Pathways to Net Zero: *Western Australia*

December 2024

NET ZERO AUSTRALIA

The University of Melbourne
The University of Queensland Australia — Create Change
Princeton University
nous

About Net Zero Australia

The Net Zero Australia project (NZAu) is analysing net zero pathways that reflect the boundaries of the Australian debate, for both our domestic and export emissions

The study is:

- **Rigorous** and **granular**
- **Scenario-based** and **evidence-driven**
- **Technology-neutral** and **non-political**

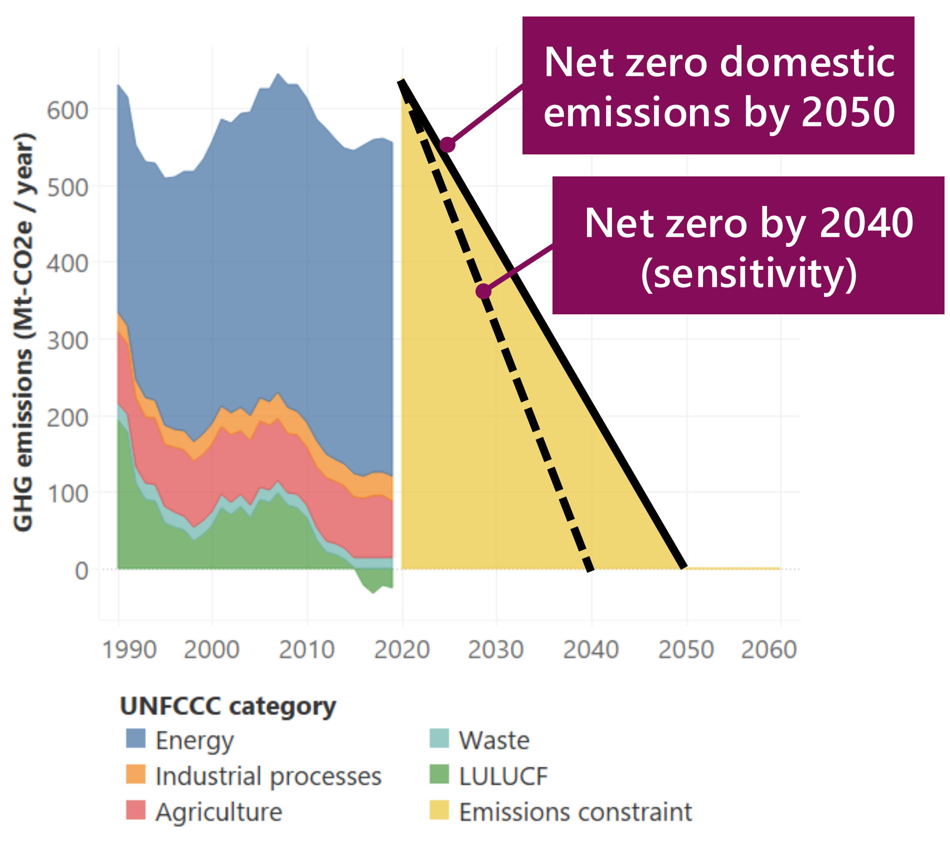
Net Zero Australia is a partnership between the **University of Melbourne,** the **University of Queensland, Princeton University,** and management consultancy **Nous Group.**

NZAu uses the modelling method developed by Princeton University and Evolved Energy Research for its 2020 ***Net-Zero America study.***

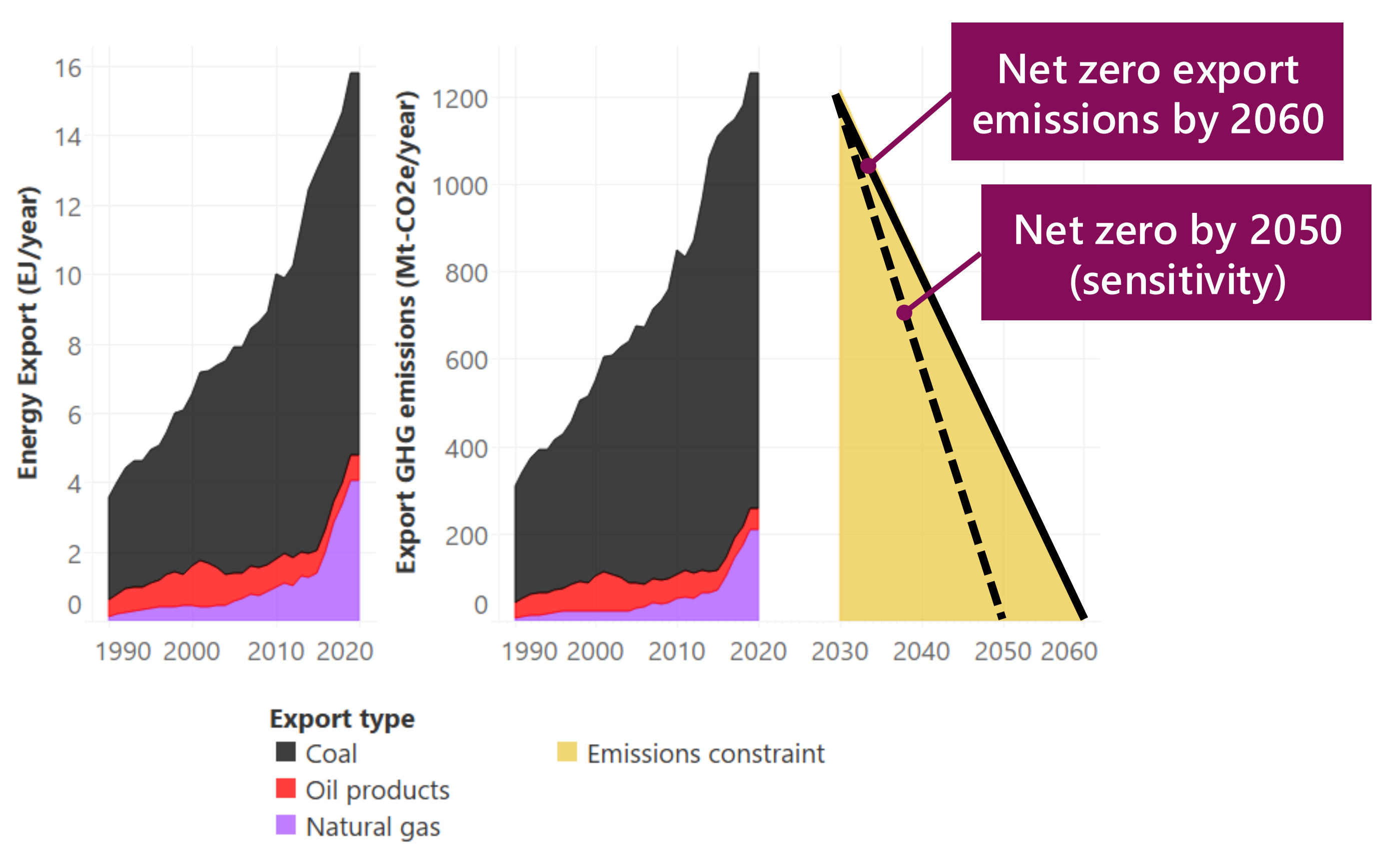
NZAu imposes straight-line emissions trajectories for domestic and exports

We model pathways for 1.8 Gt-CO_2e/year GHG emissions abatement, while providing 15EJ of clean energy to the world.

Domestic emissions



Fossil fuel energy export emissions



Notes:

- Conservative assumptions in modelling of agriculture, LULUCF and waste sector emissions mean that the 2020 domestic emissions constraint is required to be higher than actual Australian domestic emissions in 2020.
- Initial export emissions constraint based on 2020 fossil exports, using Australian inventory emissions factors.
- 34% of total GHG emissions from domestic sources, 66% from export – ~1.8Gt-CO_2e/year emissions abatement modelled.
- Net zero domestic emissions by 2040 (export by 2050) also modelled as a sensitivity (dotted lines).

We modelled six Core Scenarios

REF

Reference
- Projects historical trends, does <u>not</u> model cost impacts of fossil fuel supply constraints
- No new greenhouse gas emission constraints imposed domestically *or* on exports
- Policy settings frozen from 2020 onwards

E+

Rapid electrification
- Nearly full electrification of transport and buildings by 2050
- Renewable rollout rate almost unconstrained
- Lower cap on underground carbon storage rate.

E–

Slower electrification
- Slower electrification of transport and buildings compared to E+
- Renewable rollout rate almost unconstrained
- Lower cap on underground carbon storage rate.

E+ RE+

Full renewables rollout
- No fossil fuel use allowed by 2050
- Renewable rollout rate almost unconstrained
- Lower cap on underground carbon storage rate, which is only used for non-fossil fuel sources post 2050 (e.g. cement production).

E+ RE–

Constrained renewables rollout
- Renewable rollout rate limited to several times historical levels (to examine supply chain and social licence constraints)
- Much higher cap on underground carbon storage (to make net zero achievable).

E+ ONS

Onshoring
- Domestic production of iron and aluminum using clean energy
- Progressively displaces exports of iron ore, bauxite, alumina and fossil fuels.

The Reference Scenario has *no emissions objective*. All other Scenarios are 'net zero' for both the domestic and exported emissions separately, and start from current emissions, and track in a line to net zero emissions by 2050 (domestic) and 2060 (export). None of the Scenarios are forecasts.

National results from Net Zero Australia modelling

WHAT IT WOULD TAKE TO REACH NET ZERO		WHAT AUSTRALIA MUST DO
1	Grow **renewables** as our main domestic and export energy source	**Deliver an energy transformation** unprecedented in scale and pace
2	Establish a large fleet of **batteries**, **pumped hydro** and **gas-fired firming**	
3	Greatly increase **electrification** and **energy efficiency**	
4	Develop a large **carbon capture, utilisation and storage** industry	
5	Greatly expand our **energy transmission and distribution networks**	
6	Attract and invest $7-9 trillion of **capital** to 2060	
7	No role for **nuclear** unless costs fall sharply and renewables are constrained	
8	Transition to **clean energy** and **clean minerals exports**	**Transform our exports** an essential contribution to global decarbonisation
9	**Locate** these **new export industries** in the north; possibly also in the south	
10	Expand a **skilled workforce** from about 100,000 today to 7-800,000 by 2060	**Invest in our people and land** to reduce impacts and share benefits
11	Move the **land sector** towards net zero and potentially to net negative	
12	Carefully manage major **land use changes**, including the Indigenous Estate, ecosystems and agriculture	

