



**THE
WARREN
CENTRE**

THE COPPER TECHNOLOGY ROADMAP 2030

Asia's growing appetite for copper





THE WARREN CENTRE

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ABOUT THIS REPORT

This report is the culmination of six months of scoping and research into the major demographic trends driving the growth of transportation, electricity infrastructure and building construction in the Asia Pacific region. The project was conceived following consultation with the International Copper Association and follows work undertaken by The Warren Centre in 2004 on a Building Technology Roadmap for the Australian market.

The Technology 2030 Roadmap looks across the whole of Asia. The insights gained in this report are significant for decision makers across a wide range of industries including mining, finished copper, commodities trading and finance. As Asian economies continue their ascent and dominant place in the global economy, copper products will enable ongoing growth and infrastructure improvements.

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This report draws on the expertise, advice and insights of many individuals including industry leaders, researchers, economists, subject matter experts and regional experts. The Warren Centre gratefully acknowledges the insights gained from interviews with the International Copper Association's regional experts.

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CONTENTS

ACKNOWLEDGEMENTS	4	Buildings Drivers	13
ACRONYMS AND ABBREVIATIONS	5	Equipment Drivers.....	13
1. EXECUTIVE SUMMARY	6	OTHER FACTORS THAT AFFECT DEMAND	13
ECONOMIC AND DEMOGRAPHIC DRIVERS	7	Demand Elasticity	13
POPULATION GROWTH.....	7	Dematerialisation	13
URBANISATION	7	UNDERSTANDING DEMAND WITHIN THE COPPER SYSTEM	14
DECARBONISATION	8	THE COPPER MATERIAL SYSTEM AND MARKET	14
ELECTRICITY	8	FORECASTING METHODS	15
Decarbonisation of electricity	8	TOP-DOWN METHOD: REFINED COPPER CONSUMPTION BY COUNTRY.....	16
Decentralisation of electricity.....	8	TOP-DOWN METHOD: DEMOGRAPHIC, ECONOMIC AND URBANISATION DATA	17
TRANSPORT	8	BOTTOM-UP METHOD: SURVEY OF IN-USE STOCK	18
Light Vehicles	9	BOTTOM-UP METHOD: TECHNOLOGY FORECAST	19
Public Transport.....	9	APPLYING THE METHOD WITHIN THE ROADMAP SCOPE	19
RESIDENTIAL BUILT ENVIRONMENT	9	LEARNING FROM PREVIOUS WORK: 2004 BUILDING CONSTRUCTION TECHNOLOGY ROADMAP	19
APPLIANCES	9	4. ECONOMIC AND DEMOGRAPHIC DRIVERS	20
2. INTRODUCTION	10	NATIONAL AND REGIONAL OVERVIEW	20
PURPOSE OF THE ROADMAP.....	10	ECONOMIC GROWTH.....	20
CONTEXT.....	10	DEMOGRAPHICS	23
FACTORS CONSIDERED IN THIS STUDY	11	MAJOR MOVEMENTS OF PEOPLE, ECONOMIC SHOCKS	24
Economic growth.....	11	CONSUMER TRENDS AND PREFERENCES	24
Environmental factors.....	11	INTERDEPENDENCY	24
Technology and innovation.....	11	CLIMATE ADAPTATION	25
Past research	11	NATIONAL AND REGIONAL INSIGHTS AND OVERVIEWS	25
Audience.....	11	China	25
Scope	11	India.....	26
3. METHODOLOGY: UNDERSTANDING DEMAND WITHIN THE COPPER SYSTEM	12	Japan.....	27
IDENTIFYING DRIVERS OF DEMAND	12	Korea	27
MEGATREND DRIVERS	12	Indonesia	27
Population	12		
Demographic Drivers	13		
Economic Drivers.....	13		
Urbanisation	13		
Decarbonisation	13		
MATERIAL DRIVERS	13		
Infrastructure Drivers	13		
Transportation Drivers	13		

