ENERGY TRANSITION HUB
an Australian-German innovation partnership

Innovation and export opportunities of the energy transition

Insights from the Australian-German Energy Transition Hub

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About the Australian-German Energy Transition Hub

The Australian-German Energy Transition Hub is a bilateral initiative for applied research on energy transition opportunities. The Hub is supported by the Australian Department of Foreign Affairs and Trade and the German Federal Ministry for Education and Research.

The Hub brings together leading research organisations that are central to energy transition in each country. The Hub is providing an innovative and effective architecture for collaboration. Virtual conferencing and regular collaborations through video conferencing are enabling close working relationships and knowledge exchange. It is fostering closer links between researchers, industry, and government entities.

The bilateral relationship between Australia and Germany is strengthened through Hub research, dialogue, and stakeholder engagement that helps to identify and harness the opportunities for both countries in the transition to a net-zero emissions world economy. It has highlighted the complementary opportunities created by Germany's *Energiewende* experience and Australia's substantial energy and mineral resources. This is clearly evident two years into the Energy Transition Hub. Faster identification of policy lessons and investment and trade opportunities, and a deeper exchange of useful research methods and findings, are being enabled through this initiative.

The Hub is co-led by the University of Melbourne and the Australian National University in Australia. In Germany, the Hub is co-led by the Potsdam Institute for Climate Impact Research, the Mercator Research Institute for Global Commons and Climate Change, and the University of Münster. In addition to these five core partners, the Hub now has eight research partners: five in Australia and three in German.

This document presents some of the principal findings of research supported through the Hub. A more comprehensive collection of research, web tools and engagement undertaken is available at the Energy Transition Hub website energy-transition-hub.org

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INTRODUCTION

Energy transition is happening globally and in Australia and Germany. It is occurring in response to rapidly changing technology costs and as countries move to implement policies in line with the Paris Agreement goals. This transition poses policy and technological challenges. If managed well, it can also deliver great economic opportunities in both Australia and Germany.

Insights about the implications of the global energy transition for Australia and Germany that have become evident from the Energy Transition Hub's work include:

1. Rapid deployment of renewables in Australia is an essential part of a cost-efficient transition to a net-zero emissions economy. There is the potential to create an export industry based on Australia's renewable energy resources (as much as, or even more than, doubling Australia's domestic electricity demand).
2. Substantial and complementary export opportunities emerge for Germany and Australia as a result of the move to energy networks powered by renewables, electrification of other sectors of the economy, the transition to zero emissions synthetic fuels and growing demand for zero-emissions metals and energy intensive goods.
    - Australia, with its plentiful wind and solar energy resource, available land, and stable regulatory and institutional environment, is well positioned to become a leading exporter of renewable energy and renewable-based energy-intensive goods.
    - Germany, as a leading manufacturer and engineering innovator of energy transition technologies, can benefit from an increasingly global deployment of technologies for renewable energy transformation, conversion and the electrification of energy end-uses.
3. Large-scale carbon dioxide removal (CDR) is another essential component of any transition that limits warming to 1.5°C, or even to 2°C, unless the pace of mitigation to 2030 increases significantly. CDR is needed to complement the transformation in other sectors: it is not an alternative to rapid deployment of low-emissions technologies across the economy. CDR could create opportunities for Australia as a source of nature-based CDR solutions, bioenergy with carbon capture and storage (BECCS) or direct air capture with CCS (DACCS), and for Germany as a provider of carbon capture and utilisation (CCU) technologies.
4. Policy has an important role to play. A cost-effective, timely energy transition that unlocks the potential for new industries, supports affected regions, and protects eco-systems is not guaranteed – it is an outcome achievable in both Germany and Australia with effective policy.

Recent work on these issues is summarised in a series of papers. This paper addresses some of the issues that arise in relation to the second point: the export opportunities for Australia and Germany created by the transition to a net-zero emissions global economy.

Complementary opportunities in the global energy transition

Australia and Germany have complementary export opportunities as the world transitions to net-zero emissions, illustrated in Figure 1.

