Interim results

August 2022

NET ZERO
AUSTRALIA

THE UNIVERSITY OF MELBOURNE

THE UNIVERSITY OF QUEENSLAND AUSTRALIA
CREATE CHANGE

PRINCETON UNIVERSITY

nous

Table of Contents

About the Net Zero Australia study

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 for its 2020 ***Net-Zero America study.***

NZAu is funded by gifts and grants, and engages broadly

SPONSORS

Generous financial support has enabled this study

apa
Dow
FUTURE ENERGY EXPORTS Cooperative Research Centre
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
ACTU australian council of trade unions
CLIMATE COUNCIL
ENERGY CONSUMERS AUSTRALIA
THE ETHICS CENTRE
National Farmers Federation
National Native Title Council
St Vincent de Paul Society NATIONAL COUNCIL of AUSTRALIA Inc. good works

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

The Net Zero Australia website has more information – visit netzeroaustralia.net.au

The Net Zero Australia team

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The net zero challenge is broken down into six inter-related research streams

The research is being conducted collaboratively across partner institutions.

RESEARCH STREAMS

ENERGY SYSTEM
Electricity, coal, natural gas and hydrogen production and transmission

INDUSTRY
Cement, hydrogen, chemicals, fertiliser, iron, and steel

'DOWNSCALING'
Individual energy assets sited to a fine resolution

TRANSPORT SYSTEM
Light and heavy transport over land, sea and air

VEGETATION, LIVESTOCK, WASTE
Plantations, forests, agriculture and waste

'MOBILISATION'
Investment and public support for decarbonisation

We modelled six varied scenarios

REF

Reference
- Projects historical trends, does not 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
- No limit on renewable rollout
- Lower cap on underground carbon storage

E-

Slower electrification
- Slower electrification of transport and buildings compared to E+
- No limit on renewable rollout rate
- Lower cap on underground carbon storage rate

E+ RE+

Full renewables rollout
- No fossil fuel use allowed by 2050
- No limit on renewable rollout rate
- Lower cap on underground carbon storage rate, which is only used for non-fossil fuel sources (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)

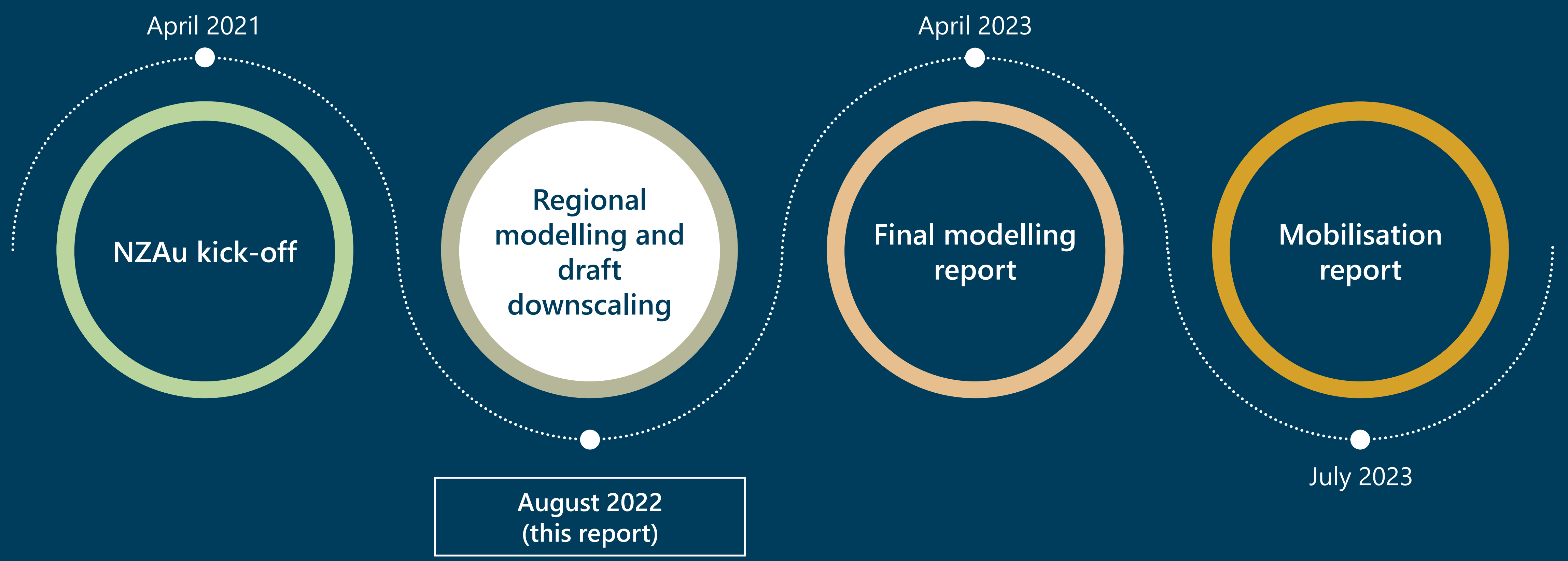
E+ ONS

Onshoring
- Local 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.

This document is the first of our public results

NET ZERO AUSTRALIA STUDY TIMELINE



About the modelling: approach and scenarios

Modelling approach

We are modelling a straight line reduction from 2020 to net zero in 2050 for Australia's **domestic emissions**.

We are modelling a straight-line reduction from 2030 to net zero in 2060 of **offshore emissions from fossil fuel exports**. The target date reflects commitments by major trading partners.

We will also model **faster decarbonisation** – net zero in 2040 for domestic emissions, and 2050 for exports.

We project **energy demand** (e.g. for lighting, cooling, mobility, and industrial production) using assumptions of economic growth and energy saving.

We use projections of **future technology costs** that are drawn from the most authoritative, independent sources and tested with experts, though the inherent uncertainty of cost projections means they are only indicative.

The model determines the **lowest-cost mixes** of energy resources and energy uses to meet the net zero target, subject to constraints imposed in each Scenario.

We have used 'downscaling' to model **changes in land and sea use** at a fine resolution.

We will run **sensitivities** to understand how the results change when different assumptions are varied (see next page).

Our public **MASS pack** details our methodology, assumptions, scenarios and sensitivities for our regional investment modelling. The complete methodology for our downscaling will be published later in the project.

Design of Scenarios

We have chosen Scenarios that reflect the **boundaries of the Australian debate** on how to achieve net zero emissions.

- Most Scenarios place no limit on the rate at which renewables can be built. One scenario (E+RE-) tests what happens if we do hit a limit, which could result from numerous factors including supply chain constraints, opposition to land use change, and skills shortages.
- One Scenario (E+RE+) allows only renewables for new build energy production. The others allow the option of fossil fuels with carbon capture, utilisation and storage (CCUS) together with renewables.
- We have set different limits on the rate at which carbon dioxide can be injected into geological storage. These limits are based on the advice of specialists and enable net zero emissions in all Scenarios.
- Opportunities for domestic electrification are assumed to be fully realised by 2050 in most Scenarios (E+). One Scenario imposes a slower rate of electrification (E-).
- We have assumed a much higher rate of energy productivity improvement than historical rates, and these arise from both electrification and energy efficiency.
- We have excluded nuclear from the core scenarios but plan to run a sensitivity in which nuclear power competes in the energy mix.

About the study

What *does* this study do?

This study **illustrates pathways to net zero**, that reflect the boundaries of the Australian debate.

Our purpose is to help individuals, communities, companies and governments appreciate:

- the **scale, complexity and cost** of the net zero task,
- different ways in which **the future could unfold**,
- **how we all might contribute** to the required changes, and
- how **unintended consequences** might be avoided and **negative impacts** reduced.

What *doesn't* this study do?

This study **does not make predictions**. What will actually happen over the coming decades may be within the boundaries of our Scenarios. However it will not be the same as any one of them.

We do not know if any one Scenario is more or less achievable than the others, and our study **does not recommend one pathway over any other**. The synchronisation of actions by many governments, businesses, communities and households, that would be required to achieve net zero by any pathway, will be explored in the mobilisation workstream.

Our study also **does not consider fossil fuel supply constraints** such as those that have driven recent rises in coal and LNG prices, and which would likely narrow the cost gap between the Reference Scenario and net zero Scenarios.

Our study **does not model the costs of inaction** on climate change, which would add substantially to the costs of the reference case.

We do not model **demand for clean energy exports**, which is uncertain.

About the modelling: possible sensitivity analyses

We will conduct sensitivity analyses, which involves varying some assumptions and inputs to explore their impact on the modelling results.

Sensitivities that we will consider running are presented in the table to the right. The final list will be decided later in the project.

Not all these examples will be run, and others may be added.

SCENARIO	SENSITIVITY	SHORT DESCRIPTION
E+	Export+	Energy exports are linearly increased to 30EJ from 2040 to 2060
E+	Export–	Energy exports decline linearly to 5EJ from 2040 to 2060
E+	Incomplete Export	Export embodied emissions do not need to go to zero (some importing countries may have option of sequestration). 50% export decarbonisation by 2060.
E+	Faster	Emissions constraint is applied to domestic emissions in a linear trajectory from 2020 to 2040, and to export emissions in a linear trajectory from 2020 to 2050.
E+	Drivers+	GDP growth 2.5% pa from 2020; population growth 1.5% pa from 2020
E+	Drivers–	GDP growth 1.5% pa from 2020; population growth 0.9% pa from 2020
E+	Cost of Capital+	Elevated costs of capital using a multiplier of 1.5 on both inflation and WACC assumptions across all asset categories
E+	Solar–	Use a less ambitious capital cost trajectory for solar PV.
E+	RE Cost+	All core E+ technologies (wind, solar, CCUS, electrolysis, Direct Air Capture (DAC)) undergo more rapid cost reductions (2x assumed learning rate)
E+	Transmission–	All interstate transmission is fixed at current capacities for electricity, CH_4, H_2 and CO_2.
E+	Landuse–	Greater restrictions on land use. No infrastructure built on lands that have: been determined exclusive for native title, more than 1 threatened species, been classified as rainfed cropping land.
E+	Fossil+	Fossil fuel prices are increased.
E+ RE–	Methane+	Fugitive methane emissions associated with fossil fuel supply chains do not decline in proportion with declining fossil fuel extraction.
E+ RE–	Nuclear	Nuclear power is allowed, with first capacity to serve from 2035 onwards.
E+/E–	Biomass+	Additional dry biomass resource available as a result of planting 5 million ha of new trees for negative Land Use, Land Use Change and Forestry (LULUCF) emissions.

Key insights

Key insights from interim modelling results

Net zero is both an immense challenge and a once-in-a-generation, globally significant and nation-building opportunity

1. Renewables will produce most or all domestic energy by 2050
2. More productive use of energy can keep domestic demand about the same, despite population growth
3. Carbon capture, utilisation and storage (CCUS) can play an important role, complementing renewables
4. Unprecedented capital investment is needed, which will produce significant benefits
5. Domestic energy's share of GDP need not rise above today's level, while being less prone to price shocks
6. Clean energy can replace our fossil fuel exports
7. The cost to export clean energy may rise, but should be competitive in a decarbonising global economy
8. A large workforce with new skills will grow across the nation, particularly in northern Australia
9. Emissions from farms, forestry and waste should fall, but are unlikely to reach net zero
10. Large changes in land and sea use will occur, and will need careful planning and community engagement

Renewables will produce most or all domestic energy by 2050

1

Solar and wind will be the main sources of renewable energy for domestic use.

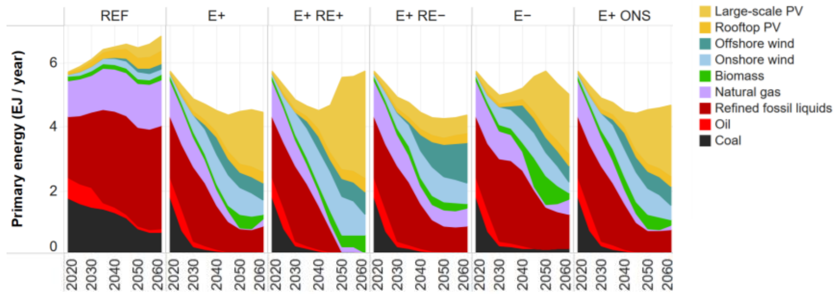
Offshore wind will begin to play a significant domestic role after 2030, as costs fall.

Rooftop solar and **biomass** will also play a significant role.

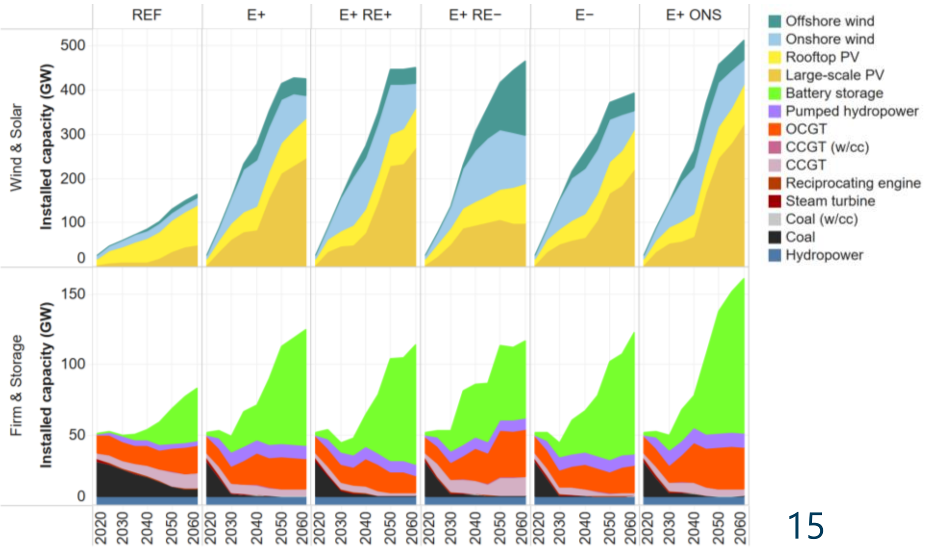
The required **rate at which renewable energy capacity is added** will be much higher than historical levels.

Natural gas and oil products will play a significant role in all Scenarios (with CCUS), except if they are not permitted (which is modelled in E+RE+).

Projected domestic primary energy (Exajoules/year)



Projected domestic electricity generation capacity (Gigawatts)



More productive use of energy can keep domestic demand about the same, despite population growth

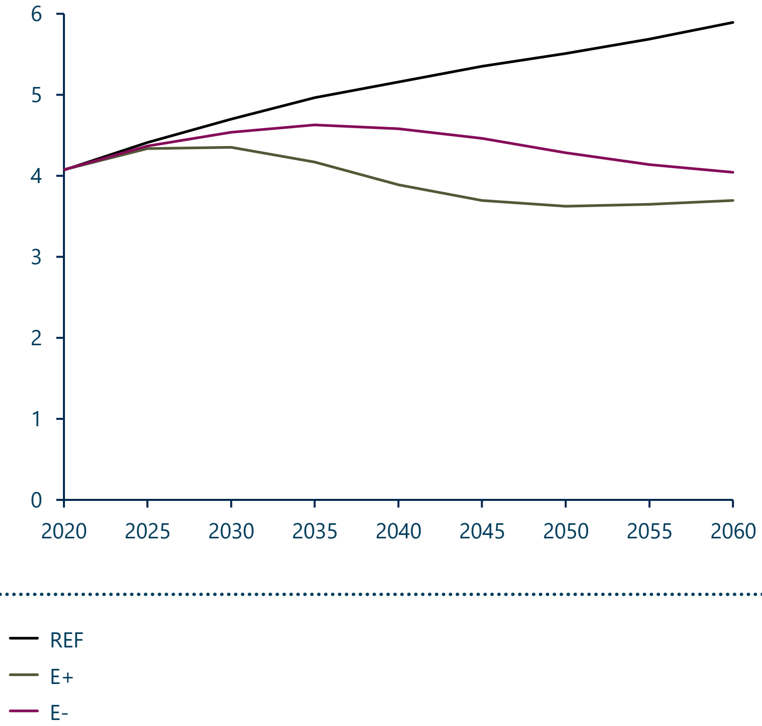
2

Progressive adoption of more **energy-efficient technology** will keep 2060 energy demand to around 2020 levels, despite substantial population and GDP growth.

Some efficiency will come from **electrification**: switching to new energy sources such as electric vehicles and heat pumps.

Some efficiency will also come from **upgrading technologies** now in use.

Projected domestic final energy demand (Exajoules/year)



Carbon capture, utilisation and storage (CCUS) plays an important role, complementing renewables

3

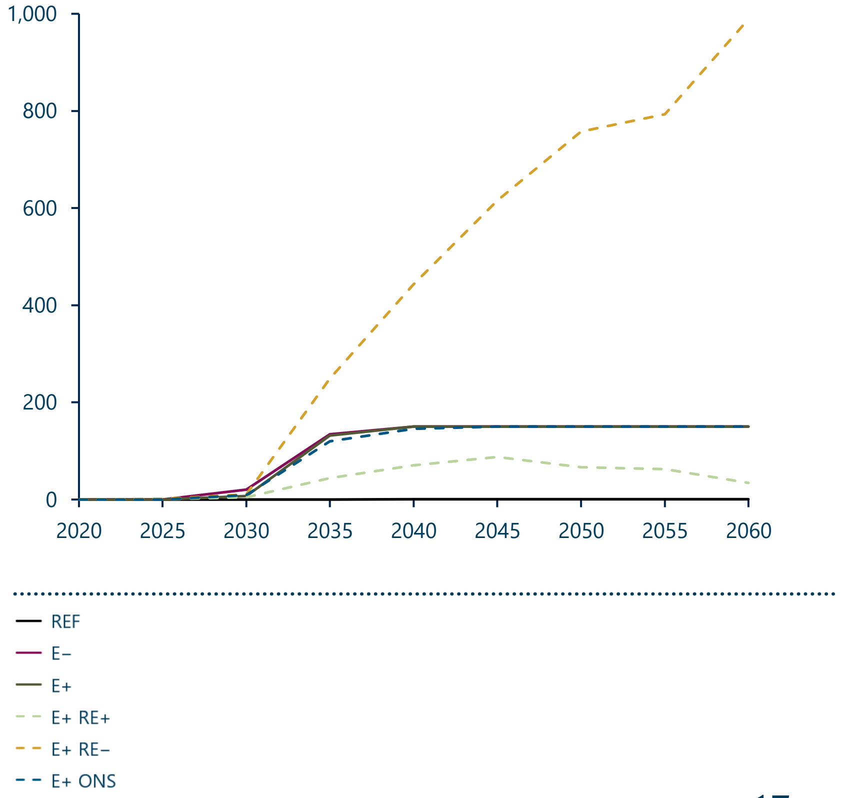
CCUS is needed in all Scenarios for:

- **non-energy uses** such as making cement and chemicals; and
- **producing 'negative emissions'**, i.e. storing carbon emissions taken out of the atmosphere using renewables ('direct air capture').

If the rate at which renewables and transmission are built encounters limits, **CCUS with fossil fuels** will help reach net zero.

Most carbon emissions will be permanently stored in **deep underground formations**, and some will be used in industry.

Geological CO_2 sequestration (Mt-CO_2/year)



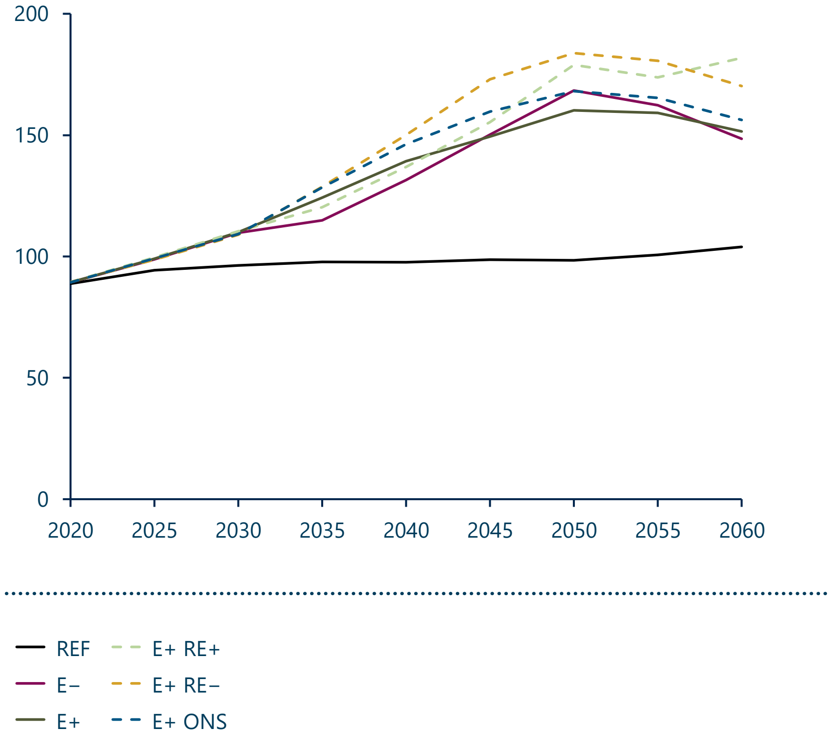
Unprecedented capital investment is needed, which will produce significant benefits

Decarbonisation needs **much higher investment** than continuing to use fossil fuels, because our current infrastructure is designed for that purpose. (This is expressed in the graph as a rise in levelised costs.)

However:

- The **costs of inaction** would be substantial if decarbonisation does not occur in Australia and globally.
- Decarbonisation will **reduce our reliance on gas and oil imports**, hence our exposure to price swings and supply constraints caused by international events.
- **Conventional technologies that use fossil fuels** (which we mostly import, such as petrol vehicles) will become less available as global decarbonisation proceeds.

Levelised domestic energy system cost
(2020 A$ billion / year)



Domestic energy's share of GDP need not rise above today's level, while being less prone to price shocks

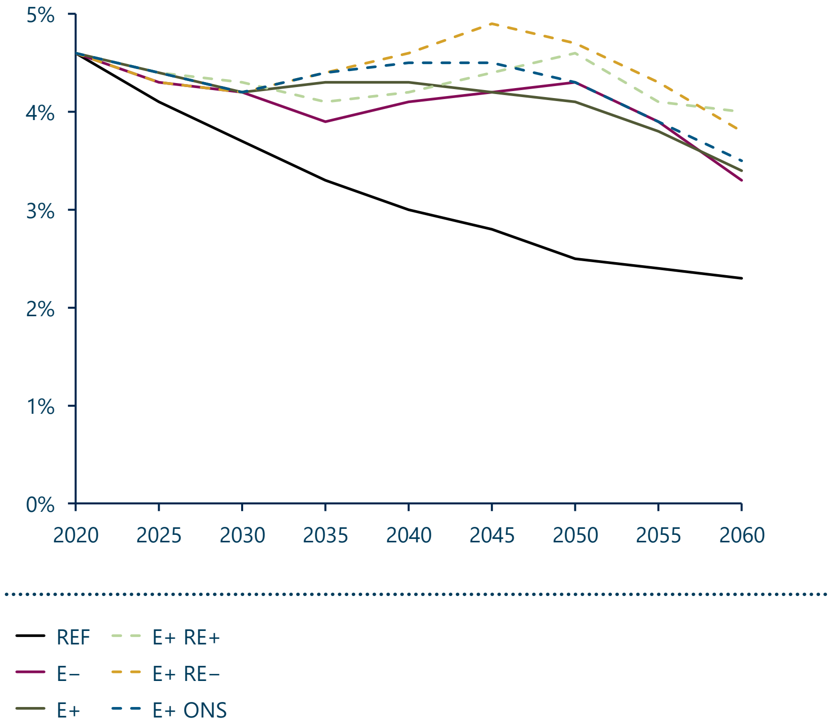
5

Domestic energy costs will account for a **similar share of the economy** in the transition to net zero as energy does now.

The shift to capital-intensive renewable electricity should reduce the economic impact of commodity **price shocks**.

Placing fewer constraints on the transition (e.g. in the choice of energy sources) results in **lower costs**.

Levelised domestic energy system cost as share of GDP
(% Australian Gross Domestic Product)



Clean energy can replace our fossil fuel exports

6

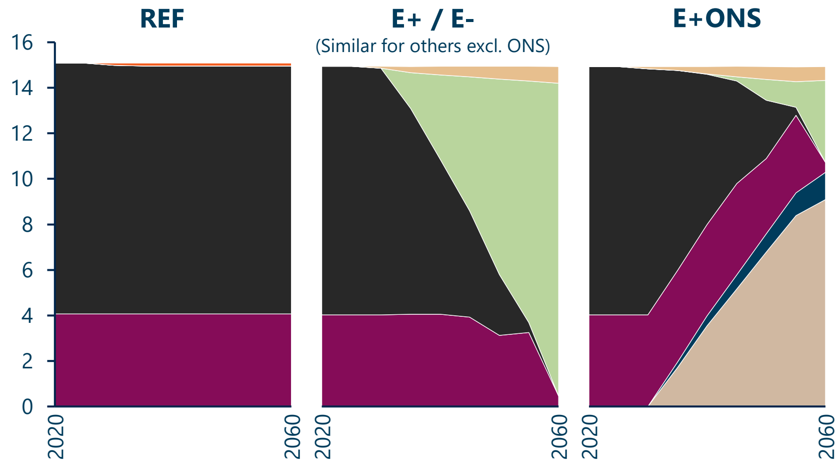
Australia has the resources to build a new **clean export industry** as coal and gas exports decline, by:

- producing **clean energy carriers** (e.g. hydrogen, ammonia); and
- **‘onshoring’** the processing of minerals domestically using clean energy.

‘Green’ hydrogen from solar (converted to ammonia or liquefied) is projected to be the largest clean energy export. Hydrogen from wind will also contribute.

‘Blue’ hydrogen (from fossil fuels with CCUS) could contribute a substantial share if the rate of renewable development encounters limits, and a very high rate of carbon storage is achieved.

Energy exports (Exajoules/year)



- Electricity export cable
- Ammonia/H2 derivative
- Black coal
- LNG
- ‘Onshored’ Aluminium
- ‘Onshored’ Iron

‘Onshored’ refers to exported ‘clean’ products which are manufactured domestically using clean energy as inputs and then exported. This progressively displaces exports of iron ore, bauxite, alumina and fossil fuels.

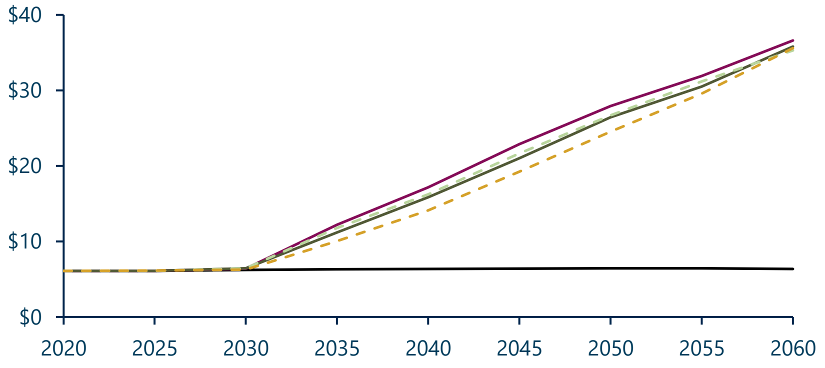
The cost to export clean energy may rise, but should be competitive in a decarbonising global economy

7

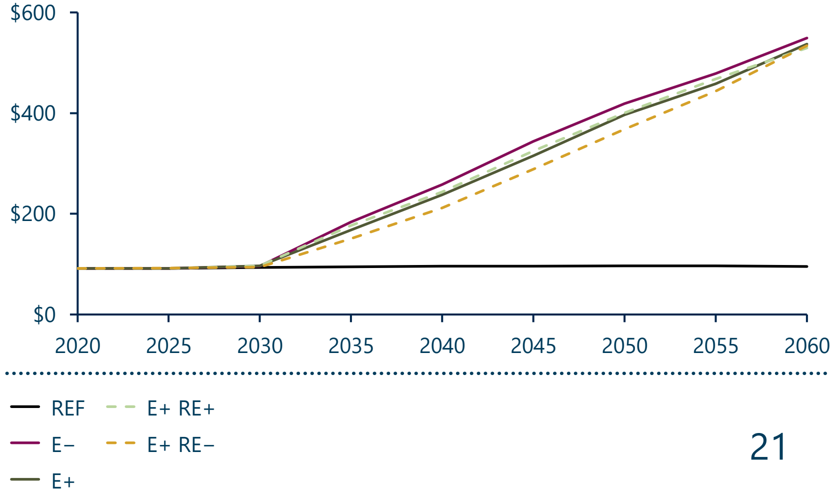
The **cost of decarbonised exports** will be higher than average pre-COVID prices of our coal and LNG exports. However:

- **Current crude oil and LNG spot prices are comparable** to our projected clean energy export costs, and our Reference Scenario does not include the impact of future fossil fuel supply constraints and disruptions.
- **Australian energy exports should be cost-competitive** with other potential exporters in a decarbonising world economy, and **import demand could be substantial** because some of our trading partners have limited clean energy resources.
- There is significant potential for **innovation in electrolysis and renewables**, which would lower export costs.
- **Onshoring avoids the costs of producing and exporting clean energy carriers**, and has high potential in Australia due to the proximity of major renewable and mineral resources.

Average annual energy export cost ($/GJ)



Levelised export system cost ($ billion/year).



A large workforce with new skills will grow across the nation, particularly in northern Australia

8

We estimate that about **1 to 1.3 million new workers** will be needed to reach net zero.