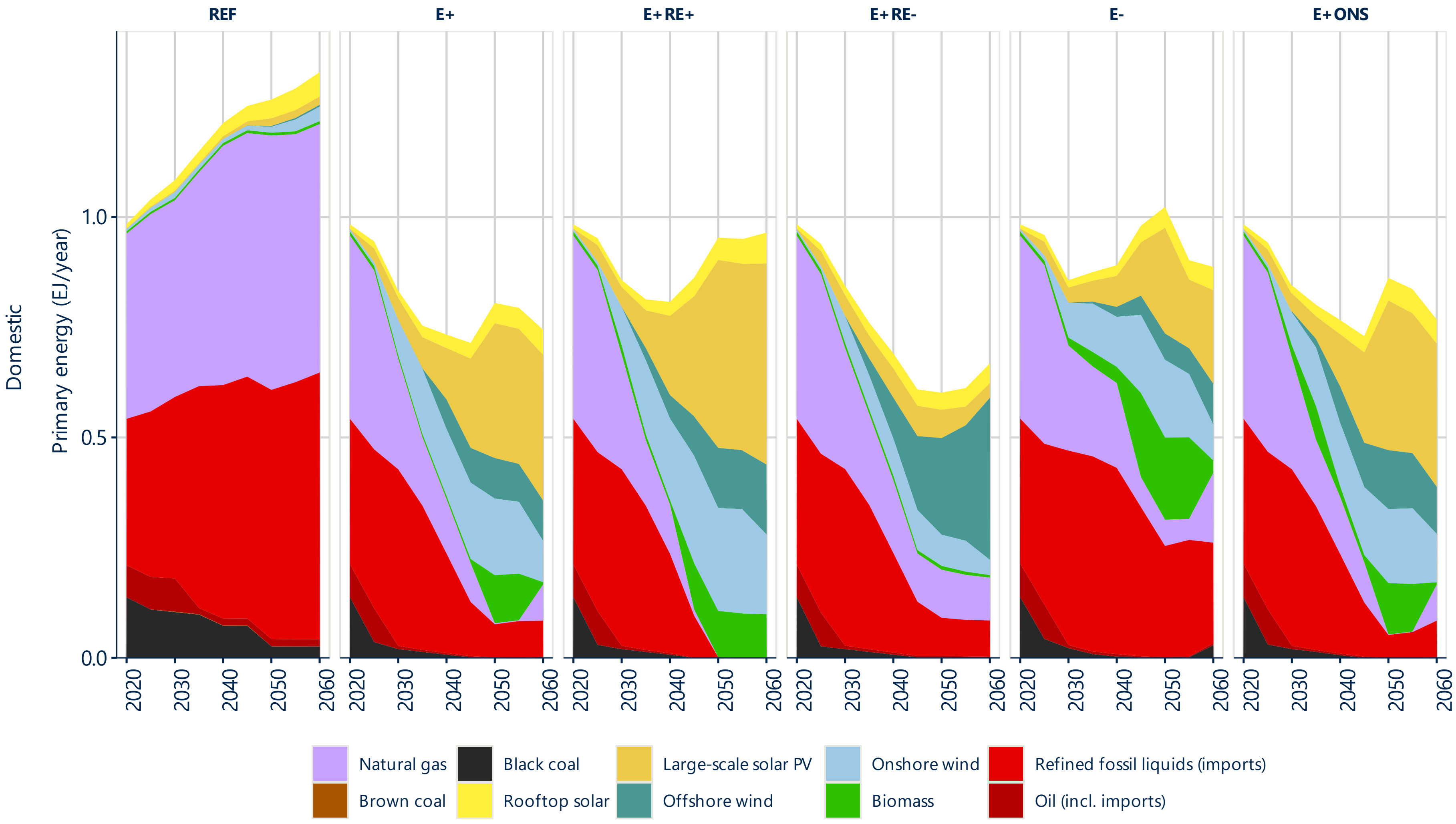
Insights for Western Australia

WHAT AUSTRALIA MUST DO	WA-SPECIFIC MODELLING RESULTS
Deliver an energy transformation unprecedented in scale and pace	1. WA's **solar and wind resources** are concentrated in the northern sunbelt, but **faces challenges** of location, labour, and community acceptance. 2. **Offshore wind** only plays a large role when solar deployment is constrained. 3. **No pumped hydro is built**, and **batteries dominate** electricity storage. 4. **Gas use decreases**, but ~2-4 GW **new gas *capacity* is needed** for firming. 5. Carbon capture, utilisation and storage **(CCUS) expands rapidly** within WA, used for direct air capture and some blue hydrogen production.
Transform our exports an essential contribution to global decarbonisation	6. WA's **export transition** is ~4 times the size of its domestic challenge, with **natural gas replaced by solar** to produce hydrogen or clean minerals in most Scenarios. 7. Under a net zero emission exports system, WA's **export** potential is highest when it makes **direct reduced iron** onshore from its iron ore and hydrogen but will require a new industrial complex, community acceptance and willing trading partners. 8. Small increases in capital costs in the sunbelt swing exports to **lower cost states**.
Invest in our people and land to reduce impacts and share benefits	9. WA's **land sector** will likely *require* offsets, not become a source of them, due to difficulties reducing enteric emissions. 10. Gross **energy sector employment** could be 175 – 245 thousand by 2060.

Most domestic energy is sourced from solar and wind

Offshore wind only plays a significant role in generation when other solar roll-out is constrained.

Projected domestic primary energy (EJ/year)



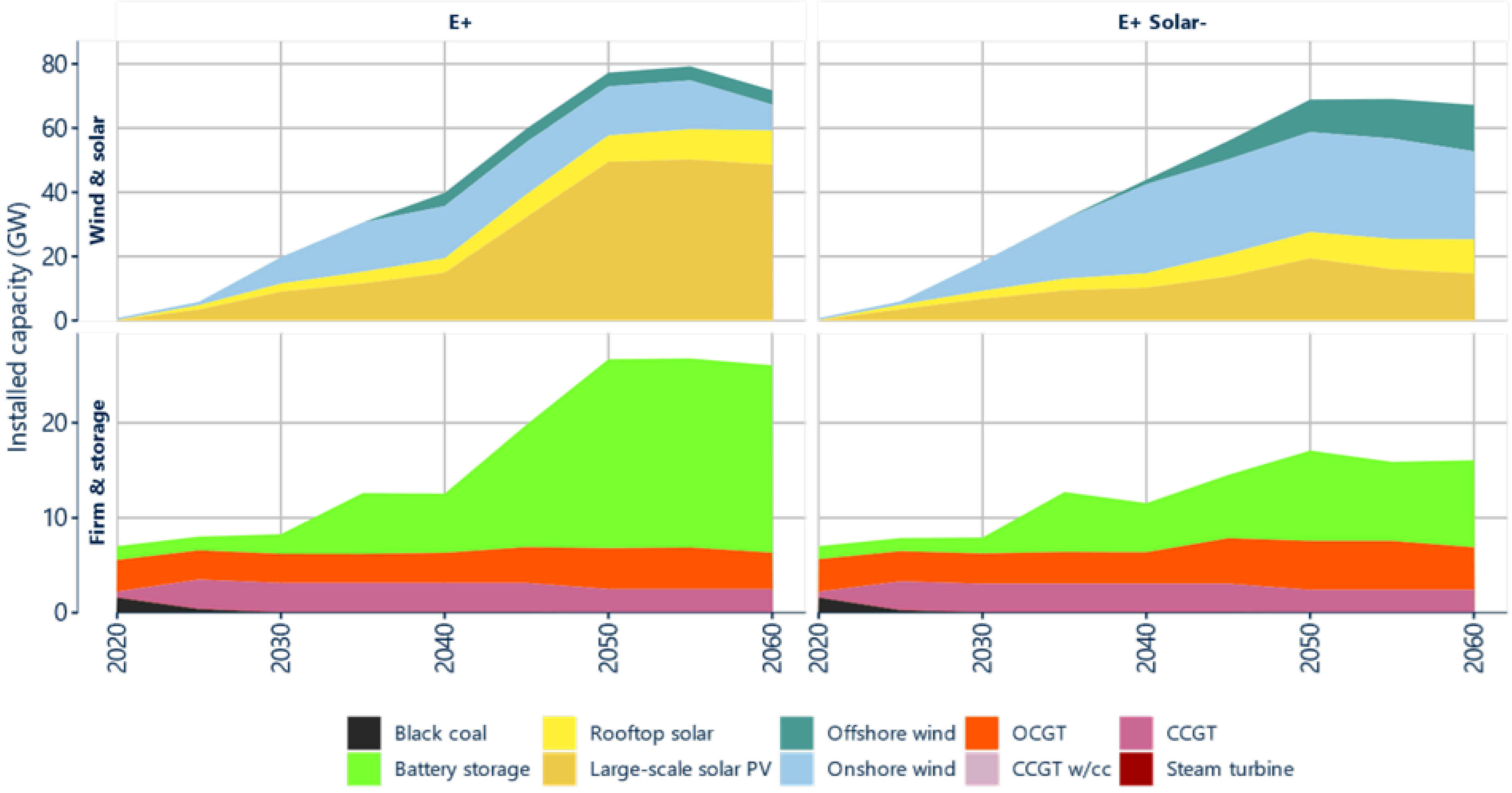
OVERALL ENERGY, EMISSIONS, AND EXPORTS

KEY TAKEAWAYS

- Renewable electricity leads energy supply in all Scenarios.
- Total domestic primary energy supply is lower than REF in all Scenarios, due to productivity gains from end-use electrification and efficiency improvements.
- Offshore wind competes domestically on cost and is significant in E+RE- due to limitations on rollout of other renewables.

Sensitivity: when solar cost reductions are less prospective, onshore wind dominates with less battery storage needed

Projected domestic electricity system capacity, by technology under the *Solar-* Scenario (GW). Note varying y-axis scales.



SENSITIVITY

Solar–

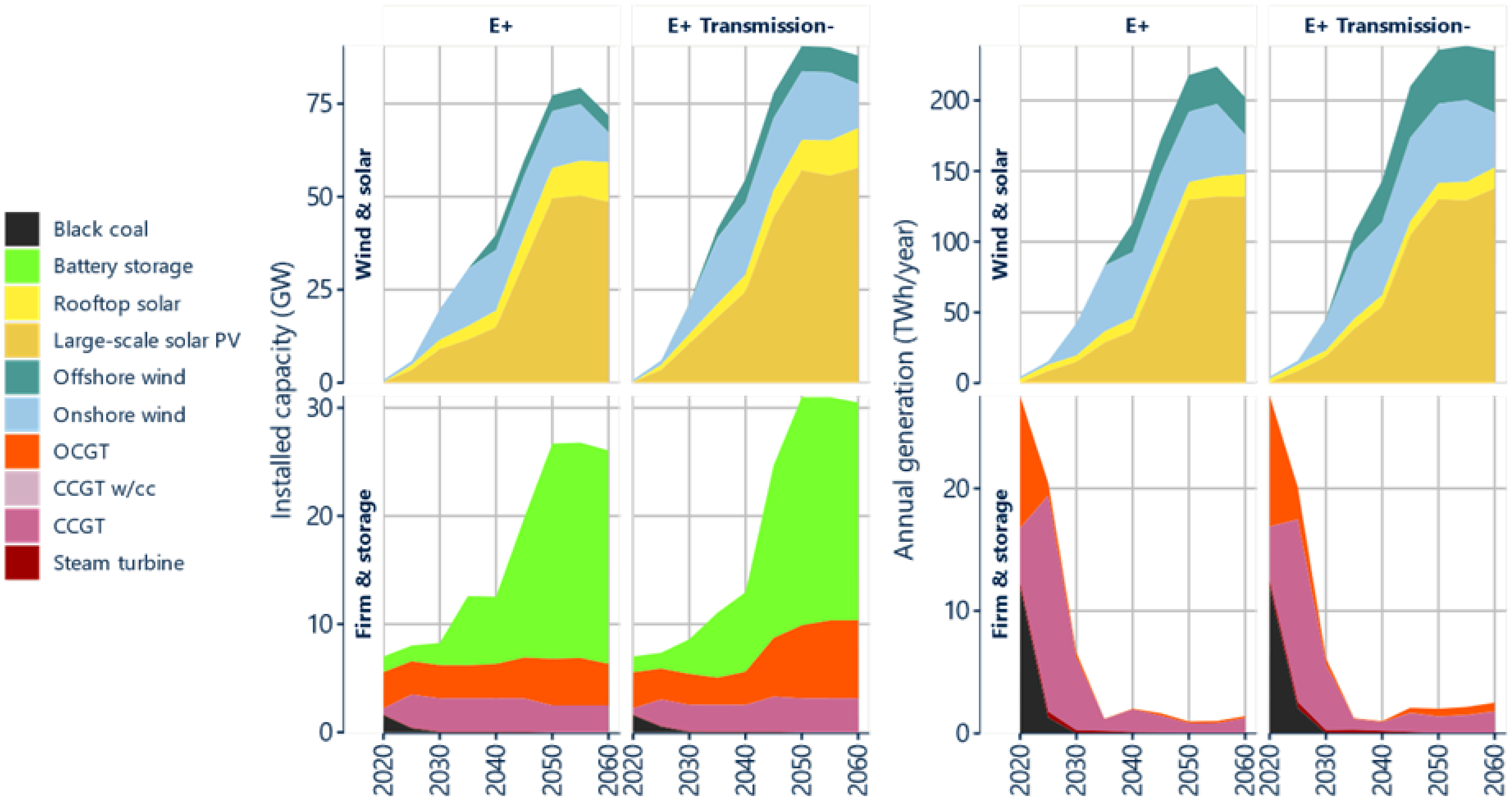
Less ambitious capital cost trajectory for Solar PV