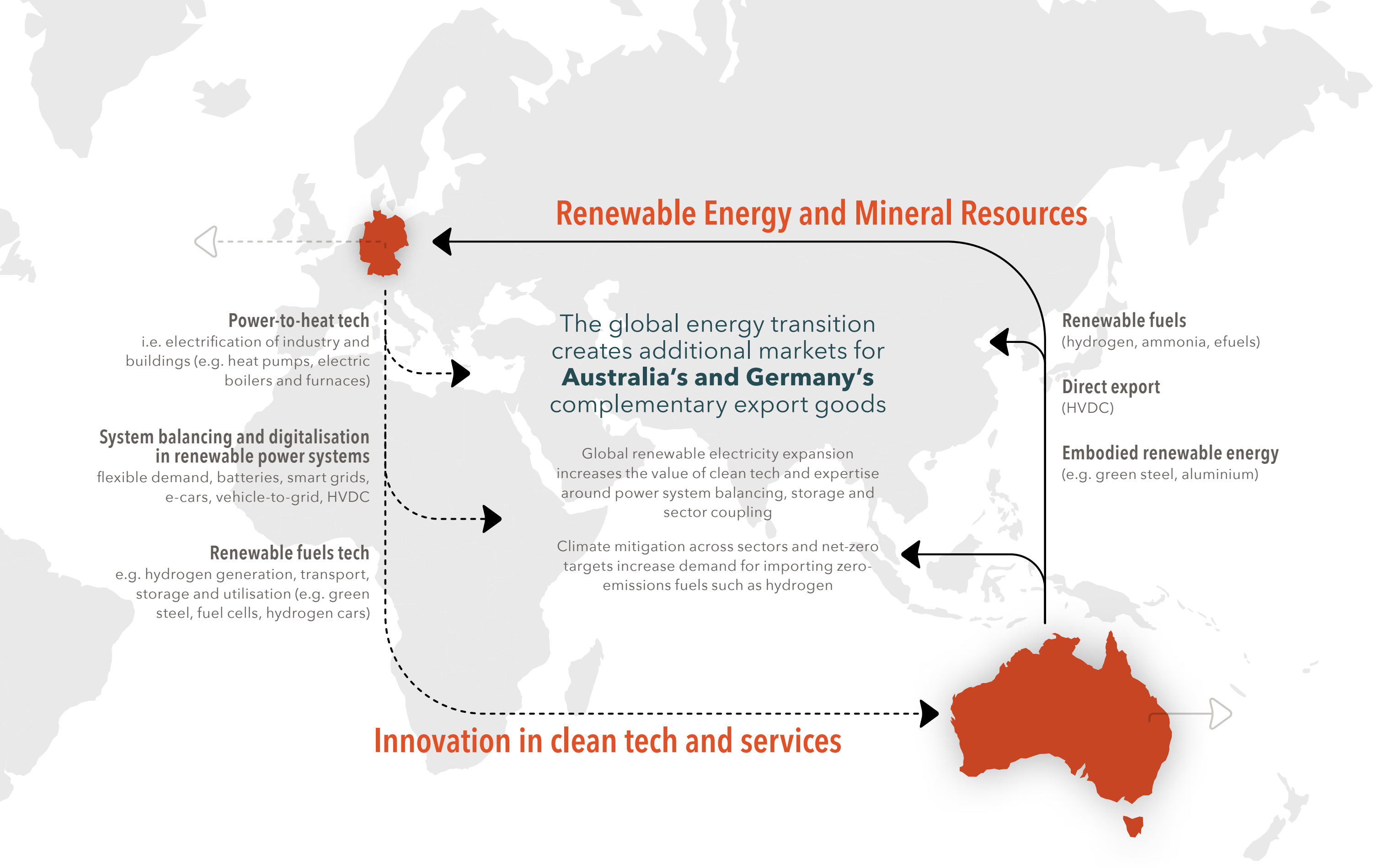

Figure 1: *Germany and Australia-complementary export opportunities*

Global demand is projected to increase rapidly for renewable energy generation and storage technologies, and technologies for low- and zero-emissions synthetic gas production, storage and use. Demand is projected to rise for metals and other energy intensive goods from low-carbon production processes (*Lord et al.,* forthcoming). Australia and Germany have complementary advantages that create export opportunities with potential benefits for both countries as the world transitions to net-zero emissions.

Australia's vast wind and solar resources are assets with increasing value as global trade and energy flows shift. Australia could be an important source of supply in global markets for:

- Renewable energy powered fuels such as hydrogen, and hydrogen-based synthetic fuels such as ammonia, methane or methanol, which are widely projected to play an increasing role in meeting global demand for energy by the middle of this century
- High-voltage direct current (HVDC) transmission lines to directly export renewable energy to South East Asian neighbours
- Energy intensive goods, including metals, produced using renewable electricity, or synthetic fuels created using renewable energy

If well managed, these export focused industries could deliver significant benefits to the domestic economy, in addition to the export revenues generated.

Germany is a major driver of demand for renewable powered fuels, and of technology innovation in these sectors. Germany could benefit from importing low-carbon energy from countries with high-quality renewable resources, such as Australia. Germany could expand its role as a leading manufacturer and engineering innovator, becoming a major exporter of energy-transition technology and intellectual property related to:

- Technologies that enable sectors across the economy to electrify or move to low-or zero-emissions fuel including on the:
    - Supply side, using hydrogen and hydrogen-based synthetic fuels
    - Demand side through direct electrification technologies such as power-to-heat technologies across industries, power-to-heat in buildings, and battery electric vehicles
- System balancing and digitalisation such as smart grids, virtual power grids, storage and vehicle-to-grid technologies
- Renewable electricity generation technologies (mainly wind) and storage (batteries)

Modelling of global and national energy transition scenarios is becoming increasingly sophisticated. The approaches being developed provide a useful set of tools to identify market and technology trends, and opportunities and challenges for Australia and Germany from changing trade and energy flows, as discussed in Box 1.

Box 1: Modelling global, regional and country specific transition scenarios

Global integrated-assessment models (IAMs) and national energy system models derive transition scenarios for the power sector, all energy supply and demand sectors, and the whole economy of a country or world regions. Using scenario data in IAMs to assess market trends, investment risks and opportunities facing sectors and companies is a new approach. It goes beyond quantifying investment needs and stranded assets in the energy sector.

The Taskforce on Climate-related Financial Disclosures (TCFD) has driven the global finance industry to become increasingly aware of the far-reaching impacts of climate change and mitigation policies on opportunities and competitiveness of companies, banks and investment portfolios (*McCollum, D. L. et al. 2018*; *McGlade, C. & Ekins, P. 2015*; *Pfeiffer, A., Hepburn, C., Vogt-Schilb, A. & Caldecott, B. 2018*). Financial industry participants and research institutes are combining their tools and perspectives in international initiatives such as United Nations Environment Programme Finance Initiative (UNEP-FI), and in national-level regulatory and legislative initiatives, to re-assess transition risks and opportunities using IAMs and other methods.

Hub core partner PIK has a leading role in international work using scenario analysis to assess transition risks and opportunities. PIK's REMIND model, the International Institute for Applied Systems Analysis, and the International Energy Agency provided the economic scenarios that underpin the 2018 report, ***Extending our Horizons***, published by the United Nations and the 16 banks piloting the TCFD recommendations. REMIND is being expanded to provide more detailed scenario modelling. Future work will consider more diverse policy scenarios, become more granular at both the geographic and sectoral levels, and build on the innovative methodological frameworks that are developed in the TCFD industry-research dialogue.

Australia: opportunity to export renewable energy via three channels

Australia has exceptional solar and wind resources and the land area to produce large quantities of cost-competitive renewable energy or energy intensive goods to help meet growing global and regional demand. The average cost of solar and wind energy in Australia is much less than in many European countries or Japan, and slightly less than in China and the US. The relative current and projected levelised cost of electricity (LCOE) of renewable technologies to 2040 in Australia and selected other countries is shown in Figure 2.