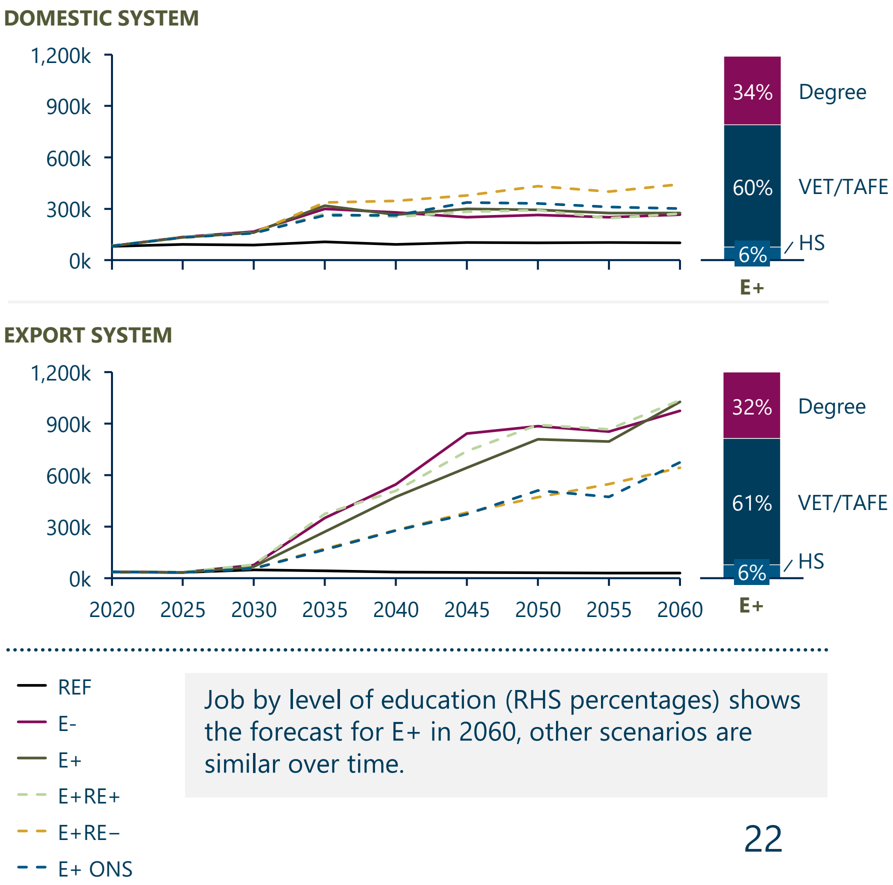
Most of their work will be in growing exports **across northern Australia**, which would experience **significant population growth**. The size of the this workforce will depend on the level of exports that is achieved.

This growth has significant implications for **First Nations** peoples, **national security** and **immigration**.

Most of the workforce will need **technical skills**, including in renewable generation, transmission, energy storage, clean hydrogen, and CCUS.

Domestic decarbonisation will require significant, though lower workforce growth, in more populated areas.

Gross energy sector employment (full time equivalent jobs)



Job by level of education (RHS percentages) shows the forecast for E+ in 2060, other scenarios are similar over time.

Emissions from farms, forestry and waste should fall, but are unlikely to reach net zero

9

Land clearing, ruminant animals (e.g. cattle) and waste produce significant carbon emissions.

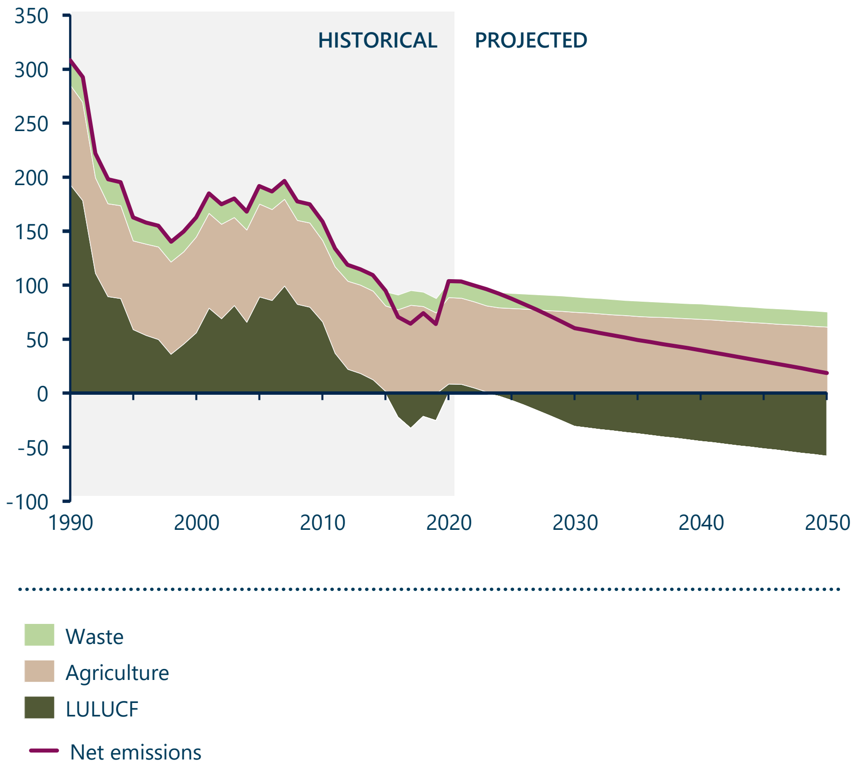
These can be reduced by **storing carbon** in revegetated land, **feeding supplements** to cattle, **adding inhibitors** to fertiliser, and **using methane** from waste as an energy source.

Our analysis finds that these **emissions are unlikely to reach net zero** although they should reduce substantially.

We will **analyse the opportunities and trade-offs** in using vegetation (e.g. farm trees, environmental plantings and timber plantations) to store carbon (creating negative emissions) or make bioenergy.

These results mean that energy and industry **may not be able to rely on offsets** from the land and waste sectors to reach net zero.

Historical and projected GHG emissions (Mt-CO_2e/year).



Large changes in land and sea use will occur, and will need careful planning and community engagement

10

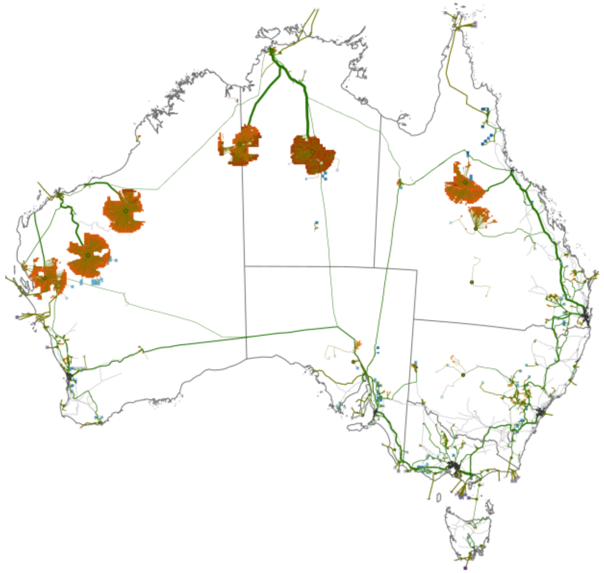
'Downscaling' our modelled results illustrates the **detailed land and sea use changes** which may arise from the net zero transition.

Many new energy sources will require **much more surface area** than the energy sources they are replacing, which is a major challenge of the renewable build.

The modelling indicates an immense level of new **transmission powerlines and pipelines** (carrying hydrogen and carbon dioxide).

This **work is preliminary**, and the results will vary significantly as we analyse different assumptions.

INDICATIVE new infrastructure build (E+ scenario in 2060).



For more detail (including legend and explanations), and essential caveats, **please see the 'Initial downscaling results' section** of this report.

Early downscaling results

We are presenting early downscaling results, with important caveats

'Downscaling' our modelled results illustrates the detailed land and sea use changes which may arise from the net zero transition.

Our modelling excludes many areas from development due to conflicting land uses (as detailed in our MASS pack).

However, **our downscaling work is continuing and additional constraints are yet to be finalised** particularly concerning native title, conservation and agriculture.

If our early results remain illustrative of the actual transition:

- Northern areas and ports would be significant exporters of clean energy, but southern states would not.
- Lands subject to native title would be in very high demand, particularly to supply energy exports across northern Australia.
- Major transcontinental powerlines and pipelines would help transfer energy between different wind and solar regimes, beginning this decade.
- Large tracts of non-irrigated farmland would host wind and solar farms and transmission powerlines and pipelines.

In reality, the location of new industries and infrastructure will be affected by such factors as:

- negotiations with Traditional Owners, rural landowners and communities; and
- decisions by governments to influence the location of export hubs and the extent of interstate transmission.

To explore the impact of different ambitions and constraints, we will engage representative bodies, and model a number of sensitivities.

Early downscaling results include national maps and regional 'snapshots'

CONTENTS OF EARLY DOWNSCALING RESULTS

1. **National** (2020 to 2050)
2. **South East of Australia** (2020, 2050) – including SA, VIC, TAS and NSW
3. **South West of Australia** (2020, 2050)
4. **South East Queensland** (2020, 2050)
5. **Central Queensland** (2020, 2060)

Future downscaling work will map other infrastructure additions, including CCUS injection sites and pipelines.

HOW TO INTERPRET MAPS AND SHADED AREAS

Downscaling maps are not the 'only way' to achieve decarbonisation. The maps show indicative results of least-cost modelling, there are many other potential projects and orientations of generation and transmission.

Shaded areas and transmission will change as downscaling is refined and sensitivities are run.

The **indicative physical footprint of solar PV farms** is **20% of the shaded areas** shown in these early results. Further downscaling may move and refine those areas.

The **indicative areas covered by wind farm projects** is **the same as the shaded areas.** However, the areas occupied by wind turbines and transmission lines is a small percentage of the project areas.

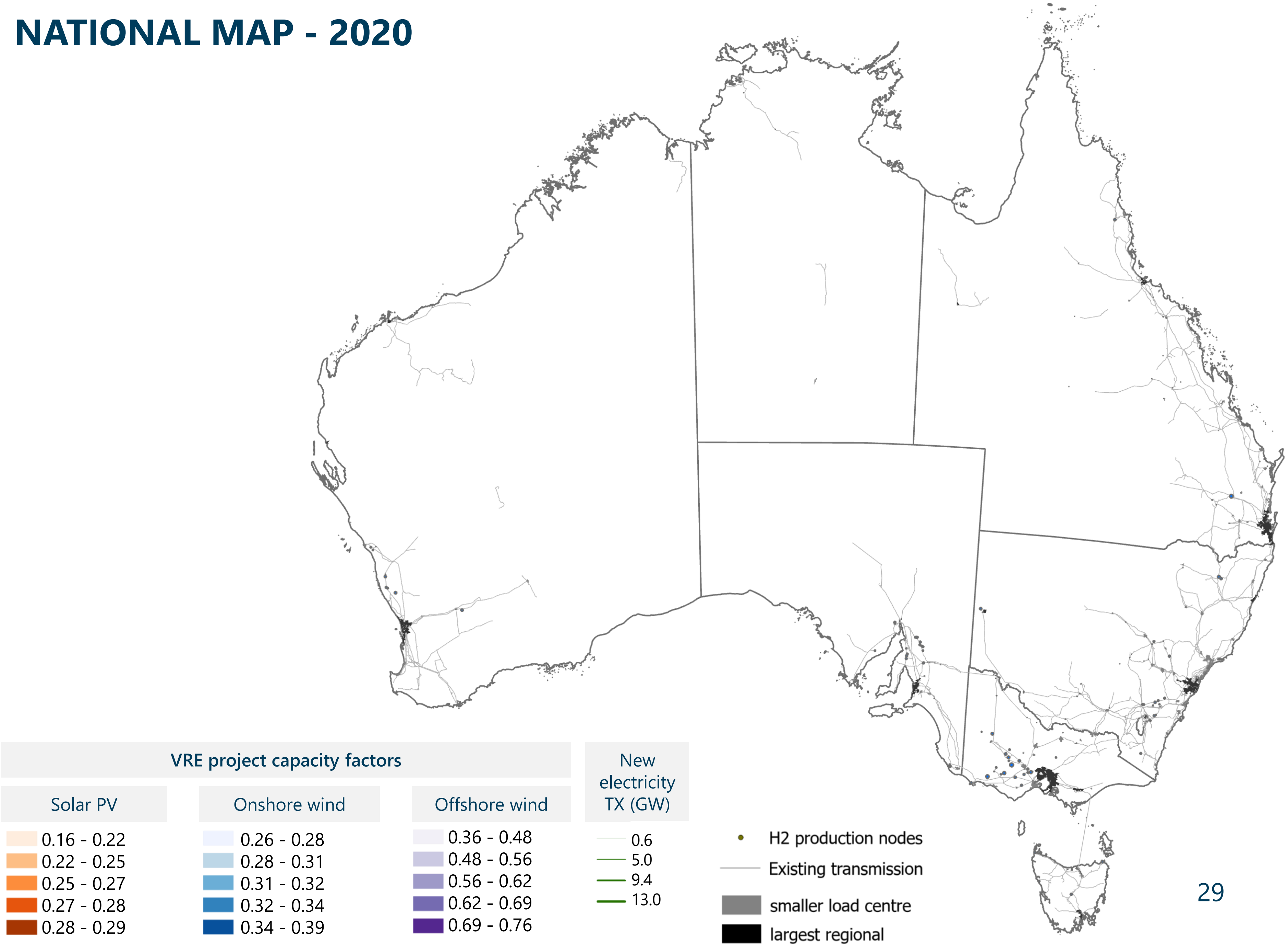
National maps

Early downscaling

E+ in 2020, solar and wind with transmission

159 pre-existing operating VRE projects

NATIONAL MAP - 2020



Early downscaling

E+ in 2030, solar and wind with transmission

196 pre-existing operating VRE projects

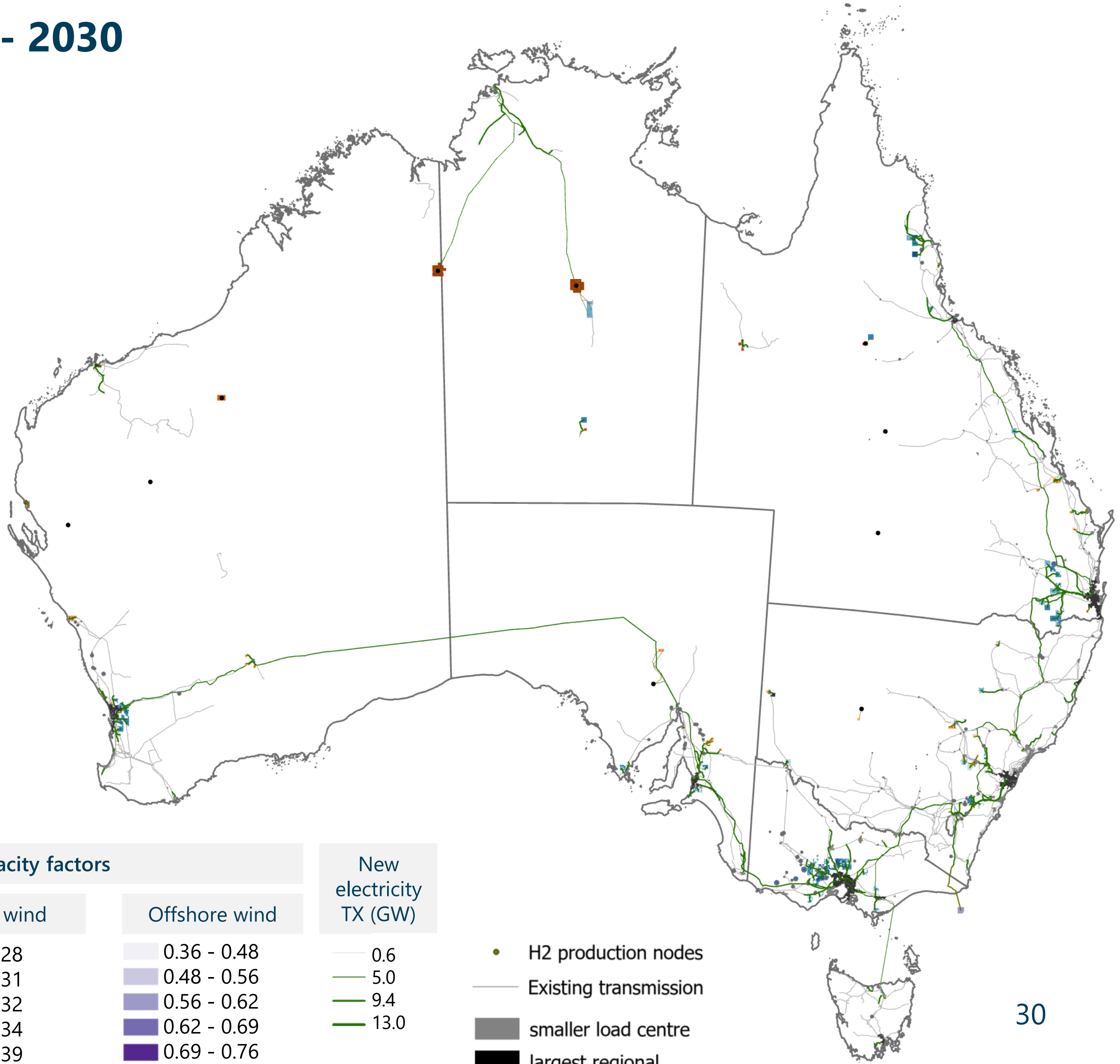
Net Zero Australia projects:

- 98 GW solar PV (135 projects)
- 49 GW onshore wind (79 projects)
- 0.5 GW offshore wind (1 projects)

Electricity generation is about **3x the capacity of the National Electricity Market** (in 2022).

NATIONAL MAP - 2030

INDICATIVE ONLY
Purpose of downscaling is to show scale and pace of change, not to identify specific projects



VRE project capacity factors			New electricity TX (GW)
Solar PV	Onshore wind	Offshore wind	
0.16 - 0.22	0.26 - 0.28	0.36 - 0.48	0.6
0.22 - 0.25	0.28 - 0.31	0.48 - 0.56	5.0
0.25 - 0.27	0.31 - 0.32	0.56 - 0.62	9.4
0.27 - 0.28	0.32 - 0.34	0.62 - 0.69	13.0
0.28 - 0.29	0.34 - 0.39	0.69 - 0.76	

- H2 production nodes
- Existing transmission
- smaller load centre
- largest regional

Early downscaling

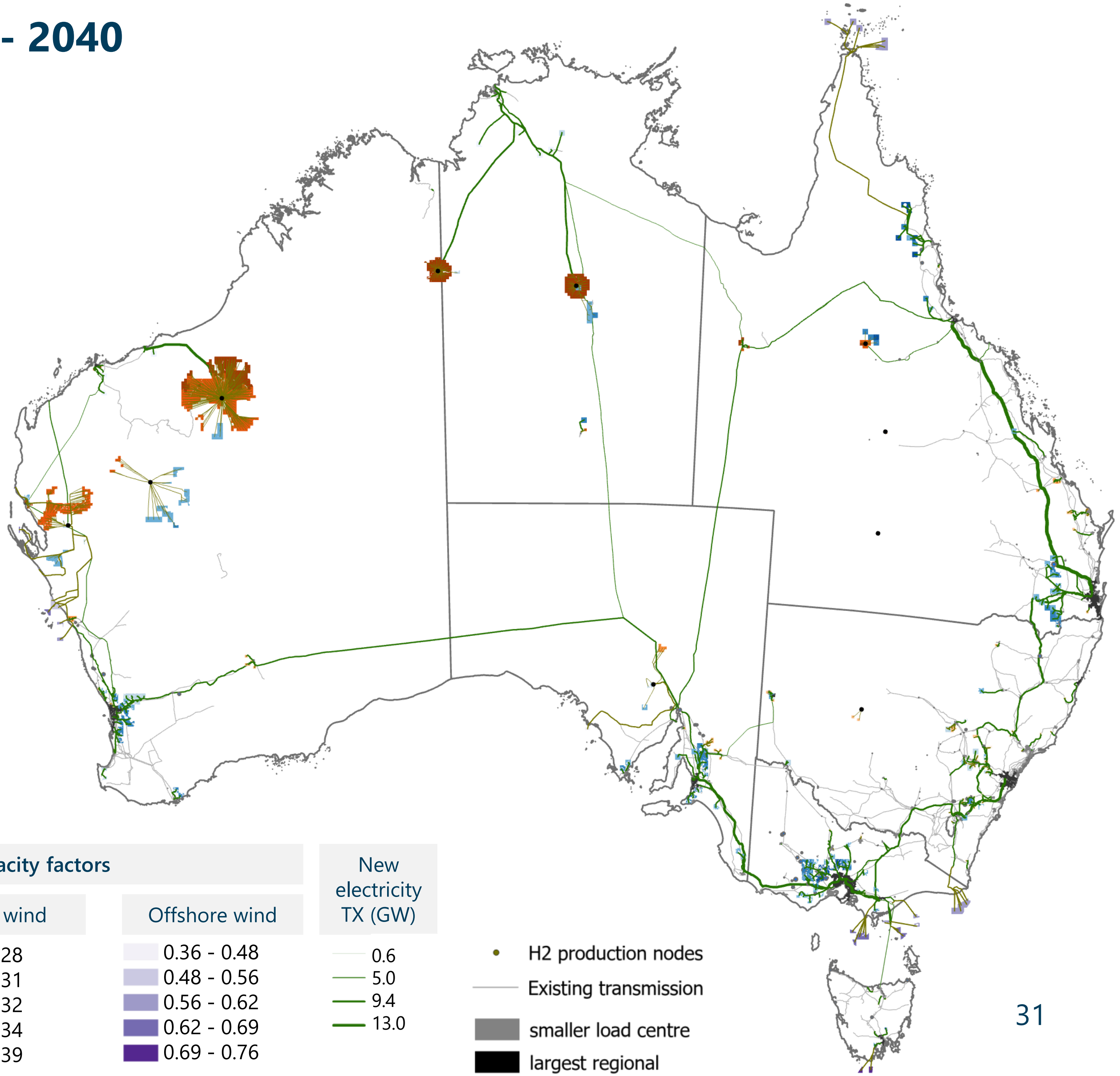
E+ in 2040, solar and wind with transmission

Net Zero Australia projects:

- 654 GW solar PV (782 projects)
- 130 GW onshore wind (187 projects)
- 41 GW offshore wind (35 projects)

Electricity generation is about **15x the capacity of the National Electricity Market** (in 2022).

NATIONAL MAP - 2040



VRE project capacity factors		
Solar PV	Onshore wind	Offshore wind
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0.25 - 0.27	0.31 - 0.32	0.56 - 0.62
0.27 - 0.28	0.32 - 0.34	0.62 - 0.69
0.28 - 0.29	0.34 - 0.39	0.69 - 0.76

Early downscaling

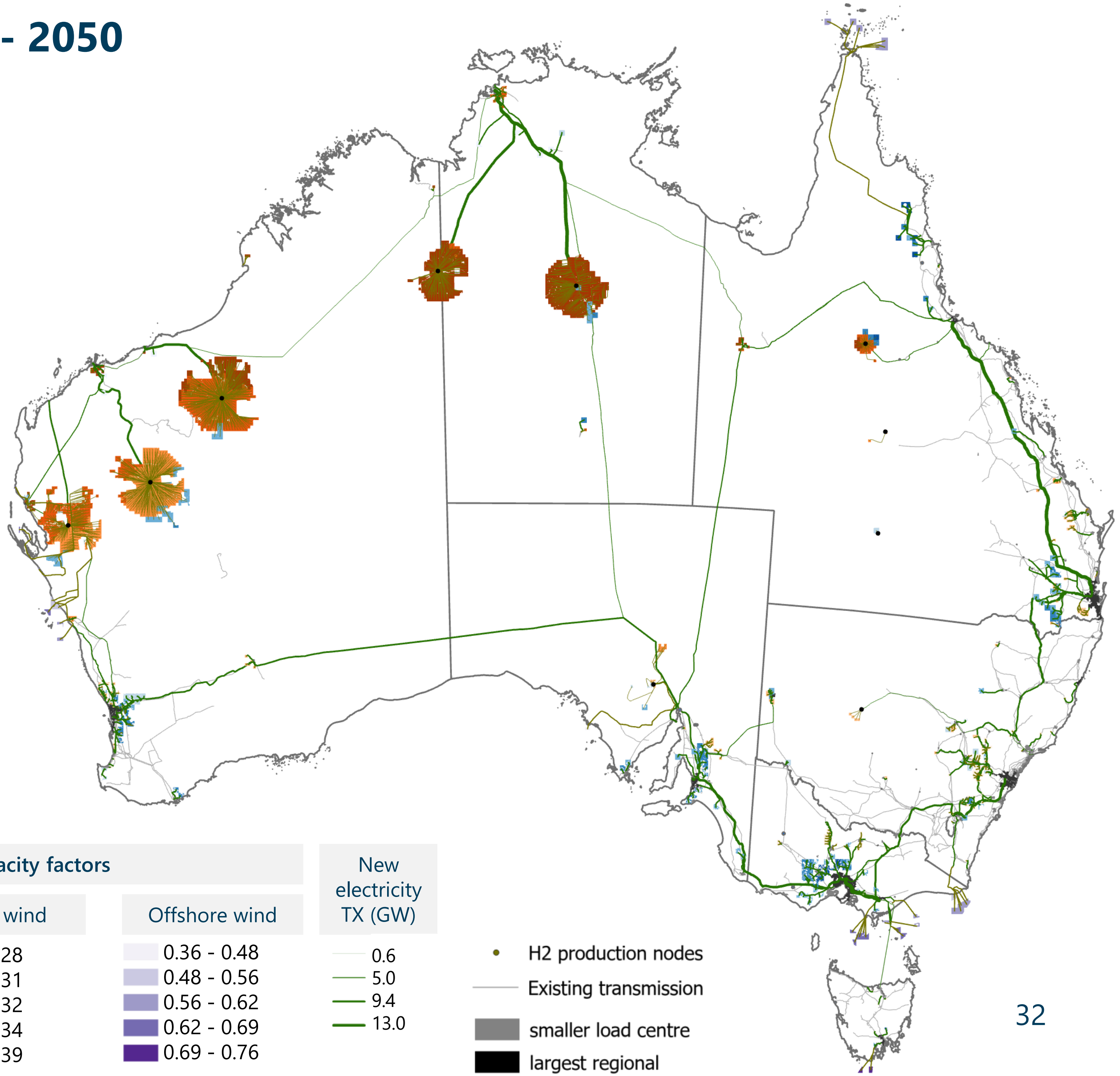
E+ in 2050, solar and wind with transmission

Net Zero Australia projects:

- 1.9 TW solar PV (2,242 projects)
- 132 GW onshore wind (194 projects)
- 42 GW offshore wind (36 projects)

Electricity generation is about **40x the capacity of the National Electricity Market** (in 2022).

