$_{el}$	475	370	306	237	207	184	166
	Opex fix	€/(kW$_{el}$·a)	7.76	6.51	5.66	5	4.47	4.04	3.7
	Opex var	€/kWh$_{el}$	0	0	0	0	0	0	0
	Lifetime	Years	30	35	35	35	40	40	40
PV single-axis tracking	Capex	€/kW$_{el}$	523	407	337	261	228	202	183
	Opex fix	€/(kW$_{el}$·a)	8.54	7.16	6.23	5.5	4.92	4.44	4.07
	Opex var	€/kWh$_{el}$	0	0	0	0	0	0	0
	Lifetime	Years	30	35	35	35	40	40	40
PV floating	Capex	€/kW$_{el}$	1425	1110	765	474	414	368	332
	Opex fix	€/(kW$_{el}$·a)	28.5	22.2	15.3	9.48	8.28	7.36	6.64
	Opex var	€/kWh$_{el}$	0	0	0	0	0	0	0
	Lifetime	Years	20	25	25	25	30	30	30
Wind onshore	Capex	€/kW$_{el}$	1150	1060	1000	965	940	915	900
	Opex fix	€/(kW$_{el}$·a)	23	21.2	20	19.3	18.8	18.3	18
	Opex var	€/kWh$_{el}$	0	0	0	0	0	0	0
	Lifetime	Years	25	25	25	25	25	25	25
Wind offshore	Capex	€/kW$_{el}$	2973	2561	2287	2216	2168	2145	2130
	Opex fix	€/(kW$_{el}$·a)	85.0	73.0	65.9	64.0	62.0	61.0	60.7
	Opex var	€/kWh$_{el}$	0	0	0	0	0	0	0
	Lifetime	Years	25	25	25	25	25	25	25
Wave power	Capex	€/kW$_{el}$	21420	6326	2777	2247	2012	1819	1731
	Opex fix	€/(kW$_{el}$·a)	1050	367	75	56	48	45	42
	Opex var	€/kWh$_{el}$	0	0	0	0	0	0	0
	Lifetime	years	20	20	25	25	30	30	30

- all capex and opex values are multiplied by a factor of 1.25 to represent costs for shipping and remoteness
- sometimes criticised as “overly optimistic” but reality surprises us with even lower costs (link).

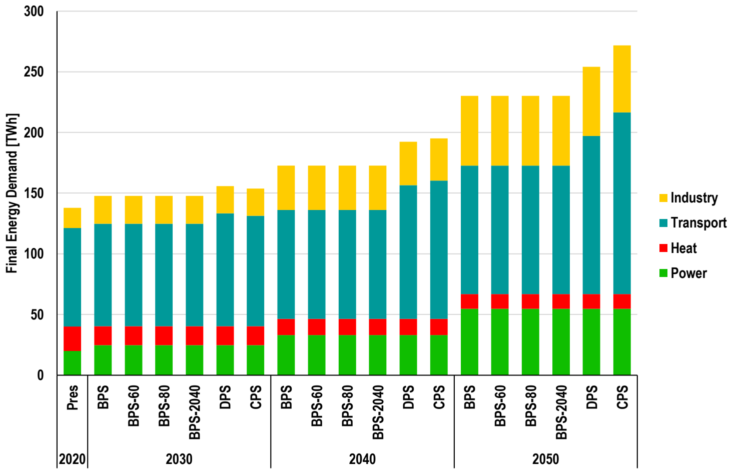
Techno-Economic Assumptions:

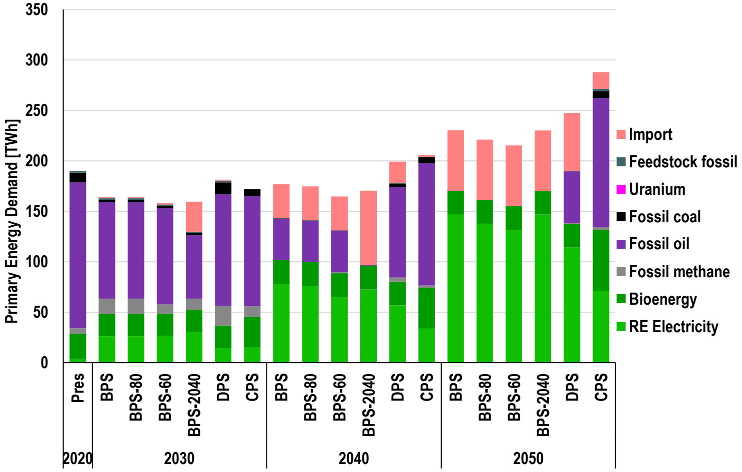
PtX, Storage and Imports

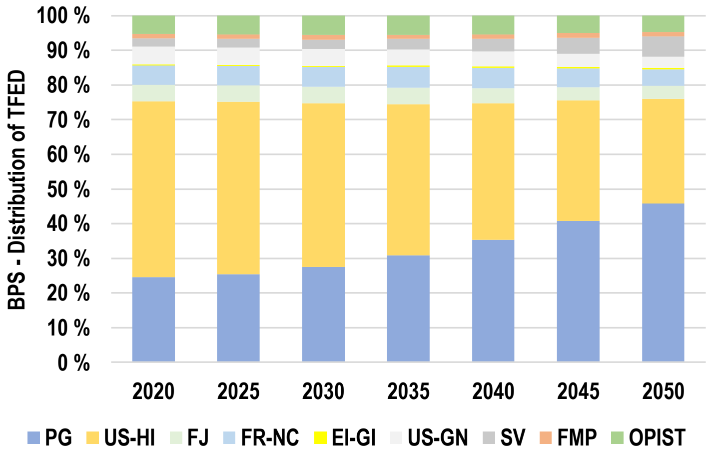
Technologies	Parameter	Unit	2020	2025	2030	2035	2040	2045	2050
Water Electrolysis	Capex	€/kW$_{H2,,LHV}$	803	586	446	381	347	313	291
	Capex	€/kW$_{el}$	1146	836	636	544	495	447	415
	Opex fix	€/(kW$_{H2,LHV}$·a)	28.1	20.5	15.6	13.3	12.1	11.0	10.2
	Opex var	€/kWh$_{H2,LHV}$	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014
	Lifetime	years	30	30	30	30	30	30	30
	Efficiency	coeff$_{LHV}$	0.701	0.701	0.701	0.701	0.701	0.701	0.701
Battery utility-scale Storage	Capex	€/kWh$_{el}$	234	153	110	89	76	68	61
	Opex fix	€/(kWh$_{el}$·a)	3.28	2.6	2.2	2.05	1.9	1.77	1.71
	Opex var	€/kWh$_{el}$	0	0	0	0	0	0	0
	Lifetime	years	20	20	20	20	20	20	20
	Round-trip	coeff	0.91	0.92	0.93	0.94	0.95	0.95	0.95
Battery utility-scale Interface	Capex	€/kW$_{el}$	117	76	55	44	37	33	30
	Opex fix	€/(kW$_{el}$·a)	1.64	1.29	1.1	1.01	0.93	0.86	0.84
	Opex var	€/kWh$_{el}$	0	0	0	0	0	0	0
	Lifetime	years	20	20	20	20	20	20	20
Hydrogen Storage	Capex	€/kWh$_{H2,LHV}$	0.28	0.28	0.28	0.28	0.28	0.28	0.28
	Opex fix	€/(kWh$_{H2,LHV}$·a)	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112	0.0112
	Opex var	€/kWh$_{H2,LHV}$	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	Lifetime	years	30	30	30	30	30	30	30
	Round-trip	coeff$_{LHV}$	1	1	1	1	1	1	1
Import e-methanol		€/MWh$_{th}$		152	138	117	96	90	84
Import e-ammonia		€/MWh$_{th}$		163	150	131.25	112.5	105	97.5
Import e-FTL fuels		€/MWh$_{th}$		216	195	165	135	123.8	113

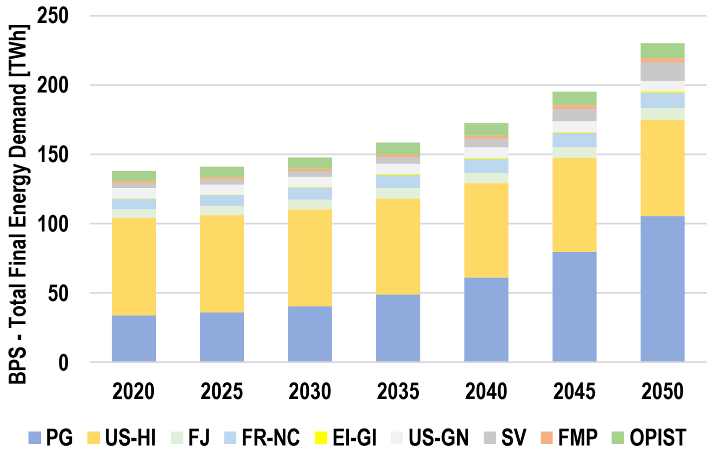
- all capex and opex values are multiplied by a factor of 1.25 to represent costs for shipping and remoteness
- e-Fuel import prices are based on global average import prices, with an additional factor of 1.5 for increased shipping distances and cost of remoteness

Energy Demand Projections









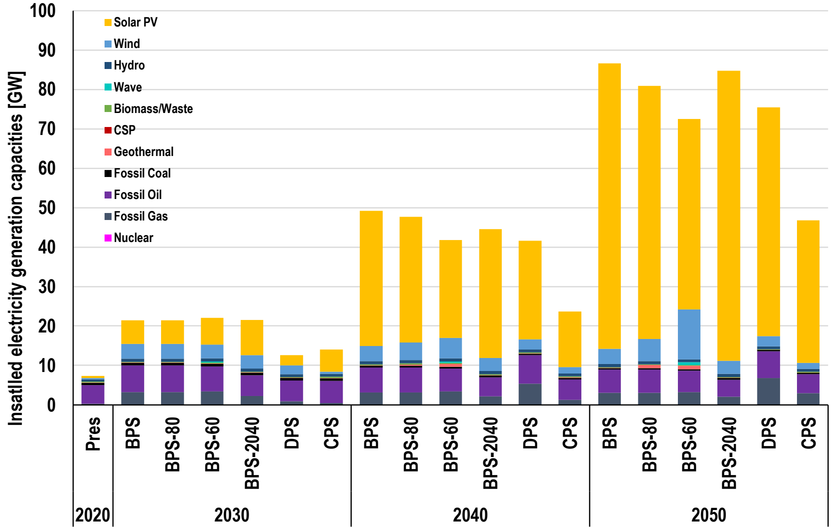
Final energy demand (TFED)

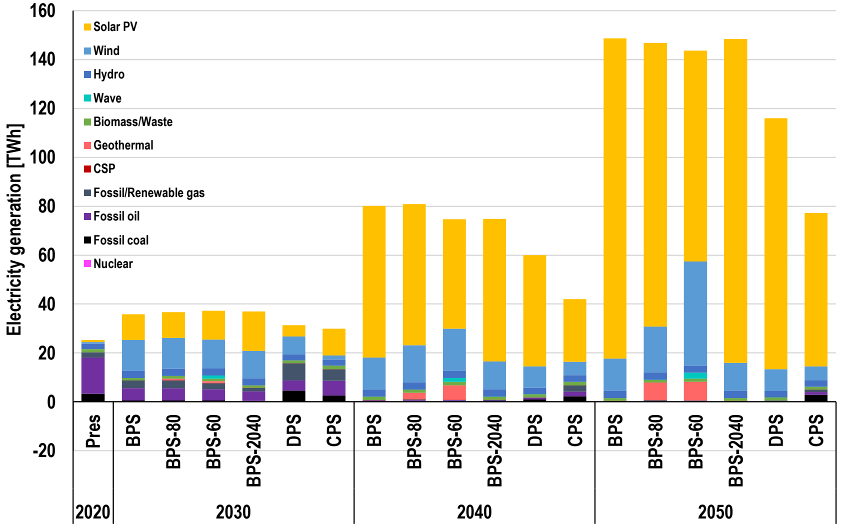
- Projected to increase over time, largely due to demand increases in Papua New Guinea (PG)
  - US-HI and PG compose >75% of the TFED in all years in the BPS
- Growth largely driven by the transport sector despite efficiency gains through direct electrification
  - Under CPS conditions, with limited electrification of heat, transport, and industry sectors, 18% higher than BPS conditions