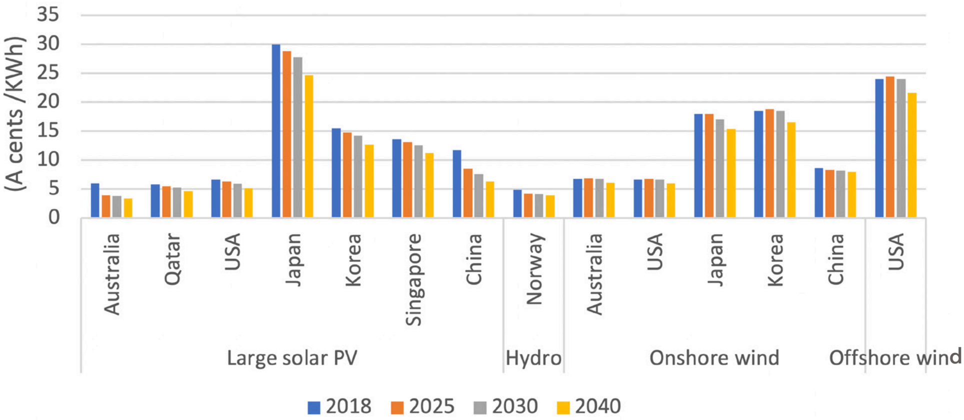

Figure 2: *LCOE of renewable technologies in selected countries 2018-2040. Source: Energy Transition Hub, Data sourced from ACIL Allen 2018, based on data from CSIRO 2018, IRENA 2018, IEA 2015.*

Renewable energy based synthetic fuels - hydrogen, ammonia and methane

Figure 3: *Key scenario assumptions for domestic electricity demand, emissions reductions, cross-sectoral electrification (referred to as sector coupling), hydrogen and other renewable energy exports*

A report commissioned by the Australian Renewable Energy Agency (ARENA) in 2018 suggested that Australia's principal hydrogen export markets could be Japan, Korea, China, and Singapore. It estimated that Australia could supply between 0.6 and 3.2 million tonnes by 2040 (*ACIL Allen 2018*), generating exports of between A$2.6 and A$13.4 billion at current prices (*ACIL Allen 2018*).

If electrolysis is used to produce this hydrogen, it will substantially increase electricity demand, with flow-on effects for investment in the electricity system. Hub researchers analysed the impact of hydrogen exports on energy systems in Australia as part of a multi-model scenario analysis undertaken by researchers from six Hub partner institutes using four models: REMIND, REMix, OpenCEM and MUREIL. A summary of the two scenarios considered in this paper (scenarios 3+ and 4+) is presented in Figure 3.

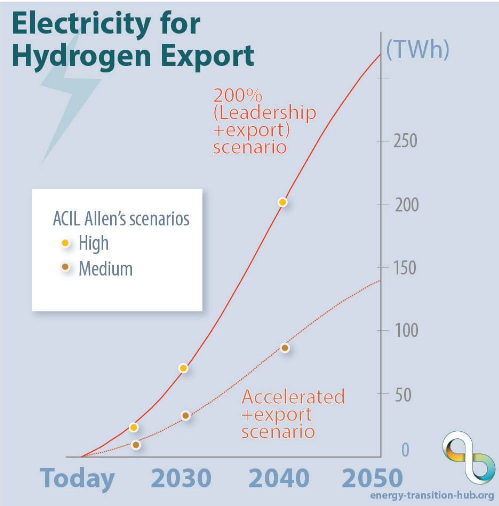

Figure 4: *Scenario assumptions on electricity consumption for renewable hydrogen exports and hydrogen for green steel exports from Australia, and comparison to assumptions in ACIL Allen 2018*

These two scenarios consider the impact of large-scale hydrogen exports on electricity demand and the energy system as a whole:

- Hub Scenario 3+, includes 140 TWh a year for hydrogen exports by 2050. This corresponds to the medium hydrogen export scenario pathway in ACIL Allen 2018 (as illustrated in Figure 4).
- Hub Scenario 4 +, includes 319 TWh a year for production of hydrogen or green steel exports by 2050, and broadly corresponds to the high hydrogen export pathway in ACIL Allen 2018

Important insights emerge from this modelling for Australia's hydrogen roadmap and energy system as a whole.

In the short term, hydrogen production costs can be minimised at locations with the best wind and solar resources and with access to sufficient water for hydrogen production. This result holds most strongly when electrolyser costs are high (around $3000/kW). In these cases, capacity factors need to be maximised by combining the highest and most complementary solar and wind resources, or hydro power. In the early years, these locations tend to be in the Pilbara, South Australia, and Tasmania, shifting to places with the best solar resources in the years to 2050. This finding is consistent with early investments in large-scale exporting of green hydrogen from Australia that are emerging. The 15-GW Asian Renewable Energy Hub, which started in 2014 in the Pilbara, plans to use around 3 GW for domestic consumption leaving around 12 GW to enable the large-scale production of green hydrogen for domestic and export markets (*AREH , n.d*).

The location of electrolysers is likely to have major implications for the use of hydrogen in the domestic Australian market. It may be more likely that hydrogen will be produced primarily for export markets if production facilities are located in remote locations. Conversely, if hydrogen production is located close to potential domestic demand sources, such as existing gas networks, it may be more likely to support greater use within the domestic economy.

Future hydrogen production costs can be minimised if electrolysers are located in and integrated with a renewable-heavy National Electricity Market (NEM). Electrolysers in the NEM can operate during times of low and moderate electricity prices and switch off at times of high demand and low supply, buffering the variability of renewable electricity generation. They can shave solar peaks and co-benefit from the NEM pooling solar PV, wind power and flexibility resources for meeting domestic electricity demand. The cost reductions due to an integrated and optimised operation of electrolysers in a renewable-heavy NEM outweigh the impact of better renewable resources at remote and isolated locations. It is also more likely that electrolysers will be located in dispersed locations around the NEM when electrolyser costs are assumed to fall over time (to $800/kW).