NATIONAL MAP - 2050



INDICATIVE ONLY

Purpose of downscaling is to show scale and pace of change, not to identify specific projects

VRE project capacity factors

Solar PV	Onshore wind	Offshore wind
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0.25 - 0.27	0.31 - 0.32	0.56 - 0.62
0.27 - 0.28	0.32 - 0.34	0.62 - 0.69
0.28 - 0.29	0.34 - 0.39	0.69 - 0.76

New electricity TX (GW)

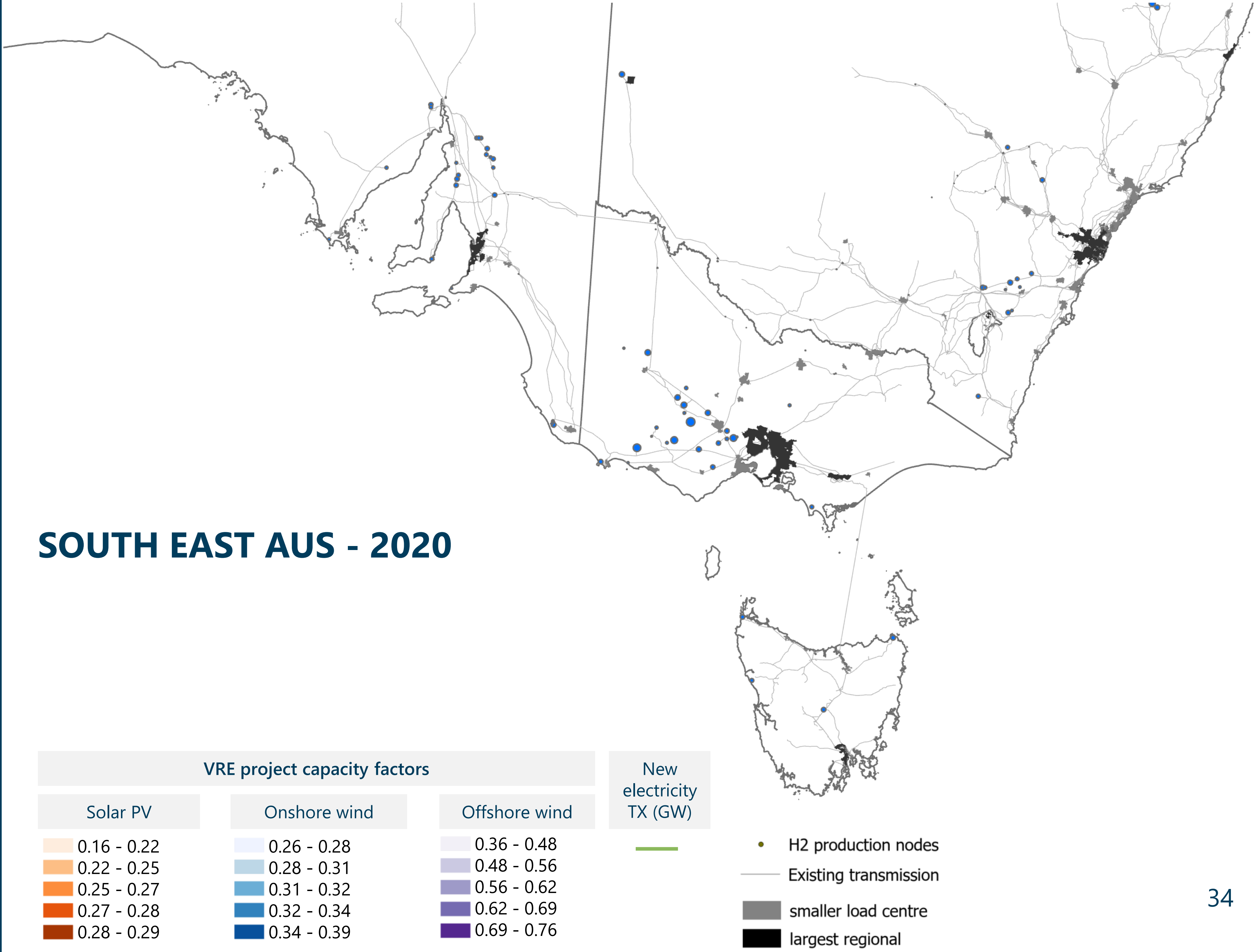
- 0.6
- 5.0
- 9.4
- 13.0

- H2 production nodes
- Existing transmission
- smaller load centre
- largest regional

South East Australia

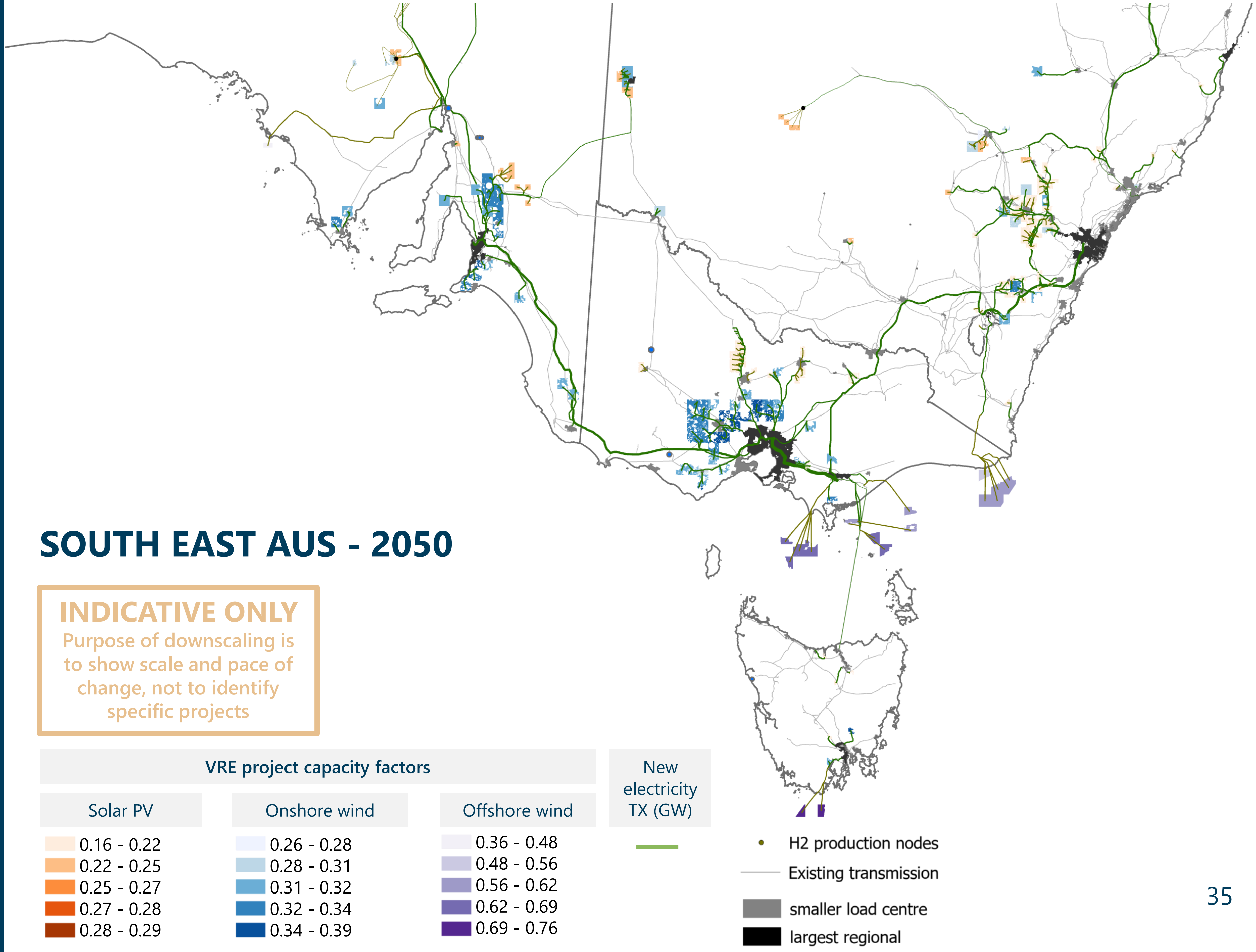
Early downscaling

E+ in 2020, solar and wind with transmission



Early downscaling

E+ in 2050, solar and wind with transmission

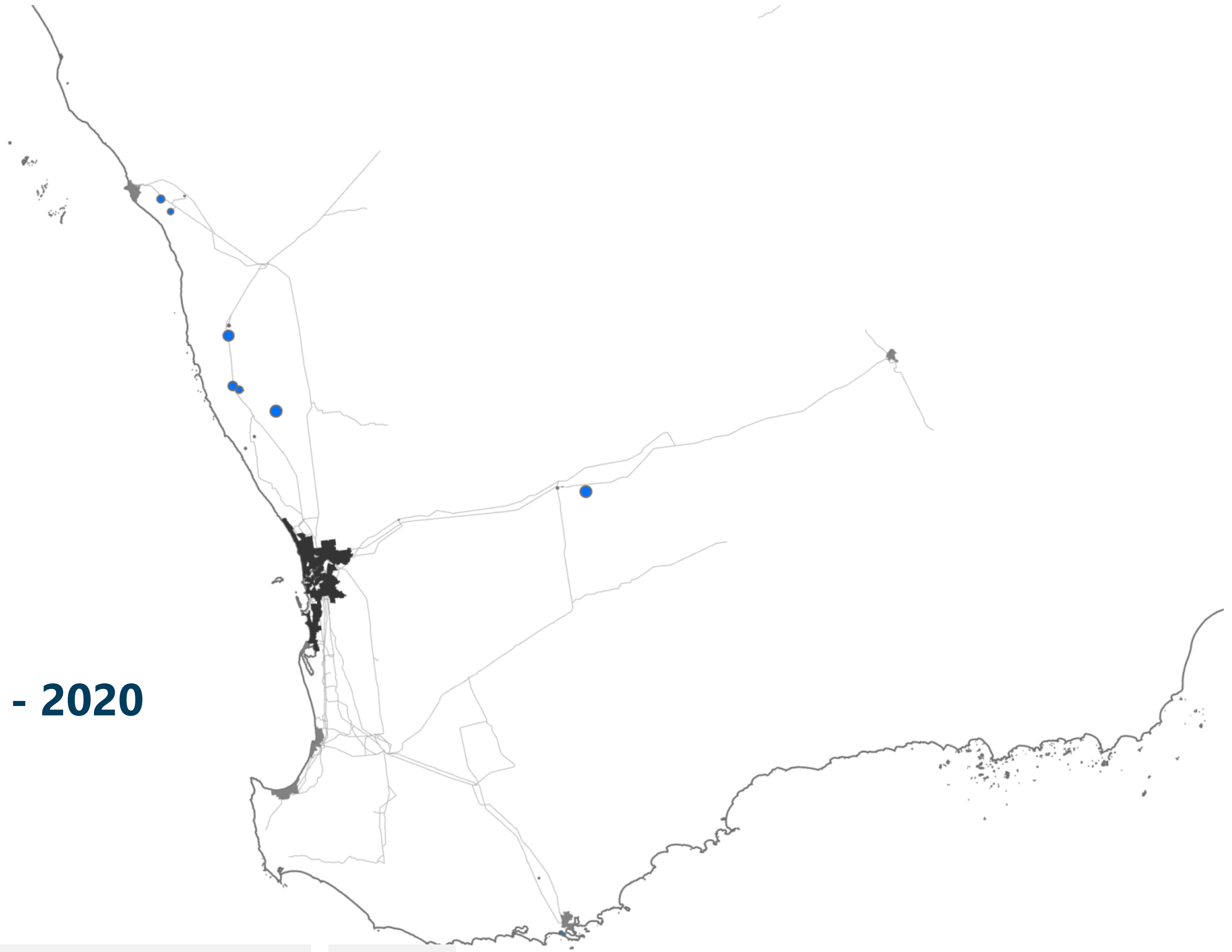


South West Australia

Early downscaling

E+ in 2020, solar and wind with transmission

SOUTH WEST AUS - 2020



VRE project capacity factors

Solar PV	Onshore wind	Offshore wind
0.16 - 0.22	0.26 - 0.28	0.36 - 0.48
0.22 - 0.25	0.28 - 0.31	0.48 - 0.56
0.25 - 0.27	0.31 - 0.32	0.56 - 0.62
0.27 - 0.28	0.32 - 0.34	0.62 - 0.69
0.28 - 0.29	0.34 - 0.39	0.69 - 0.76

New electricity TX (GW)

H2 production nodes
Existing transmission
smaller load centre
largest regional

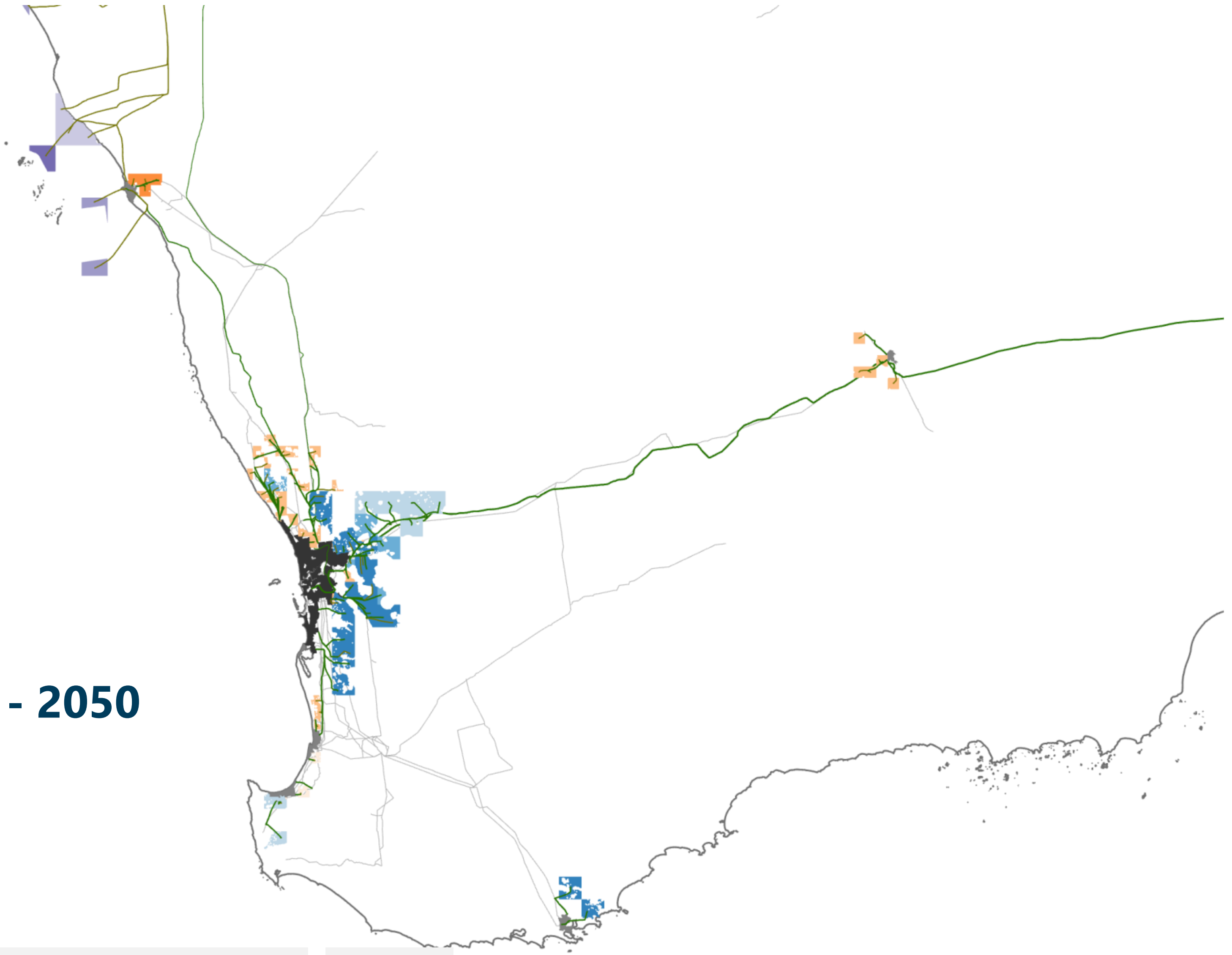
Early downscaling

E+ in 2050, solar and wind with transmission

SOUTH WEST AUS - 2050

INDICATIVE ONLY

Purpose of downscaling is to show scale and pace of change, not to identify specific projects



VRE project capacity factors

Solar PV	Onshore wind	Offshore wind
0.16 - 0.22	0.26 - 0.28	0.36 - 0.48
0.22 - 0.25	0.28 - 0.31	0.48 - 0.56
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0.27 - 0.28	0.32 - 0.34	0.62 - 0.69
0.28 - 0.29	0.34 - 0.39	0.69 - 0.76

New electricity TX (GW)

H2 production nodes

Existing transmission

smaller load centre

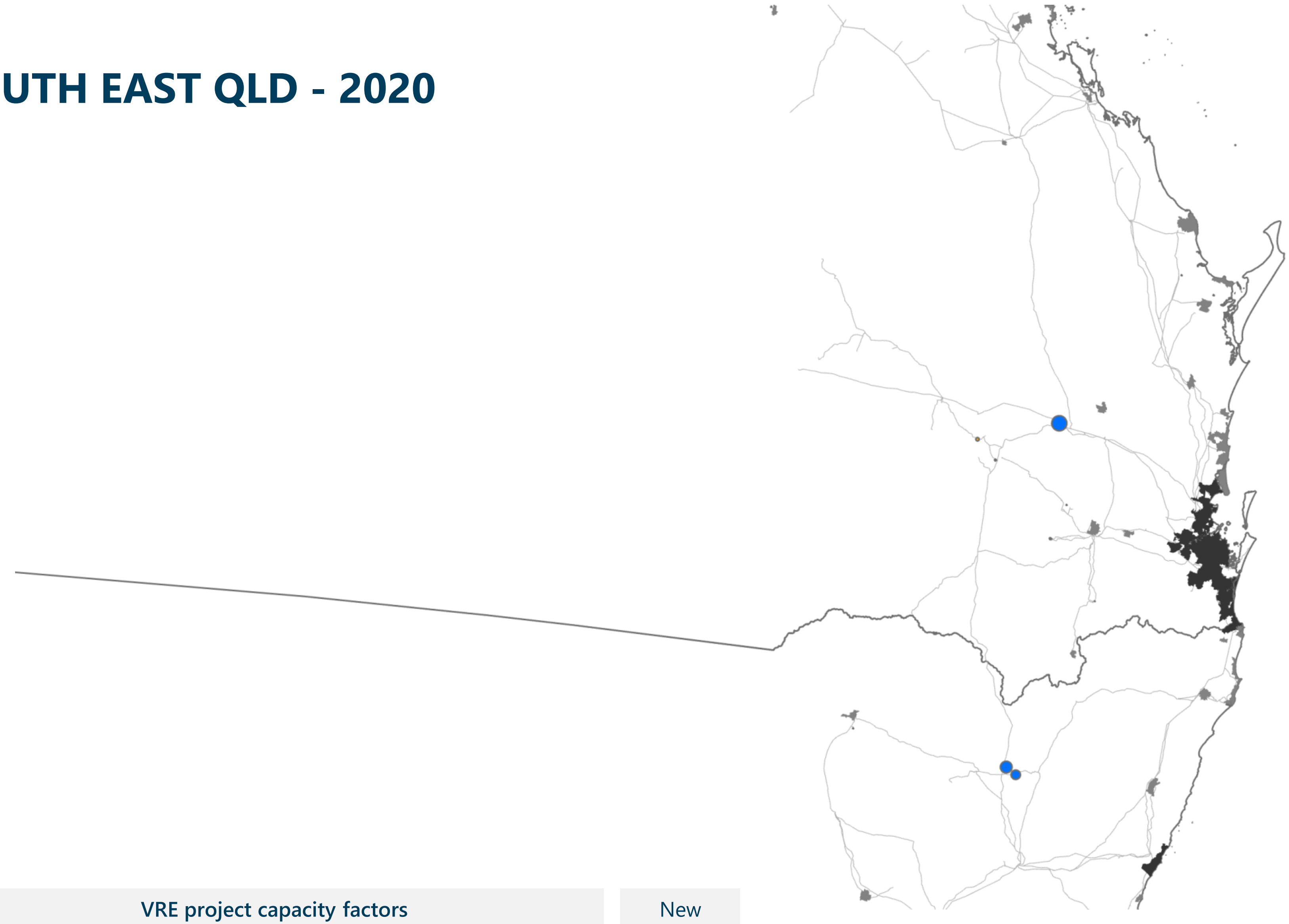
largest regional

South East Queensland

Early downscaling

E+ in 2020, solar and wind with transmission

SOUTH EAST QLD - 2020



VRE project capacity factors

Solar PV	Onshore wind	Offshore wind
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0.27 - 0.28	0.32 - 0.34	0.62 - 0.69
0.28 - 0.29	0.34 - 0.39	0.69 - 0.76

New electricity TX (GW)

H2 production nodes

Existing transmission

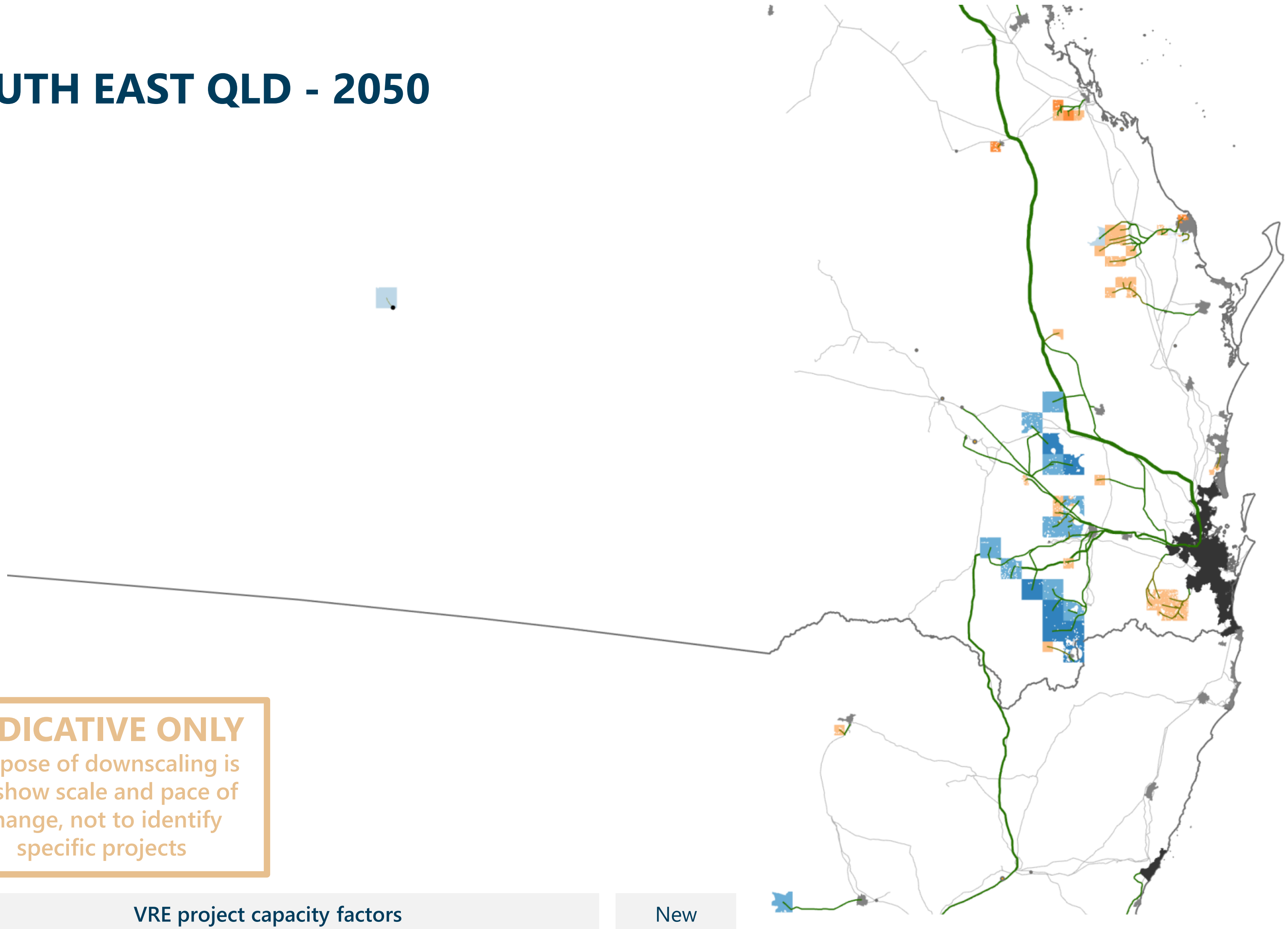
smaller load centre

largest regional

Early downscaling

E+ in 2050, solar and wind with transmission

SOUTH EAST QLD - 2050



INDICATIVE ONLY
Purpose of downscaling is to show scale and pace of change, not to identify specific projects

VRE project capacity factors			New electricity TX (GW)
Solar PV	Onshore wind	Offshore wind	
0.16 - 0.22	0.26 - 0.28	0.36 - 0.48	
0.22 - 0.25	0.28 - 0.31	0.48 - 0.56	
0.25 - 0.27	0.31 - 0.32	0.56 - 0.62	
0.27 - 0.28	0.32 - 0.34	0.62 - 0.69	
0.28 - 0.29	0.34 - 0.39	0.69 - 0.76	

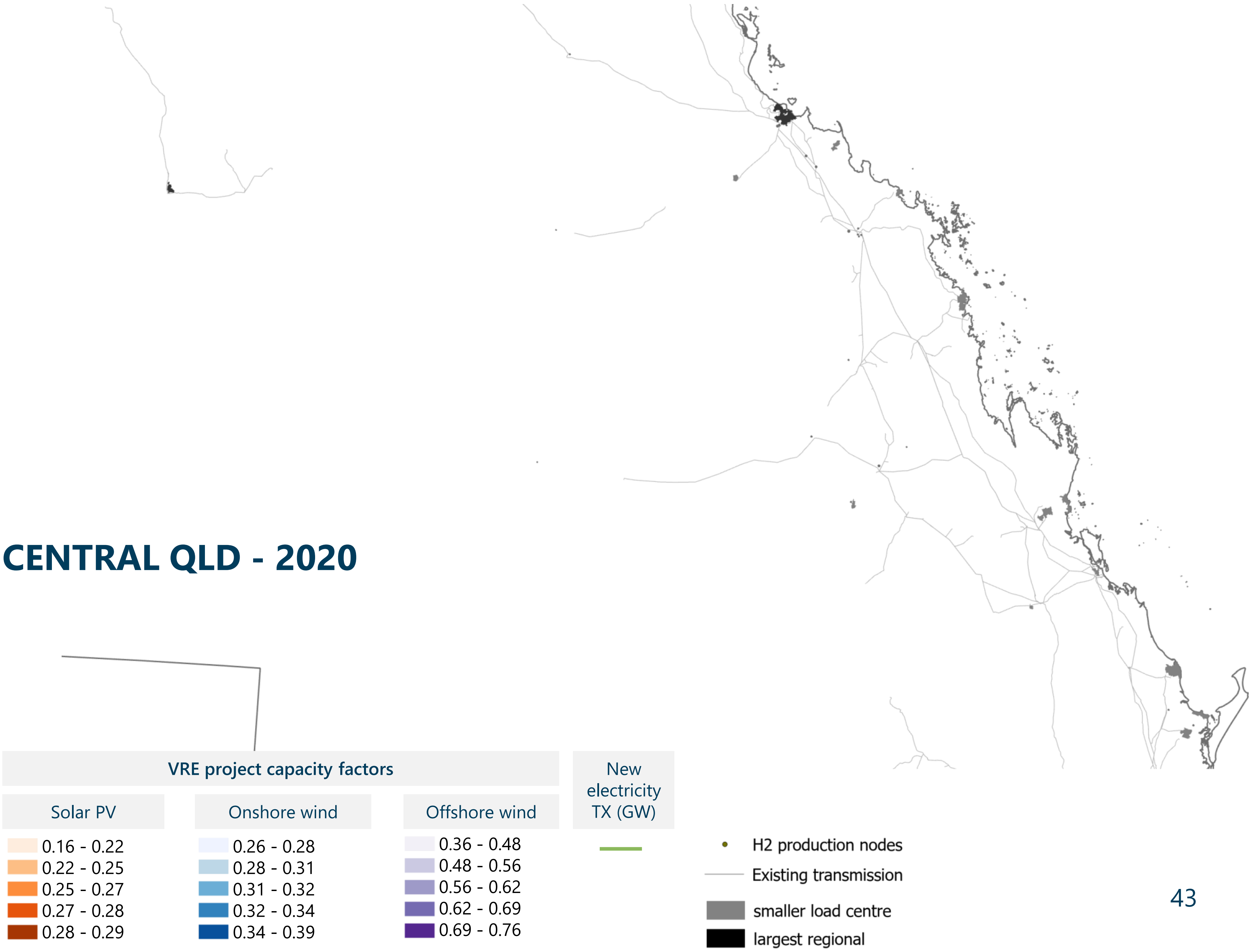
- H2 production nodes
- Existing transmission
- smaller load centre
- largest regional

Central Queensland

Early downscaling

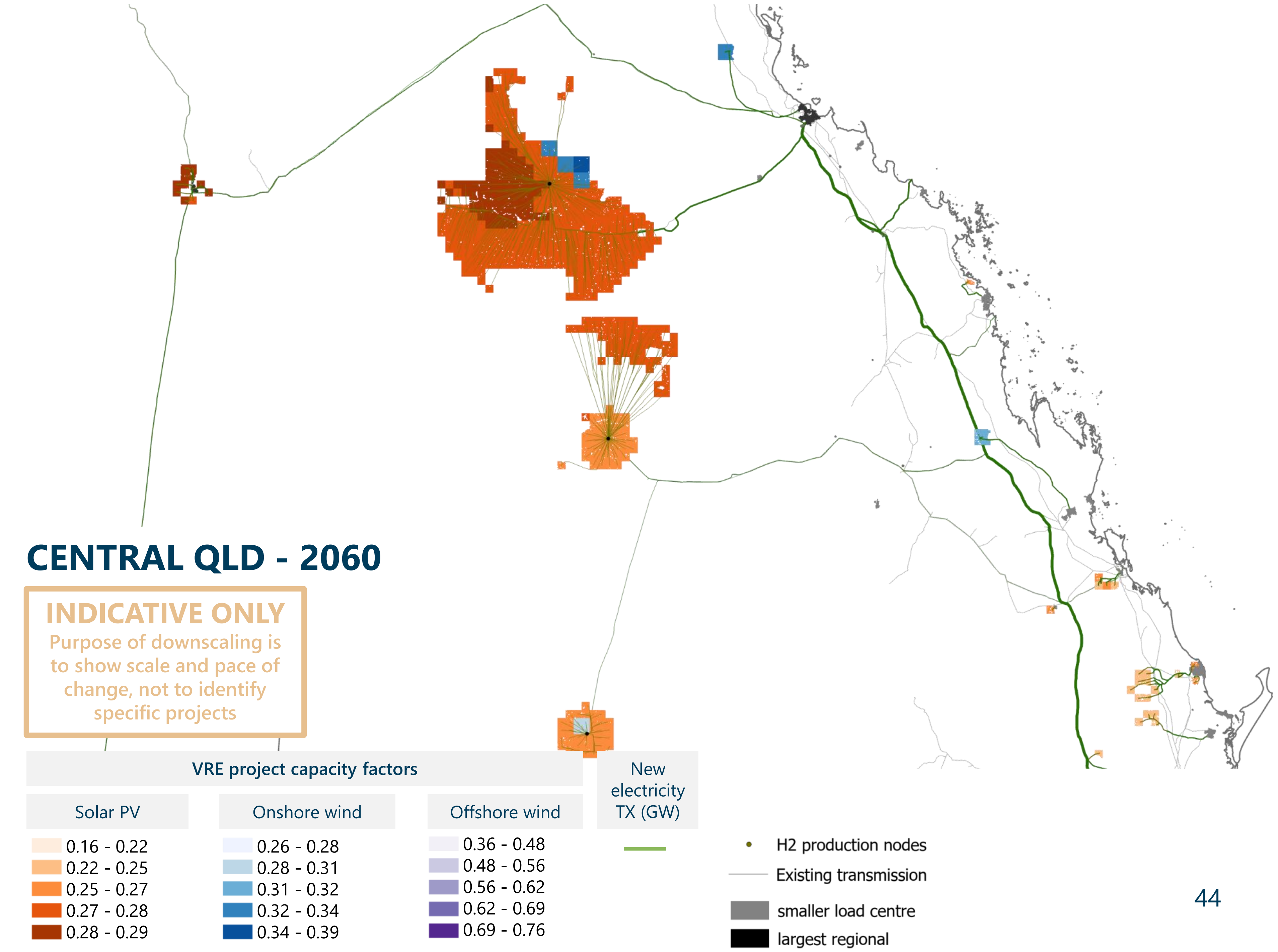
E+ in 2020, solar and wind with transmission