Other ASEAN Countries	27	Vietnam	57
Australia	27	Philippines	58
Regional dynamics	28	Singapore	58
POPULATION GROWTH	28	Taiwan	60
Summary statistics	30	NATIONAL ELECTRICITY DEMAND FORECAST SUMMARY	60
URBANISATION	31	SOUTH-EAST ASIAN OR GLOBAL SUPERGRID	62
WHAT IS URBANISATION?	31	IMPLICATIONS FOR COPPER	62
WHY DOES URBANISATION MATTER?	31	DECARBONISATION OF ELECTRICITY	62
HOW DOES THE LEVEL OF URBANISATION IMPACT DEMAND FOR COPPER?	31	THE GLOBAL SHIFT FROM COAL TO RENEWABLES	62
REGIONAL BREAKDOWN: KEY COUNTRIES	32	REGIONAL RENEWABLE RESOURCES	63
Country urbanisation data	32	IMPACT ON COPPER OF INCREASING LEVELS OF RENEWABLES	64
China	32	Photovoltaics	65
India	33	Wind generation	67
Japan	33	Future Technological Innovations	68
Korea	33	CENTRALISED AND DECENTRALISED ENERGY	68
Indonesia	33	BALANCE OF CENTRALISED AND DECENTRALISED ENERGY	68
5. DECARBONISATION	34	TRENDS IN TRANSMISSION AND DISTRIBUTION	68
DRIVERS OF DECARBONISATION	34	Implications of Renewables for Transmission	69
NATIONAL DECARBONISATION COMMITMENTS AND TARGETS	35	Trend towards higher transmission voltage	69
COUNTRY SUMMARIES	36	DC Transmission	70
India	36	DISTRIBUTED ENERGY RESOURCES	71
China	37	Energy Storage as an Enabler of Decentralised Energy	73
Indonesia	39	Impact of decentralised energy resources on transmission and distribution	73
Japan	39	PROJECTIONS FOR PENETRATION OF DECENTRALISED ENERGY	73
Korea	40	Australia	73
Australia	40	India	74
SUMMARY OF NATIONAL CLIMATE POLICY GOALS	41	China	75
IMPLICATIONS FOR COPPER:	42	Summary	76
IMPACT OF CARBON PRICING ON COPPER DEMAND	42	IMPLICATIONS FOR COPPER	76
6. ELECTRICITY SYSTEM	44	Transmission and distribution	76
COUNTRY AND REGIONAL OVERVIEWS	44	Decentralised Energy	77
ASIAN DEMAND GROWTH	44	SUMMARY AND CONCLUSION	77
COUNTRY OVERVIEWS	46	7. INFRASTRUCTURE AND TRANSPORT	78
India	46	INFRASTRUCTURE AND TRANSPORT OVERVIEW	78
China	49	GROWING ASIAN INFRASTRUCTURE NEEDS	78
Other nations	51	WATER INFRASTRUCTURE	79
Japan	51	TRANSPORT INFRASTRUCTURE	79
Korea	52	SELECTED COUNTRY SUMMARIES	79
Australia	53		
ASEAN generally	54		
Indonesia	55		
Thailand	56		
Malaysia	56		