Domestic and export hydrogen production integrated in a renewable-heavy NEM can provide system benefits and reduce domestic electricity prices. Hydrogen electrolysis reduces curtailment and the need for electricity storage and transmission investment. This outcome delivers benefits to the whole economy. It also results in lower energy costs for hydrogen producers in future decades than locating in remote areas isolated from the grid. This requires functioning electricity and flexibility markets with temporally and regionally resolved electricity prices that transmit these benefits to investors and operators.

A system perspective is important in considering pathways towards a hydrogen export economy.

Hub scenario analysis highlights that the geospatial distribution of electrolysers is strongly influenced by: i) their capital cost; ii) the share of renewable electricity and the capacity of electrolysers to provide demand response to benefit the energy system as a whole; and iii) the magnitude of hydrogen generation (export and domestic) and number of electrolysers in the system.

The scenario analysis suggests that it is unclear if large-scale hydrogen exports will be produced from grid connected electrolysers, particularly in the early years, without policy intervention. It will depend on individual investors' views on the future costs of electrolysis and the evolution of energy markets.

The scenarios suggest the energy system cost of electricity (per MWh) in the NEM and cost of hydrogen from Australia falls as the quantity of renewable electricity generated in the NEM for hydrogen export production increases.

Producing the volumes of hydrogen exports assumed in Scenario 3+ and 4+ from grid-connected electrolysers reduce energy system costs by around 20 percent. The average energy system cost is projected to continue to fall until generation for hydrogen exports reaches around 1,000 TWh, over five times the quantity of electricity delivered in the NEM in 2018. This generation is sufficient to produce between 22,500 kilotonnes and 28,500 kilotonnes of hydrogen a year, depending on electrolyser efficiency. Taking into account the losses associated with liquefaction and pipelines etc., this could generate export revenue of around $65 billion using the 2040 export price (cost including freight) adopted by ACIL Allen 2018. This is around four to five times the quantity of hydrogen exports in the ACIL Allen 2018 high scenario in 2040.

It suggests that a large hydrogen export industry in Australia could generate both substantial export revenue and substantial benefits to the domestic economy, if electrolysers are located within the grid and reduce other investment in storage and transmission. The projected reduction in the energy system costs at different quantities of generation for hydrogen export is illustrated in Figure 5.

Additional Hub research using these newly developed hydrogen and energy systems models will develop more fine-grained scenario analyses of different demand scenarios. Coupled with assessments of market growth in the Asia-Pacific region, this represents a robust scenario-based model for assessing the economic opportunities of export markets to assist with decarbonisation and energy system planning.

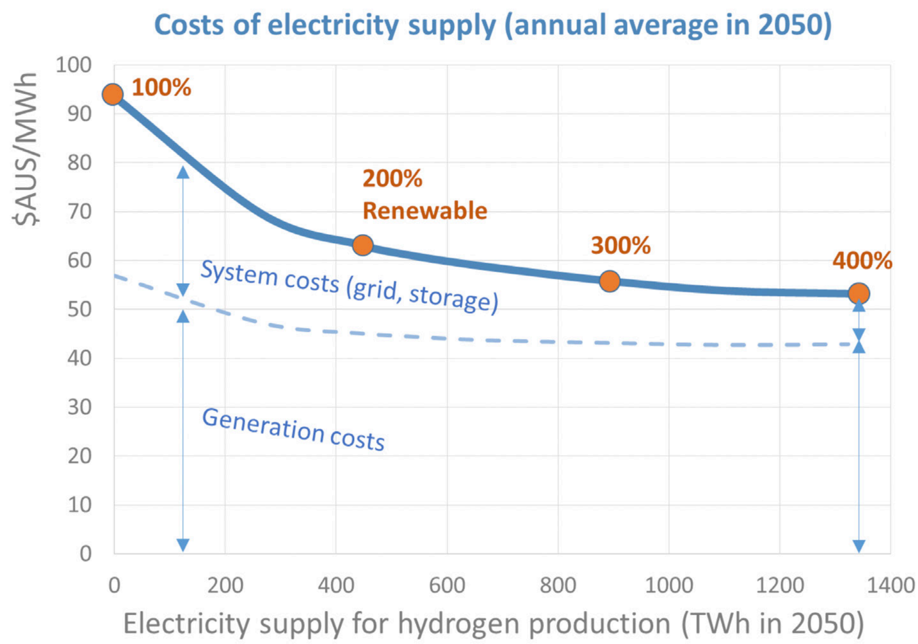

Figure 5: *Change in 2050 energy system costs in the NEM ($/MWh) as generation for hydrogen based exports increases in scenarios when the NEM contains a high proportion of renewables, high electrification of other sectors (Scenarios 3+ and 4+)*

HVDC

It may be technically viable and cost-effective for Australia to supply electricity to South East Asian countries via sub-sea HVDC transmission links, although geopolitical issues need to be resolved.

HVDC cables transmit electricity up to several thousand kilometres with fewer losses than regular AC transmission. They can be laid on the seabed to a depth of 3.5 kilometres – deep enough for the route from Australia to Indonesia. Technical issues need to be addressed but do not appear to be major barriers.

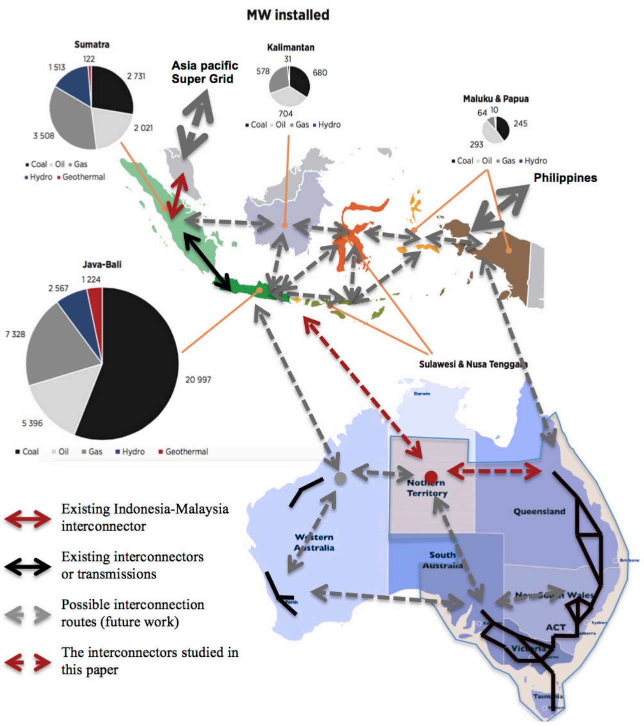

Figure 6: *Schematic of the NEM and potential interconnection in Australia and to South East Asia. Pie charts show the current installed capacity in Indonesia (MW). Possible interconnection between NEM - Java-Bali grids analysed in Wang, et al. 2018 (shown by the red lines).*