CENTRAL QLD - 2020



Early downscaling

E+ in 2060, solar and wind with transmission

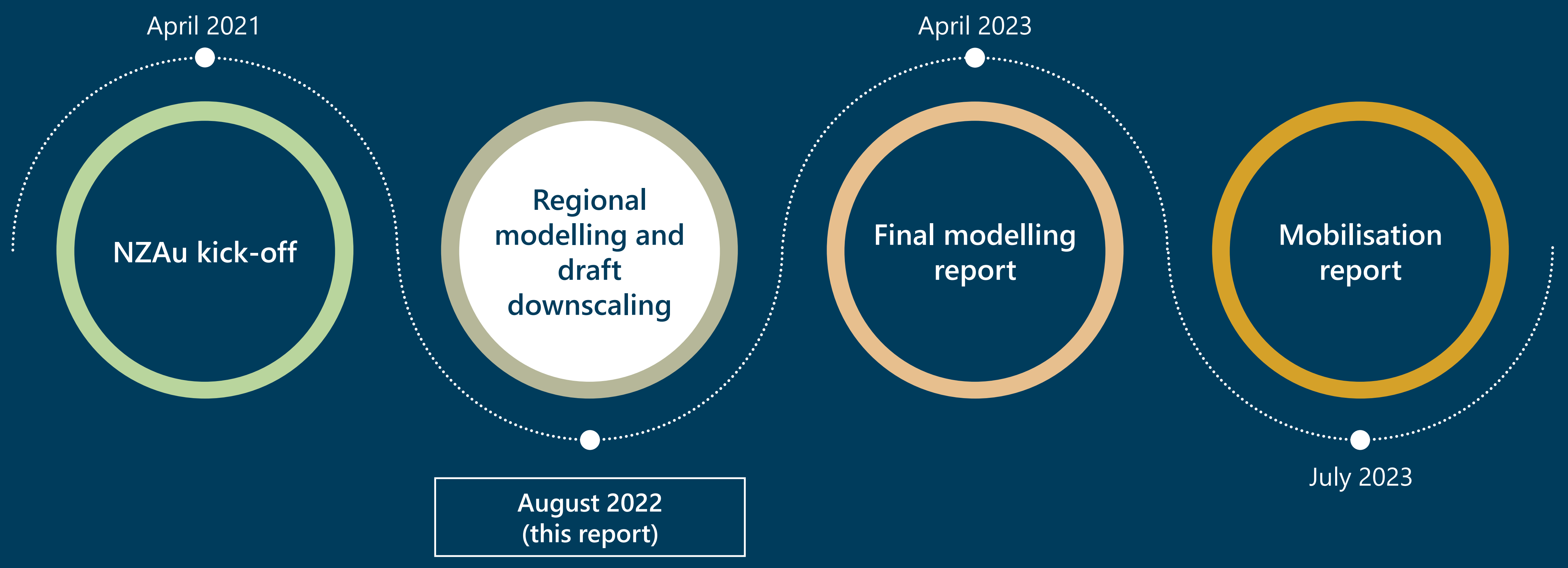


This figure shows 2060 instead of 2050, unlike other snapshots. 2060 is chosen for this snapshot as it includes a major export energy zone which is fully developed in 2060.

Next steps

This document is the first of our public results

NET ZERO AUSTRALIA STUDY TIMELINE



Approach to mobilisation

Our mobilisation work will identify and assess action that may be taken by governments, companies and communities to achieve these four crucial goals

MOBILISE INTEGRATED DEPLOYMENT, AT PACE

- Drive the unprecedented **pace of deployment** of physical assets and the extraordinary volume of capital needed for the transition.
- **Coordinate deployment and withdrawal** of assets to maintain supply security and to minimise economic and social cost.

MANAGE WORKFORCE & REGIONAL CHANGE

- Ensure a **fair transition of workforces** in fossil fuel-dependent industries and the regional communities in which they are concentrated.
- **Grow workforces** to implement the net-zero transition and service expanded regional populations, such as in renewable energy zones.

ENGAGE & SUPPORT THE PUBLIC

- **Maximise landowner and community benefits** from large-scale construction projects and changing landscapes.
- **Support households** in adopting new behaviours, appliances and vehicles, and maintain affordability, particularly for those on low incomes.

MANAGE IMPACT ON ENVIRONMENTS

- **Enhance environmental outcomes** and minimise negative impacts from infrastructure development, on biodiversity, ecosystem function and non-renewable resource levels.

Our mobilisation work will comprise three principal activities

1

ILLUSTRATE

Translate the modelling into **decarbonisation timelines** that illustrate the sequence and pace of transition – economy-wide and for selected cohorts, sectors and regions

2

ANALYSE

Identify and assess **methods and strategies** that could mobilise the required investment, mitigate its adverse impacts and secure public support

3

ADVISE

Develop **insights and guidance** for governments, households, communities, industries and unions to mobilise and manage the transition

Appendix: Modelling results

Summary of the interim modelling results

The following results are the technical and quantitative findings of the modelling to date.

Results are structured around the **six pillars of decarbonisation** and **three general insights.**

For detailed background information, see the Methods, Assumptions, Scenarios and Sensitives document on the NZAu website.

SIX PILLARS OF DECARBONISATION (drawn from Net-Zero America)

1. **End use energy efficiency, electrification and exports**
2. **Clean electricity** (wind and solar generation, transmission, firm power)
3. **Zero-carbon fuels and feedstocks** (including bioenergy)
4. **CO_2 capture, utilisation and storage**
5. **Non-CO_2 emissions**
6. **Enhanced land sinks**

GENERAL INSIGHTS

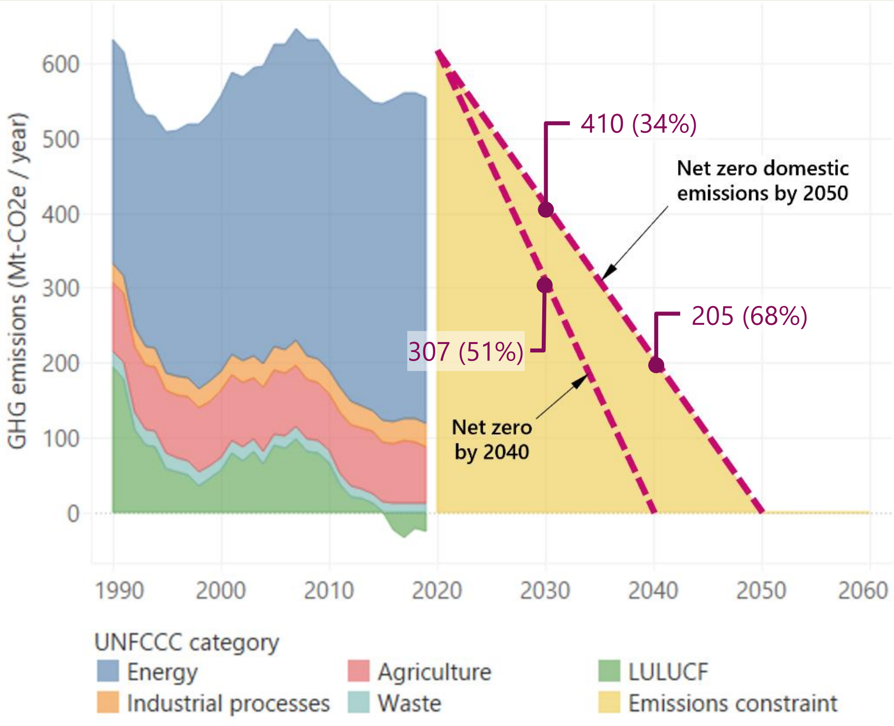
- OVERALL ENERGY, EMISSIONS, AND EXPORTS
- DOMESTIC SYSTEM COSTS
- EMPLOYMENT

Our modelling approach

NZAu imposes straight-line emissions trajectories

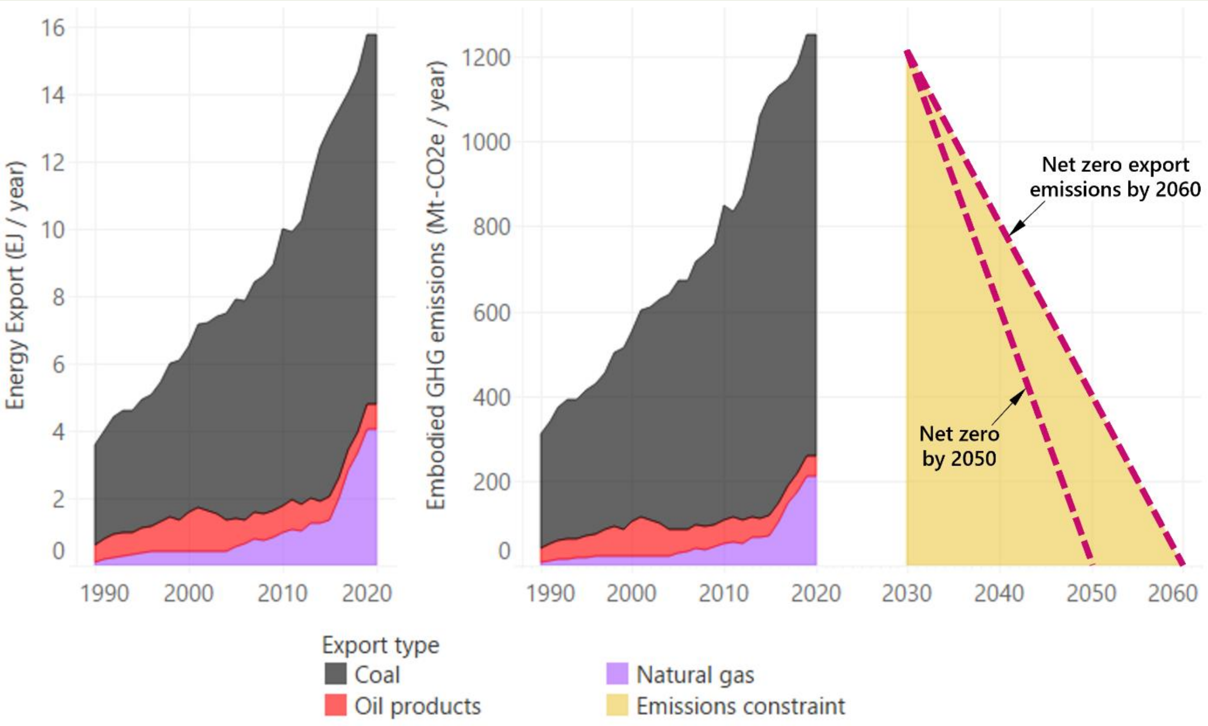
Domestic emissions

615 Mt-CO2e p.a. in 2020, to zero in 2050



Fossil fuel energy export emissions

1,215 Mt-CO_2e p.a. in 2030, to zero in 2060



Notes:

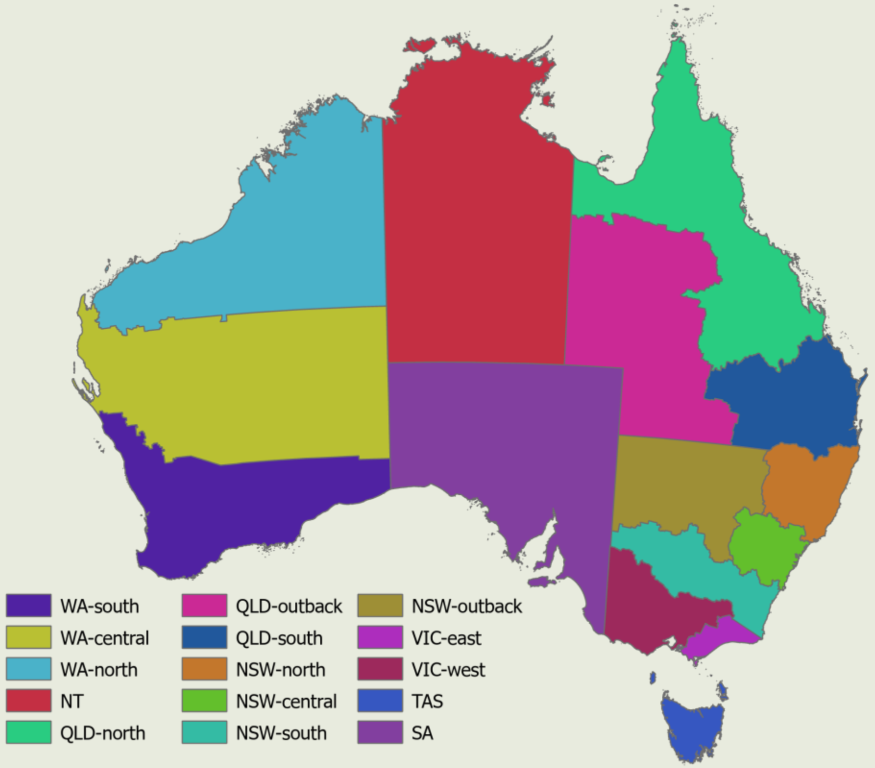
- Export emissions based on weighted emissions intensity of 2020 fossil exports, using Australian inventory emissions factors
- 34% of total GHG emissions from domestic sources, 66% from export
- Net zero by 2040 is also being modelled as a sensitivity (dotted line above)

Energy is modelled over 16 regions

Energy flows between regions, and necessary transmission, are incorporated into the model.

1 EXPORT REGION

15 DOMESTIC REGIONS



Note: To see the full set of assumptions, and associated discussion and explanation, refer to the NZAu Methods, Assumptions, Scenarios and Sensitivities document.

Key assumptions underlie the modelling across scenarios

Growth assumptions underlie forecast energy demand:

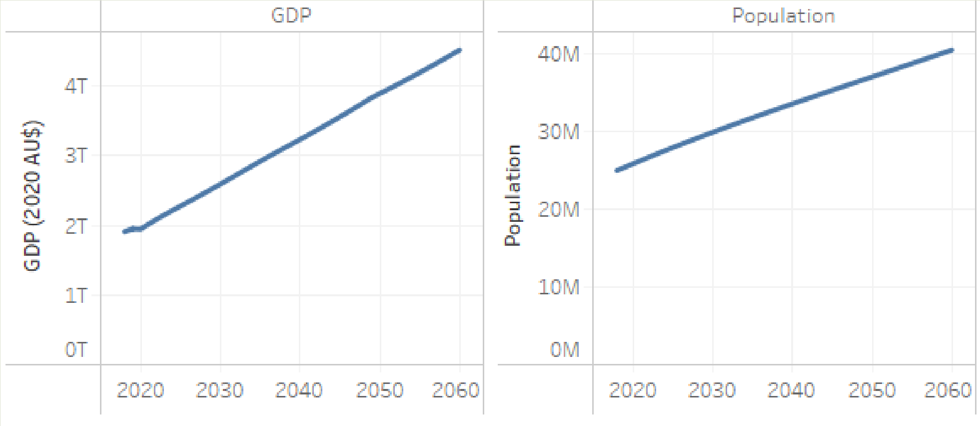
- GDP: 2.1% per year from 2020
- Population: 1.2% per year from 2020

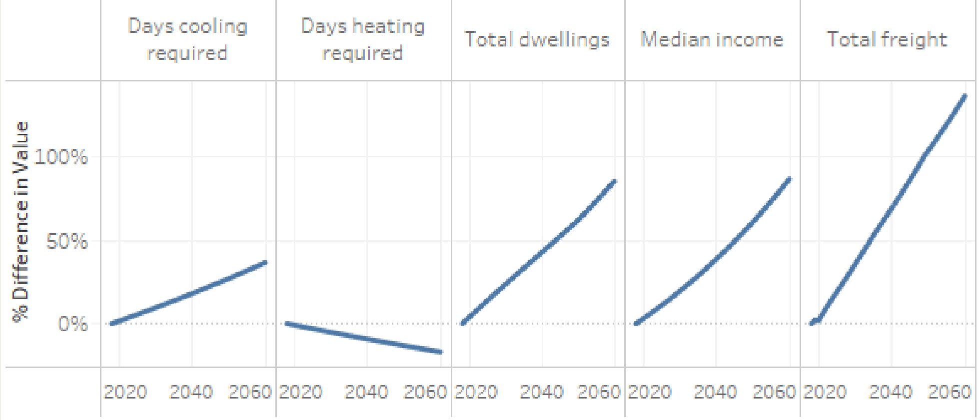
Capacity constraints are assumed, including:

- Geologic storage of CO_2 capped at 300 Mt CO_2 p.a. (in all scenarios except for E+RE-)
- Biomass supply capped at 1,050 PJ p.a.
- Climate scenario modelled using an IPCC Representative Concentration Pathway (RCP 8.5)

Our assumptions are:

- drawn from the most authoritative and traceable references
- grounded in what is currently occurring





Note: To see the full set of assumptions, and associated discussion and explanation, refer to the NZAu Methods, Assumptions, Scenarios and Sensitivities document.

Detailed overview of the NZAu's modelling approach

MODELLING WORK TO DATE

Asset capacities by region

EnergyPATHWAYS Tool from Evolved Energy Research (EER)

- Bottom-up stock accounting model that projects demand for energy services and the evolution of end-use technologies to meet that demand.
- Outputs time-varying demand for electricity and fuel blends to the RIO model.

Regional Investment and Operations (RIO) Tool from EER

- Spatially and temporally resolved optimisation.
- Supplies electricity, fuel blends and carbon storage at lowest system cost while respecting scenario constraints (e.g. net zero).
- Runs every five years with perfect foresight from 2020 to 2060, with seamless integration between sectors.

'Downscaling' by sector

- Validation and visualisation of results from RIO through spatially explicit analysis including land and sea use, labour, air quality, viewscapes, resource potential, and capital flows.

Outputs

Some iteration required for internal consistency

Sited assets that meet regional capacities

Note: To see the full set of assumptions, and associated discussion and explanation, refer to the NZAu Methods, Assumptions, Scenarios and Sensitivities document.

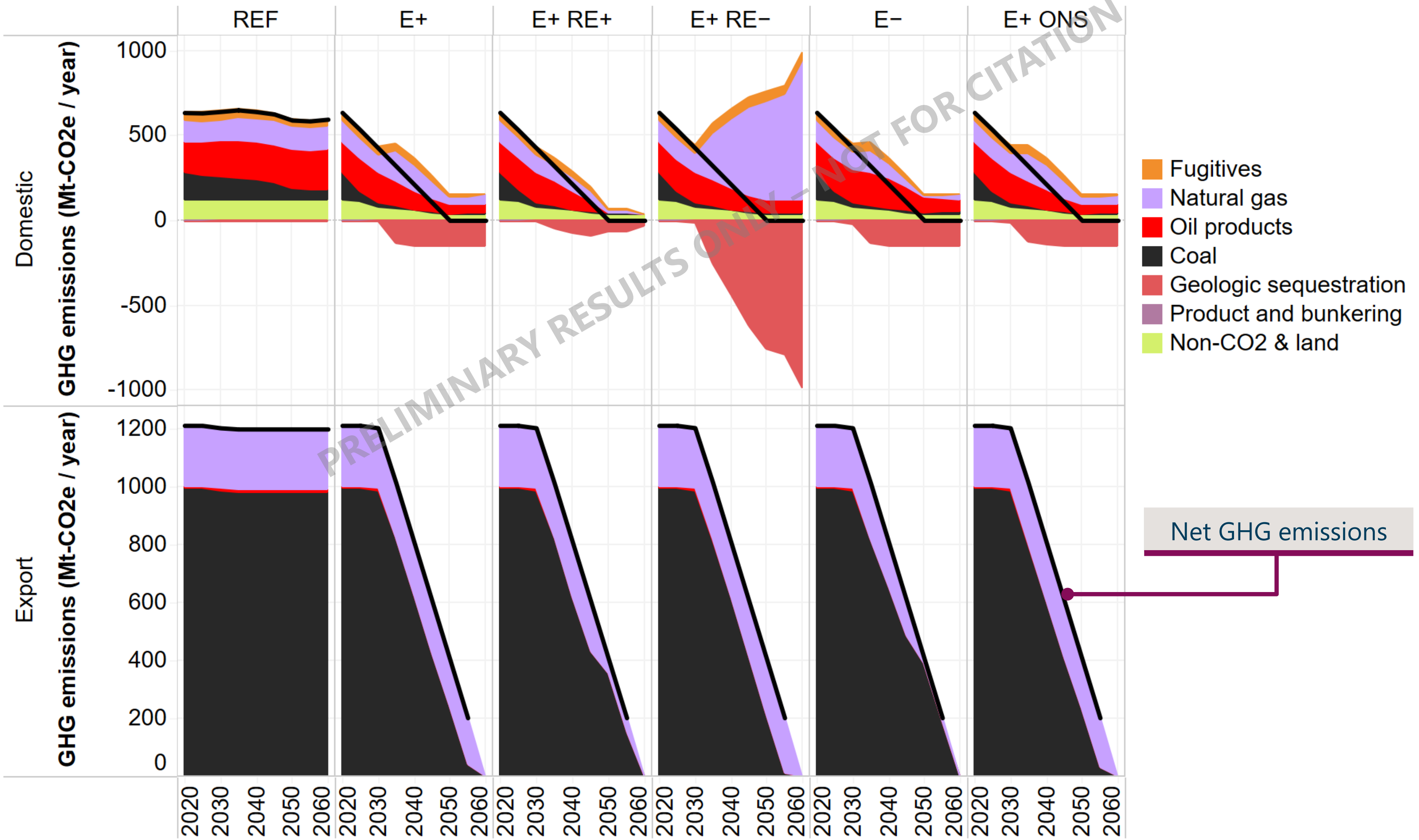
General insights: **Overall energy, emissions, and exports**

KEY FINDINGS

Net zero pathways for Australia, and for Australian energy exports, are available	• Domestic emissions target is net zero by 2050; export emissions target is net zero by 2060 • Wind and solar dominate primary energy supply • Fossil energy exports are replaced by low-emissions energy carriers

Domestic emissions target is net zero by 2050; export emissions target is net zero by 2060

Projected domestic and export emissions (Mt-CO_2e/year). Note varying y-axis scales.

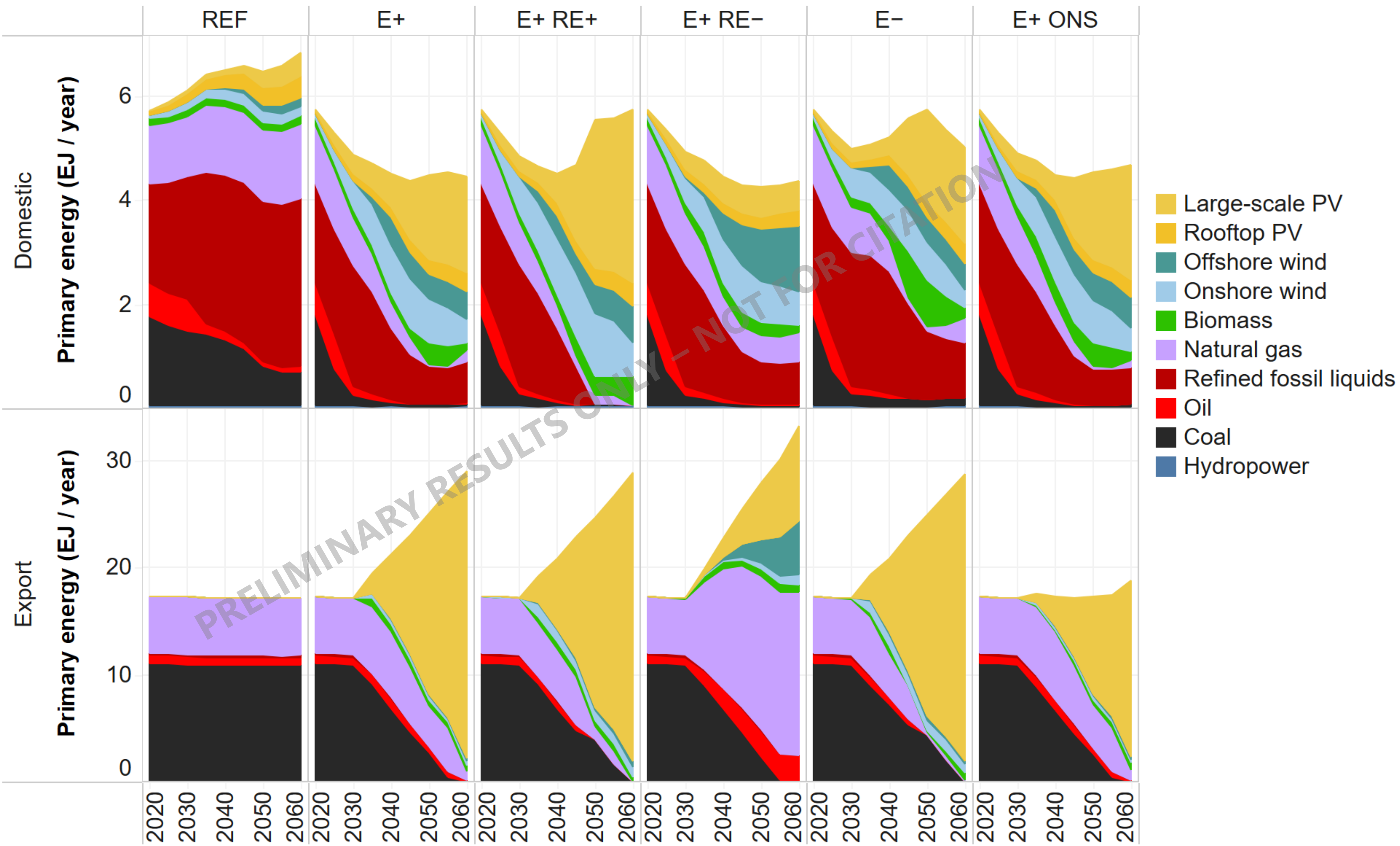


KEY TAKEAWAYS

- Full capacity of geological sequestration is used by 2040 in both E+ and E− (low end of the CCUS range)
- Domestic coal emissions decline most rapidly, followed by oil and gas
- Export decarbonisation abates 2× the emissions of domestic decarbonisation

Wind and solar dominate primary energy supply

Projected primary energy (EJ/year). Note varying y-axis scales.