Primary energy demand (TPED)

- Under BPS conditions, TPED sees significant reduction in fuel demand as renewable electricity reaches 61-64% of TPED.
  - Fuel demand decreases by 63% compared to 2020 in BPS, only 32% and 2% in the DPS and CPS
  - Lowest TPED found in the BPS-60 due to increased supply complementarity
- Renewable electricity and e-fuel imports dominate the primary energy supply

Electricity Generation





Electricity capacity

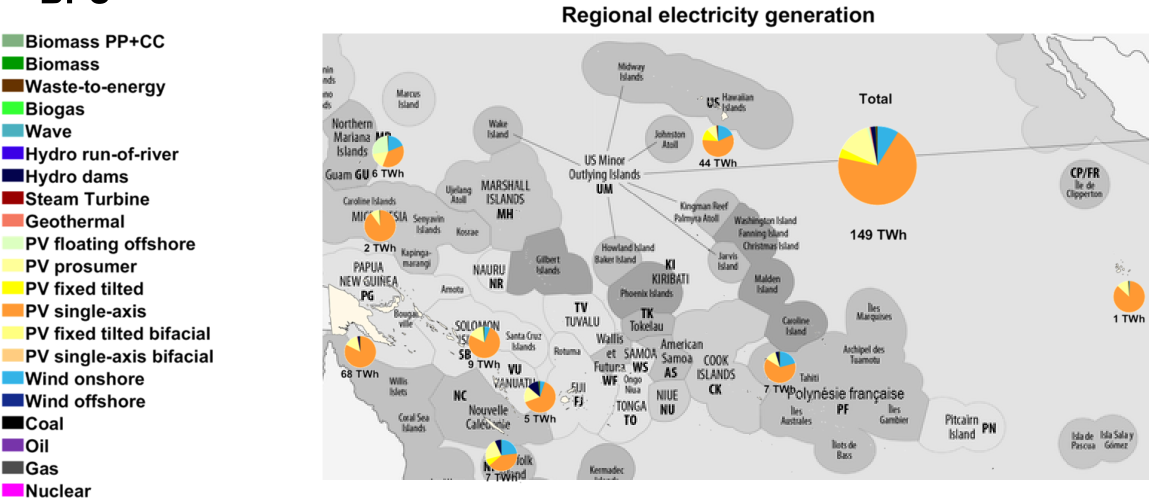
- Total installed capacity significantly increases in the BPSs from 7 GW in 2020 to 73-87 GW in 2050
  - Solar PV composes 67-87% of installed capacity
    - Largest installed capacity in PG, with 38 GW
    - Across the Pacific, prosumers contribute 13.7 GW
- DPS also sees significant capacity growth to 76 GW, and the CPS sees only moderate growth to 47 GW
- Solar PV-dominant structure apparent for all regions
  - Wind power growth follows, with 3-13 GW across BPSs

Electricity generation

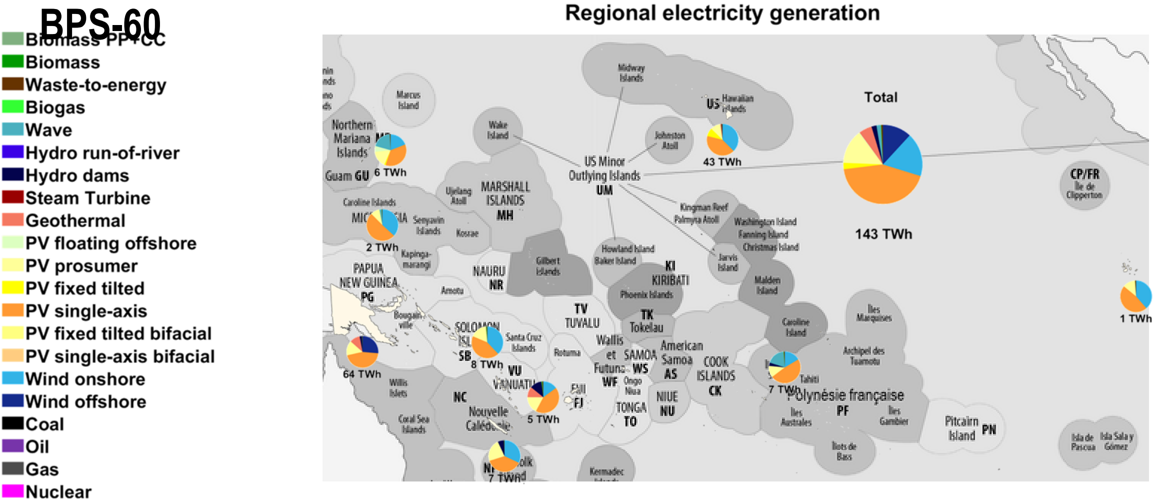
- Electricity generation increases from 26 TWh to 144-150 TWh in the BPSs
  - Dominated by solar PV (58-89%), followed by wind power (8-58%)
    - Prosumers contribute 13-14% of electricity generation in BPS, 14% and 20% in the DPS and CPS
- By 2040, 99% of all electricity generation comes from renewable electricity
  - Small amounts of hydrogen used in combustion generators
- Electricity generation in the DPS and CPS reach 116 TWh and 78 TWh