There are different views about the timeframe and conditions in which it is viable and cost-effective for Australia to export energy via HVDC into countries in South East Asia. Although hydro, geothermal, and biomass are abundant and competitive in parts of the ASEAN region, solar and wind are also likely to play an important role in a decarbonised electricity supply (*Fuentes et al 2018*). The LCOE of solar PV in the ASEAN region is one of the highest in the world, and twice that of OCEANIA (Australia/NZ) (*Fuentes et al 2018*). A solar panel at a good site in Indonesia will generate about 30 percent less electricity than one at a good site in Australia while an 80 metre (hub height) wind turbine at a good site in Indonesia will generate about 180 percent less electricity than one in Central Northern Territory (with average monthly capacity factor of 15 percent vs. 42 percent), according to the NASA MERRA-2 meteorological database (*Gelaro et al 2017*).

Indonesia could reduce the cost of its zero-carbon transition and smooth the variable output of its own renewables using under-sea HVDC cables connecting northern Australia to Indonesia's Java-Bali grid, according to recent Hub analysis (*Wang et al 2018*). This study provides one of, if not the, first detailed least-cost optimisation models of power system decarbonisation planning for both the Australian NEM and Indonesian Java-Bali power grids that incorporates HVDC interconnections. It finds that:

- If Indonesia adopts strong emission reduction targets (100 percent by 2050), the model optimises by selecting a large interconnector after 2035, and the maximum interconnector capacity allowable in the scenarios considered (an additional 20 GW in both 2045 and 2050), to deliver a total of 43 GW of interconnection over the period to 2050
- Under business-as-usual conditions and in the absence of emissions targets, however, the model suggests that the Java-Bali grid will meet demand growth through increased coal and gas generation and no HVDC link will be built

This is the first stage of a study on a series of possible interconnection routes (shown by the grey dashed lines in Figure 6) in the Australasian area that Hub researchers are proposing to deliver. This work also indicates that the NEM could benefit from the additional HVDC interconnectors. They reduce curtailment and lower the wholesale electricity price in Australia compared to the alternative (of no HVDC interconnection). The potential exports of renewable energy via HVDC interconnection found are in line with views emerging from other studies and commercial ventures: a 3-GW cable to Indonesia from north-west Australia could supply competitively priced electricity within just 5 to 10 years, according to the Pilbara Development Commission (2017); and Sun Cable recently announced plans to build a 3-GW, 3,800-km HVDC link from the Northern Territory to Singapore (*Sun Cable 2019*).

The concept of cross-border trade in electricity using HVDC and ultra HVDC interconnectors is becoming part of the emerging geography of energy transition within the region, but legal and diplomatic challenges still need to be overcome.

Processes are underway to begin to address regulatory barriers. The ASEAN Power Grid program includes regulatory changes to facilitate cross-border electricity trade in the region (*ASEAN Centre for Energy 2019*). China has also proposed the Global Energy Interconnection Development and Cooperation Organisation (GEIDCO) initiative, aiming to connect countries across the Asian region. There is a role for policy and international engagement to support initiatives to address international regulatory barriers to direct exports via HVDC.

Using renewables to manufacture energy-intensive goods for export

Australia has an opportunity to use renewable energy to make energy-intensive goods for export.

The energy required to make some materials, including many metals, represents around one third of the costs of production. Abundance of low-cost renewable energy gives Australia a source of competitive advantage in the zero-emissions production of such materials.

By manufacturing with renewable energy, Australia would tap into growing global demand for products with lower embodied emissions.

International corporations are making ambitious climate commitments that include targets for reducing emissions from the products that they buy. More than 600 global corporations have joined the Science Based Targets initiative, which requires them to reduce emissions in line with the Paris Agreement (*Science Based Targets Initiative 2019*).

Using renewable energy to produce low- or zero-emissions refined metals is a major opportunity for Australia.

Australia is already a major producer of metal ores. It is the world's largest exporter of iron ore, bauxite and lithium and is among the top three producers of several other ores including zinc, manganese and titanium (*US Geological Survey 2019*). The majority of these ores are exported with minimal processing. By refining more of its ores domestically, Australia could add significant value to its mineral resources and supply a growing market for low-emissions metals.

Australia could be a global pioneer in low-emissions steel.

Steel-making accounts for seven percent of global emissions so it is vital to develop sustainable production methods. One promising alternative process involves substituting renewable hydrogen for fossil fuels. At least four European steelmakers (including Thyssenkrupp and Salzgitter) are pursuing long-term strategies to process steel through the hydrogen-DRI process (*Knitterscheidt 2019*). The process is not substantially different from conventional direct reduction with natural gas and has already been proven at a commercial scale by a plant in Trinidad (*Lord 2018*). Australia, with its abundance of iron ore and renewable energy, is likely to be a lower-cost location than existing major steel producing locations such as Japan, South Korea, Germany.

Australia currently supplies the iron ore for over 30 percent of the world's steel (*U.S. Geological Survey 2019a*). By converting just 18 percent of its current iron ore output into low-emissions steel, Australia could create new export industry with turnover of over A$80 billion per year. This is larger than any other single Australian export today (*DFAT 2019*). This would enable Australia to produce 100 million tonnes of crude steel per year, as much as Japan today. Making this steel with renewable hydrogen would require dedicated renewable energy capacity of around 160 GW (almost three times the generation capacity of the NEM today). Hub scenario analysis (*Scenario 4+*) includes 106 TWh for production of hydrogen for green steel exports and an additional 53 TWh for non-hydrogen related energy, sufficient to produce approximately 34 million tonnes of crude steel a year (*Lord et al* forthcoming).