KEY TAKEAWAYS

- Using a less ambitious cost curve for Solar PV leads onshore wind to play a much greater role in WA energy supply.
- Battery storage falls, highlighting its role in shifting solar generation to evening peaks.
- Gas capacity is consistent across all Scenarios due to its use for firming, highlighting the need for accelerated deployment.

When transmission is constrained, more firming and storage capacity is required

Projected domestic electricity system capacity and annual generation by technology under the *Transmission-* Scenario (GW and TWh/year). Note varying y-axis scales.



SENSITIVITY

Transmission–

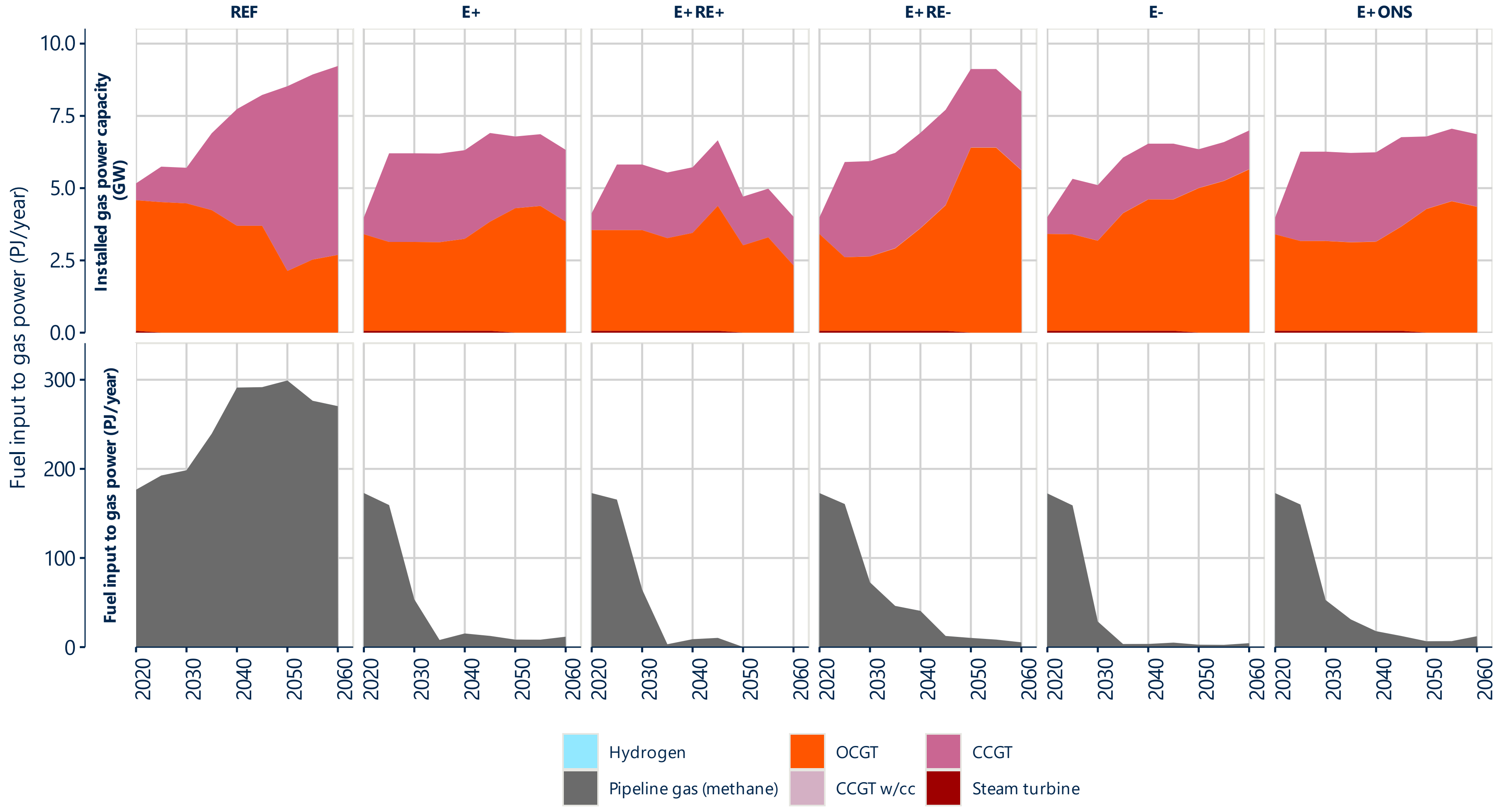
All inter-regional transmission capacity is frozen

KEY TAKEAWAYS

- Constraining interregional transmission capacities to current capacities creates greater need for both gas turbine firm capacity and battery storage.
- *E+ Transmission–* installs an additional ~3 GW of OCGT and ~3 GW of batteries, relative to E+.
- WA requires comparatively less additional firming and storage to other states as it is less populous.
- Energy imports from NT and SA are lower cost options in the modelling. If constrained (this sensitivity), offshore wind plays a larger role in meeting domestic demand in WA.

Gas use decreases, but ~2-4 GW new gas capacity is needed for firming.

Gas power – installed capacity (GW) and fuel input (PJ/year). Note varying y-axis scales.



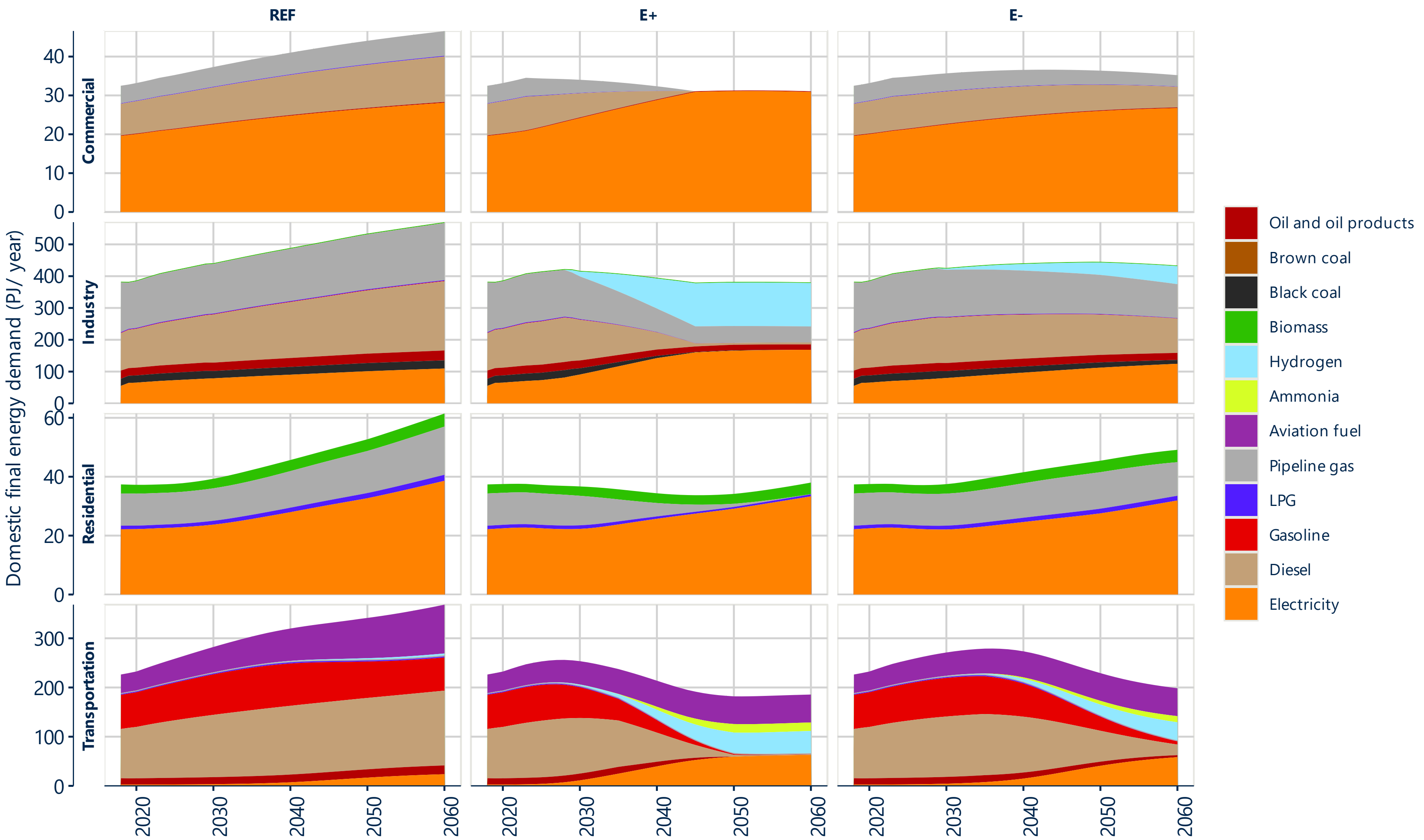
KEY TAKEAWAYS

- New gas power capacity is required across all Scenarios.
- However, gas power is used much less often, with capacity factors reduced to <10%.
- Gas turbines respond to reliability events just a handful of times per year. These are mostly associated with prolonged periods of low renewable generation.
- Much new capacity could be sited on brownfield sites of retiring coal generators.
- We find minimal blending of hydrogen into gas power.

Electrification drives significant energy productivity gains in most sectors

Domestic final energy demand by sector (EJ/year). Note varying y-axis scales.

E+RE+ and E+RE– are not shown because they use the same demand projections as E+.