Regional Electricity Generation

BPS

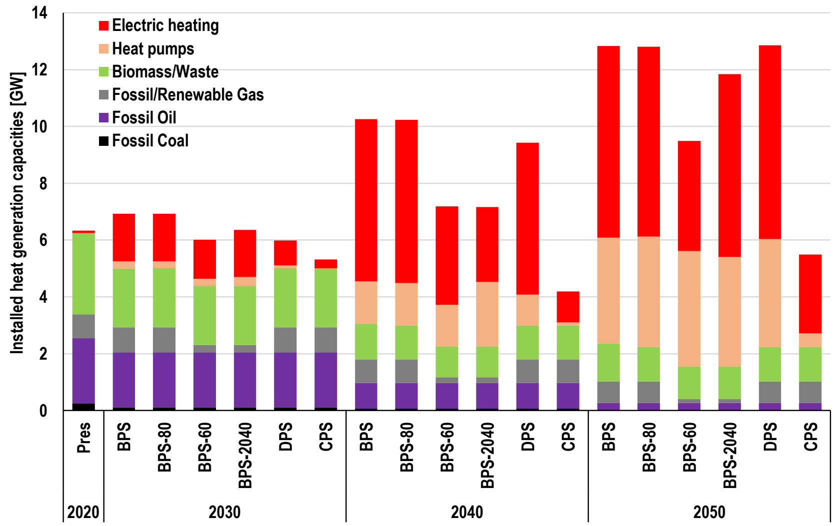


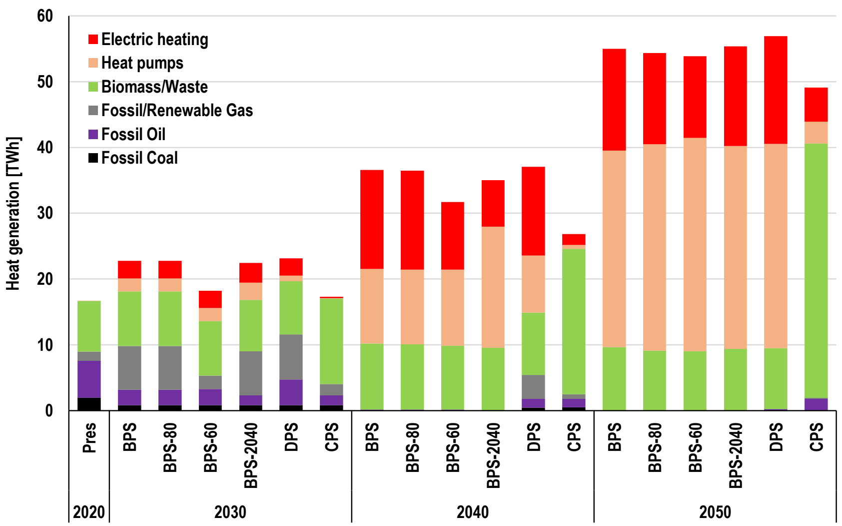
BPS-60



- For most regions, onshore resources are sufficient to satisfy growing demands
  - In BPS, US-GN offshore floating PV (27%) is required
  - In BPS-60, offshore wind power (26%) is required in PG, offshore floating PV in US-GN (5.9%), and wave power (2%, 19%, and 20%) in OPIST, US-GN, and FMP
  - Geothermal is also relevant in PG and US-GN in BPS-60, at 11% for both regions
- Under BPS conditions, onshore wind power contributes >18% of generation supply in US-HI, FR-NC, US-GN, and OPIST
- Limited hydropower potential across the Pacific leads to a maximum 12% share in FJ in the BPS
  - In BPS-60, FR-NC slightly increases hydropower to 6%

Heat Generation





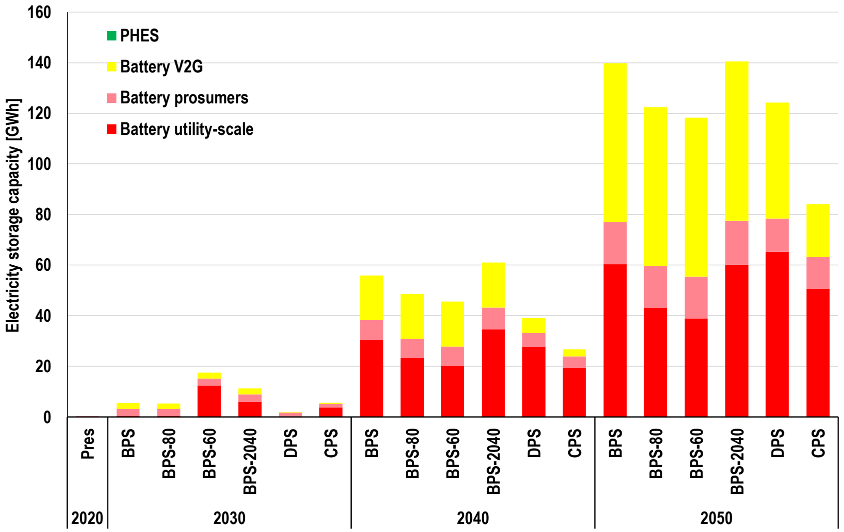
Heat capacity

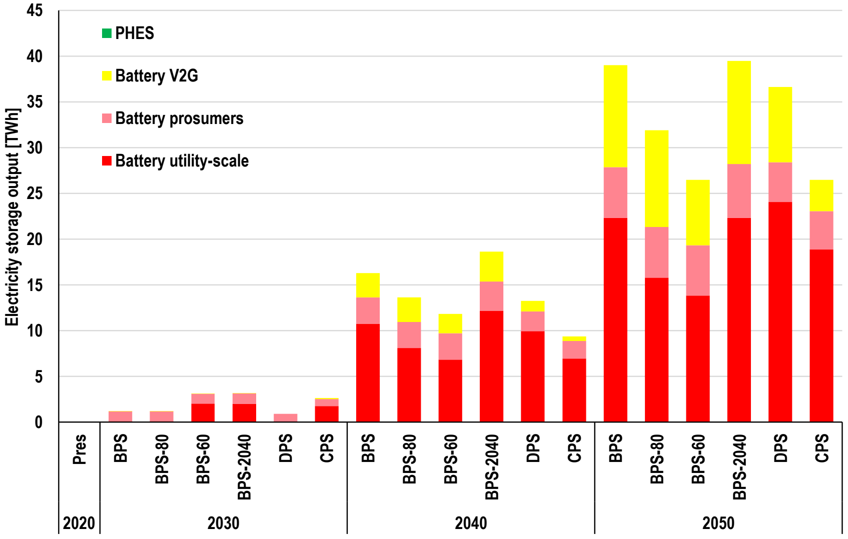
- Increased integration of low-cost renewables along with growing demands lead to a doubling of heat capacity from 2020 to 2050
- First, direct electric heating installed, reaching 7 GW, followed by heat pumps, at 4 GW
- Higher supply diversity in the BPS-60 reduces required heat capacity as supply is more aligned with demand
- Rapid transition in BPS-2040 leads to reduced capacity compared to BPS conditions
- DPS also sees a trend towards electrification of heat supply
- CPS prefers high-FLH technologies, resulting in the lowest heat capacity