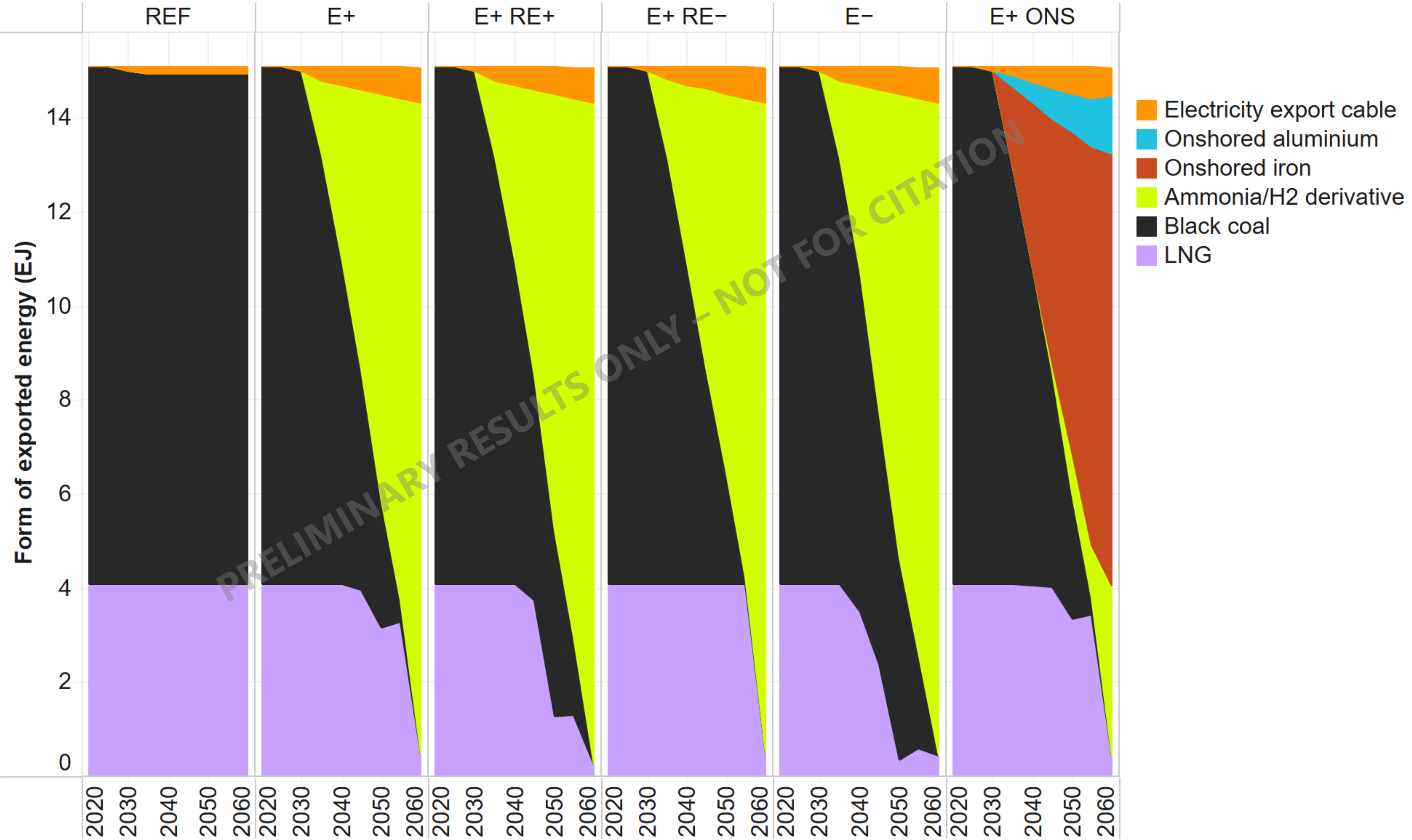


KEY TAKEAWAYS

- Large difference in scale between domestic and export primary energy – noting that final export demand is held constant
- Large rise in primary energy for exports is due to losses from converting renewable power to low-emission carriers and fuels
- Renewable electricity is the dominant primary energy source except in E+RE-, because changes to maximum CCUS rate results in natural gas dominating exports
- Offshore wind competes domestically on cost in all scenarios and is significant in E+RE- exports

Fossil energy exports are replaced by low-emissions energy carriers

Projected exported energy form (EJ)



OVERALL ENERGY, EMISSIONS, AND EXPORTS

KEY TAKEAWAYS

- Energy export demand is held constant at 15EJ/year – about 3× 2050 domestic demand
- Ammonia is seen as a prospective liquid energy carrier for export
- Undersea electricity cable link to Singapore comprises modest share of export energy

PILLAR 1: **End use energy efficiency and electrification**

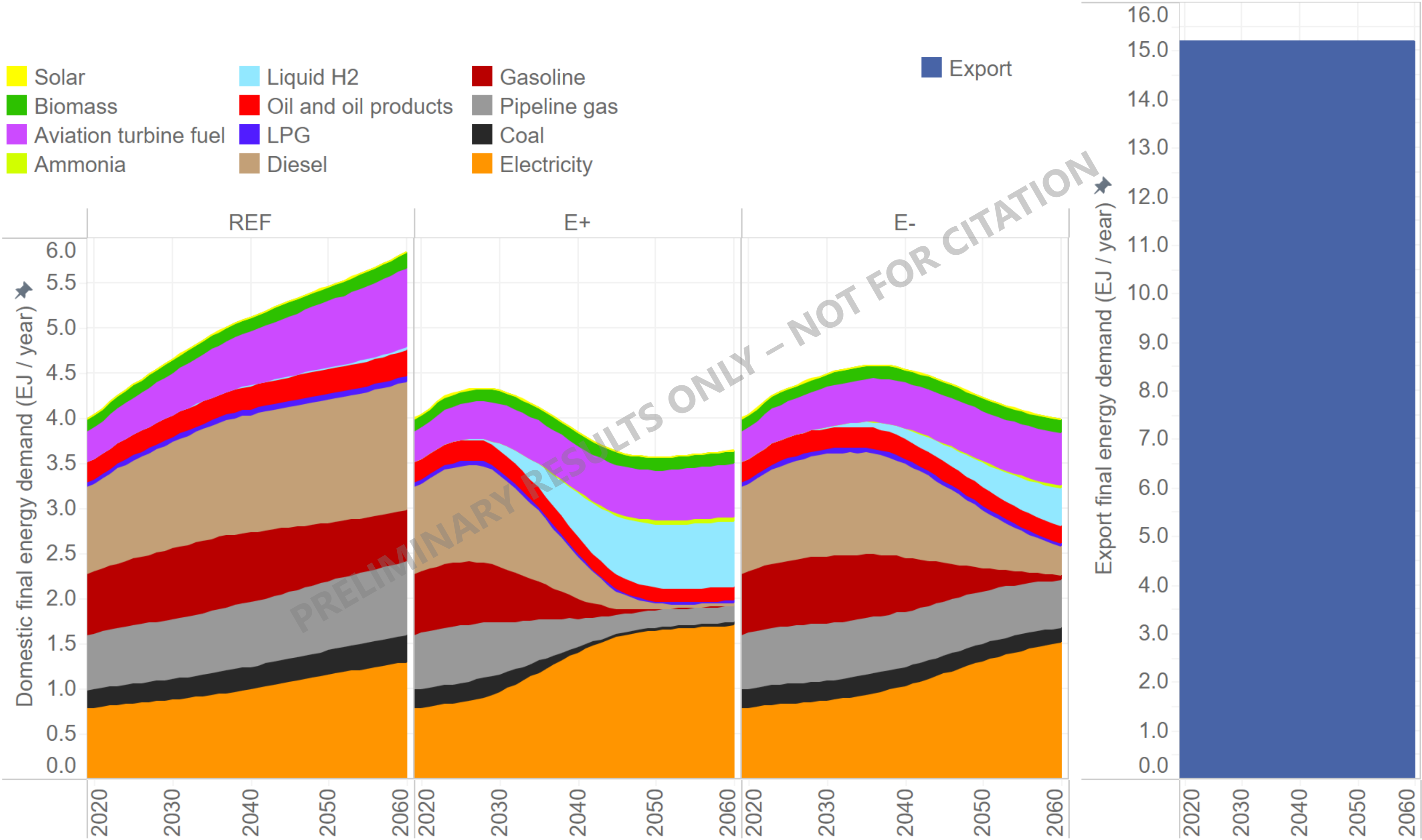
KEY FINDINGS

Energy productivity will keep Australia's domestic energy demand in 2060 at – or below – 2020 levels

- Domestic energy productivity improves from efficiency and fuel switching
- Electrification drives significant energy productivity gains in all sectors – except aviation
- Uptake of passenger EVs in 2020s and 2030s enables saturation of zero-emissions fleet by 2050

Domestic energy productivity improves from efficiency and fuel switching

Domestic and exported final energy demand (EJ/year).



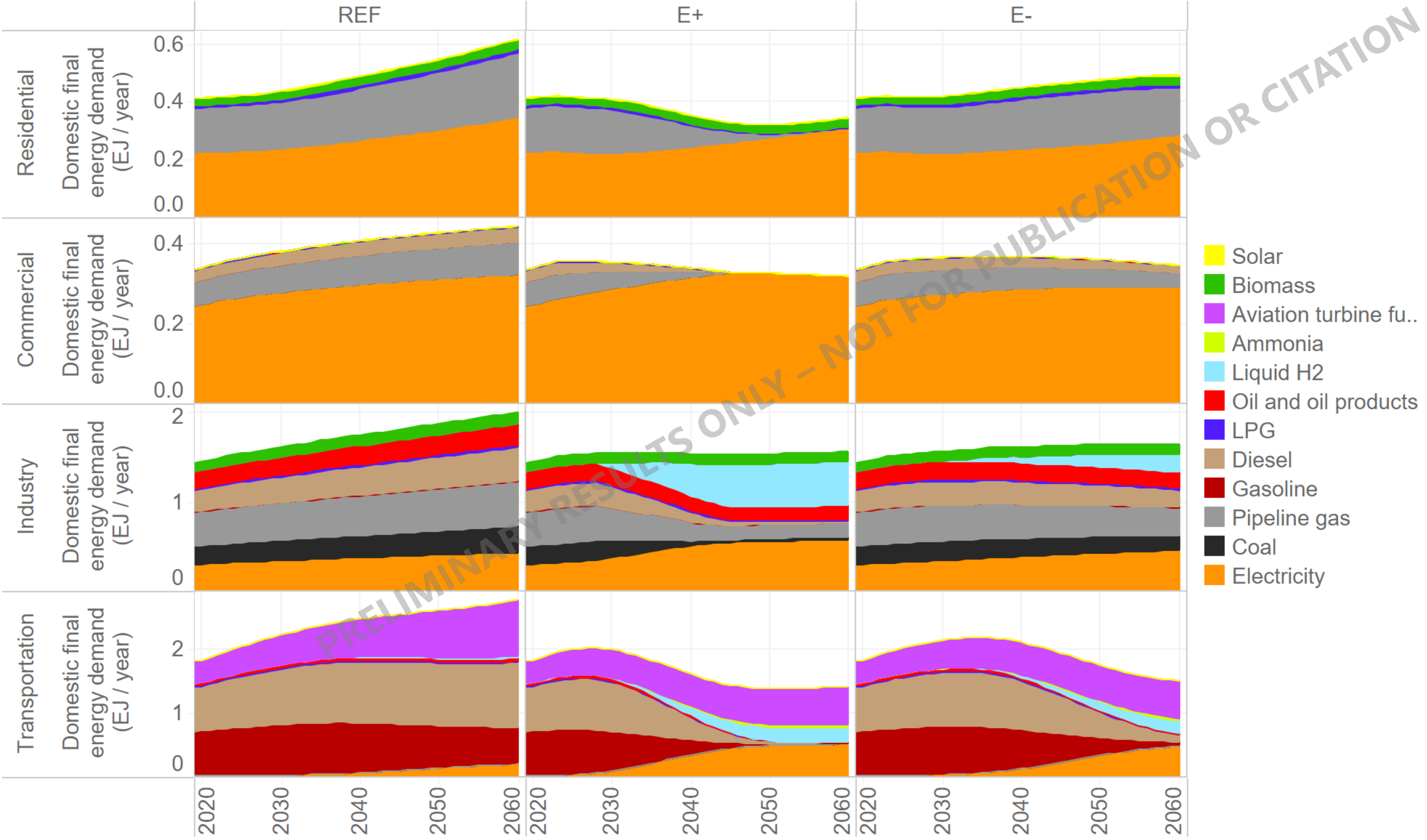
KEY TAKEAWAYS

- Domestic demand driven by population, GDP, technology efficiency and fuel switching
- Domestic energy demand in 2050 is ~1/3 of export energy demand (which is held constant at 15 EJ/year)
- Energy efficiency improvements drive ~40% of productivity gains, averaging ~0.5% p.a. for REF and ~1% p.a. for other scenarios
- End-use electrification drives ~60% of productivity gains
- Residual demand for fossil fuels in E− requires decarbonisation before final consumption

Electrification drives significant energy productivity gains in all sectors – except aviation

Domestic final energy demand by sector (EJ/year)

E+RE+ and E+RE- are not shown because they consider same demand projections as E+.

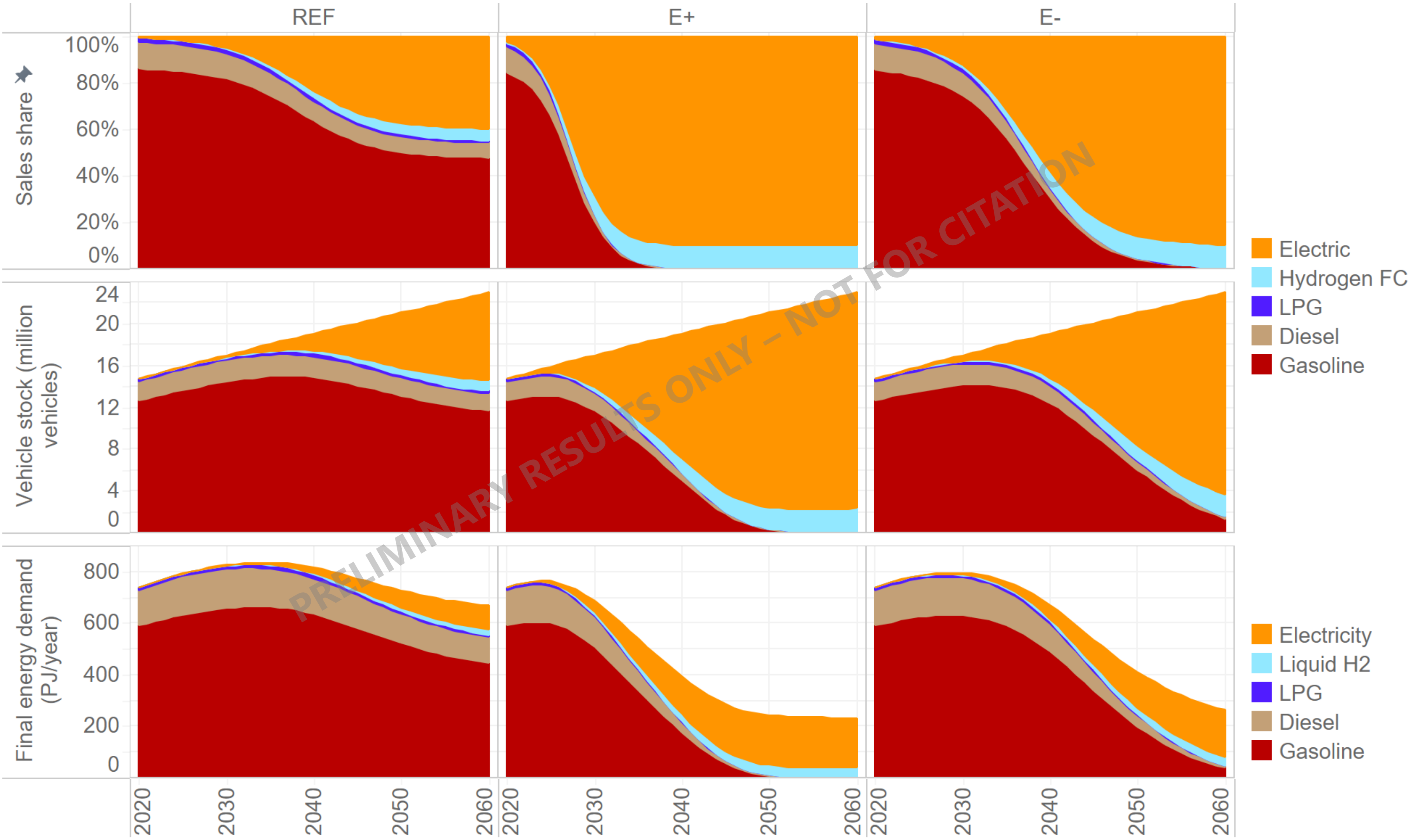


KEY TAKEAWAYS

- **Residential and commercial sectors** are nearly fully electrified by 2060 (E- results in high volumes of pipeline gas to 2050, consisting of biogas and synthetic gas)
- **Industry** energy demand uses increased electricity, but is mostly liquid and gaseous fuels (made from wind, solar, biomass and fossil fuels with CCUS)
- **Transport** undergoes high electrification, but low-emission fuels will supply more demand (aviation, shipping and some land transport)

Uptake of passenger EVs in 2020-30s enables saturation of zero-emissions fleet by 2050-60s

Passenger vehicle sales share, stock composition and final energy demand (PJ/year).



KEY TAKEAWAYS

- E+ and E− show significant drop in passenger vehicle energy demand through uptake of EVs
- Hydrogen plays larger roles for larger vehicles classes
- E- can rely on diesel and petrol past 2050 due to higher use of biomass than E+

PILLAR 2: **Clean electricity: wind and solar generation, transmission, firm power**

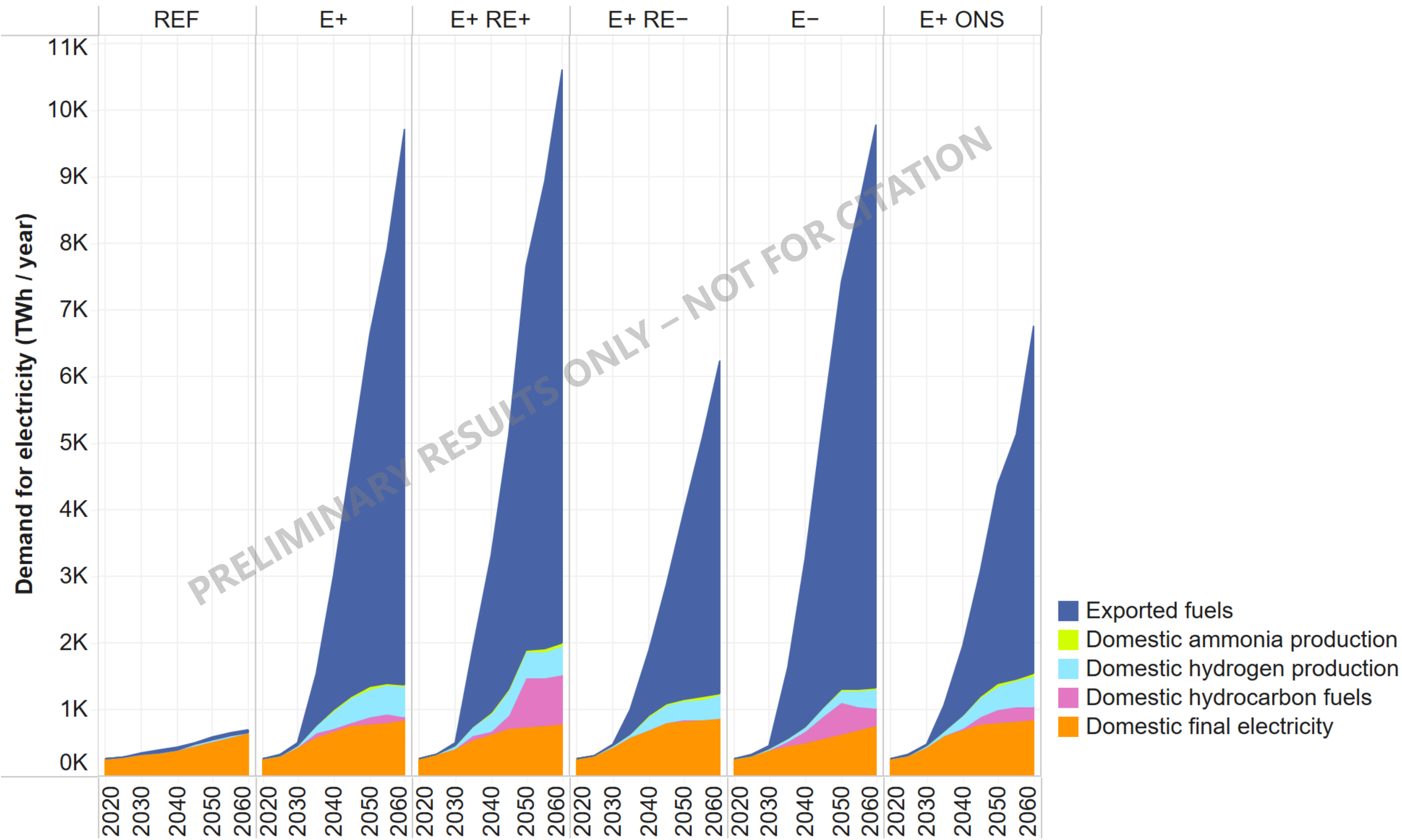
KEY FINDINGS

Exports will drive electricity generation in 2050 to 8-15× current levels, primarily solar PV complemented by major storage and new transmission

- Exports will drive electricity generation in 2050 to 8-15× current levels
- Rapid growth in renewable electricity generation outpaces a rapid fall in fossil generation
- Large scale solar generates most of the export electricity
- Solar PV will primarily come from the northern sunbelt, in parts of Western Australia, the Northern Territory and Queensland
- Significant storage capacity is needed alongside variable renewables, with supporting gas turbines
- 60-130 GW expansion of inter-regional electricity transmission is required in all scenarios

Exports will drive electricity generation in 2050 to 8-15× current levels

Projected demand for electricity generation (TWh/year)

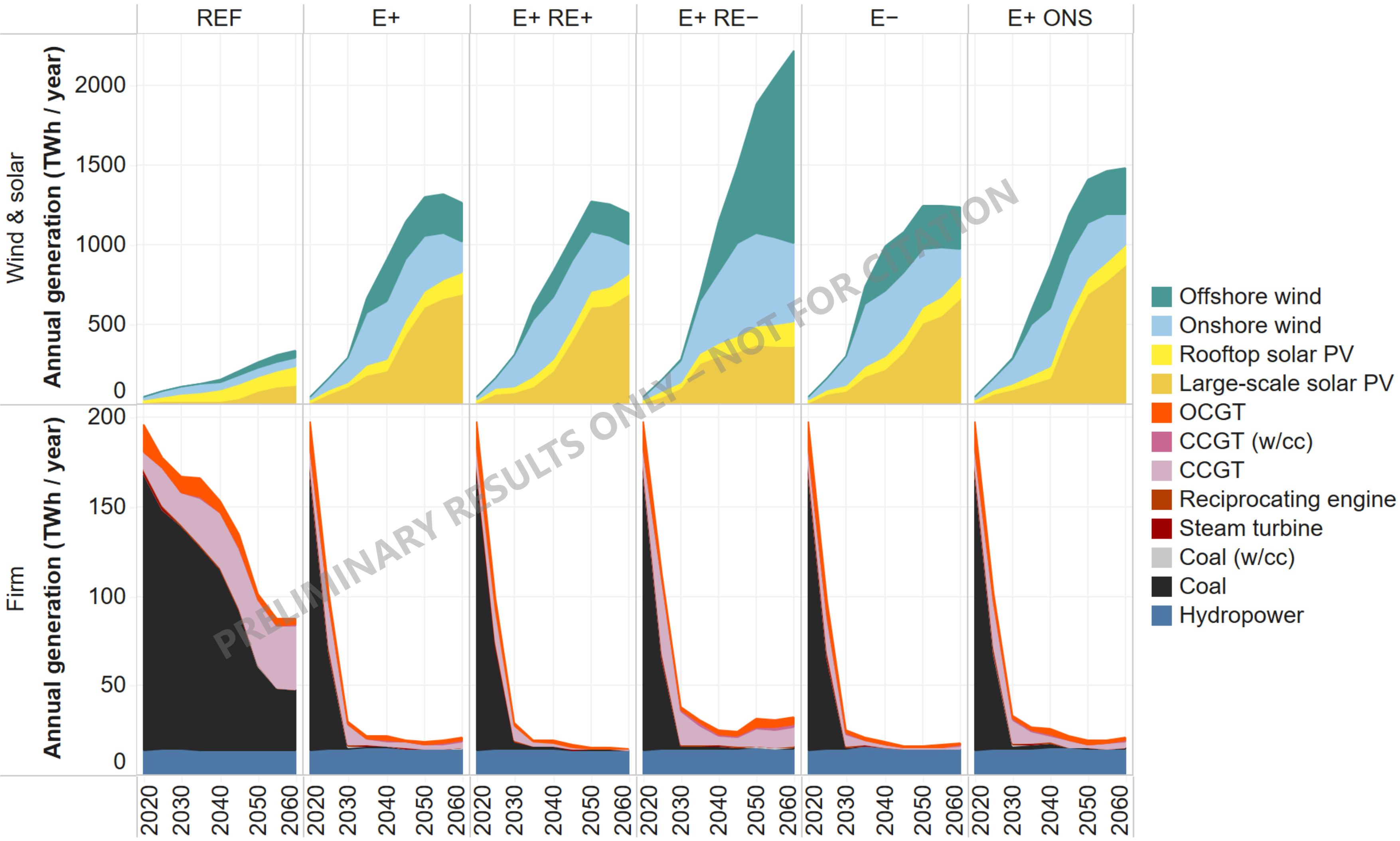


KEY TAKEAWAYS

- Domestic electricity demand is more than double the REF case
- 25-50% of domestic electricity demand is used to produce clean fuels (liquid and gas) –increase is due to replacement of oil imports with domestic sources
- 80% of electricity generation supplies export energy carriers
- Exports would take the form of hydrogen (and/or derivatives) and electricity by cable

Rapid growth in renewable electricity generation outpaces a rapid fall in fossil fuel generation

Projected domestic electricity generation by technology (TWh/year). Note varying y-axis scales.

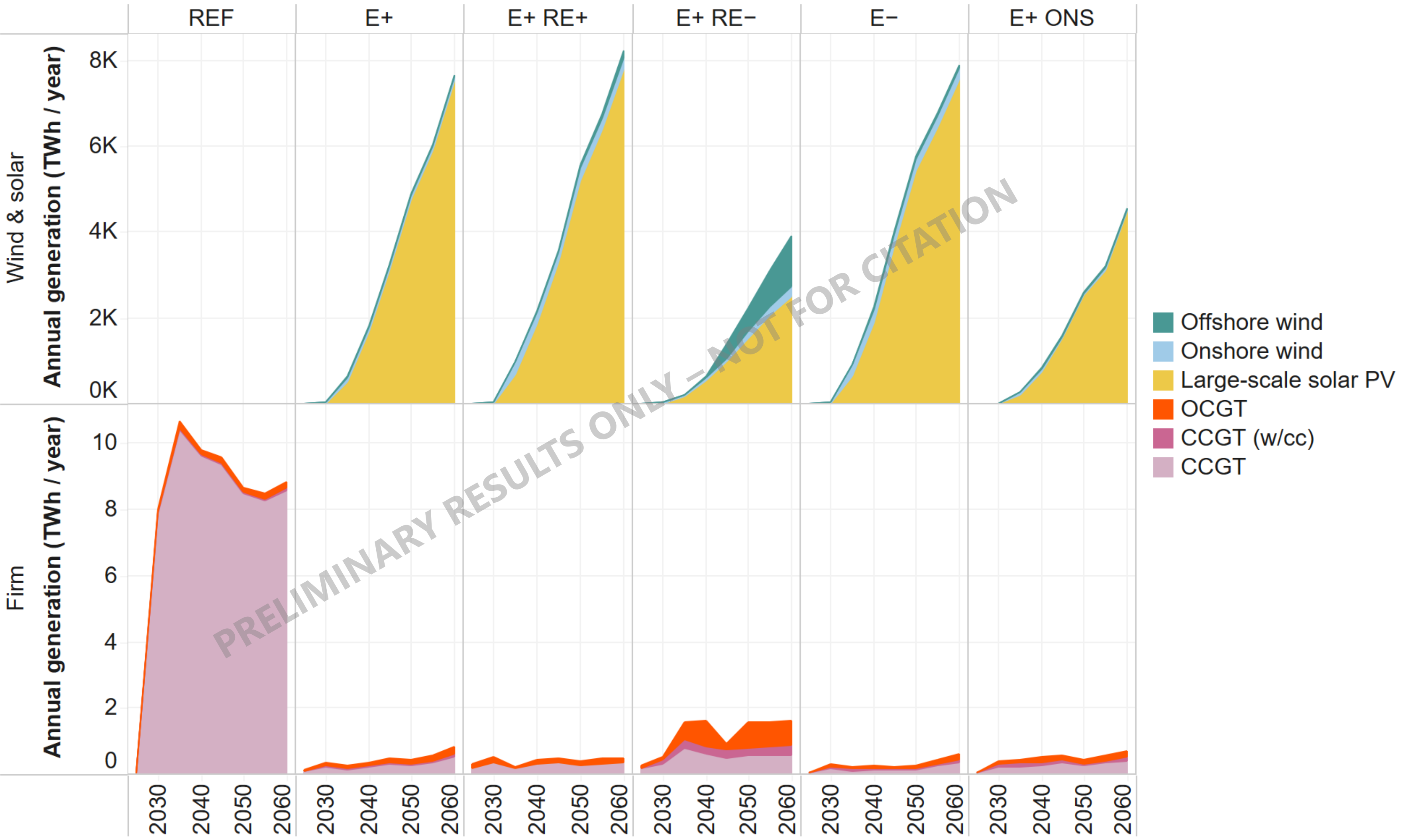


KEY TAKEAWAYS

- Electricity generation from fossil fuel has a rapid decline of ~80% from 2020 to 2030
- Fossil fuel generation with CCUS does not play a significant role in any scenario as storage is constrained and needed for hard-to-abate sectors
- Offshore wind is higher in the constrained renewables case than full renewables, because onshore wind constraint binds

Large scale solar generates most of the export electricity

Projected export electricity generation by technology (TWh/year). Note varying y-axis scales.