Australia could become an important exporter of other refined metals such as aluminium, copper, manganese, nickel, silicon and zinc.

These metals can be refined in electrolytic processes that can be substantially decarbonised by switching to renewable electricity. Australia could produce low-emissions metals using current ore output. For example, by converting the entire domestic alumina output to aluminium, Australia could create an export industry with revenue of over A$27 billion (*Lord et al* forthcoming). This would require renewable energy capacity of around 44 GW.

In addition to zero-emissions metals, Australia could target energy intensive exports with higher margins.

One possibility is to venture further down the metals value chain, by producing more complex chemicals, such as lithium hydroxide, high-purity manganese and nickel sulphate. Companies in Western Australia are already setting up plants to manufacture lithium hydroxide and electrolytic manganese metal (*Lord et al* forthcoming). Other energy intensive high-tech goods that Australia could make using renewable energy include carbon fibre, composites and polymers.

Australia risks missing opportunities arising from demand for low- and zero-emissions metals if it does not engage with international pilots and commence similar pilots to build capacity and support investment in Australian facilities.

Despite its likely cost advantages, it is not guaranteed that Australia will become a significant producer of green steel or other low- and zero-emissions metals. These opportunities need to be pursued before costs are sunk in processing facilities in other locations.

A few metal producers in Australia are taking the first steps towards lower emissions operations. Sun Metals has built a 125-MW solar farm to supply a third of the energy required by its zinc refinery in Queensland, and is now considering adding wind power and battery storage. Element 25 is planning to use a high proportion of solar and wind energy to power production at a new mine high-purity manganese facility in Western Australia. Companies are already taking advantage of renewable hydropower in Tasmania to process aluminium, zinc and manganese. Australia's two steel-makers, BlueScope and Liberty One Steel, have started using some renewable energy as a way of lowering costs. Liberty plans to go further by supplying its entire electricity demand with renewables.

Germany: opportunity to export energy transition technologies

Demand for the technologies required to produce renewable energy and synthetic fuels is projected to increase rapidly, even in the short-term. The value of the global market for technologies to support renewable power generation, energy storage and hydrogen production was calculated at €508 billion in 2016 and is projected almost double by 2025, to €897 billion (Figure 7).

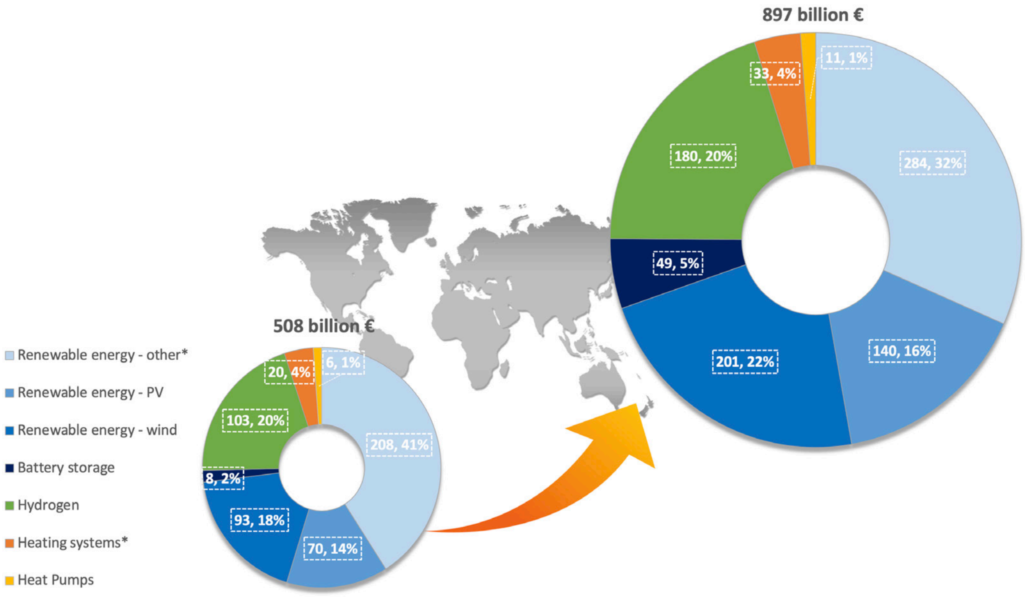

Figure 7: *Global market value for selected clean techs in 2016 and 2025. Source: Energy Transition Hub drawing on Roland Berger GmbH 2018; IEA 2017; Future Market Insight 2016; Grand View Research 2016. *Renewable energy – other incudes: hydropower, solar thermal, geothermal, biomass.*

Being a first mover in the energy transition has helped to make Germany a clean technological leader and a significant exporter of the associated technologies.

Germany became a leader in global energy transition with its Renewable Energy Act (EEG) in 2000, which guaranteed feed-in tariffs to renewable electricity. This drove demand for clean technologies within Germany, building on long-established engineering and innovative strength of Germany's industry and business sectors.

Rapidly expanding industries of solar PV, wind power, and biomass electricity and heat made Germany the first major industrial country to transition from conventional to renewable-based electricity. Renewable technology exports quickly exceeded domestic sales making Germany a major clean technology export country. A survey across German clean technology businesses shows that in 2016 the export rate (i.e. fraction of revenues from sales abroad) is 30 to 50 percent depending on the sector (*Roland Berger GmbH 2018*).

It is possible that production of goods that can be mass-produced at lower cost elsewhere, due to factors such as lower labour costs and strong governmental support, may move from Germany to other countries over time. The expansion in production of lower-cost solar PV in China from 2008 reduced the exports of that technology from Germany. Germany's exports may, therefore, rely on continuous innovation in emerging markets for high-tech products and services.

The next phase of the energy transition promises new first mover advantages for Germany.