Heat generation

- Heat generation increases from 17 TWh in 2020 to 49-57 TWh in 2050
- High oil prices in addition to CO_2 emissions prices largely lead to a rapid phase-out of oil heat
  - Gas heating remains relevant for PG
- Sustainable bioenergy use in BPSs and DPS remains constant at ~10 TWh
- CPS sees unsustainable use of bioenergy for heating, with limited penetration of electric heating

Electricity Storage





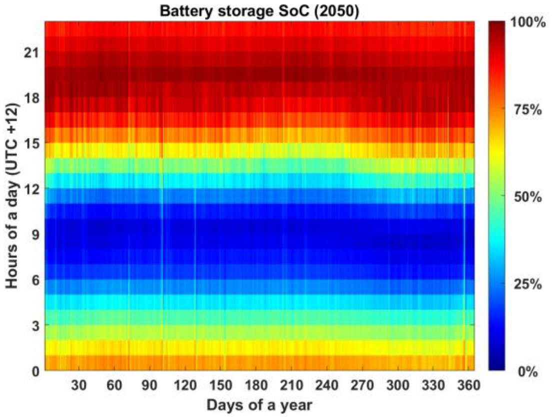
Storage Capacity

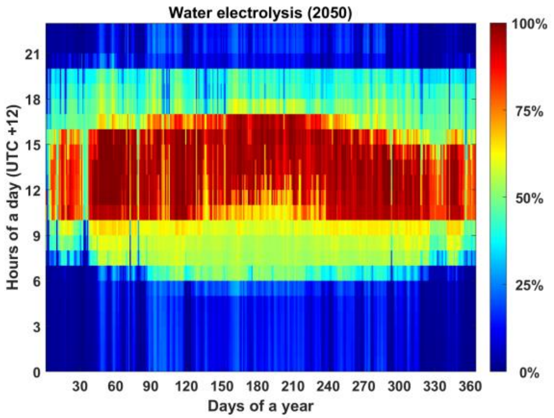
- Total storage capacity increases to 84-140 GWh in 2050 across scenarios
  - Increased supply diversity in BPS-60 leads to 15% reduced capacity compared to BPS
- Electrification of transport leads to 63 GWh of available V2G capacity in 2050 in the BPS
  - 46 GWh in the DPS, and 21 GWh in the CPS
- Battery storage essential in the Pacific as there is no PHES potential

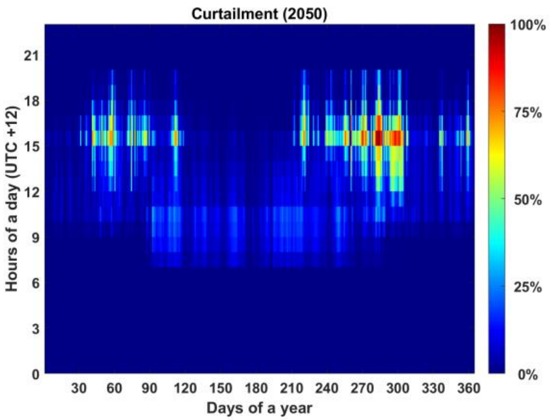
Storage throughput

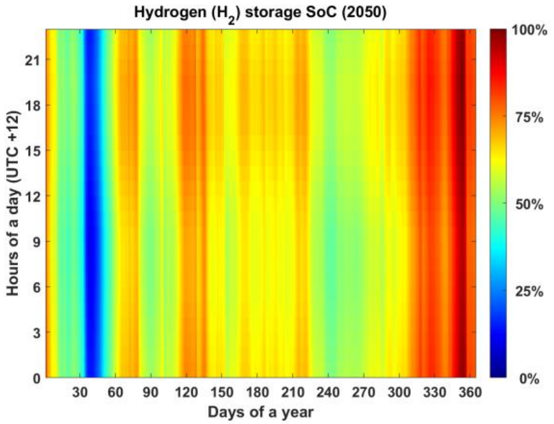
- Storage throughput in 2050 dominated by utility-scale batteries (50-71%), followed by V2G (13-33%), and prosumer batteries (12-21%)

Operational Dynamics - BPS


Battery storage SoC (2050)


Water electrolysis (2050)


Curtailment (2050)

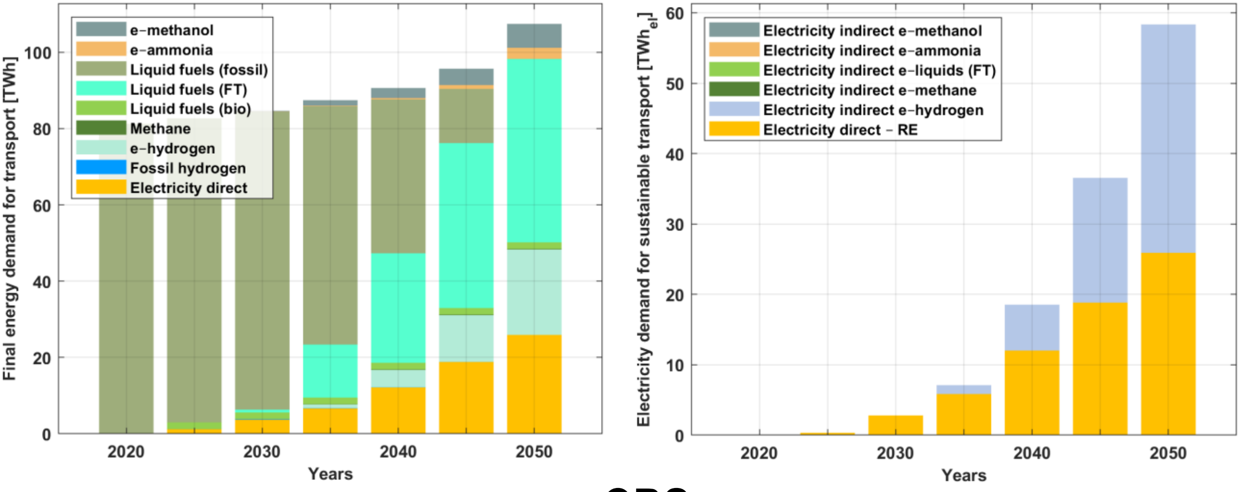

Hydrogen (H_2) storage SoC (2050)