PILLARS

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End use energy efficiency and electrification

KEY TAKEAWAYS

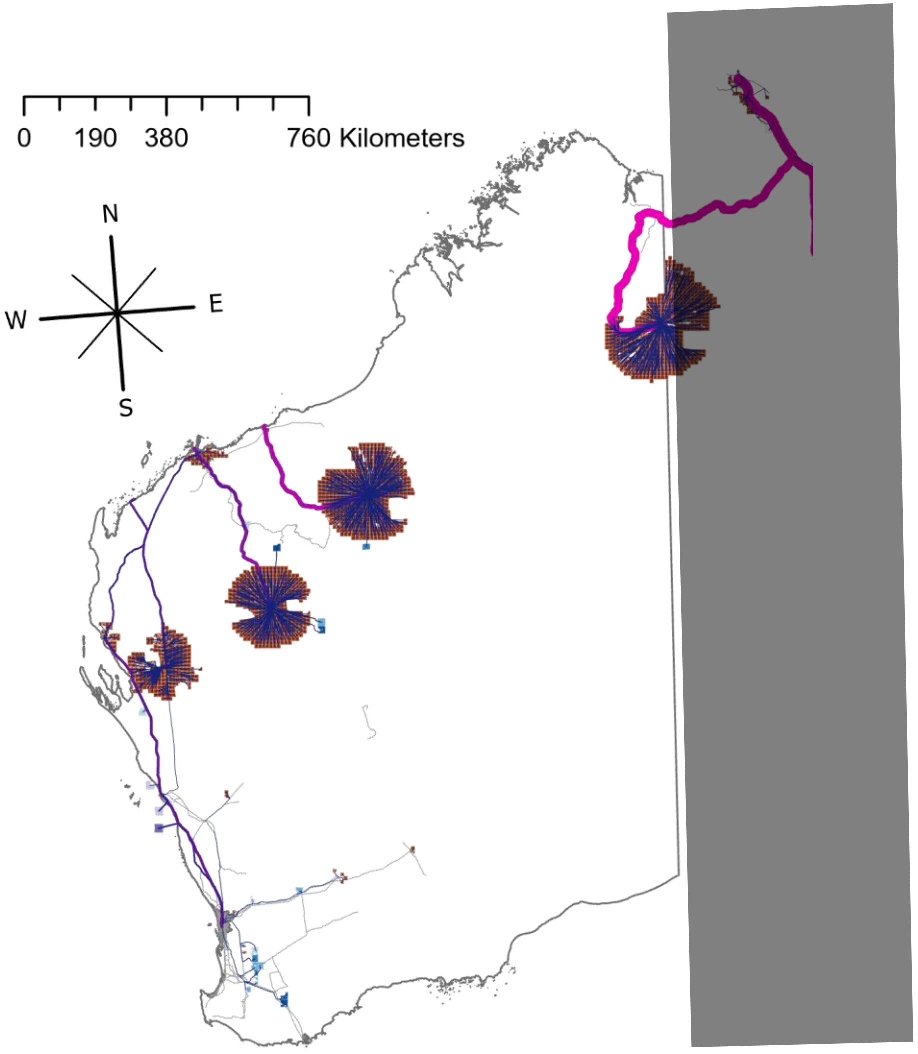
- **Residential and commercial** sectors are nearly fully electrified by 2050 in E+. E- retains similar volumes of pipeline gas (methane) which is decarbonised by producing bio-synthetic natural gas.
- **Industry** energy demand electrifies and switches to hydrogen where possible. Residual demand for liquid and gaseous fuels requires production of low-emissions fuels (made from wind, solar, biomass and fossil fuels with CCUS), or offsetting.
- Additional and upgraded electricity infrastructure will be needed to both accommodate technology switching and support increased demand.
- Residual aviation emissions are offset with negative emissions (e.g. DAC with renewables or biomass gasification, both with CCUS).

INDICATIVE ONLY

E+ 2060

- WA's **export transition** is ~4 times the size of its domestic challenge, with **natural gas replaced by solar** to produce hydrogen or clean minerals in most Scenarios.

	Wind	Solar
Capacity installed (GW)		
	17.8	1195.7
Area used (1000 km2)		
Total	5.87	26.57
Direct	0.06	24.18
Transmission added (GW-km)		
Capacity domestic area		13165
Capacity export zone		135356
Capacity not sited		5781



Transmission (MW)

- 5
- 6,627
- 13,255
- 19,882

VRE project capacity factors

Solar PV	Onshore wind	Offshore wind
0.175343 - 0.197406	0.205740 - 0.256460	0.200044 - 0.358361
0.197407 - 0.209959	0.256461 - 0.280110	0.358362 - 0.462947
0.209960 - 0.220120	0.280111 - 0.296584	0.462948 - 0.557233
0.220121 - 0.233899	0.296585 - 0.312936	0.557234 - 0.657356
0.233900 - 0.350000	0.312937 - 0.376620	0.657357 - 0.804897

ABS SA2 region with population > 5,000 people & density > 100 people/km^2

E+RE- Constrained renewables 2060

- Increased offshore and onshore wind as the model reaches the constrained build rate for solar PV
- Transmission between WA South and SA increases by ~3x times

INDICATIVE ONLY

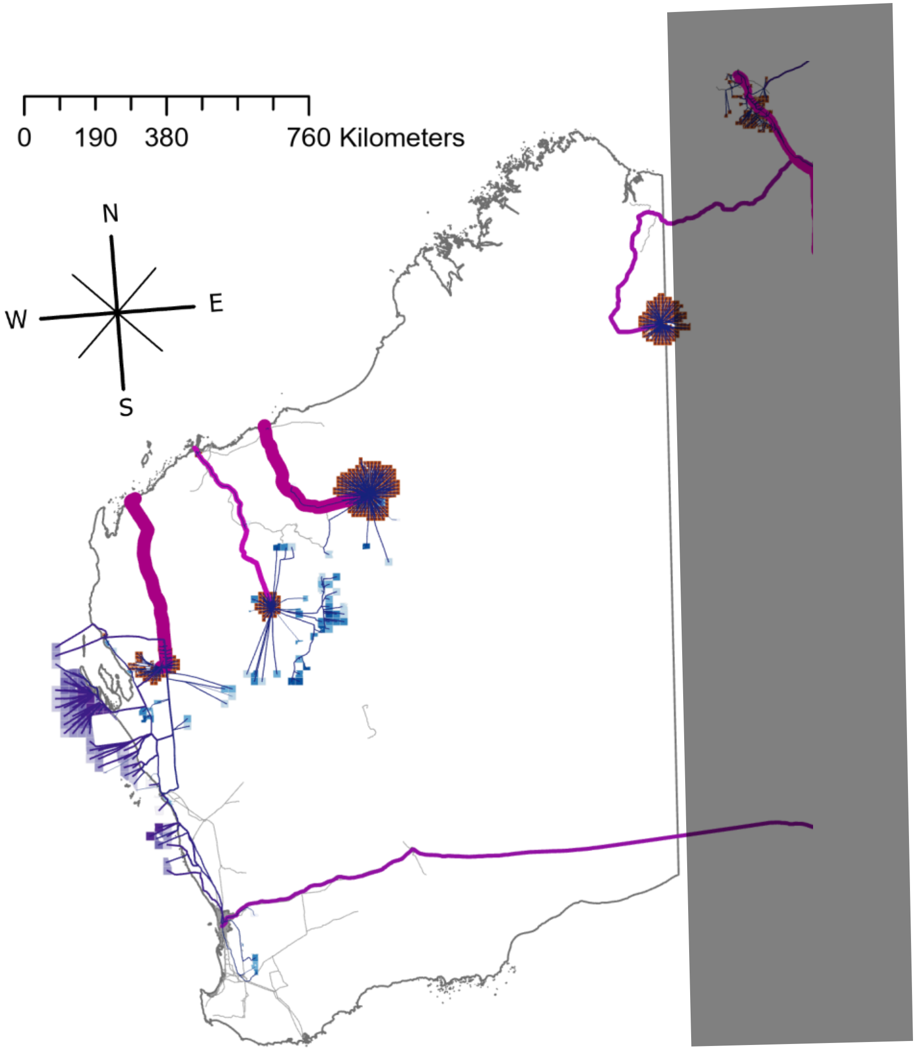
	Wind	Solar
Capacity installed (GW)		
	195.8	356.1
Area used (1000 km2)		
Total	52.17	7.91
Direct	0.52	7.2
Transmission added (GW-km)		
Capacity domestic area		19322
Capacity export zone		99756
Capacity not sited		3123

Core scenario definition

- More constrained renewable rollout
- Higher cap on annual underground carbon storage (to make net zero exports achievable)

Transmission (MW)

- 5
- 6,627
- 13,255
- 19,882



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0.233900 - 0.350000	0.312937 - 0.376620	0.657357 - 0.804897

ABS SA2 region with population > 5,000 people & density > 100 people/km^2

E+ Onshore 2060

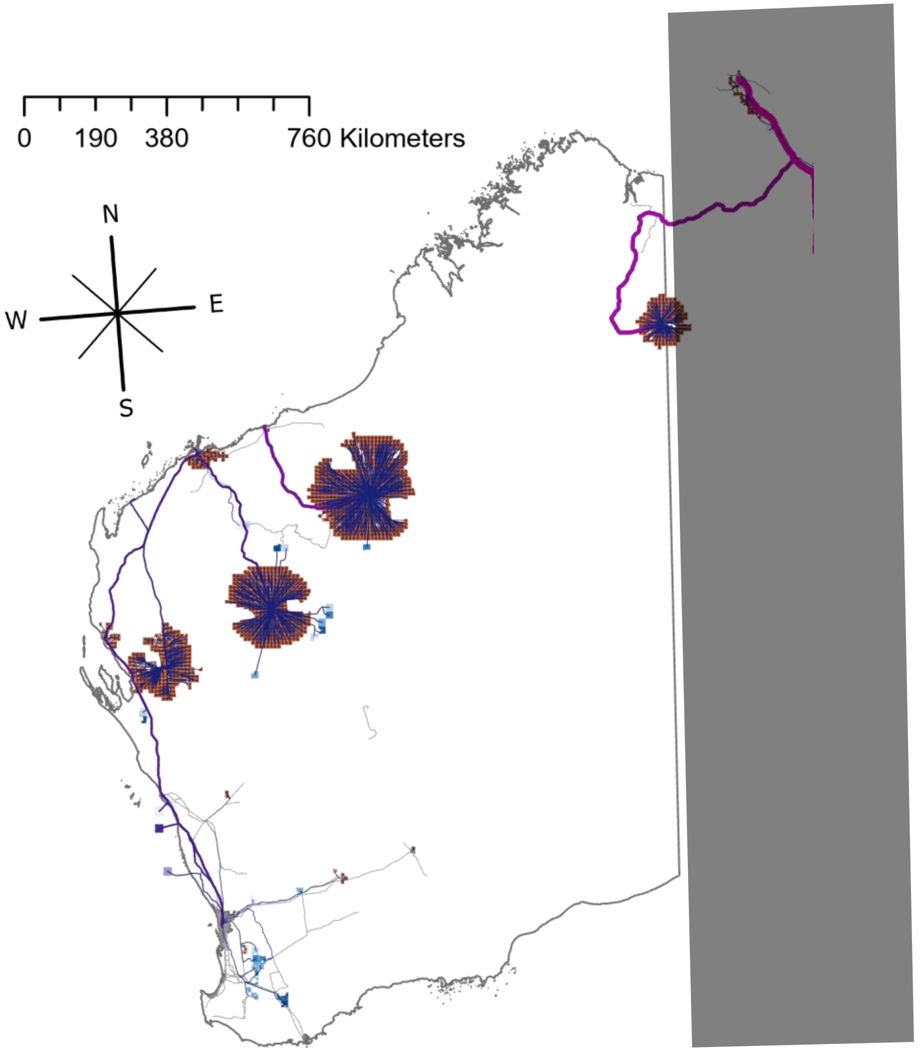
- **Export potential is highest when WA makes direct reduced iron** onshore from its iron ore and hydrogen but will require a new industrial complex, community acceptance and willing trading partners.