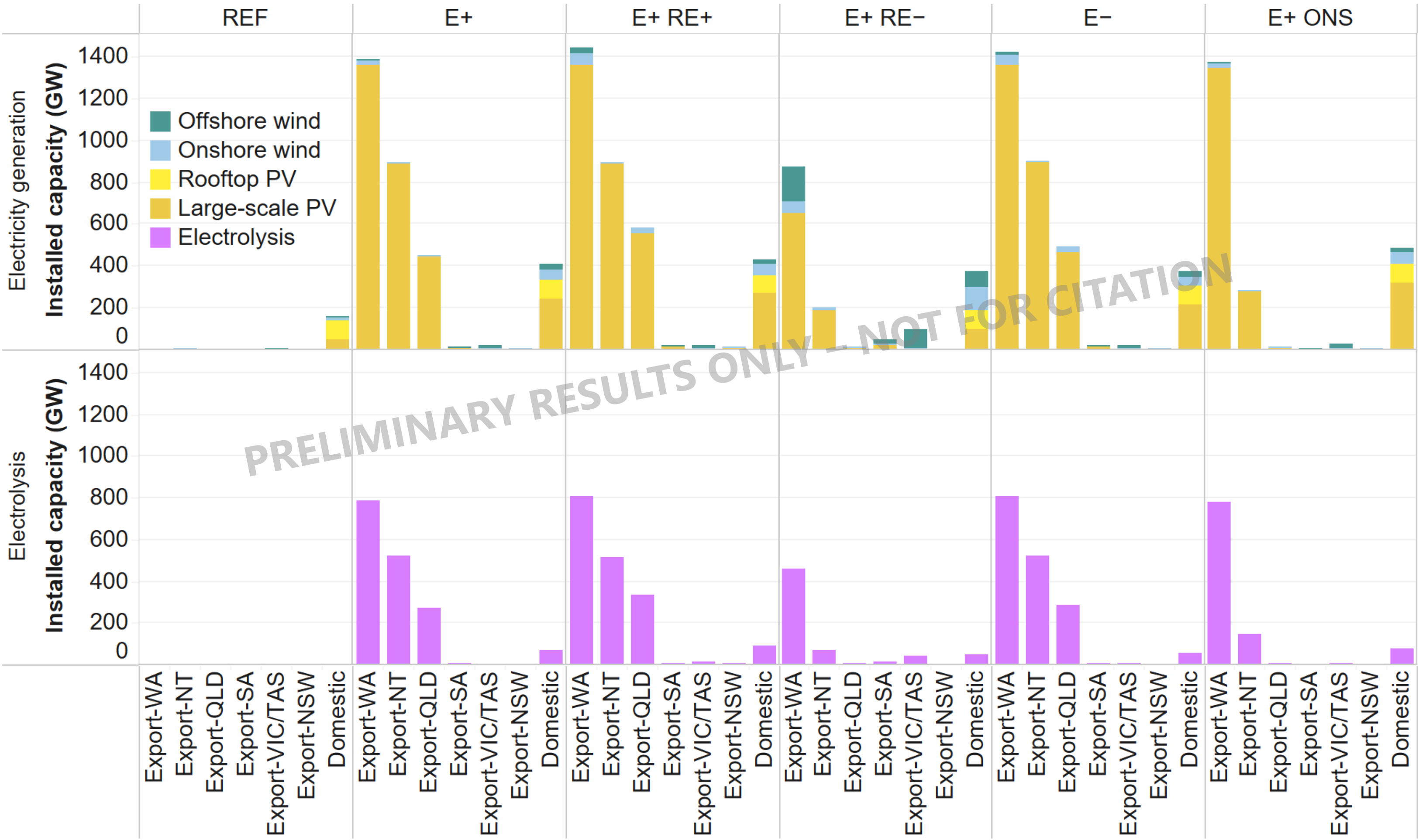


KEY TAKEAWAYS

- The low cost of large scale solar leads to solar generating near 100% of export generation in all net zero scenarios, except for E+ RE-.
- Onshore constraints grow the uptake of offshore wind generation in E+ RE-

Solar PV will primarily come from the northern sunbelt, in parts of Western Australia, the Northern Territory and Queensland

2060 Installed variable renewable and electrolyser capacity, by zone (GW).

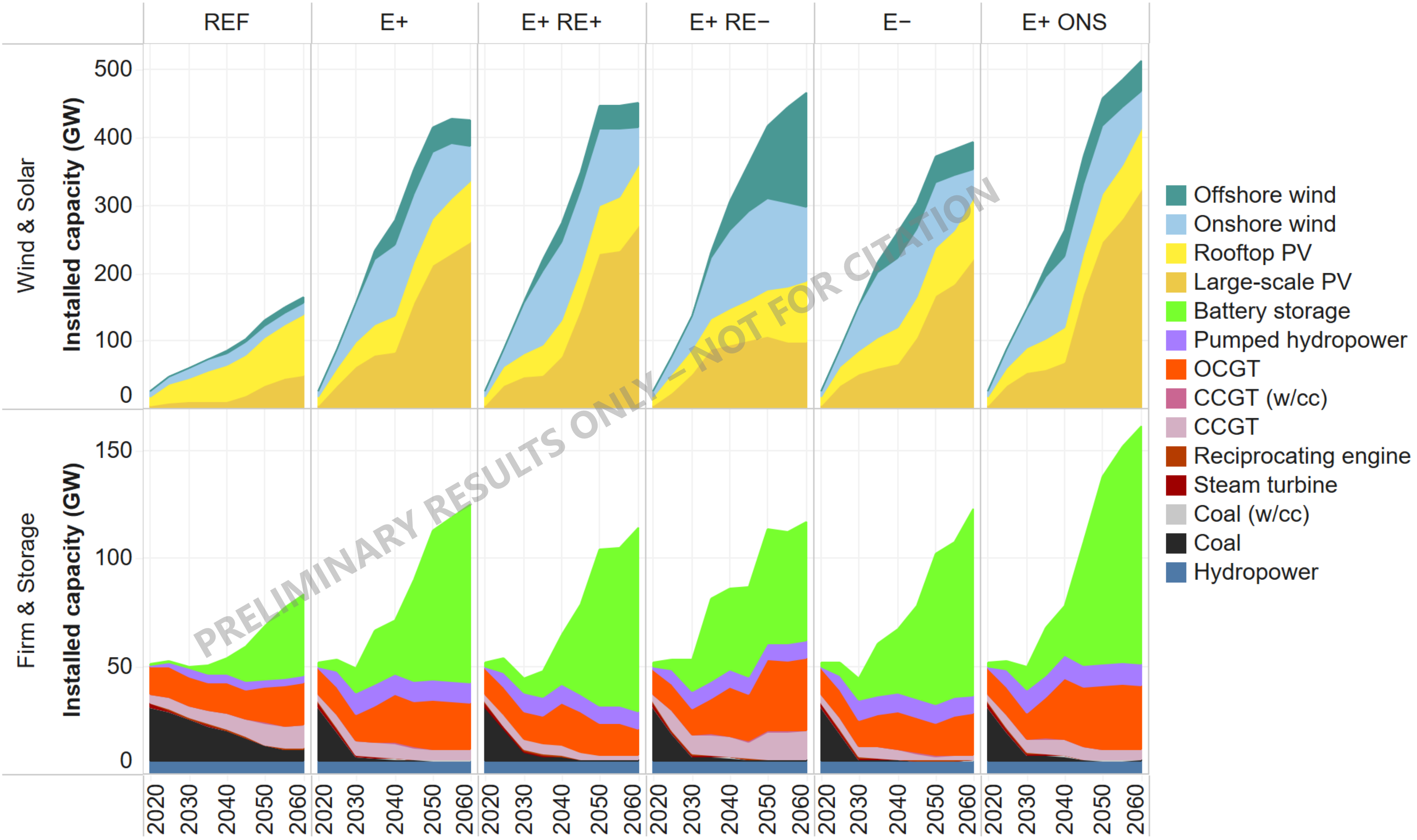


KEY TAKEAWAYS

- Northern WA, NT and QLD host major solar export zones, having the best solar resources
- E+RE- also includes substantial blue ammonia exports due to assumed high CCUS capacity
- Integration into export value chain required

Significant storage and generation capacity is needed to firm renewables (1/2 – domestic)

Projected domestic electricity generation capacity by technology (GW). Note varying y-axis scales.

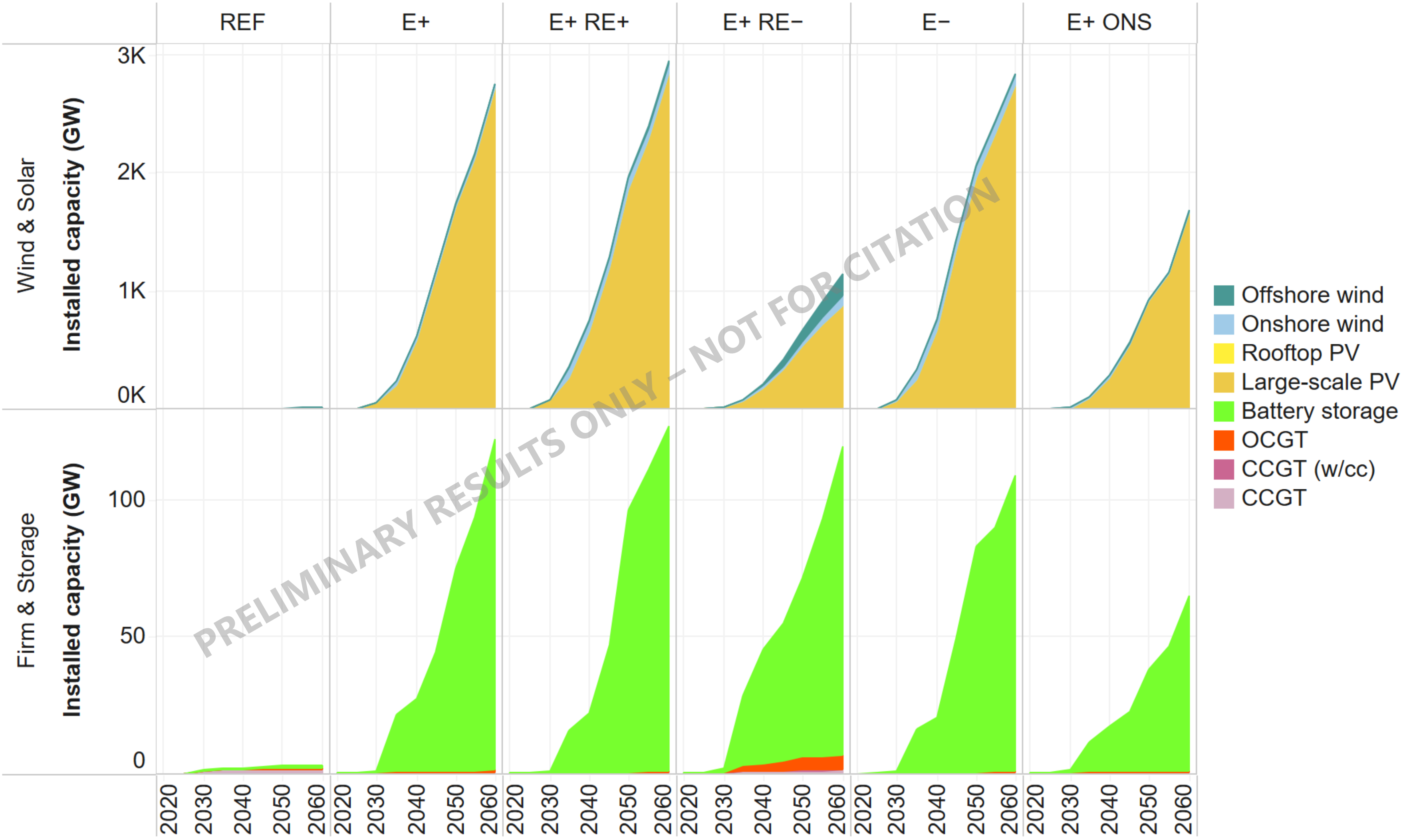


KEY TAKEAWAYS

- Solar dominates domestic electricity generation in all scenarios, except for E+RE- where most of the generation is wind (split ~50/50 onshore and offshore)
- 50-120 GW of energy storage (mostly batteries) help to firm growing variable renewable generation
- 30-50 GW of firm generation also needed – mostly hydro and gas turbines burning zero-carbon fuels – the total output of which falls (as per following slide) as the installed capacity rises
- Domestic offshore wind is highest in E+RE- (150 GW) and supplies domestic demand in all net zero scenarios

Significant storage and generation capacity is needed to firm renewables (2/2 – export)

Projected export electricity generation capacity by technology (GW). Note varying y-axis scales.

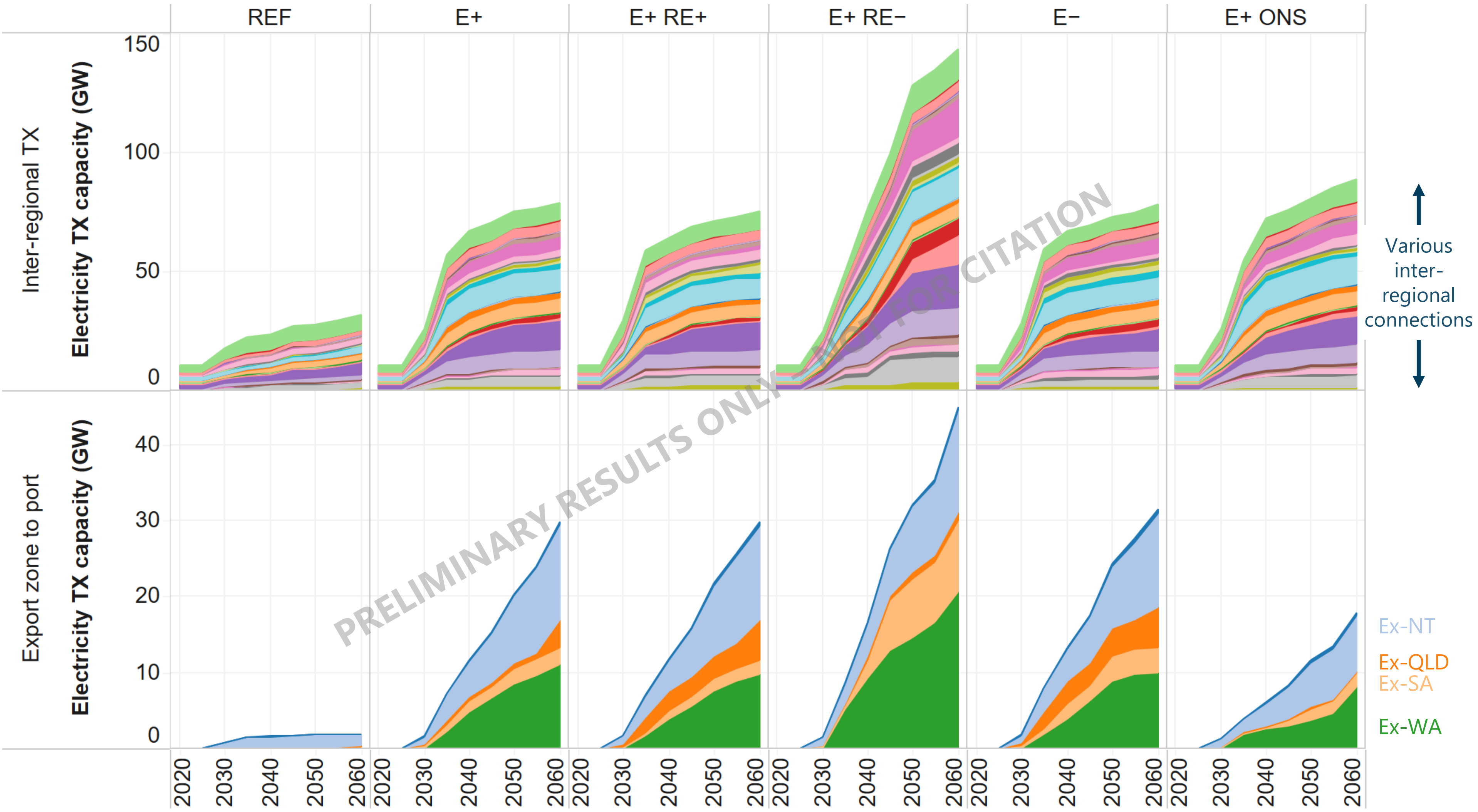


KEY TAKEAWAYS

- Almost all electricity serving the export market is generated from large scale Solar PV (1-3 TW)
- Similarly, almost all firming and storage of export electricity is provided by battery storage (60-140 GW)

60-130 GW expansion of inter-regional electricity transmission required in all scenarios

Projections of inter-regional and export-to-port electricity transmission capacity (GW)



KEY TAKEAWAYS

- Twice the inter-regional transmission needed in RE- compared to other scenarios, driven by higher use of wind, which is less proximate to demand than solar
- Electricity transmission to port is low compared to generation capacity as hydrogen transmission is favored to electricity transmission (see hydrogen transmission slide)

PILLAR 3: **Zero-carbon fuels and feedstocks** (including bioenergy)

KEY FINDINGS

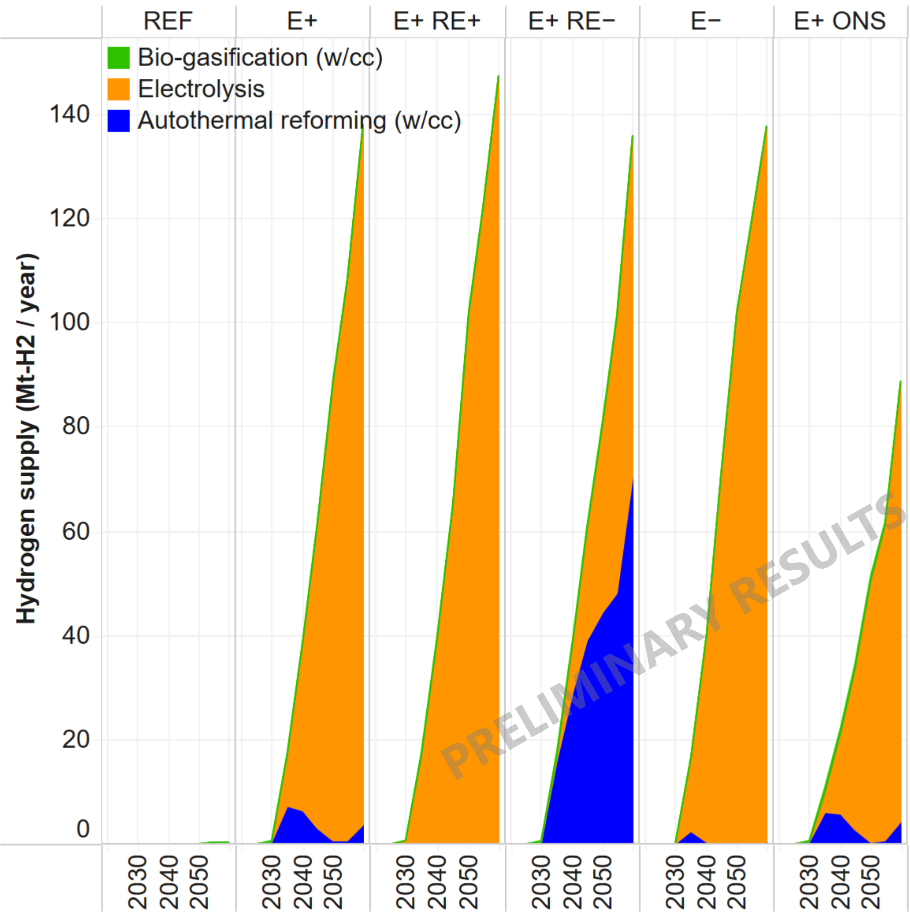
Clean fuel production will use 25-50% of domestic electricity – but 90% of all electricity, given export demand

- Most Australian hydrogen will be produced through electrolysis and exported
- Major underground hydrogen storage capacity is needed for the domestic system, and multiples more for exports
- All scenarios mostly phase out pipeline gas by 2060, except for RE- where pipeline gas doubles
- Bioenergy potential is limited by supply but nevertheless expands seven-fold to ~900 PJ/year
- Aviation remains fully dependent on fossil fuels, except in RE+, which prohibits fossil fuel use

Most Australian hydrogen will be produced through electrolysis and exported

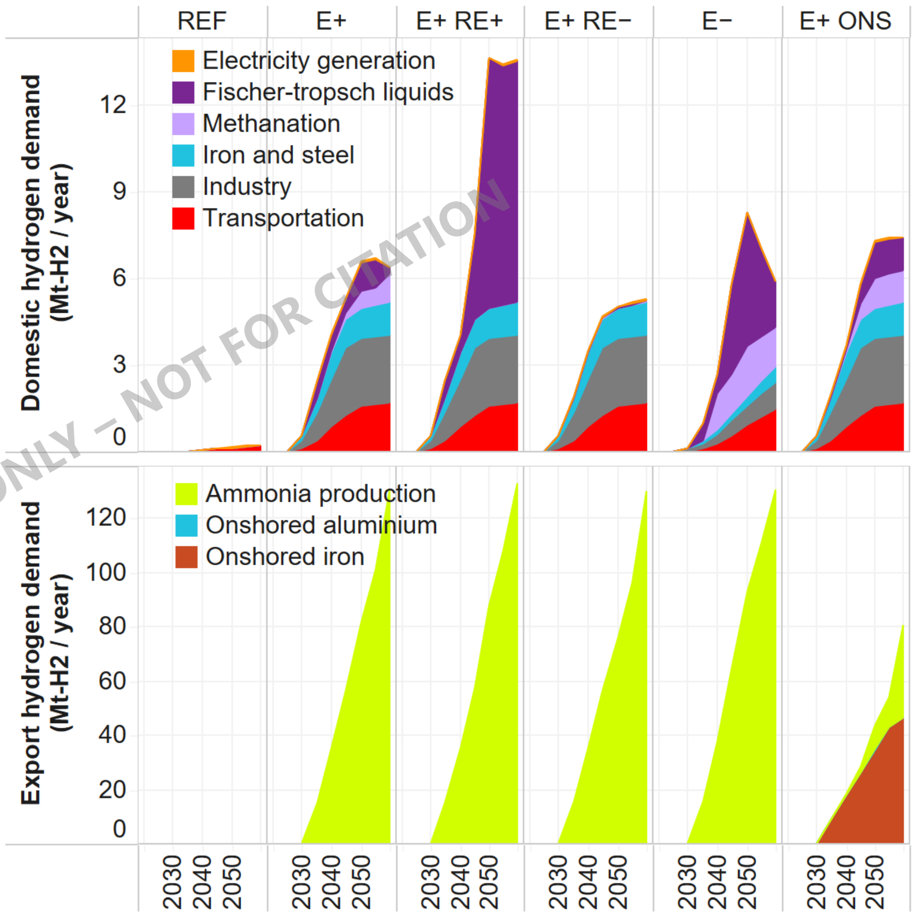
Projected hydrogen supply, by technology

($Mt\text{-}H_2$/year)



Projected hydrogen use, by sector/technology

($Mt\text{-}H_2$/year). Note difference of 10x in y-axis scale

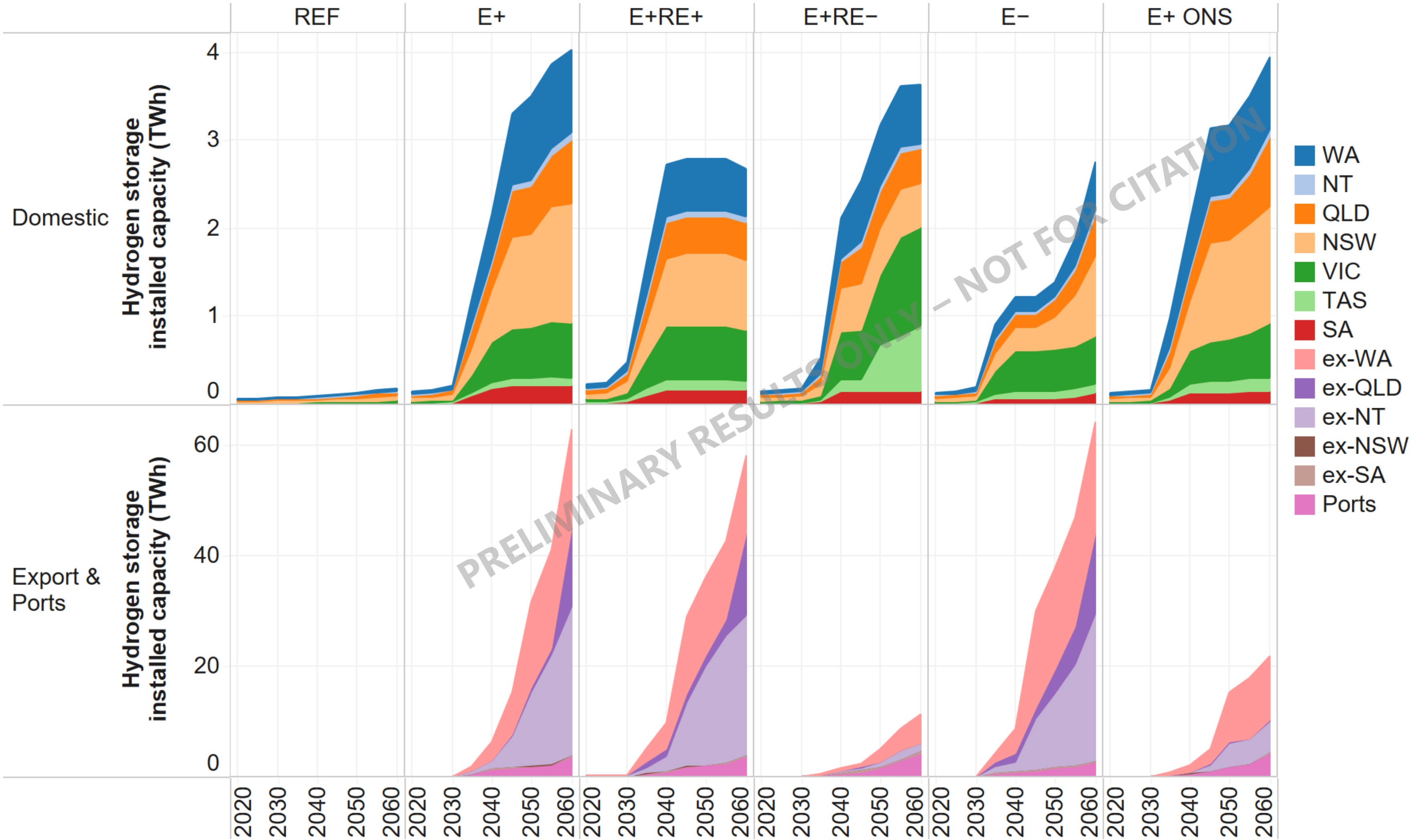


KEY TAKEAWAYS

- More than 140 Mt/year of hydrogen produced to substitute current fossil energy exports with clean carriers
- Haber-Bosch ammonia production assumed for exports
- Electrolysis dominates hydrogen production capacity in most scenarios
- Blue hydrogen supplies a small early share in E+ and E-, none in E+RE+, and substantial share in E+RE- due to increase in maximum CCUS capacity

Major underground hydrogen storage capacity is needed for the domestic system, and multiples more for exports

Projected capacity of underground hydrogen storage, by region (TWh). Note varying y-axes.

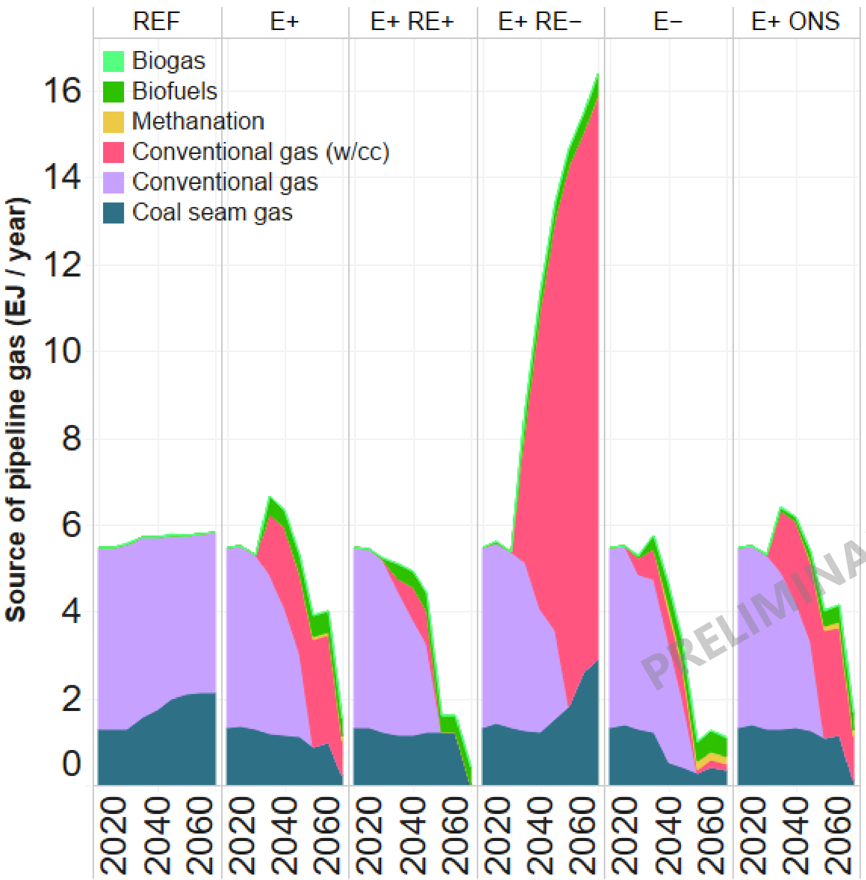


KEY TAKEAWAYS

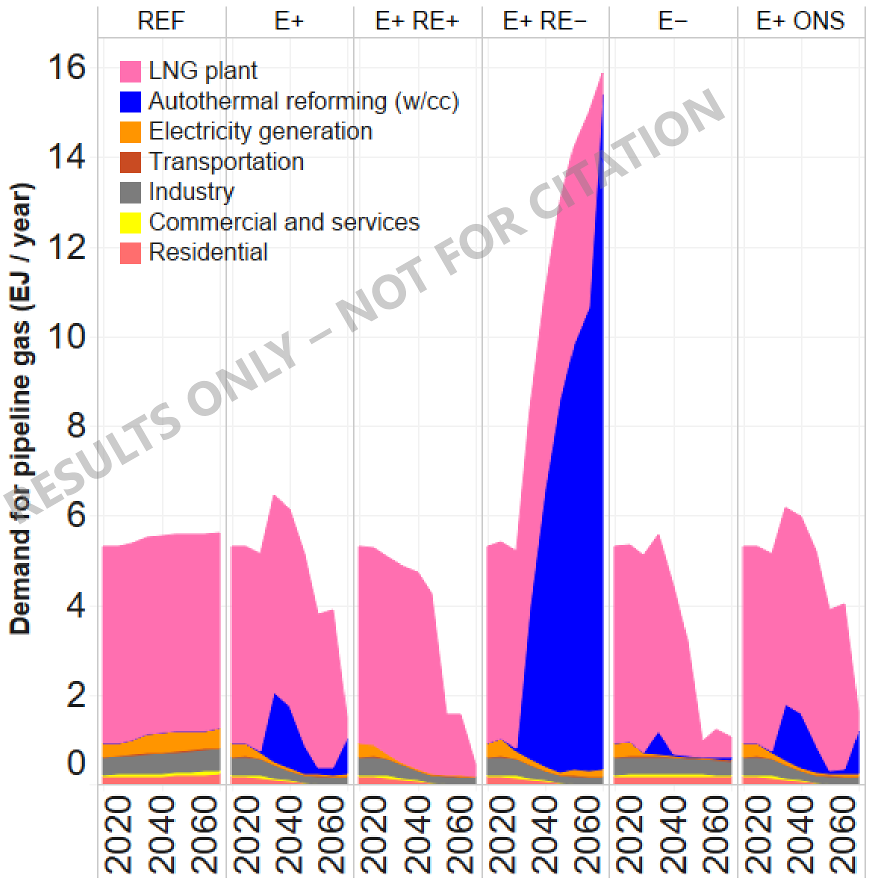
- Major underground hydrogen storage capacity is needed across the country to serve the domestic system. Capacity must rapidly scale up in 2040 in all scenarios, except for E- which takes a 2 staged approach
- Export and ports will require 2-15x the hydrogen storage of the domestic system, mostly in the NT.