Dynamics of key energy system components

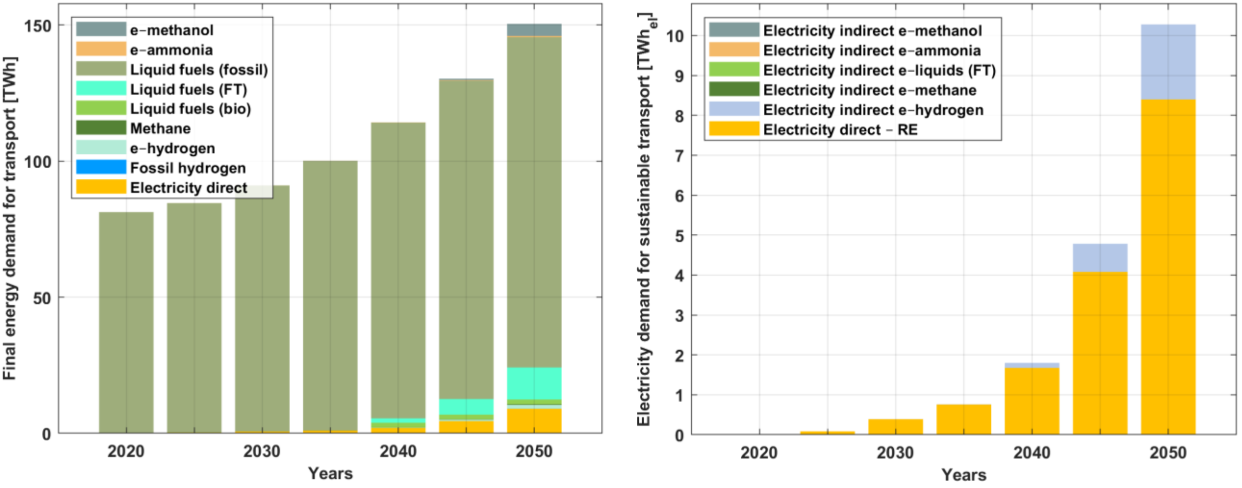
- Energy systems with high shares of variable renewables require flexibility: supply complementarity, demand response, sector coupling, grids, and storage
- On island systems with e-fuel imports, demand response through electrolysers and grids may be limited
- Battery storage essential in balancing daily demands
  - Charging during the day and discharging at night
  - Slight seasonal variation and influence of wind power
- Electrolysers required for direct e-H_2 demands, operate when excess solar PV and wind electricity is available
  - H_2 storage to balance e-H_2 supply and demand in transport and for high temperature heating, largely shows a seasonal balancing
- Curtailment across the Pacific remains low in the BPS, at an average of 2.7% of demand in 2050
  - SV has the highest curtailment at 5.9%

Transport Sector – BPS and CPS

BPS, BPS-80, BPS-60, BPS-2040



CPS



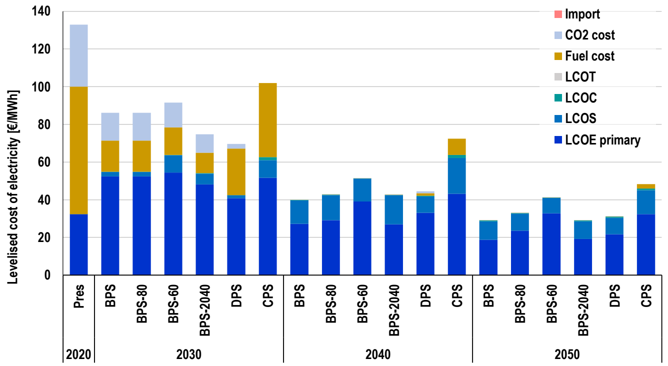
BPSs

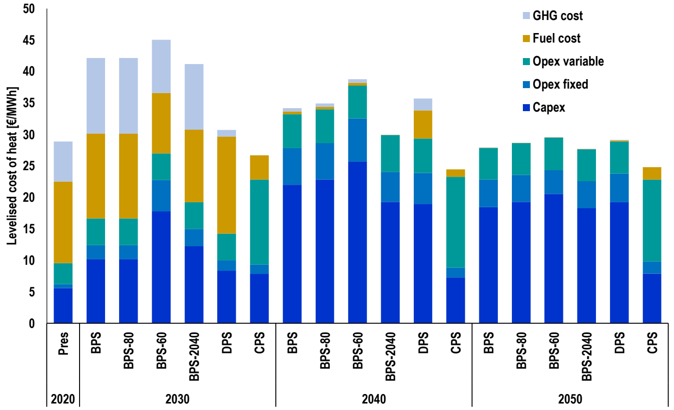
- Total fuel demand decreases with electrification of road vehicles
- Fuel demand remains high due to the high share of aviation, increasing from ~40% in 2020 to ~60% in 2050
  - Consequently, the share of e-FTL remains high
  - Hydrogen for short distance flights leads to significant growth in direct e-H_2 usage
  - e-Methanol and e-ammonia demand grows for marine transport
- Total electricity demand for transport reaches 58 TWh in 2050, with the majority for e-H_2