INDICATIVE ONLY

	Wind	Solar
Capacity installed (GW)		
	25.2	1138.9
Area used (1000 km2)		
Total	8.55	25.31
Direct	0.09	23.03
Transmission added (GW-km)		
Capacity domestic area		14026
Capacity export zone		101622
Capacity not sited		6346

Core scenario definition

- Domestic production of iron and aluminium using clean energy
- Progressively displaces exports of iron ore, bauxite, alumina and fossil fuels



Transmission (MW)

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ABS SA2 region with population > 5,000 people & density > 100 people/km^2

INDICATIVE ONLY

E+ 2060
Sensitivity: RemoteCost+

- Small increases in capital costs in the sunbelt swing exports to **lower cost states.**

	Wind	Solar
Capacity installed (GW)		
	20.0	166.8
Area used (1000 km2)		
Total	6.67	3.71
Direct	0.07	3.37
Transmission added (GW-km)		
Capacity domestic area		23280
Capacity export zone		16089
Capacity not sited		4171

Sensitivity definition

- RemoteCost+: capital costs +30% in WA-north, WA-export, and NT, +15% in QLD-north and QLD-export

Transmission (MW)

- 5
- 6,627
- 13,255
- 19,882

VRE project capacity factors

Solar PV	Onshore wind	Offshore wind
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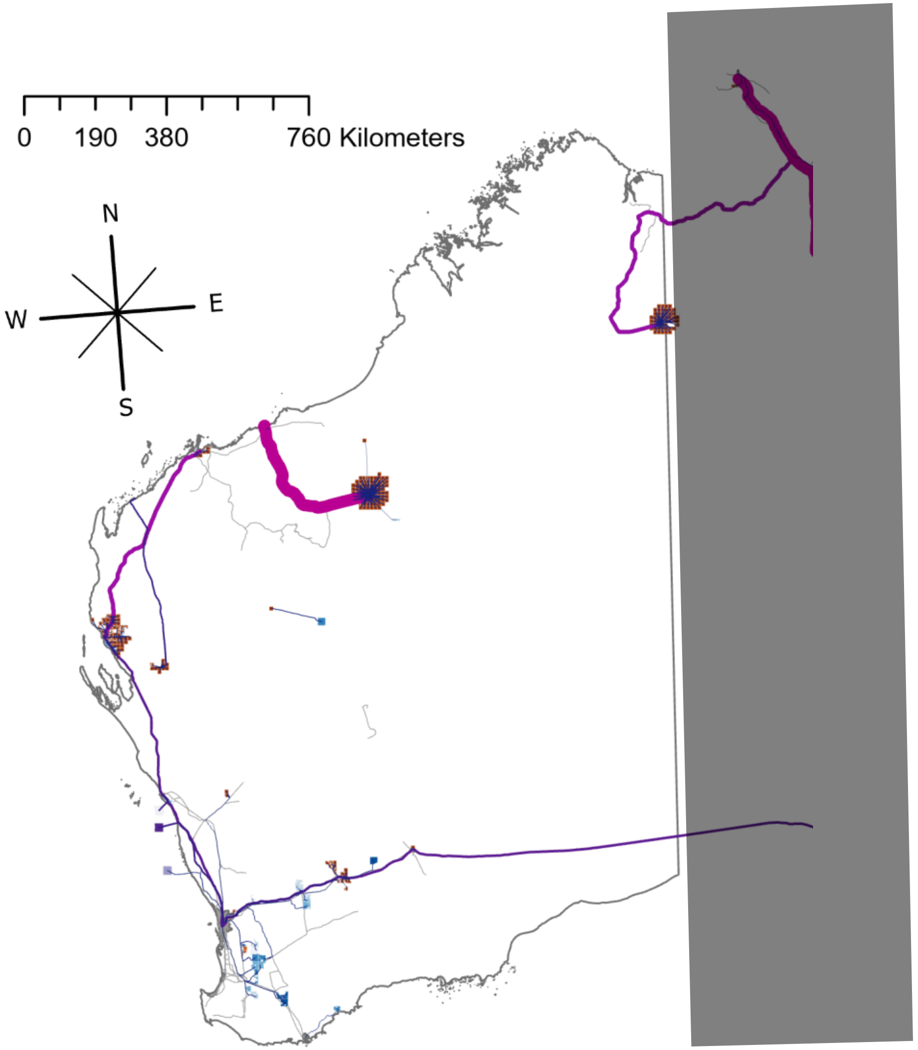
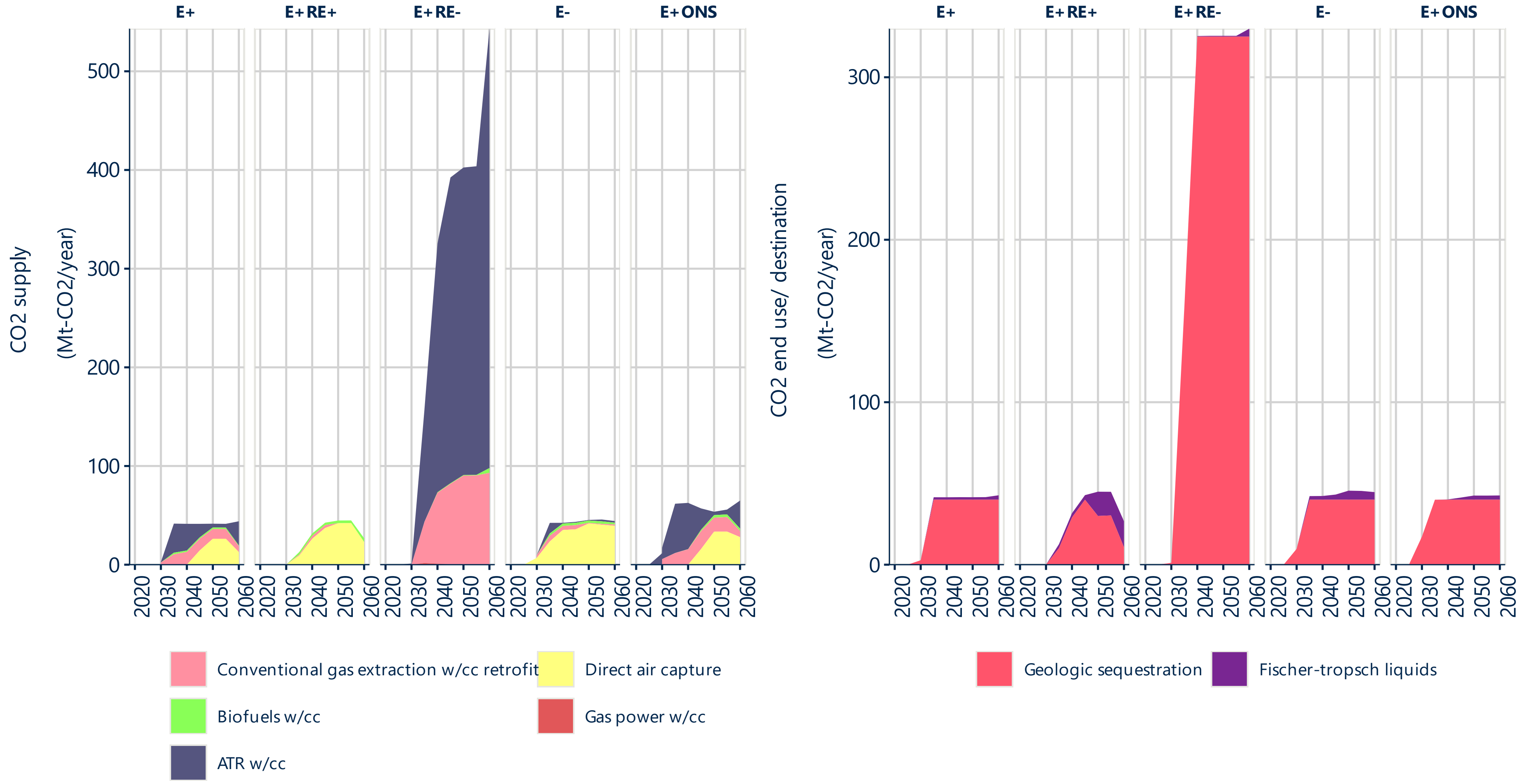


ABS SA2 region with population > 5,000 people & density > 100 people/km^2

Carbon capture, utilisation and storage (CCUS) expands rapidly within WA reflecting its CO2 storage potential

Projected CO_2-supply, by technology (Mt-CO_2/ year). Note varying y-axis scales.