China	79	SUMMARY	96
India	80	IMPLICATIONS FOR COPPER	96
Japan	81	High Speed Rail	96
Korea	81	Urban Rail	97
Australia	82	Electric Buses	97
IMPLICATIONS FOR COPPER	82	8. RESIDENTIAL BUILT ENVIRONMENT	98
LIGHT VEHICLES	82	RESIDENTIAL BUILDINGS	98
DISRUPTION IS COMING	82	NEED TO UNDERSTAND BUILDING	
THE CHANGING OWNERSHIP MODEL	82	NUMBERS AND TYPES IN 2030	98
THE LIKELY TECHNOLOGY COMBINATION	83	COUNTRY BREAKDOWNS	98
Propulsion technology	83	India	98
Control technology	83	China	101
THE DRIVERS FOR CHANGE	84	Japan	102
Local air quality	84	Korea	103
Road network congestion	84	Australia	103
HOW BIG WILL THE CHANGE BE?	84	IMPLICATIONS FOR COPPER DEMAND	104
Autonomous cars	84	APPLIANCES	104
Electric Vehicle penetration	85	RELEVANCE OF APPLIANCES TO	
GEARING UP FOR CHANGE - COUNTRY		THE 2030 ROADMAP	104
BREAKDOWN OF POLICIES	86	PATTERN OF MARKET DEVELOPMENT	
China	86	FOR APPLIANCES	104
India	87	WHICH APPLIANCES MATTER MOST?	105
Japan	88	HVAC	105
Korea	88	Consumer Goods	105
Australia	88	COUNTRY BREAKDOWNS	105
SUMMARY	89	China	105
IMPLICATIONS FOR COPPER	89	India	106
PUBLIC TRANSPORT	89	Indonesia	106
MASS TRANSIT AND URBAN MOBILITY	89	SUMMARY	107
HIGH SPEED RAIL	91	INSIGHTS FOR IMPACT ON COPPER	107
URBAN RAIL	91	9. SUMMARY OF IMPACT ON	
ELECTRIC BUSES	91	2030 COPPER DEMAND	109
MOBILITY AS A SERVICE		INSIGHTS FOR IMPACT ON COPPER BY 2030	109
INCORPORATING PUBLIC TRANSPORT	91	ECONOMIC AND DEMOGRAPHIC DRIVERS	109
COUNTRY BREAKDOWNS	92	DECARBONISATION	110
China	92	ELECTRICITY	110
India	93	Decarbonisation of electricity	110
Japan	94	Decentralisation of electricity	110
Korea	95	TRANSPORT	110
Indonesia	95	Light Vehicles	111
Malaysia	95	Public Transport	111
Vietnam	95	RESIDENTIAL BUILDINGS	111
Thailand	95	APPLIANCES	111
Philippines	95	REFERENCES AND FURTHER READING	112
Australia	96		
Singapore	96		

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We conducted a total of 17 interviews, with the following experts:

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- Dr John Daley, CEO Grattan Institute
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We conducted a total of 6 interviews with the following International Copper Association staff:

- Richard Xu (China)
- John Fennell (Australia)
- Hal Stillman (Global)
- Mayur Karmarkar (India)
- Wenson Zheng (China)
- Frank Gao (China)
- James Li (China)
- Danny Wong (China)
- Gabriel Zhang (China)
- Sanjeev Ranjan (India)
- Amol Kalsekar (India)

LEADING ACADEMIC RESEARCHERS FROM THE UNIVERSITY OF SYDNEY

We have conducted a total of 6 interviews with the following experts at the University of Sydney:

- Professor Joe Dong, Head of School, Electrical and Information Engineering
- Dr Gregor Verbic, Centre for Future Energy Networks, Electrical and Information Engineering
- A/Professor Tihomir Ancev, Environmental and Resource Economics