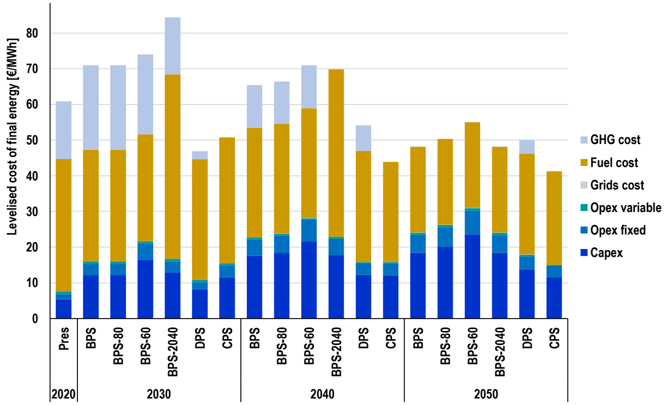
CPS

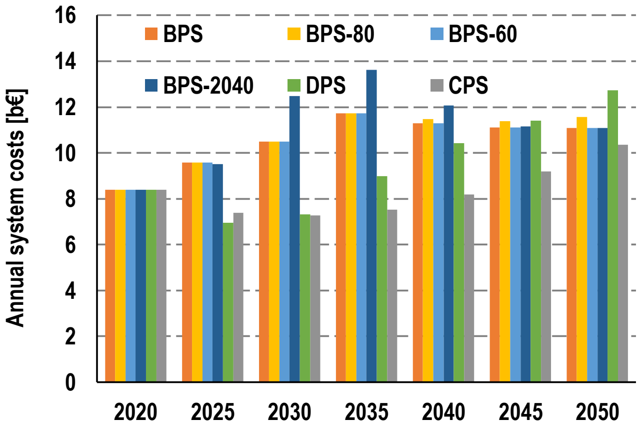
- Without GHG pricing and electrification, oil remains the dominant fuel for transport in the CPS
  - Electricity and e-fuels only compose 10% of the transport FED
- Electricity demand for transport only reaches around 10 TWh

LCOE and Levelised Cost of Final Energy





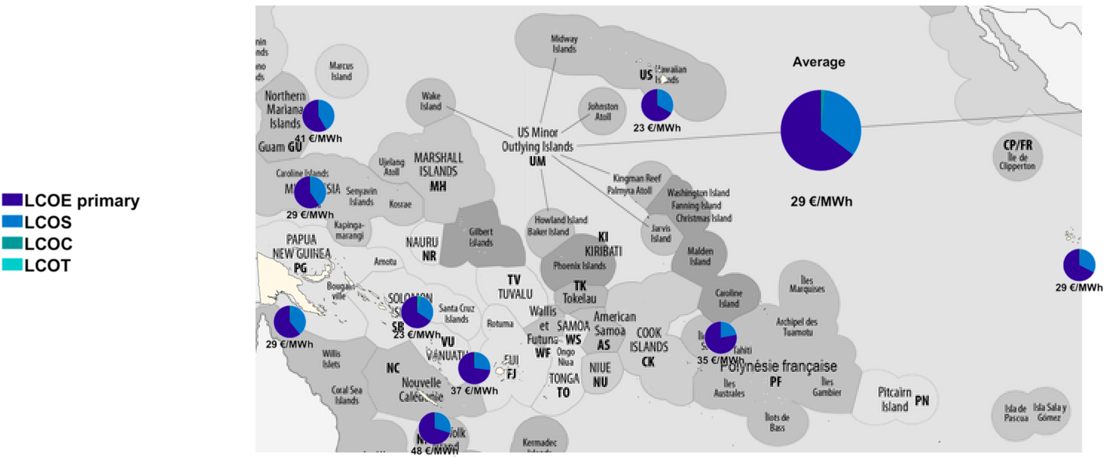




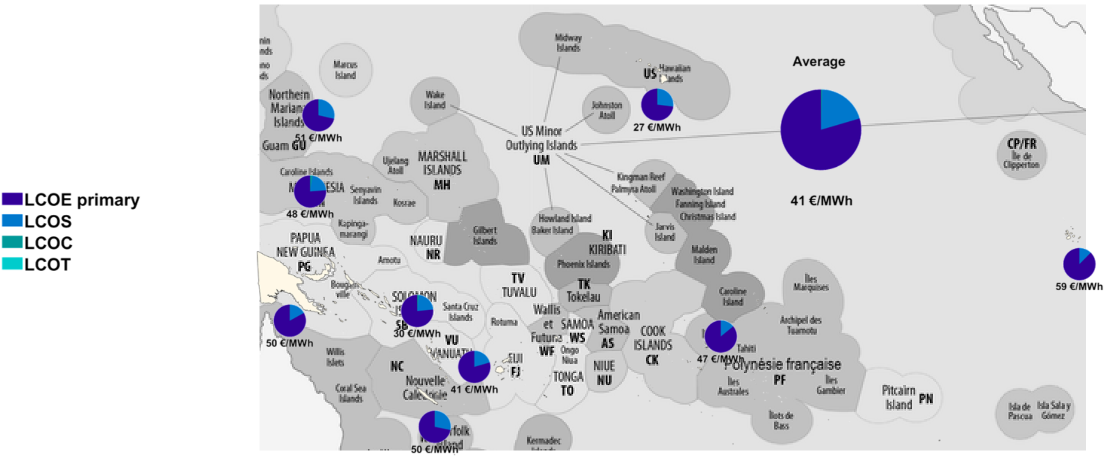
- All scenarios see significant reductions in LCOE from 100 €/MWh in 2020 without GHG emissions costs to 30-49 €/MWh in 2050
  - Limited electrification and flexibility in CPS leads to a higher share of storage (LCOS) in the LCOE
  - Increased supply diversity in BPS-60 leads to higher capex requirements, particularly for wind power
- Levelised cost of heat increases in the short-term before electric heating becomes the least-cost supply
  - LCOH reaches cost-parity relative to 2020 (28.9 €/MWh) in 2050 across scenarios (27.7-29.5 €/MWh)
- Levelised cost of final energy (LCOFE) decreases from 61 €/MWh in 2020 to 41-55 €/MWh
  - BPS-60 leads to highest costs, whereas CPS, without GHG emissions costs, leads to the lowest
- Accelerated transition in BPS-2040 leads to an LCOFE equal to that of BPS