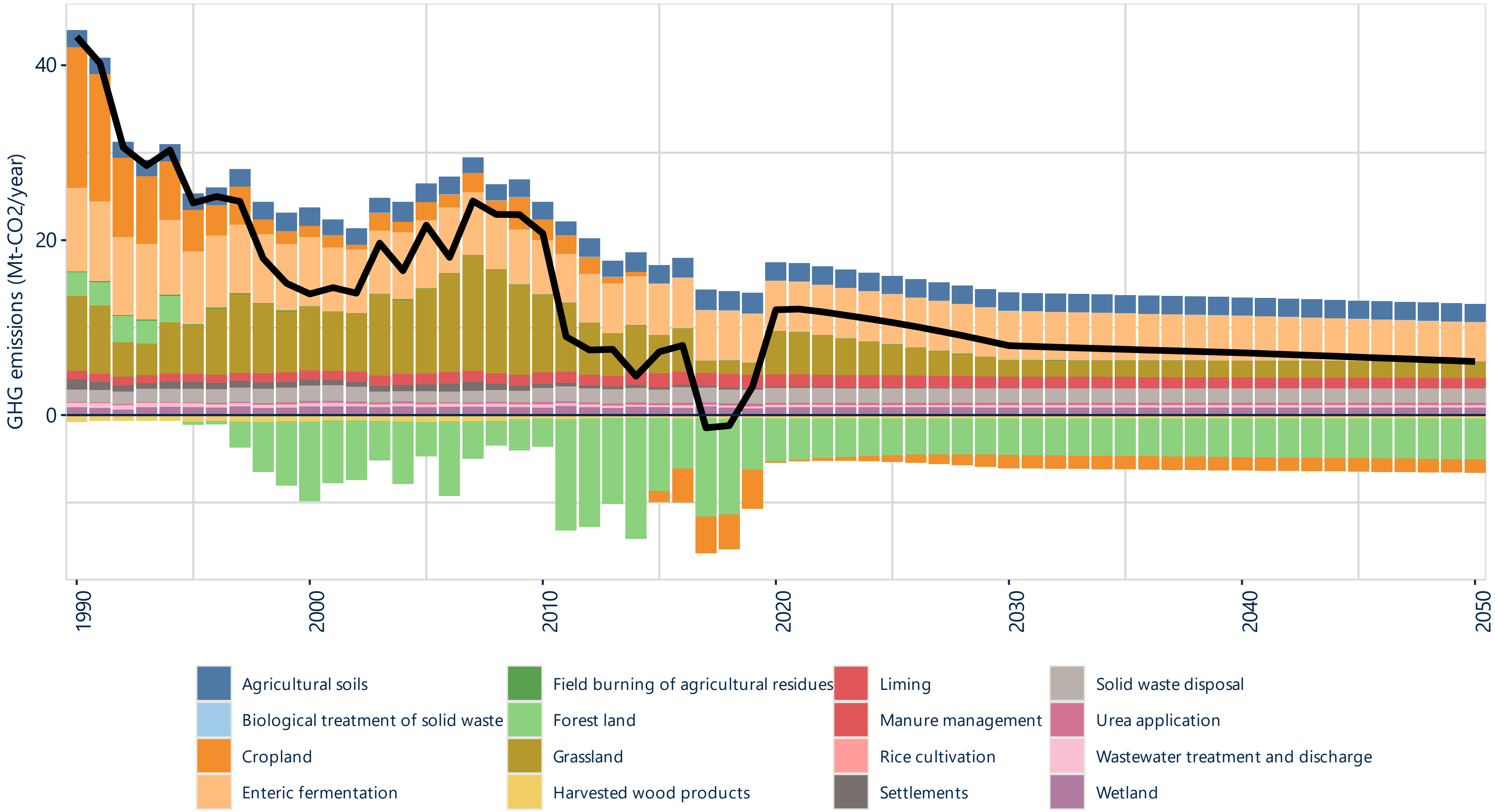


KEY TAKEAWAYS

- Geological sequestration limit is rapidly reached in E+, E−, and E+ONS by 2035; used for cement process emissions, biofuels, and direct air capture (DAC).
- E+RE− assumes a higher geologic sequestration limit, which is required to meet constant annual export energy demand. Expansion of conventional gas production in E+RE− requires capture and sequestration of process CO_2 emissions from both gas extraction and autothermal reforming.
- WA captures and stores comparatively higher levels of CO_2 reflecting the amount of available CO2 storage potential within the state.

Western Australia's land sector approaches but does not reach net zero by 2050

GHG emissions trajectory for the combined land sector (agriculture, waste and LULUCF)
(Mt-CO_2e/year). Black line shows net GHG emissions



KEY TAKEAWAYS

- Combined land sector emissions stabilizes at 2025 and remains at ~5 Mt-CO_2e/year by 2050.
- Enteric fermentation is the most substantial contributor to GHG emissions.
- This means that the land sector will likely *require* offsets, not become a source of them.

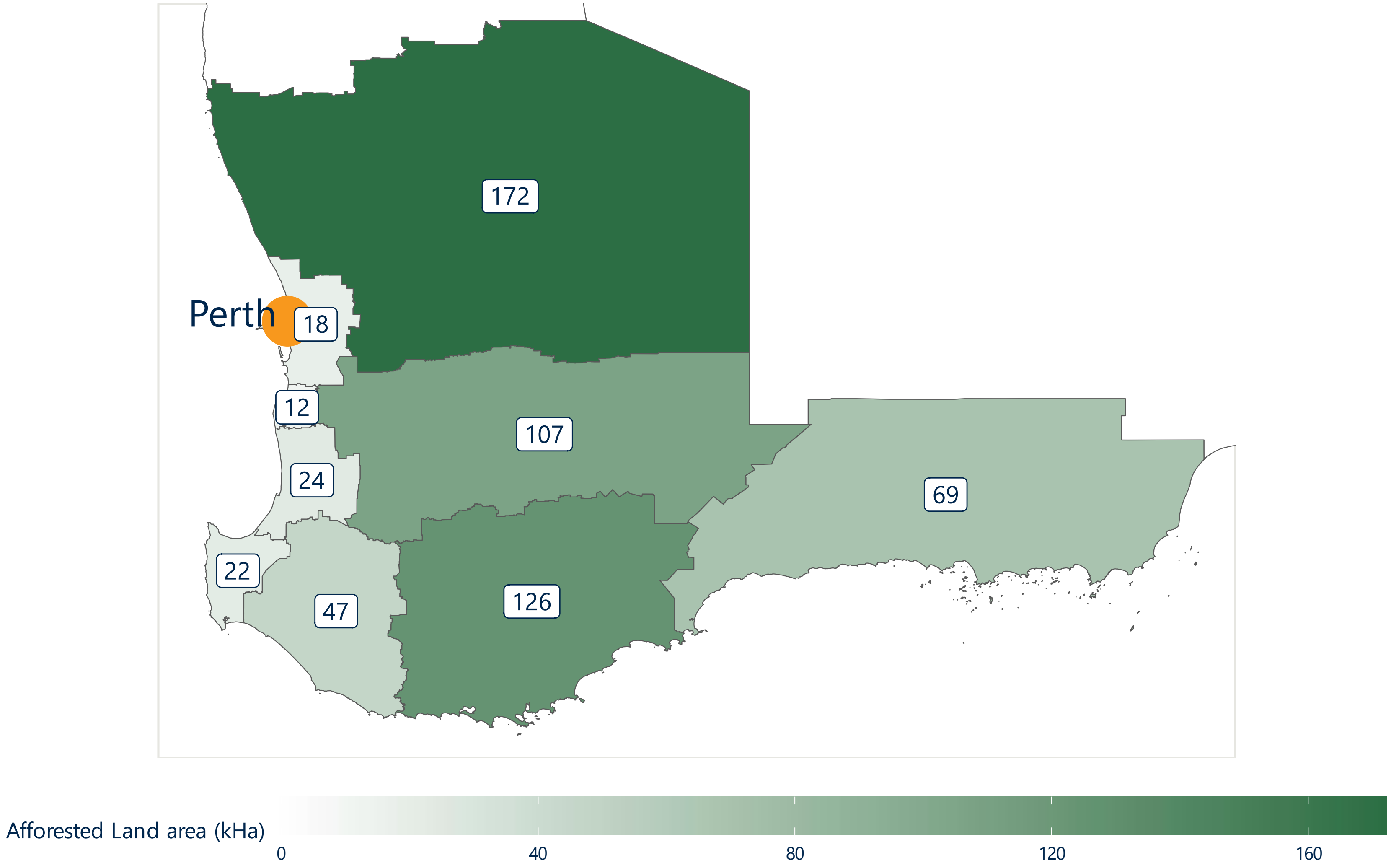
Afforestation of 597 thousand hectares of farmland is possible in Western Australia

SENSITIVITY

Land+

Combined land sector goes to modest net negative emissions

Downscaled farmland afforestation in Western Australia by ABS Statistical Areas 4 (kHa).



KEY TAKEAWAYS

- Any program establishing trees on farmland should consider: the impact of natural disturbances and climate change, the need for carbon monitoring improvement, and the impacts on stakeholders.
- Farmland afforestation is primarily available within the southern part of WA. Midlands makes up the highest proportion (32.5%) of available land for afforestation.

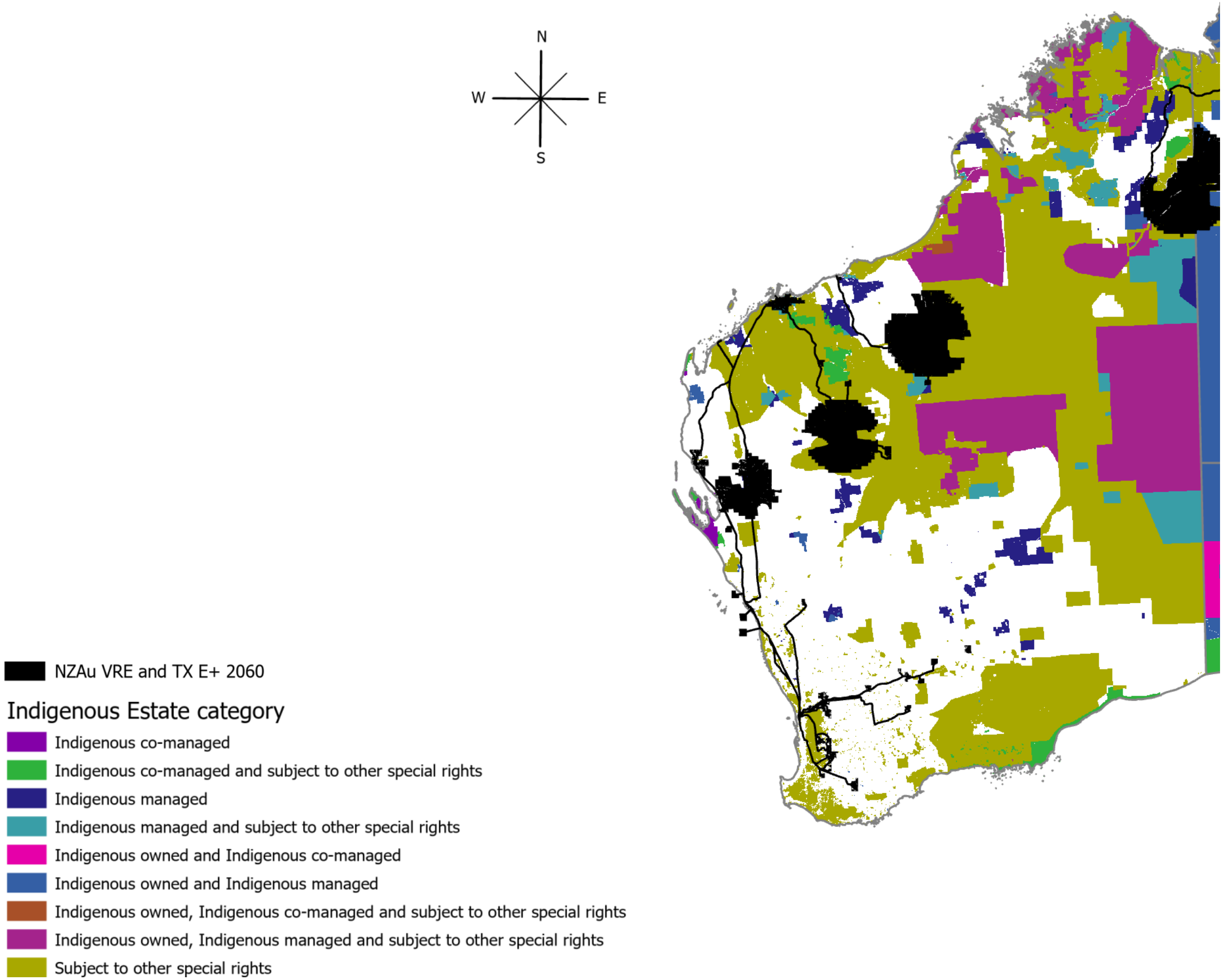
Note: The diagram zooms in on the area around Greater Perth. ***The other regions of WA are modelled to have 0 afforestation.***

INDICATIVE ONLY

LAND IMPACTS E+ 2060

Indigenous Estate

- No Indigenous Estate [1] category was excluded from the siting of VRE or transmission (unless part of CAPAD).