ACRONYMS AND ABBREVIATIONS

AC	Alternating Current	IDS	Intelligent Driving System
ACSR	Aluminium-steel Composite Cable	IEA	International Energy Agency
ADAS	Advanced Driver-Assistance Systems	IEEFA	The Institute for Energy Economics and Financial Analysis
ADB	Asian Development Bank	INDCs	Intended Nationally Determined Contributions
AIB	Asian Infrastructure Investment Bank	KOSIS	Korean Statistical Information Service
APEC	Asia-Pacific Economic Cooperation	kt	Kilotonne
ASEAN	Association of Southeast Asian Nation	kWp	Kilowatt peak
BAU	Business as Usual	LED	Light Emitting Diode
BEV	Battery Electric Vehicle	LPG	Liquid Petroleum Gas
CEO	Chief Executive Officer	LTS	Low Temperature Superconductors
CCS	Carbon Capture and Storage	LV	Low Voltage
CCUS	Carbon Capture, Utilisation and Storage	MgB2	Magnesium Diboride (a superconductor)
CAGR	Compound Annual Growth Rate	MNRE	Ministry of New and Renewable Energy (India)
COP21	21st Conference of Parties at 2015 Paris Climate Conference of the UNFCCC	MRI	Magnetic Resonance Imaging
CO ₂ e	Carbon Dioxide (equivalents)	MRTS	Mass Rapid Transit System
CSIRO	Commonwealth Scientific and Industrial Research Organisation	Mt	Megatonne
DC	Direct Current	MW	Megawatt
DDPP	Deep Decarbonisation Pathways Project	NPB	National Policy on Biofuels (India)
DG	Distributed Generation	NUTP	National Urban Transport Policy (India)
EITE	Emissions-Intensive Trade-Exposed (industry)	OEM	Original Equipment Manufacturers
ERIA	Economic Research Institute for ASEAN and East Asia	PEI	Power Engineering International (magazine)
ETS	Emission Trading Scheme	PHEV	Plug-in Hybrid Electric Vehicle
EU	European Union	PPP	Public Private Partnership
EV	Electric Vehicle	PV	Photovoltaic (solar)
FCV	Fuel Cell Vehicle	RDB	Regional Development Bank
FY	Financial Year	RE	Renewable Energy
FYP	Five Year Plan (China)	RES	Renewable Energy Source
GDP	Gross Domestic Product	SEA	South East Asia
GHG	Greenhouse Gas	SGCC	State Grid Corporation of China
GWh	Gigawatt hours	T&D	Transmission and Distribution
HTS	High Temperature Superconductors	TWh	Terrawatt hours
HVAC	Heating Ventilation and Air Conditioning	UHVDC	Ultra High Voltage Direct Current
HVDC	High Voltage Direct Current	UN	United Nations
ICA	International Copper Association	UNFCCC	United Nations Framework Convention on Climate Change
ICE	Internal Combustion Engine	UNSW	University of New South Wales (Sydney, Australia)
ICMM	International Council on Mining and Metals	WB	World Bank

1

EXECUTIVE SUMMARY

COPPER HAS BEEN VITAL TO INDUSTRIALISED HUMAN DEVELOPMENT IN ELECTRICITY, PLUMBING AND COMMUNICATIONS. PATTERNS OF DEMAND HAVE CHANGED AS NEW MATERIALS HAVE REPLACED SOME TRADITIONAL USES OF COPPER, HOWEVER COPPER REMAINS A CRUCIAL MATERIAL FOR HUMAN DEVELOPMENT. RAPID ECONOMIC DEVELOPMENT IN THE ASIAN REGION HAS REQUIRED, AND WILL REQUIRE, SUBSTANTIAL VOLUMES OF COPPER.

MANY OF THE ISSUES DISCUSSED IN THIS REPORT ARE HIGHLY INTERDEPENDENT. THOUGH TEMPTING, IT IS UNHELPFUL TO TREAT EACH ISSUE INDEPENDENTLY AND ASSUME THE OUTCOME IS THE SUM OF EACH PART.

ECONOMIC AND DEMOGRAPHIC DRIVERS

The Asian countries of interest studied comprise 27.8% of the global economy in 2010 and will grow to be 36% of the global economy in 2030. The combined compound annual GDP growth of the Asian countries of interest to 2030 is predicted to be 4.37% compared to 2.30% for the rest of the world. The Asian middle class will grow significantly by 2030 increasing the share of services in the economies and lowering per capita resource consumption. Asian populations are ageing rapidly, reducing the economic means of many countries. Unplanned movement of people including refugees is likely to put pressure on security and infrastructure, as will shocks such as pandemics. Economies that are well prepared with established public health and other infrastructure will fare better than others.

People need solutions to problems rather than particular products or services; for example thermal comfort, lighting, communications and mobility. Adoption of new solutions is typically not linear and is more influenced by social norms and attitudes than economically rational thinking. Companies need to maintain a social license to operate in the context of evolving social norms, and governments will be under pressure to provide transparency and accountability. There is an evolving sustainability awareness in Asia, exemplified by growing dissatisfaction with food safety and air quality in China, which will favour investment in sustainable infrastructure.

The development paths of China and India are the main levers for the Roadmap 2030 issues considered here. Straight-line projections based on today's practices are unlikely to be accurate. Forecasters must consider technology shifts, productivity gains and the efforts of these two countries to deliver sustainable prosperity to their populations. China is clearly flagging its sustainable development intentions in the Thirteenth Five-Year Plan while India is setting ambitious goals to increase sustainable standards of living.