Germany has broadened its energy transition from the power sector to the whole economy. A country-wide emission reduction target of -55 percent by 2030 relative to 1990 is broken down into sectoral targets for energy supply, industry, buildings, transport and agriculture. The overarching technological strategy of achieving this is a continuous expansion of renewable electricity and a deep electrification of non-electric energy demands often referred to as sector coupling (Box 2). Industrial electrification and industrial process transformation will be major drivers of increased electricity demand and innovation in the coming decades (Box 3). These targets and associated policies and regulation will drive domestic innovation, which is likely to translate into export opportunities for German firms.

Box 2: Sector coupling

The term 'sector coupling' describes the integration of the various energy supply and demand sectors: it means the use of (renewable) electricity to meet currently non-electric energy demands in transport, buildings and industry.

Electrification can be direct or indirect. Direct electrification includes changing end-use applications on the demand side to those that directly use electricity, such as battery electric vehicles, heat pumps, electric boilers or furnaces. Indirect electrification includes renewable hydrogen and related hydrogen-based fuels (sometimes called e-fuels or synthetic). Combusting low-emissions synthetic fuels is a straight-forward way of replacing fossil fuels but has significantly lower energy efficiencies than direct electrification alternatives, particularly in the transport sector. Hydrogen and synthetic fuels are helpful where direct electrification is difficult such as in the aviation, marine and parts of heavy-duty freight transport and some energy-intensive industries.

Box 3 - Industry electrification and opportunities for industrial process transformation:

Industry is responsible for 19 percent of direct global CO_2 emissions, but is responsible for 36 percent if CO_2 generated from electricity and heat is also counted. It is possible to entirely replace fossil fuels used in industrial processes with renewables and renewable powered synthetic fuels, using a combination of direct and indirect electrification technologies.

The majority of the energy consumed in industry is from fossil fuels combusted in thermal processes (*Philibert 2017*). Renewable electricity could be converted into clean heat (power-to-heat or direct electrification), contributing to the significant decarbonisation of industry while often also providing opportunities for flexible load to facilitate the integration of variable renewable power supply. While electrical heaters and chillers are mature technologies, fired systems have historically been preferred for large-scale applications due to the lower relative cost of fossil fuels in the past.

Up to 70 percent of global industrial energy demand could be met through direct electrification. Of this, up to 50 percent could be readily electrified with technologies that are already fully commercialised. The remaining global industrial energy demand must be met by indirect electrification: this energy is primarily from chemicals feedstocks and reducing agents (e.g. coke, coal) used in metallurgical processes. More than half of the energy demand from the chemical industry is for fossil fuels used as feedstocks and cannot be electrified via power-to-heat. Indirect electrification options include ammonia synthesis using hydrogen produced via electrolysis. Green hydrogen could also substitute traditional carbon-based reducing agents used in iron and steel manufacture. Source: *Maddedu et al. 2019*

Six core fields of innovation and export opportunities on the supply and demand side of sector coupling are illustrated in Figure 8 and described in the following paragraphs.

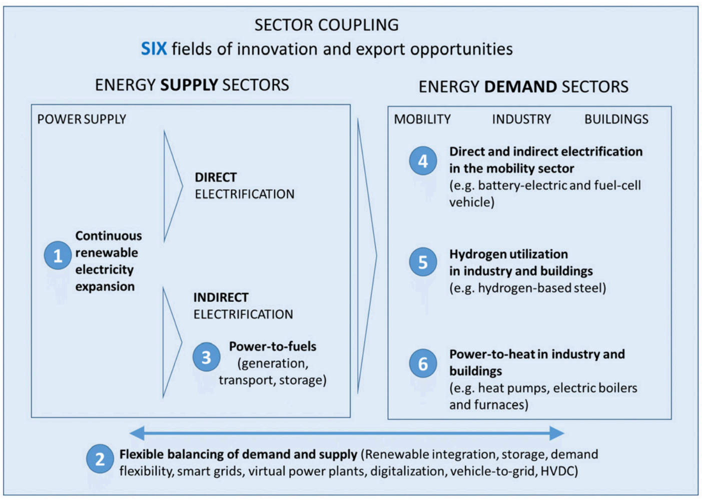

Figure 8: *Six core fields of innovation and export opportunities of sector coupling.*

1. **Continuous renewable electricity expansion**: The backbone of a transition towards a net-zero energy system is the further increase of renewable electricity supply, to meet both existing electricity demand and new end-use demands across sectors that are not yet electrified.

2. **Flexible balancing of electricity demand and supply**: Growing shares of weather-dependent electricity supply from wind and solar PV increase the role of flexibility options to balance supply and demand. Variable renewables can be efficiently combined with a flexible generation mix, enhanced grid infrastructure, energy storage and demand flexibility. With electrification and sector coupling, new sources of demand flexibility emerge. Matching supply and demand in a more concerted, integrated and flexible way, will create markets for new technologies, products and services making use of digitalisation, virtual power plants, vehicle-to-grid and smart grid concepts.

   The German market value for renewable energy generation, storage, and distribution was estimated at €79 billion in 2016, and is expected to increase to €135 billion by 2025 (*Roland Berger GmbH 2018*). The major drivers for this market expansion will be storage technologies, which have been projected to grow from €5 billion to €18 billion (*Roland Berger GmbH 2018*). In 2017, Germany comprised seven percent of the energy storage capacity worldwide and many projects have been already commissioned that will enable to at least double its volume (*IRENA 2017*). Among these, Europe's largest battery storage plant has been installed in Jargelund, with a capacity of 50 MWh achieved with 10,000 lithium-ion batteries (*EnspireME – Eneco Group 2019*).

   Digitalisation is key to achieving well-integrated and efficient energy systems. The SINTEG project funded by the Federal Ministry for Economic Affairs and Energy is one of the most ambitious initiatives to push forward smart grids implementation (€600 million invested). It involves more than 300 partners from industry, research, and institutions, and aims at developing state-of-the-art solutions for the energy supply across Germany (*BMWi 2018*).