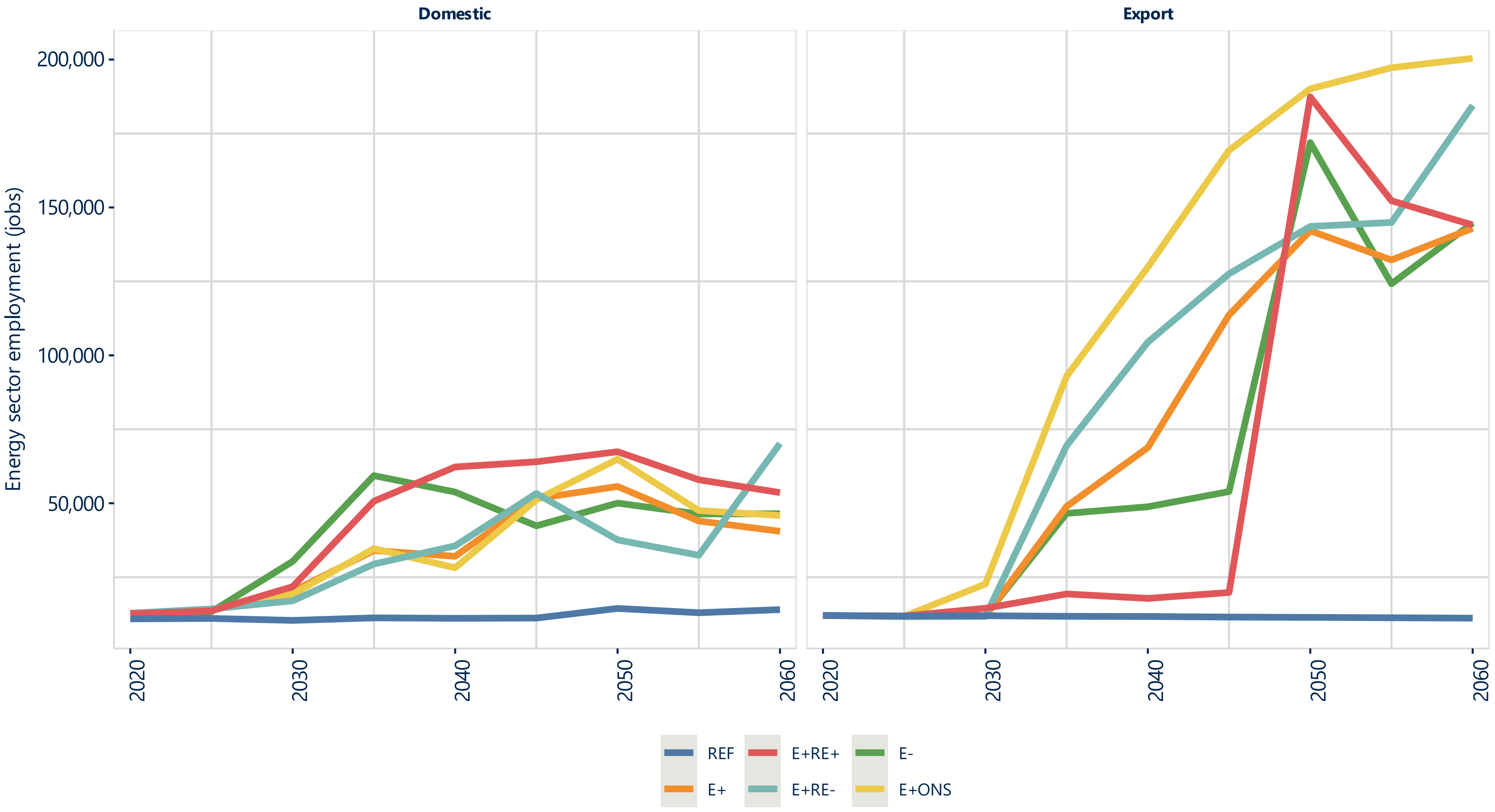
Note: the specific location of export zones are assumed not optimised

L. Lymburner, P. Tan, A. McIntyre, M. Thankappan, and J. Sixsmith, "Dynamic Land Cover Dataset Version 2.1," Geoscience Australia, Canberra, 2017. Accessed: June 21, 2021. [Online]. Available: http://pid.geoscience.gov.au/dataset/ga/83868a

Gross energy sector employment could be 175 – 245 thousand by 2060, across both domestic and export energy systems

EMPLOYMENT

Net energy sector employment (Jobs), domestic system and export system



KEY TAKEAWAYS

- Thousands of jobs are needed to serve energy systems in all Scenarios.
- Gross domestic jobs do not significantly vary between most Scenarios, with between ~40-55 thousand jobs required in 2060 for all scenarios.
- Gross export jobs also do not significantly vary, with between ~135-200 thousand jobs modelled for all net zero Scenarios in 2060.
- Gross export jobs are highest in the E+ONS Scenario, due to WA's potential for large scale processing of minerals.

Modelling note

- Gross jobs represent the total number of jobs in each year employed in the energy sector.

CONCLUSIONS – STRATEGIC DIRECTIONS

OPTIONS

- **Accelerate all options** that could make a material contribution to decarbonisation.
- Strengthen deployment drivers of **renewables**, **transmission**, and **electricity storage.**
- Build a large fleet of **gas-fired peaking generation** to help accelerate renewable growth, and close coal power on time.
- Do not factor **nuclear power** into renewable, storage, and firming targets.
- Work with other states to **prepare CCUS networks and basins** for large-scale use.

EXPORTS

- Western Australia should pursue **both clean energy and clean processed minerals** as export opportunities.
- **A clean energy export framework will be needed** to ensure that we phase out fossil fuel exports and grow clean energy exports in an **orderly, fair, and net zero-compatible transition**

IMPACTS

- The speed of **land use change** will be essential and requires proactive management, particularly for First Nations communities and farming communities.
- Minimising public impacts requires **orderly asset closures**, supported by multiple policy mechanisms.
- **Low-income households** and **fossil fuel regions** will need support to mitigate impacts.

ROLES

- **Governments** must stimulate and coordinate **private action**, and decide who pays, and how.
- Private sector **investment risk** will be too high in many cases, unless mitigated by government.
- Building net zero workforces and supply chains requires a certain, large, and long **investment pipeline.**
- Net zero must be a **high national priority** for decades, requiring sustained leadership and collaboration.

NZAu is funded by gifts and grants, and engages broadly.

SPONSORS

Generous financial support has enabled this study

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FUTURE FUELS CRC

MINDEROO FOUNDATION

Worley energy | chemicals | resources

Gift and grant agreements protect the project's independence

ADVISORY GROUP

Crucial input is being provided by diverse advisers

AUSTRALIAN CONSERVATION FOUNDATION

ENERGY CONSUMERS AUSTRALIA

CLIMATE COUNCIL

National Farmers Federation

THE ETHICS CENTRE

St Vincent de Paul Society NATIONAL COUNCIL of AUSTRALIA Inc. good works

National Native Title Council

INDEPENDENT MEMBERS

SPONSOR NOMINEES

ENGAGEMENT

Numerous briefings have been provided to:

COMMONWEALTH MINISTERS AND DEPARTMENTS

STATE MINISTERS AND DEPARTMENTS

NON-GOVERNMENT ORGANISATIONS

RESEARCH BODIES

A website has also been established netzeroaustralia.net.au

NZAu has consulted widely with the project's sponsors, Advisory Group members and many stakeholders, but is independent of all of them. NZAu does not purport to represent their positions or imply that they have agreed to our methodologies or results.

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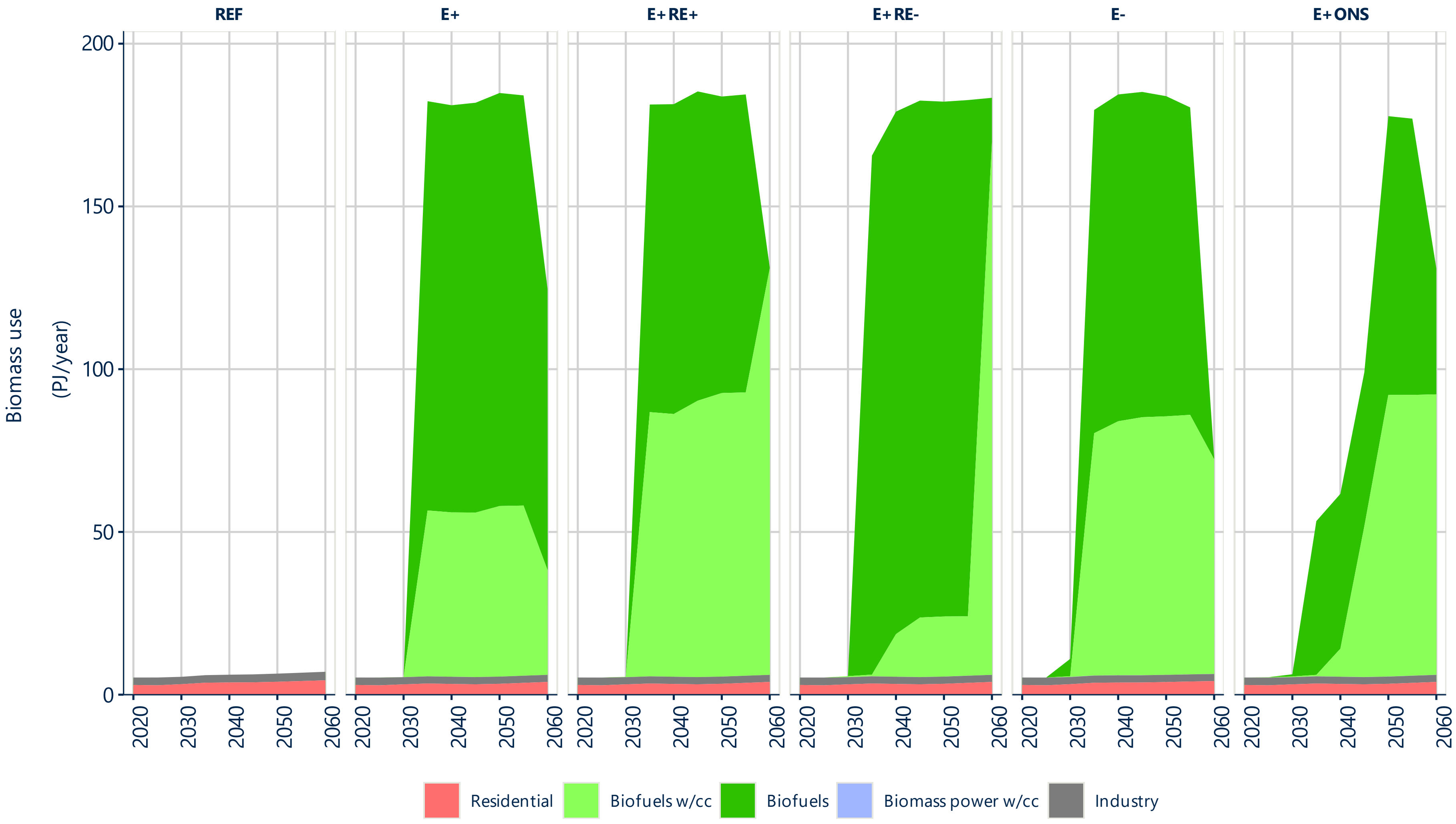
Bioenergy potential is limited by sustainable supply of biomass, but still expands by ~20× to ~165 PJ/year

Projected biomass use, by sector/ technology (PJ/ year).