All scenarios mostly phase out pipeline gas by 2060, except for RE- where pipeline gas doubles

Source of gas into pipelines (EJ/year)



Demand for gas from pipelines (EJ/year)

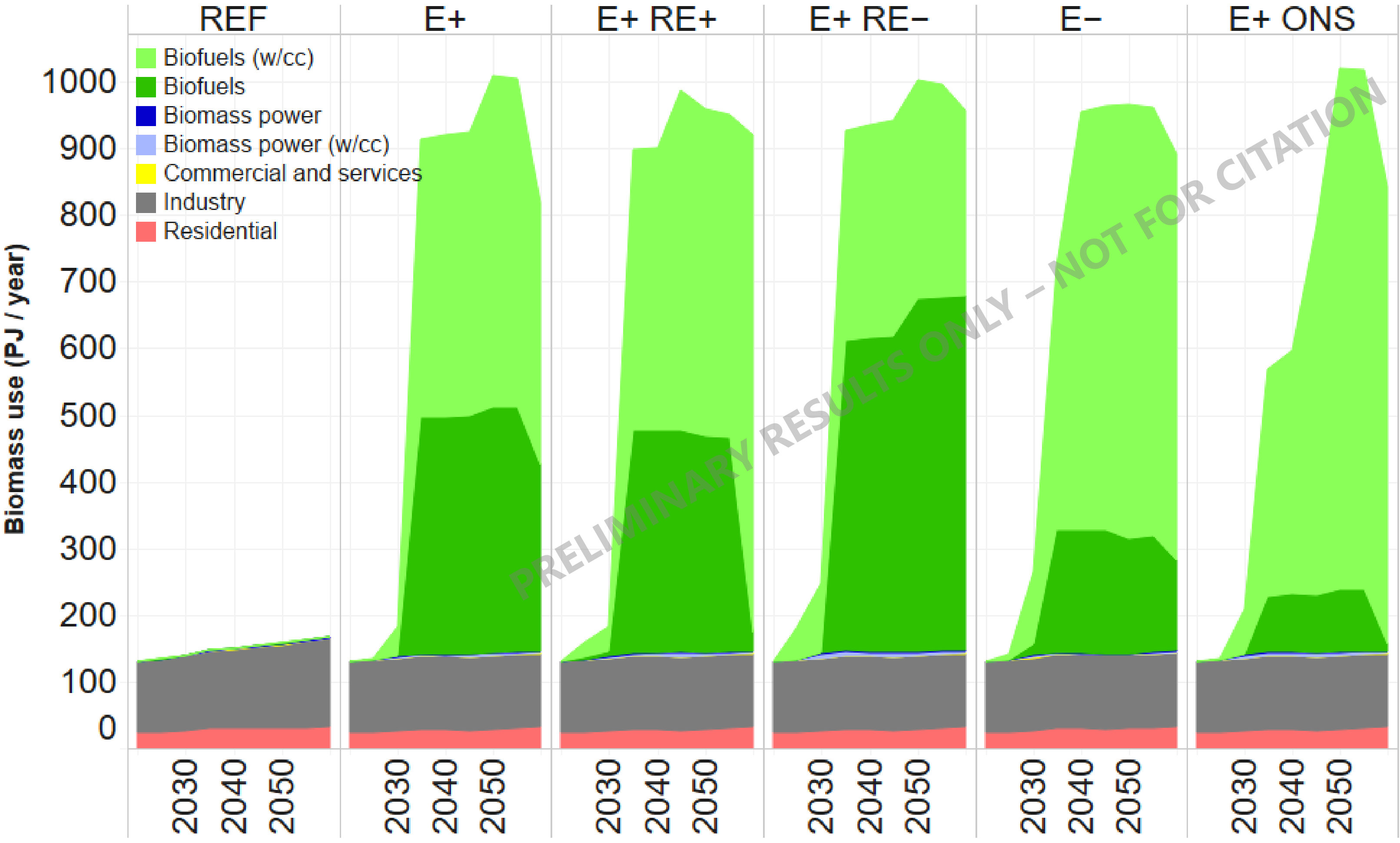


KEY TAKEAWAYS

- RE- has double the current use of gas in 2060, with autothermal reforming and high CCUS capacity
- This maintains energy export target given constrained renewables

Bioenergy potential is limited by supply but nevertheless expands seven-fold to ~900 PJ/year

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



KEY TAKEAWAYS

- Australia's limited biomass supply mostly used to produce fuels and chemical feedstocks
- 30-50% of biofuel production is coupled with CCUS – less than previously modelled
- New biofuel demand mostly goes to pipeline gas – used across residential and industry

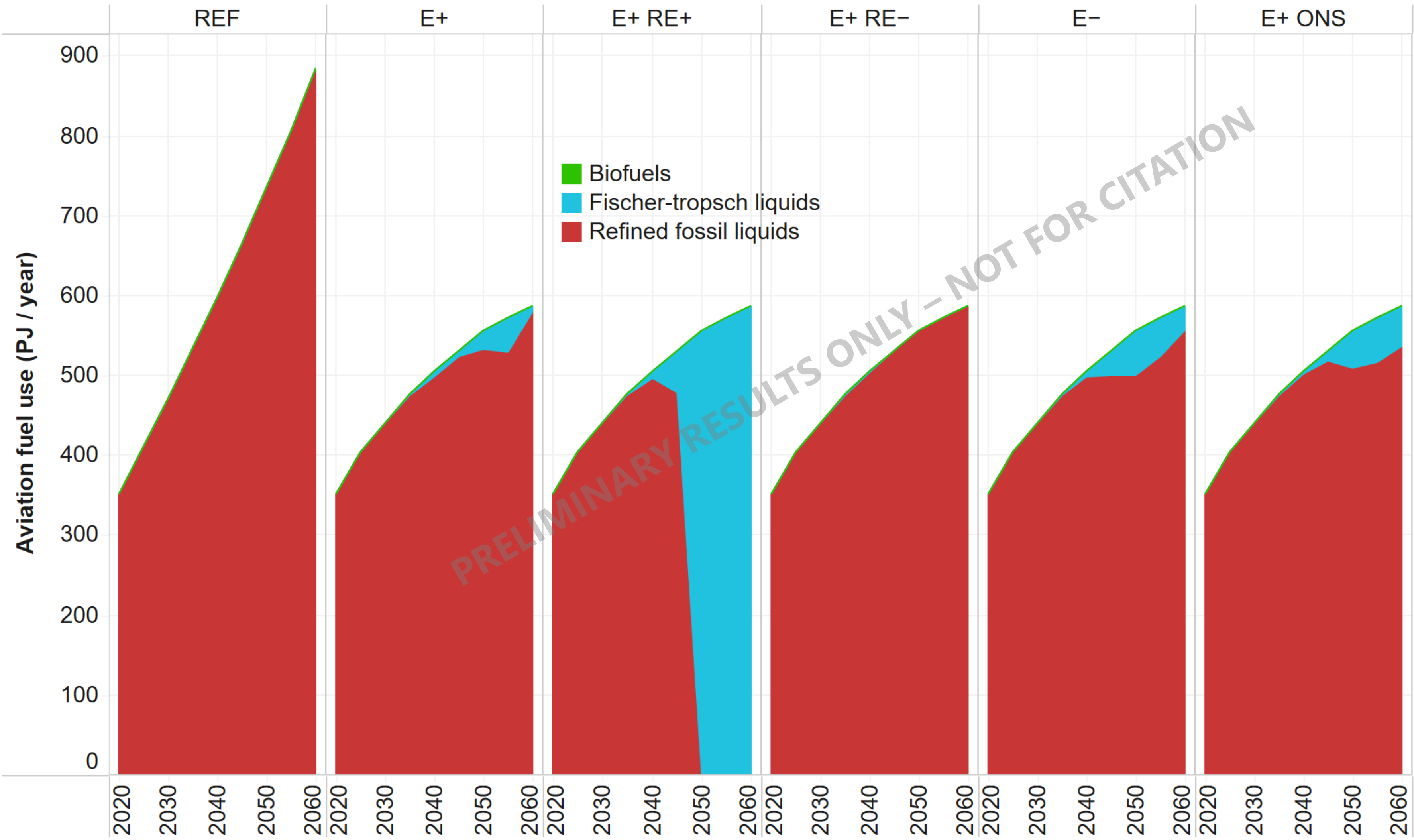
Aviation remains fully dependent on fossil fuels, except in RE+, which prohibits fossil fuel use

PILLARS

1 2 3 4 5 6

Zero carbon fuels and feedstocks

Projected aviation fuel use, by fuel source (PJ/year)



KEY TAKEAWAYS

- Other than E+RE+, residual aviation emissions will need to be offset with negative emissions (bioenergy with CCUS and DAC)
- Biofuels play less of a role than previous results, due to minor changes in relative costs of all fuels/feedstocks – to be tested through sensitivity analysis

PILLAR 4: CO_2 capture, transport, utilisation and storage

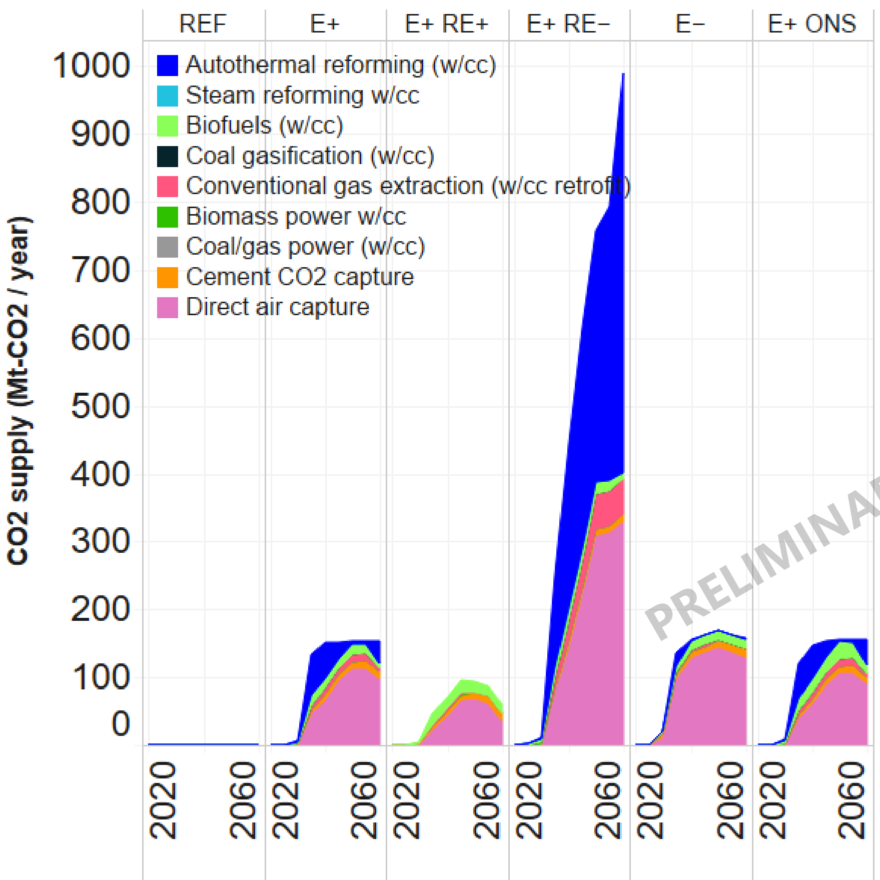
KEY FINDINGS

CCUS expands rapidly across all scenarios, including the high renewables scenario (RE+)

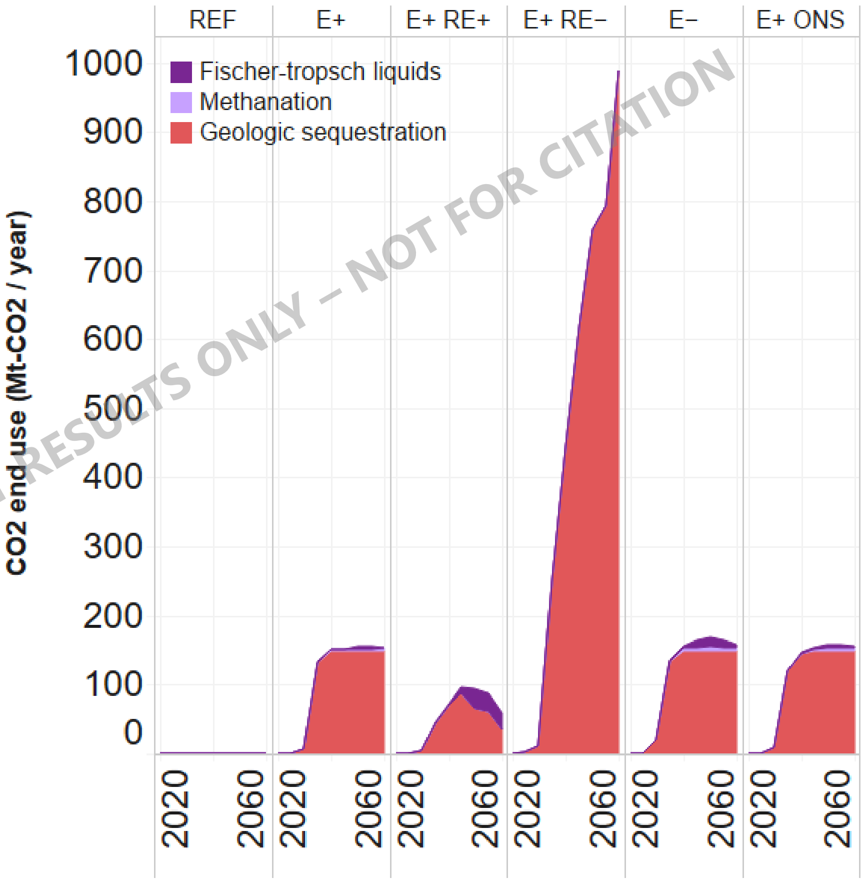
- Carbon capture, utilisation and storage (CCUS) expands rapidly across all scenarios
- Direct air capture features in all scenarios, but RE- uses most because of high CCUS capacity

Carbon capture, utilisation and storage (CCUS) expands rapidly across all scenarios (1/2)

Projected CO_2 supply, by technology
(Mt-CO_2/year)



Projected CO_2 end use/destination
(Mt-CO_2/year)

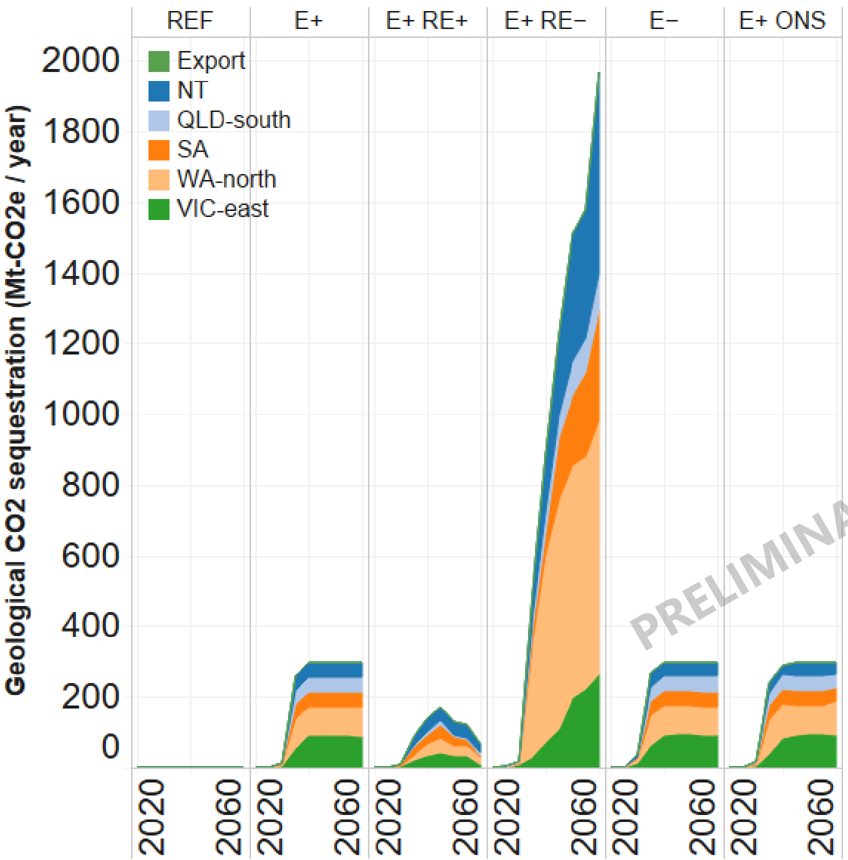


KEY TAKEAWAYS

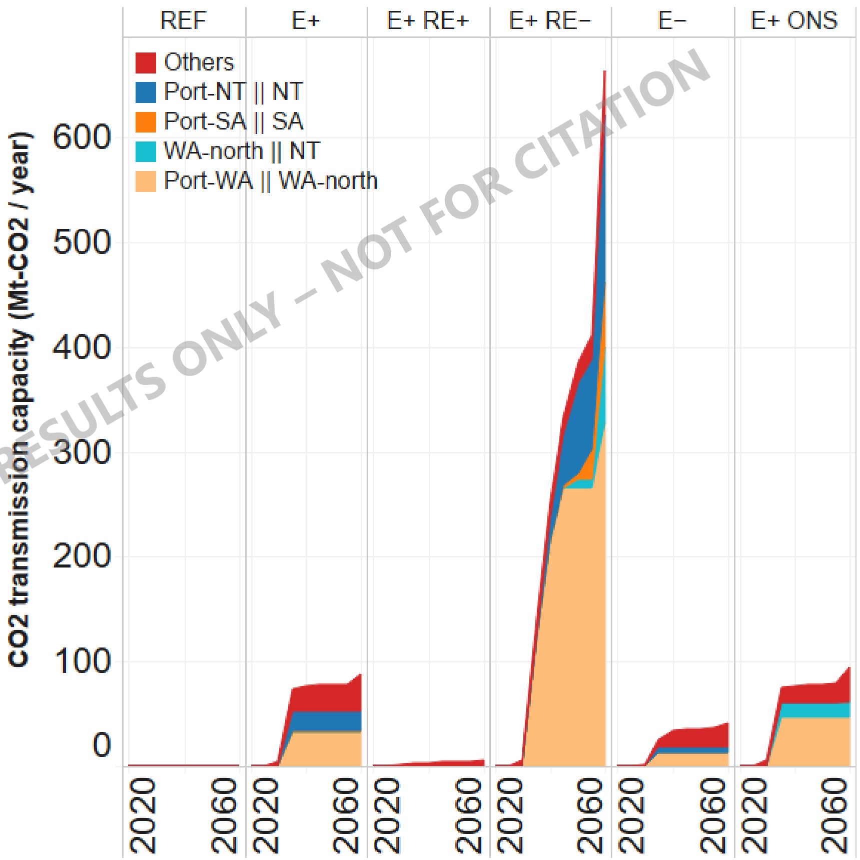
- E+RE- sequestration is near to the new maximum (~1.2Gt p.a., 6x previous for that scenario only)
- Gas (supplying ATR-CCUS) outcompetes coal gasification even where long-distance CO2 transport is needed from gas production to carbon storage basin
- Direct air capture provides carbon for net-zero hydrocarbons, including Fischer-Tropsch liquids and some chemical feedstocks
- Significant CCUS demand from biofuels and cement (the only permitted use of CCUS in E+RE+)

Carbon capture, utilisation and storage (CCUS) expands rapidly across all scenarios (2/2)

Projected CO_2 sequestration (Mt-CO_2/year)



Projected CO_2 transmission capacity (Mt-CO_2/year)

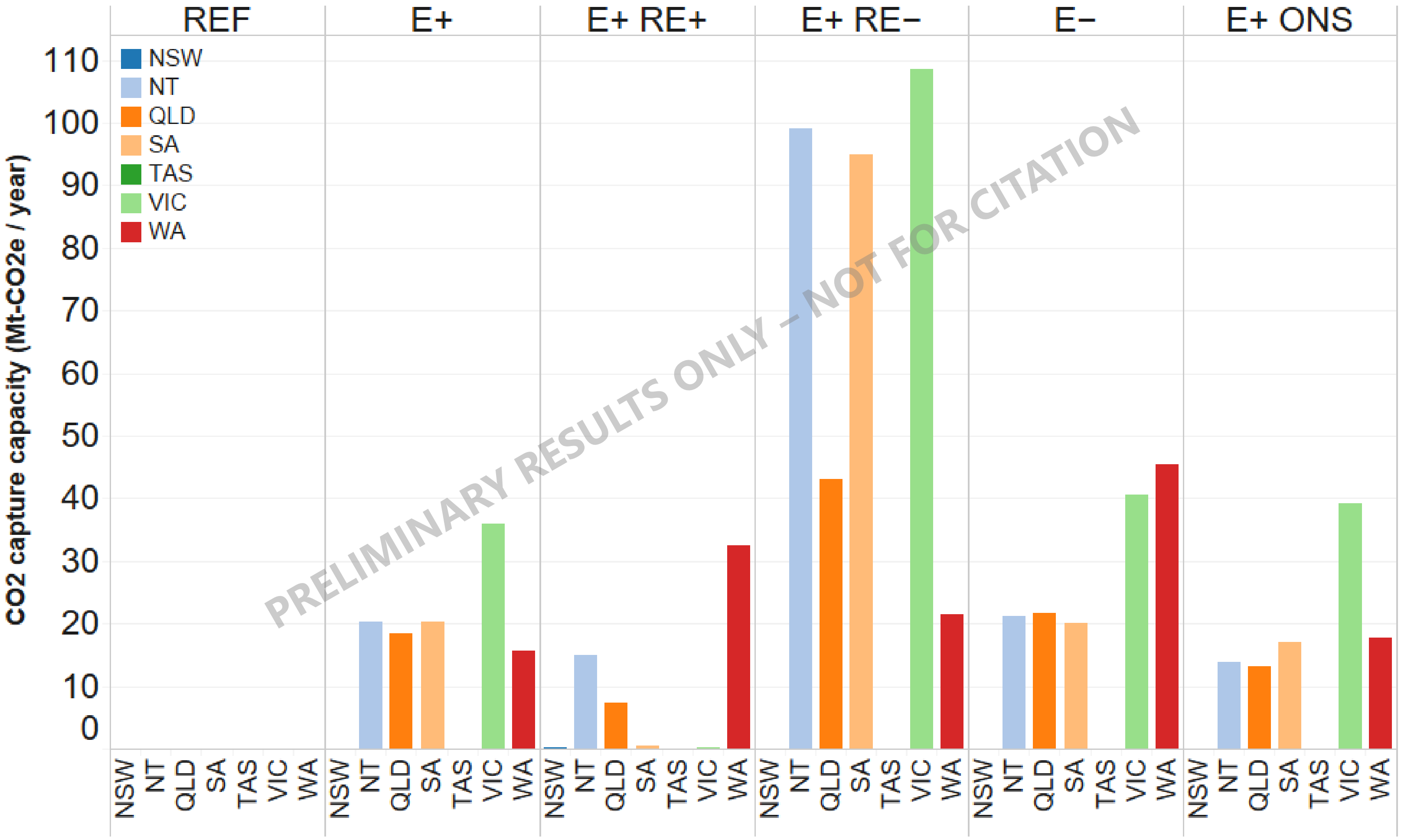


KEY TAKEAWAYS

- Geological sequestration limit is rapidly reached in E+ and E- by 2040
- Significant transmission capacity required to transfer CO2 to sequestration sites – except in E+RE+
- CO2 transmission capacity is typically less than total sequestered because DAC is located near sequestration sites, avoiding the need for CO2 transmission
- The largest geo-sequestration and CO2 transmission use is in E+RE-, mostly for export

Direct air capture features in all scenarios, but RE- uses most, to offset residual emissions from high CCUS operations

Projected 2060 direct air capture capacity (Mt-CO_2/year)



KEY TAKEAWAYS

- RE- has larger sequestration potential and therefore has 5× DAC rollout of other scenarios to offset expanded natural gas use
- DAC facilities located in regions with CO_2 sequestration potential

PILLARS 5&6: Non-CO_2 emissions and land sinks

KEY INSIGHTS

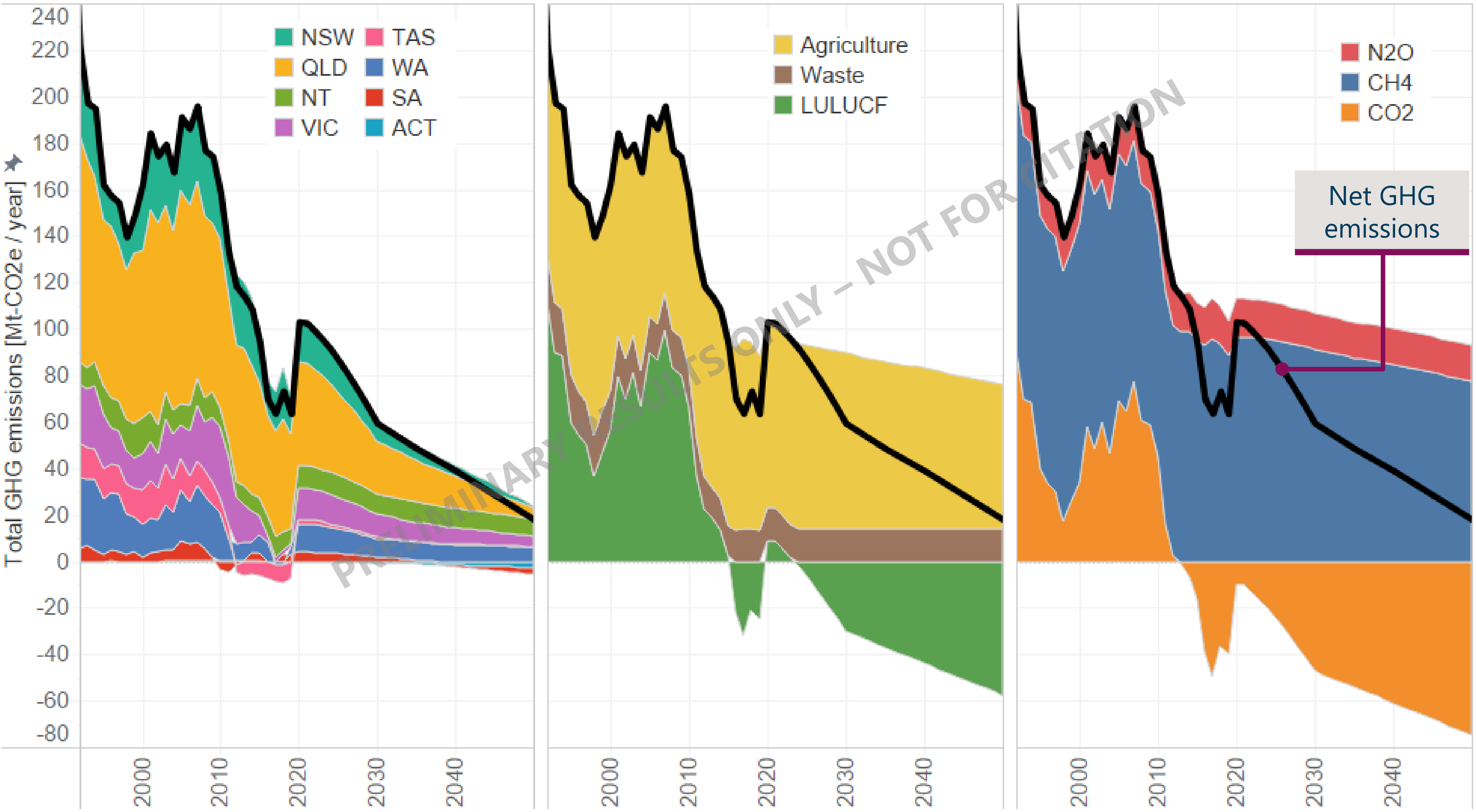
Non-CO_2 and land sector GHG emissions projected to reduce, but remain small net source of emissions

- Biosequestration opportunity is limited, and should not be relied on to offset emissions of other sectors
- Five million hectares of new tree plantings to provide a net sink of 60 MtCO2 per year, requiring 8 per cent of Australia's land 'mainly used for cropping and improved pastures.'