Regional LCOE

Components of Levelised Cost of Electricity



Components of Levelised Cost of Electricity



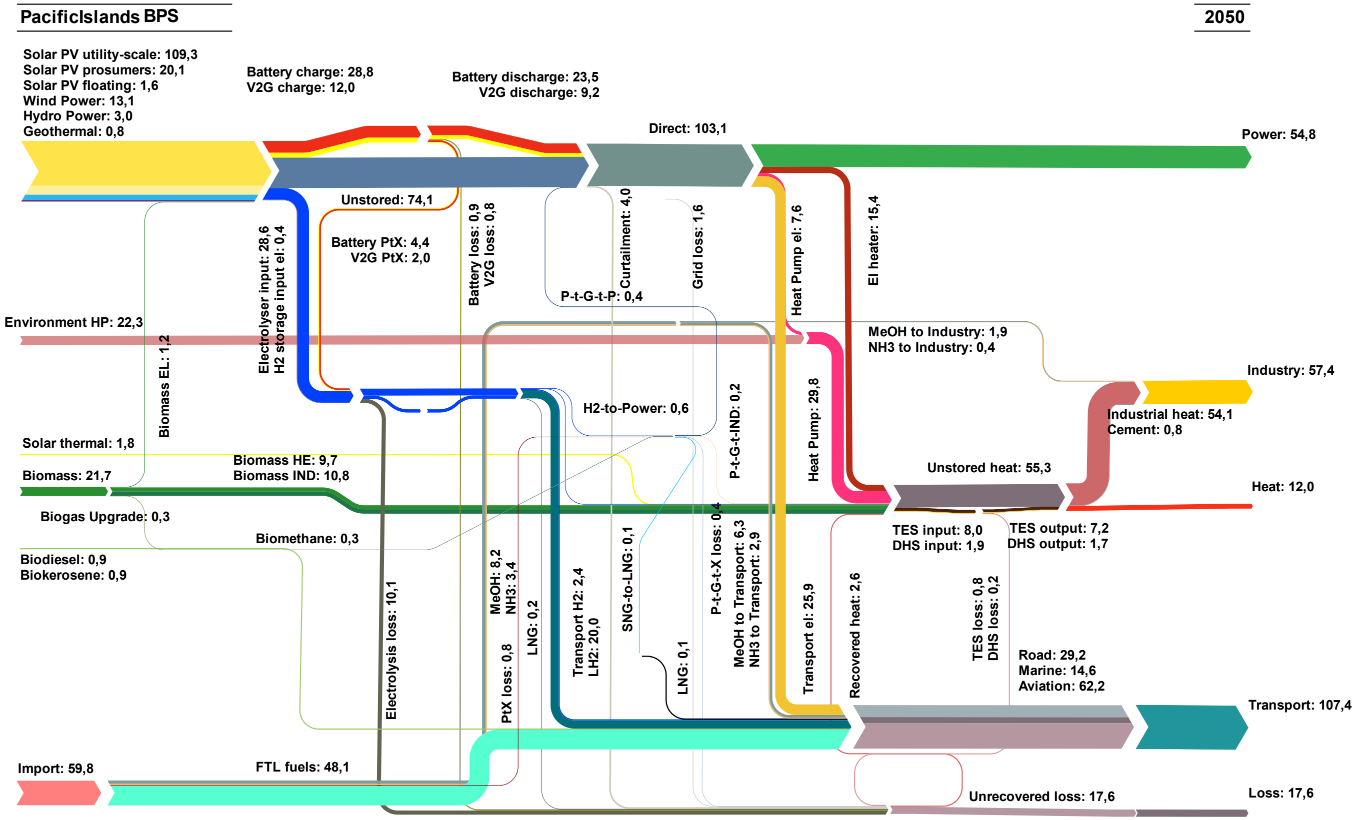
BPS

- The average LCOE of 29 €/MWh varies significantly across regions
  - High demand regions of US-HI and PG have low LCOEs at 23.3 and 29.4 €/MWh
  - SV has the lowest LCOE at 22.9 €/MWh, despite having the highest share of curtailment in LCOE
- Small demand islands can also reach low LCOEs, such as GI-EI, with an LCOE of 28.7 €/MWh
- FR-NC and US-GN have the highest LCOEs, at 47.9 and 40.6 €/MWh, largely due to higher-than-average LCOS shares

BPS-60

- US-HI and SV largely not affected by solar PV supply limits, with LCOEs at or below 30 €/MWh
- GI-EI most affected, as LCOE increases to 59 €/MWh
  - PG and FR-NC also have LCOEs at or above 50 €/MWh
- Despite increases in LCOE in BPS-60 compared to BPS, all regions see significant reductions in LCOE compared to present conditions

Energy Flows in Power-to-X Economy for the Pacific



- **Primary energy becomes dominated by renewable electricity and e-fuels imports**
  - **Limited bioenergy and solar thermal used for individual and industrial heating**
- **The energy flow is best described as a Power-to-X Economy where electricity is used wherever possible, along with strong sector coupling and hydrogen use if direct electricity is not possible**
- **Solar PV composes 77% of all local primary energy demand, 57% including imports**
- **e-Fuel imports compose 26% of TPED**
  - **All fuel demands under BPS conditions are reduced by 63% compared to 2020**

More information on the Power-to-X Economy:

[Breyer, Lopez, et al., 2024. Power-to-X Economy. International Journal of Hydrogen Energy](#)

Summary

The Pacific Islands are rich in renewable energy opportunities

- Expansion of renewable electricity can reduce electricity generation costs and overall energy system costs
- An accelerated transition to net-zero emissions by 2040 leads to similar energy system costs (as net-zero emissions by 2050)
- Solar PV contributes the large majority of local primary energy demand
- For islands with limited land availability, offshore floating PV, offshore wind power, and wave power are available
- Altogether, this is a chance to reduce dependence on oil imports

General findings

- Electrification of energy demands on small islands increases flexibility and, along with low-cost battery storage, reduces curtailment
- Current policy scenario (CPS) may defossilise power sector, but keeps heat and transport sectors largely fuel dependent
- GHG emissions pricing mechanisms can help facilitate transitions to high shares of renewable energy
- Power-to-X Economy, with solar PV at its core, is attractive for the region to increase self-sufficiency

Thank you for your attention …
… and to the team!

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