3. **Power-to-fuels**: Power-to-fuels includes the electrochemical generation, transport and storage of hydrogen from (renewable) electricity and the synthesis of hydrocarbons. Electrolysers powered with renewable electricity provide clean hydrogen with near net-zero emissions. Hydrogen can be used as fuel, fed to fuel cells and converted into electricity, or used to synthesise various hydrocarbons, e.g. methane.

   Only four percent of hydrogen is currently produced via electrolysis (green hydrogen). The majority is manufactured via steam methane reforming of natural gas (*E4tech & Element Energy 2014*). The German Ministry of Transport and Digital Infrastructures estimated that the cumulative installed electrolysers capacity could expand from less than 100 MW in 2020 to more than 10 GW in 2030 (*NOW Gmbh 2018*). In line with Germany's commitment to become a leader in green hydrogen supply, Shell's Rhineland refinery will host the world largest hydrogen electrolysis plant, with a capacity of 1,300 tonnes of green hydrogen per year (*REFHYNE 2019*).

4. **Electrification in the mobility sector**: Roland Berger (2018) estimated the value of the German market for sustainable mobility at €74 billion in 2016. The study estimated that this could increase to €157 billion in 2025 (*Roland Berger GmbH 2018*). The major market expansion is attributed to alternative drive technologies, e.g. electric and hybrid vehicles, and fuel cells drive systems, the value of which will rise from €1 billion to €37 billion. Volkswagen has recently announced an investment of €9 billion in e-mobility and aims to raise its production of electric vehicles to 40 percent (*Volkswagen 2019b*). One of the major projects funded by the National Innovation Program Hydrogen and Fuel Cells Technology (NIP) is H2Mobility, a joint venture that aims at expanding the capacity of hydrogen refueling stations in Germany. The consortium includes among others Linde, Daimler, and associated partners from the car industry like BMW and Volkswagen (*H2Mobility 2019*).

5. **Hydrogen utilisation in industry and buildings**: Hydrogen could be used to supply heat and power in the residential and commercial sector (stationary fuel cells) and as hydrogen feedstock for the industry sector, including hydrogen-based steel manufacturing and for synthetic basic chemicals (ammonia, methane). Stationary fuel cells can be used to convert hydrogen into power and heat to supply clean energy to buildings. In 2006, the German government launched the National Innovation Program Hydrogen and Fuel Cells Technology (NIP), which entered its second phase in 2016 (*McKinsey & Company Inc., & NOW Gmbh 2017*). Around €710 million was invested in R&D throughout the first decade and Germany is now the leading country in Europe for fuel cells installed, accounting for more than 70 percent of installations (*Market Research Future 2019b*).

   The use of green hydrogen as feedstock can significantly reduce CO_2 emissions from the industry sector, currently the main consumer of hydrogen (*Hydrogen Council, 2017*). The integration of green hydrogen in manufacturing processes has already attracted large investments in Germany. The OCP Group, one of the largest producers of fertilisers, is collaborating with the Fraunhofer Institute and building a pilot plant in Leuna to produce green ammonia (*FIMMS 2018*). ThyssenKrupp and Salzgitter are investigating the production of steel via direct iron-hydrogen reduction, and ArcelorMittal has announced a €65 million investment to build a demonstration plant in Hamburg (*AlcelorMittal 2019; Salzgitter n.d.; Thyssenkrupp 2019*).

6. **Power-to-heat in industry and buildings**: Power-to-heat refers to the direct electrification of industry and building heat based on heat pumps, electric boilers and furnaces as well as hybrid applications that are partially electric. Renewable electricity can substitute fossil fuels to supply clean energy for the residential and industry sectors. Many well-established companies operate in Germany in the production of heating equipment (e.g. Bosch, Siemens, Viessmann). Compression heat pumps are particularly relevant as they are at least three times more efficient than gas boilers (*European Commission 2016*).

   Another advantage is that they can be installed as hybrid systems coupled with fired boilers, enabling higher flexibility and minor risks due to fuels price fluctuation. Germany is the second largest producer of heat pumps in Europe. These appliances could supply 23 percent of the heat demand up to 100°C from the German industry (*Arpagaus et al. 2018*). The Fraunhofer Institute launched several projects that focus on heat pumps for the residential sector. Among these, the HPsmart in Existing Building project investigates the potential for supplying space heating with heat pumps in existing buildings.

OUTLOOK

Transition of the Australian, German and global economies is happening at a rapid pace, driven both by technology costs and policies to deliver the Paris Agreement goals. The pace and scale of the transition to renewable energy is projected to grow rapidly in the coming decades, and to continue through the middle of this century.

Australia and Germany have complementary advantages that create export opportunities with significant potential benefits for both countries as the world transitions to net-zero emissions. Hub work summarised in this paper outlines some of the opportunities. It also highlights the role for policy to help deliver broader benefits from this transition in some cases. It clearly suggests, for example, that the development of the National Hydrogen Strategy in Australia should address the energy system implications of the location of electrolysers. The location of electrolysers and the impacts on the energy system as a whole will have a substantial effect on the benefits to the Australian economy from a hydrogen export boom. In contrast to the experience of the growth of LNG exports, large-scale grid connected hydrogen production for export could drive down electricity prices for all parties connected to the NEM.

Nearly all of the work described has uncovered additional important areas of research that should be pursued using the models, analytical tools and collaborative methods and relationships that have emerged in the last two years. Priorities for the coming years include:

- Refining the REMIND whole-system energy-economy-climate modelling system to provide more detailed and diverse policy scenarios, become more granular at both the geographic and sectoral levels, and build on the methodological frameworks that are developing in the TCFD industry-research dialogue. This can inform the analysis of opportunities and challenges for both Australia and Germany as global trade and energy flows shift as a result of the transition to a global net-zero economy.
- Deepening the analysis of the energy system and policy implications of hydrogen production, HVDC regional interconnection and renewable powered energy intensive goods in Australia using the multi-model scenario analysis framework. This is providing insights into important issues that, at present, are not being addressed by others.
- Expanding work on opportunities for Australia and Germany from industrial process transformations and in particular the emerging demand and production methods for zero-emissions metals. This will expand into the chemicals sectors in the years to come.

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