Non-CO_2 and land sector GHG emissions projected to reduce, but remain small net source of emissions

PILLARS
1 2 3 4 5 6
Non-CO2 emissions; Enhanced land sinks

Historical and projected Agriculture; Land Use, Land Use Change and Forestry; and Waste sector GHG emissions ($Mt\text{-}CO_2e$/year).



KEY TAKEAWAYS

- Agriculture and waste emissions are projected to continue to 2050
- LULUCF will drive a small net negative shift through reforestation
- Reforestation includes 5 million hectares of new tree plantings to provide a net sink of 60 MtCO2 p.a.; requiring 8% of Australia's land "mainly used for cropping and improved pastures"
- Residual 19 $Mt\text{-}CO_2e$/year must be offset elsewhere in modelling.
- Overall finding is comparable to other studies

General insights: **System costs**

KEY FINDINGS

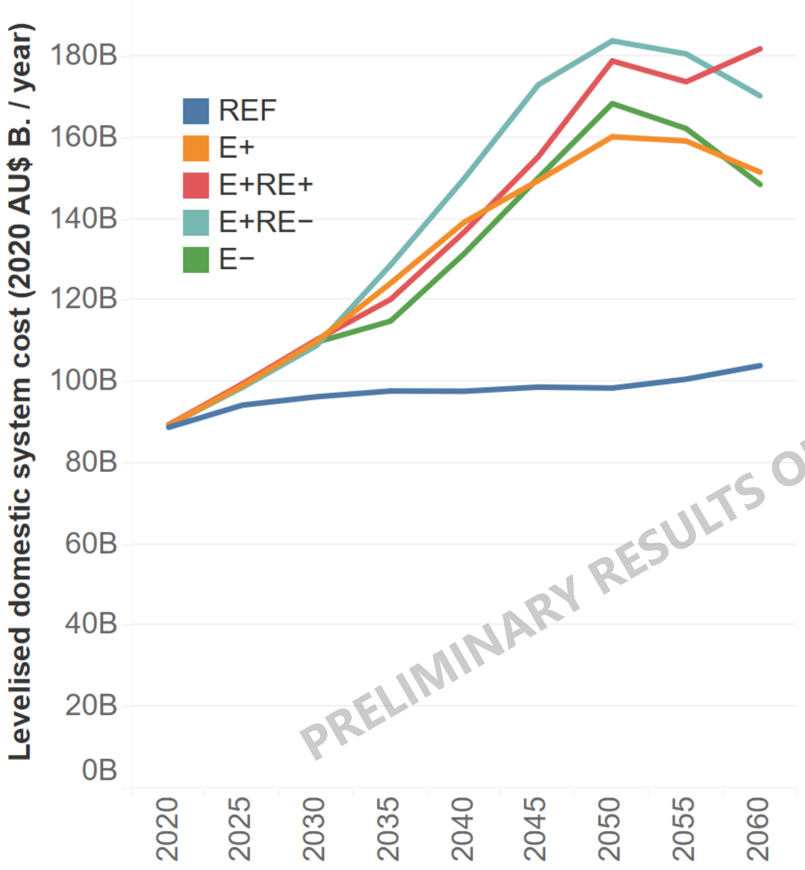
Domestic system costs will fall as a percentage of GDP, while export system costs will rise to reflect the new economics of green energy exports

- Domestic system costs rise in absolute terms (1.5-1.8x reference case by 2060), but fall as a share of GDP
- The lower cost of reference case reflects existing pre-investment, but does not model future fossil fuel supply constraints
- System costs are dominated by capital costs of renewables and electrolysis
- Decarbonised export system will cost 5× more than reference case
- The cost of exporting green hydrogen falls below blue hydrogen in ~2045

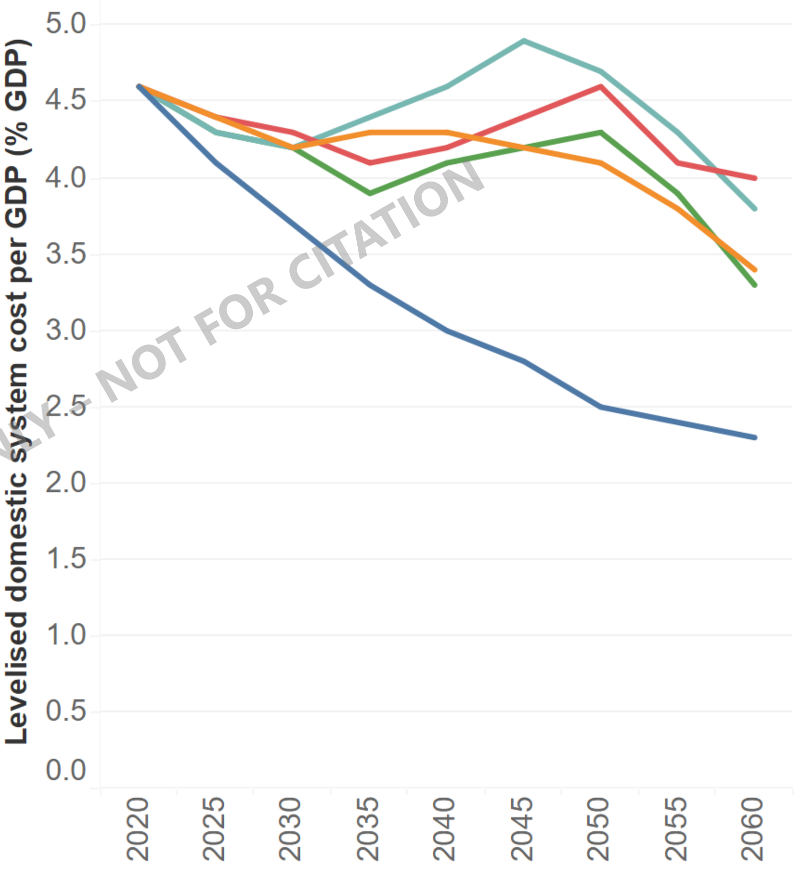
Domestic system costs rise in absolute terms (1.5-1.8x reference case by 2060), but fall as a share of GDP

DOMESTIC SYSTEM COSTS

Levelised domestic system cost
($ billion /year)



Levelised domestic system cost per GDP
(%GDP)



Note: E+ ONS is not shown as costs modelling is still being refined.

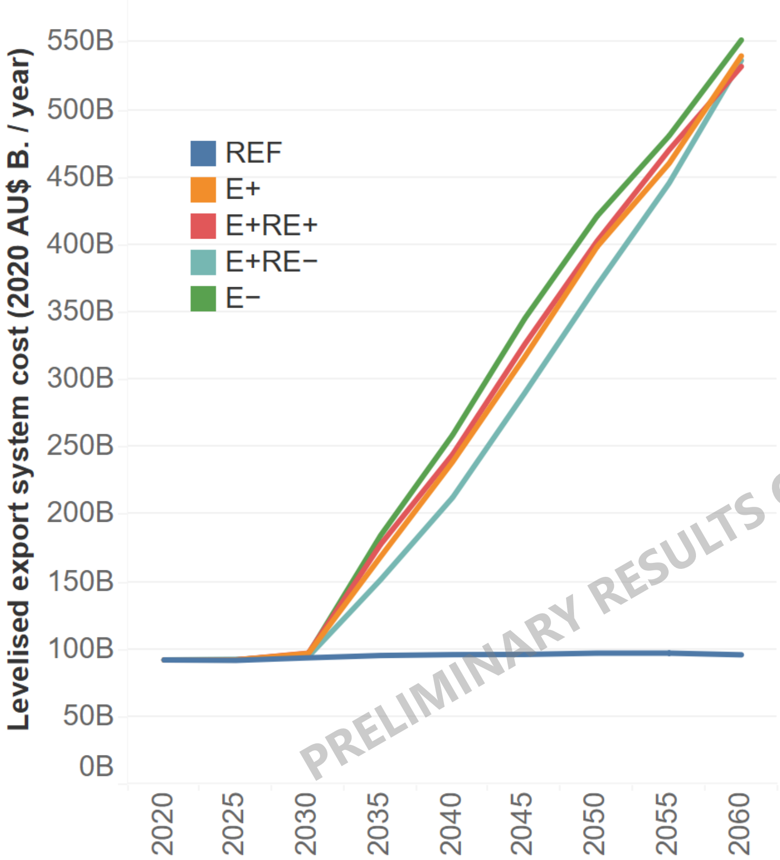
KEY TAKEAWAYS

- Domestic system costs remain around or lower than current share of GDP (but 1.5-1.8x REF by 2060)
- Costs of REF reflect existing pre-investment
- Fossil fuel supply constraints are not reflected in future oil and gas prices
- System costs are dominated by capital costs of renewables and electrolysis
- For least-cost pathways (E+ and E-) renewables dominate, and fossil fuels with CCUS supplement
- E+RE+ and E+RE- cost more than E+ because constrained energy mixes are sub-optimal

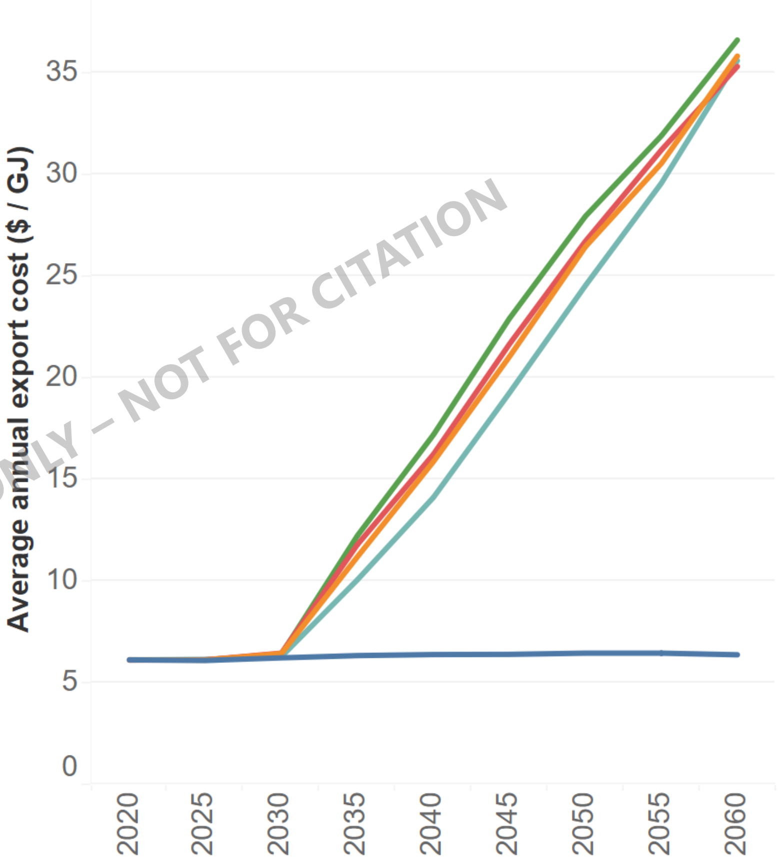
Decarbonised export system will cost 5× more than reference case

EXPORT SYSTEM COSTS

Levelised export system cost ($ billion/year).



Average annual export cost ($/GJ).



Export mix over time

KEY TAKEAWAYS

- Cost differences between net zero scenarios are small
- Exports costs are 5× REF – due to high starting costs, and energy conversion losses which counteract renewable energy cost reductions due to learning
- However the REF and E+RE- cases do not consider price impacts arising from future fossil fuel supply constraints
- The impact of high $/GJ costs on demand for exports have not been modelled

Note: E+ ONS is not shown as costs modelling is still being refined.

General insights: **Employment**

KEY FINDINGS

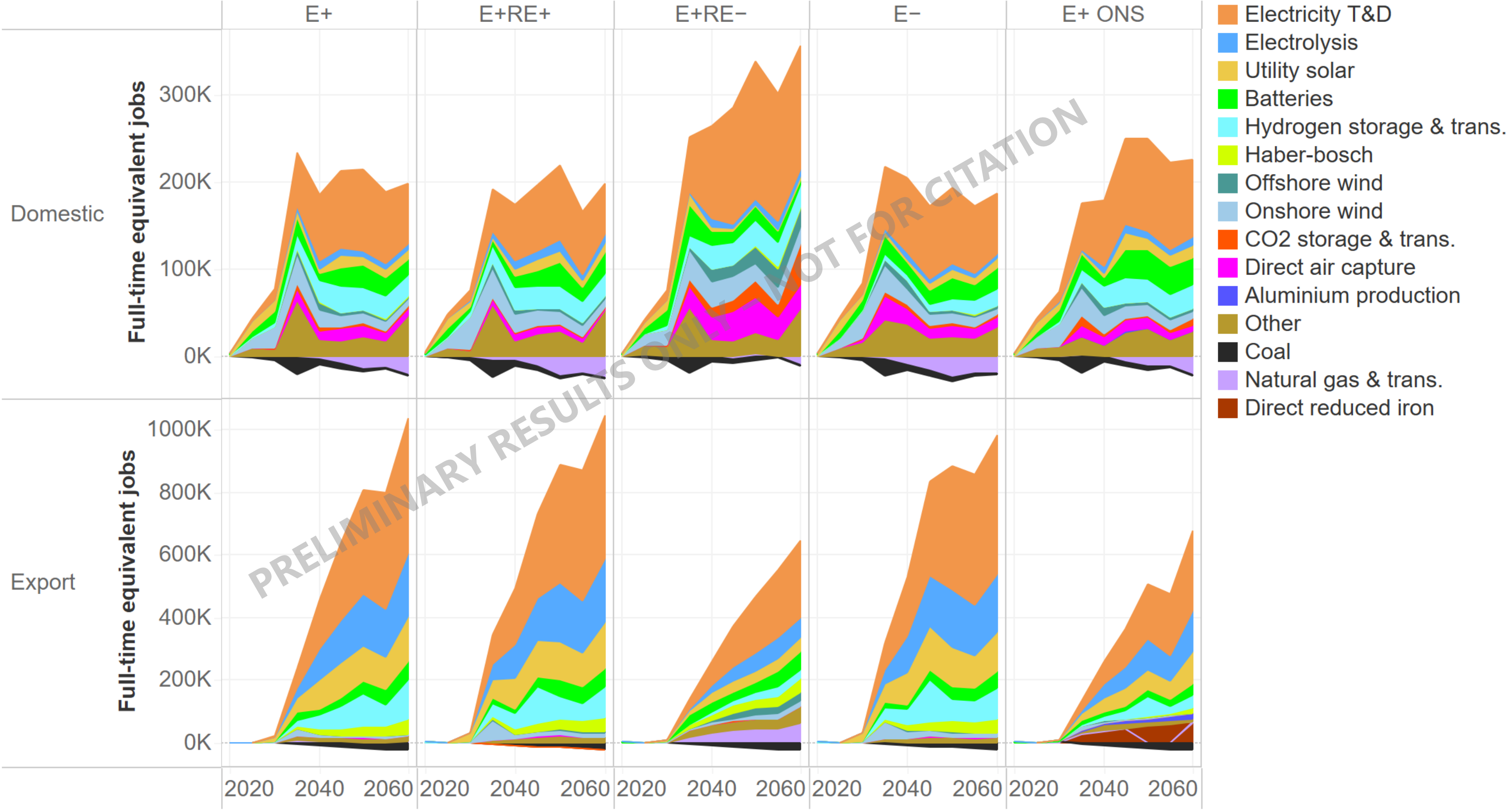
Across all net zero scenarios, the transition will create an additional million jobs in the energy sector.

- A net increase of ~0.8-1.2 million jobs in the energy sector, of which 0.6-1 million will support exports
- There will be significant job growth at all levels, with the largest growth in VET roles
- The largest job opportunities will be serving exports in Australia's north, in WA, NT and Queensland

Net increase of ~0.8-1.2 million jobs in the energy sector, of which 0.6-1 million will support exports

Net employment by technology

(Full Time Equivalents (FTE)). Note varying y-axis scales.



EMPLOYMENT

KEY TAKEAWAYS

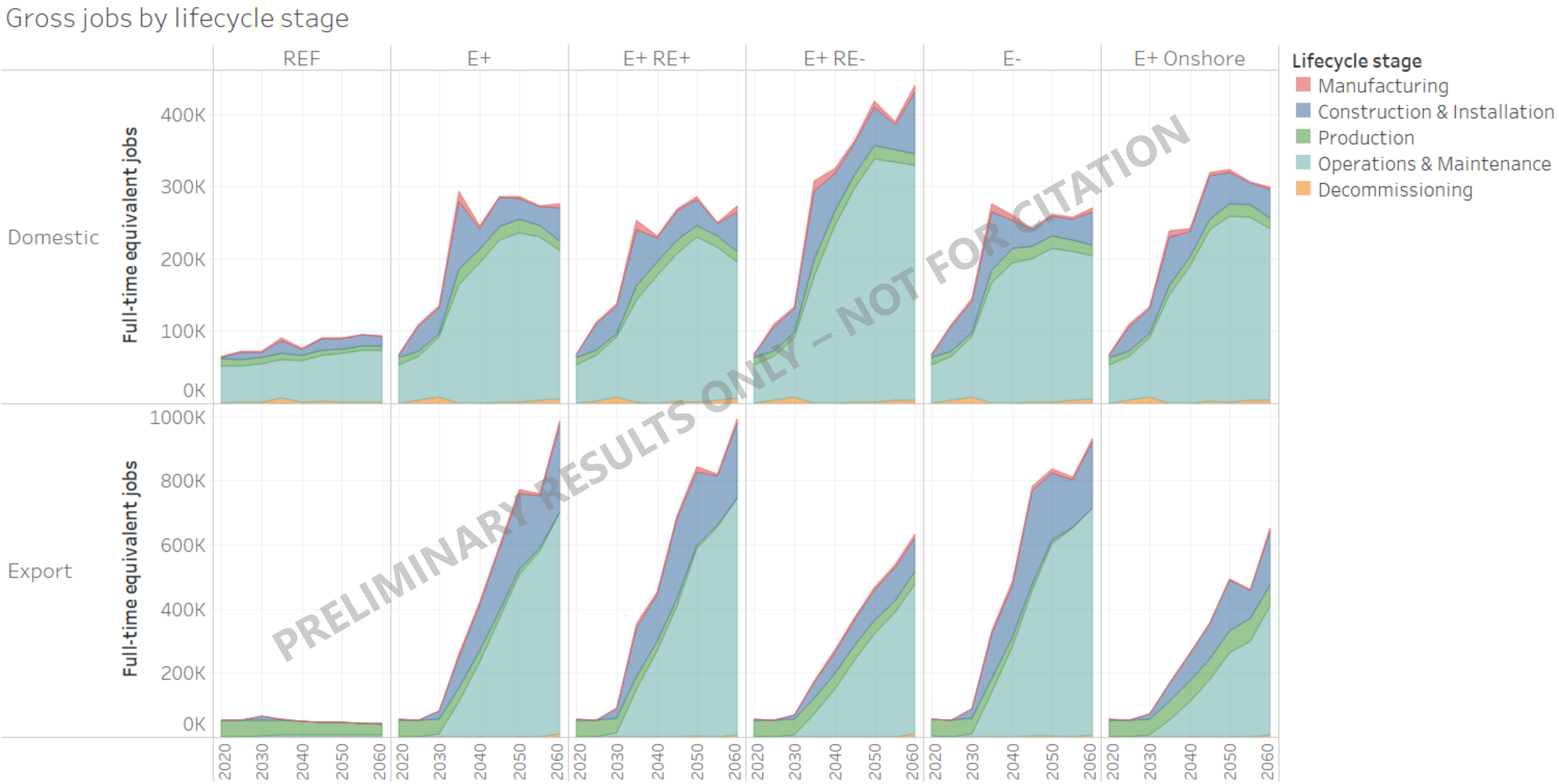
- Job losses concentrated in coal and natural gas.
- Majority of jobs created to serve export demand.

A large proportion of new jobs are ongoing O&M roles – mostly in electricity distribution and transmission

EMPLOYMENT

Gross jobs by type (stage in project lifecycle)

(Full Time Equivalents (FTE)). Note varying y-axis scales.



KEY TAKEAWAYS

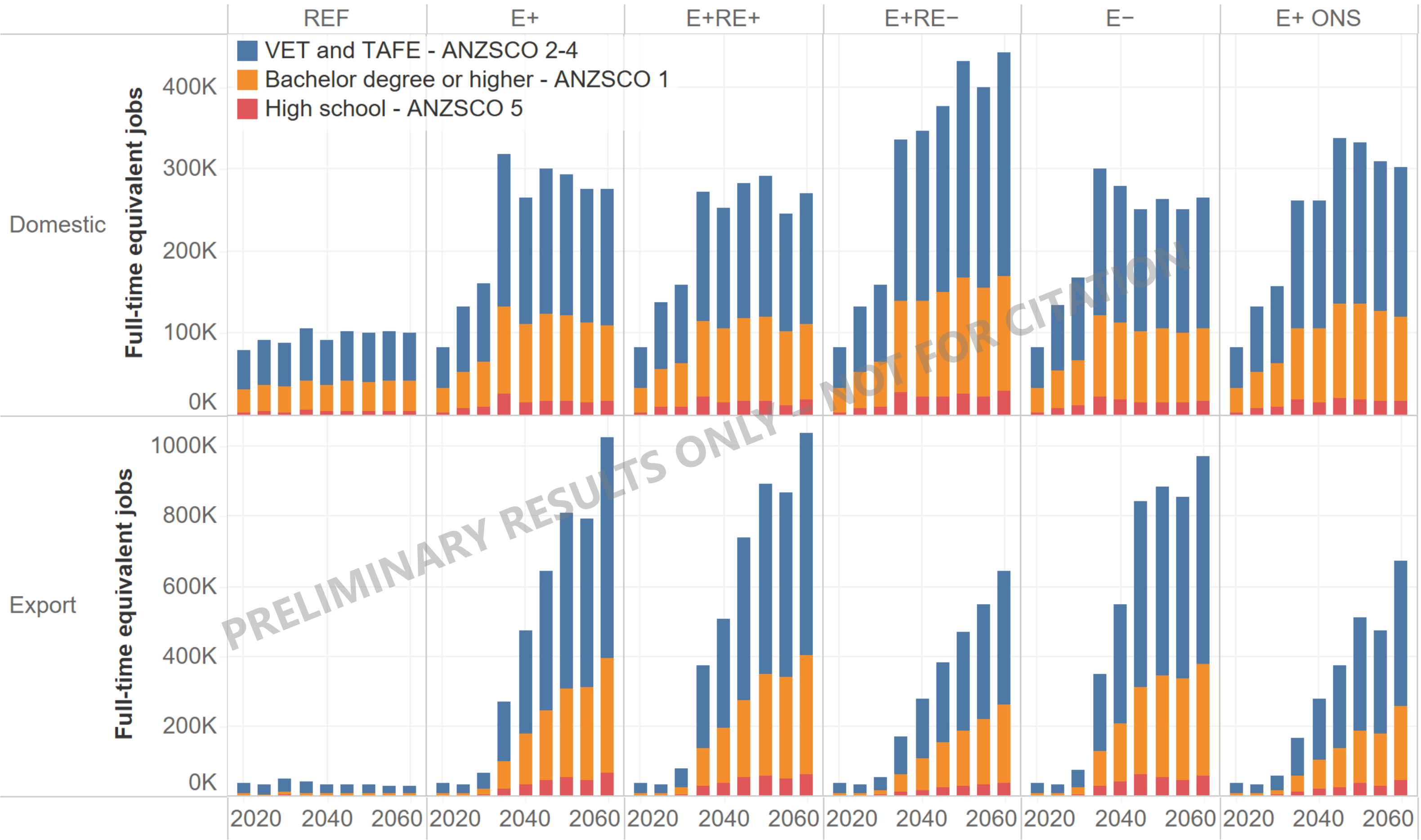
- Net zero scenarios will create an additional 200,000 - 350,000 ongoing domestic system O&M jobs
- New jobs are initially mostly construction and installation roles, but then transition to be mostly O&M roles by 2030s.

There will be significant job growth at all levels, with the largest growth in VET roles

EMPLOYMENT

Gross jobs by level of education

(Full Time Equivalents (FTE)). Note varying y-axis scales.

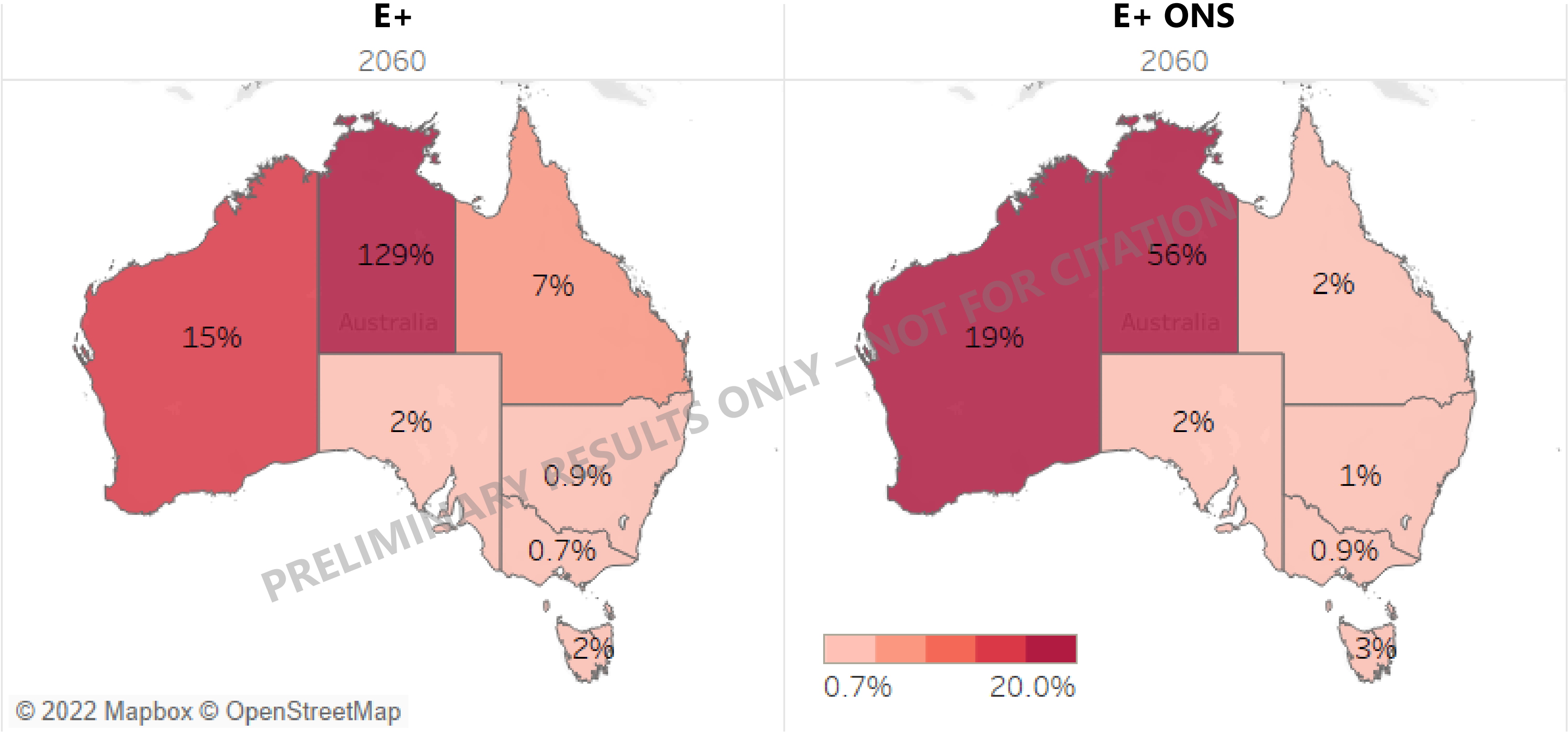


KEY TAKEAWAYS

- Large growth in jobs of all types
- Majority of jobs created are for VET/TAFE graduates
- Export sector employment becomes proportionately more skilled

The largest job opportunities will be serving exports in Australia's north, in WA, NT and Queensland

Proportion of projected workforce employed in energy sector by state
(Percentage of workforce working in energy sector)



EMPLOYMENT

KEY TAKEAWAYS

- Current energy sector jobs account for less than ~2% of jobs in each state
- Energy sector employment increases massively across the northern sunbelt
- Majority of growth driven by export sector
- Sensitivity to projected exports and thus scenario