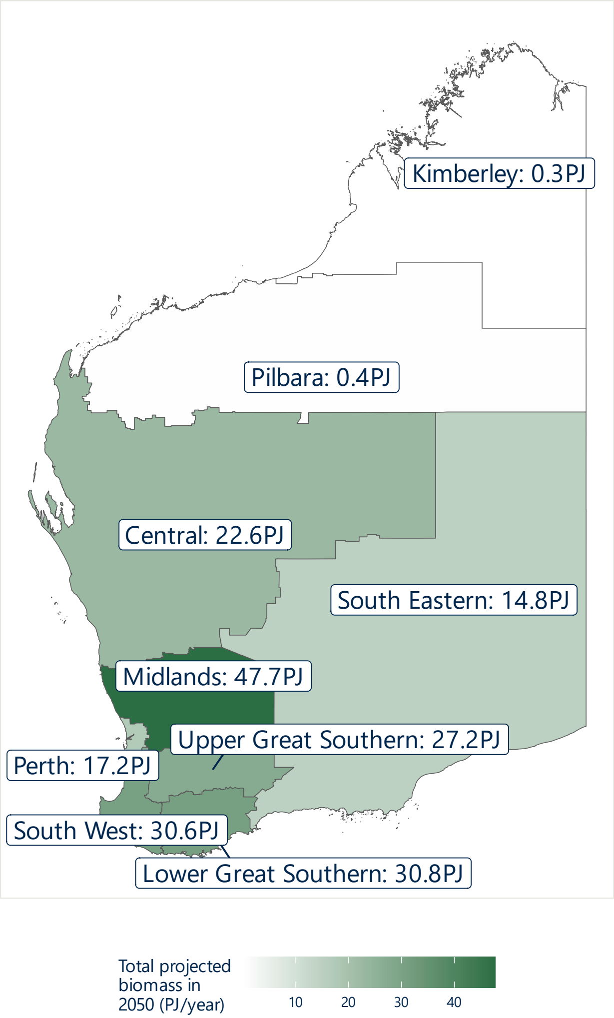


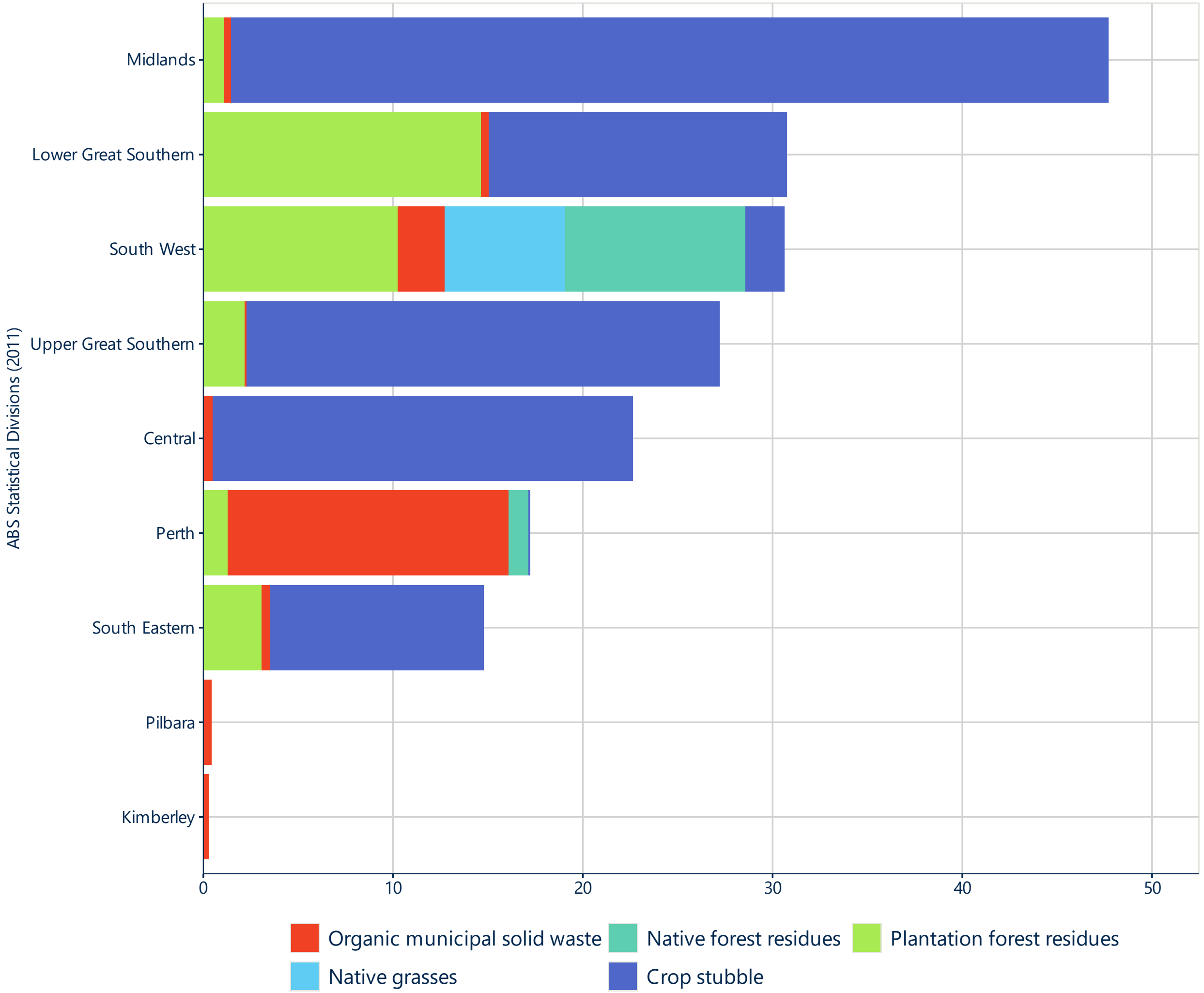
KEY TAKEAWAYS

- Western Australia's limited biomass supply is used up to sustainable resource availability in all Scenarios to produce biofuels, including bio-synthetic natural gas, hydrogen, and bio-oils.
- ~60-65% of biofuel production is coupled with CCUS, which constitutes atmospheric CO_2 removal (i.e. negative emissions).

Western Australia's biomass resource is mostly made up of crop stubble produced in southern regions

2050 biomass resource availability (PJ/year). Aggregated by resource type and ABS statistical division





PILLARS

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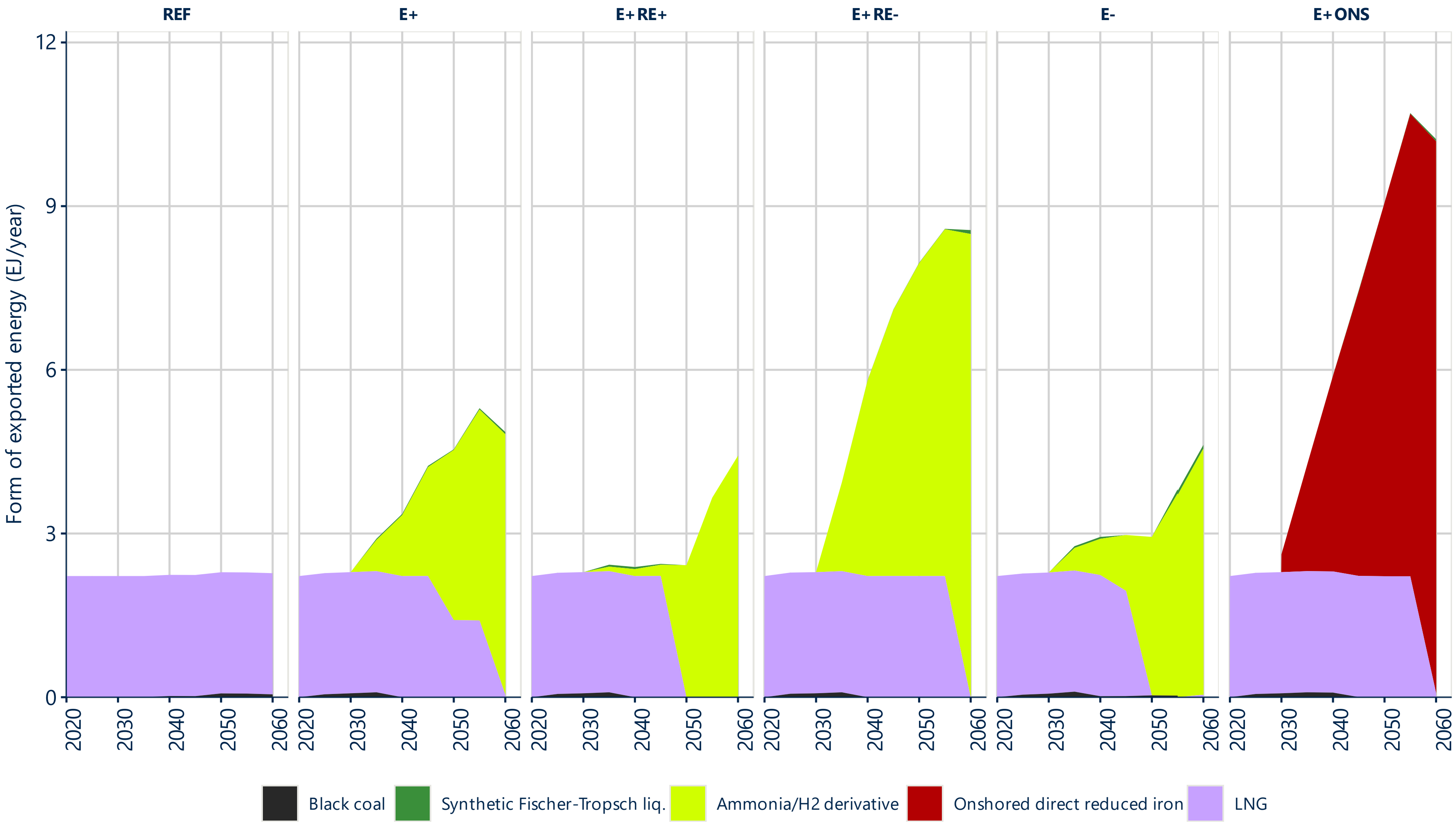
Zero carbon fuels and feedstocks

KEY TAKEAWAYS

- Approx. 191.6 PJ/year is available dry biomass resource, comprising organic municipal waste from cities, waste residues from cropping and forestry, and native grasses.
- Biomass is used primarily to produce low-emissions gaseous fuels (methane/SNG and hydrogen via biogasification) for pipeline injection.
- Treatment largely occurs in the south western regions, through SNG biogasification, with some carbon capture.
- Limited liquid biofuels production in some Scenarios.

WA's export potential is highest when it onshores production of direct reduced iron – from its iron ore and hydrogen

Projected form of exported energy (EJ/year)



KEY TAKEAWAYS

- Hydrogen (assumed here to be in the form of ammonia) dominates energy exports in most Scenarios except in E+ONS, where onshored processing of WA iron ores dominates.
- WA's export potential is greatest, up to 5 times REF, when it onshores direct reduced iron due to the coincidence of large iron ore deposits and world class solar resources.
- Exports of hydrogen are higher when renewables are constrained due to use of natural gas to produce hydrogen through auto-thermal reforming with the resultant CO2 stream sequestered in WA and interstate fields.