A systems approach is needed to understand the likely future of the region in 2030. National leaders will be called upon to adopt holistic approaches in adaptation to climate change impacts, particularly ensuring infrastructure resilience at the city level. Forecasters must recognise the diversity of countries, diversity within countries, and the international relationships and trade agreements that will influence 2030 outcomes.

POPULATION GROWTH

China's population will stabilise at slightly over 1.4 billion by 2030 while India's population will exceed that level by around 2023 and continue to grow to over 1.5 billion by 2030. Indonesia's population will grow to almost 300 million by 2030. Japan's population

is expected to decline while Korea should experience little or no population growth over the period to 2030. India and the ASEAN nations are generally growing in population, with the fastest rates in India followed by Indonesia and the Philippines.

URBANISATION

Urbanisation is a cited indicator of economic development and a significant driver of demand for goods and services. Urban areas in China and India have fewer occupants per household, more floor space per capita and higher infrastructure demands than in rural areas. By 2050, half of Asia's countries will have levels of urbanisation greater than 72 per cent. Whilst China is currently 54% urbanised, this is expected to rise to 69% by 2030. India's urbanisation will grow from 33% today to almost 40% as the nation aims to provide electricity and water infrastructure to 300 million people currently living in substandard housing. Implementing its "Affordable Housing for All" policy by 2022 is critical to India's economic development aspirations. The most urbanised nations will be Singapore, Japan, Australia, Korea and Malaysia.



People walking on Nanjing Road, Shanghai

DECARBONISATION

Nations have acknowledged the need to decarbonise their economies to remain within a global carbon budget which reduces the environmental and economic risk associated with climate change. Carbon emission reductions, formalised in the Paris Agreement process, will drive change in the electricity and transport sectors in particular. We expect China and India will lead the world in decarbonisation, using emissions reduction as an economic opportunity as well as essential risk mitigation. The main levers to achieve this are:

- a shift from fossil fuel to renewables in the electricity sector;
- increased electrification in sectors including building and transport; and
- enhanced energy efficiency.

ELECTRICITY

Despite improvements in energy efficiency, the combination of population growth, increased rates of electrification and new electric loads will create considerable electricity demand growth in Asia by 2030. The Asian region is predicted to represent about 43% of world electricity demand by 2035, as China and India grow to become two of the three largest electricity markets by 2030, more than doubling current generation in each country. The 2030 electricity demand for the countries of interest is 18,500TWh, two thirds of which is represented by China. We predict that at least Vietnam and Indonesia will join the top twenty countries globally in terms of generation.

Residential demand growth will be a driver of overall growth in China and particularly in India. The Indian government has initiated a radical transformation of the Indian coal, renewable energy, power generation and electricity distribution sectors. Yet in China, there are signs of slowing electricity demand growth in due to industrial transition and improving energy efficiency. Air pollution in China is driving a rapid change in the generation mix, and the country has now installed renewable energy capacity larger than the rest of the world combined while coal plant utilisation has dropped below 50%. Coal generation may already have peaked in China, and the Thirteenth Five-Year Plan shows wind, solar and electric vehicles becoming new economic growth engines producing 3.9% of GDP by 2030 and 6.2% of GDP by 2050.

There are plans in China for a series of international power connectors, leading to the future vision of a globally-interconnected system. We believe a decentralised future is more likely, but the final outcome depends on complex factors.

Decarbonisation of electricity

Coal generation may already have peaked, and the Asian countries of interest have installed significant amounts of renewable generation with immense plans to increase deployment by 2030.

Decentralisation of electricity

A decentralisation trend, apparent in electricity networks since the turn of the century, is gathering pace. Local energy generation and distribution systems are emerging which will change the balance of centralised and decentralised energy. Australia is likely to have a relatively high decentralisation index of 30% in 2030, followed by India at around 7% or slightly higher. China will retain the most centralised power system among the three at around 2% decentralisation.

Distributed energy resources often duplicate existing distribution systems, though areas with little or no grid connection may be powered with distributed energy rather than connected to the grid. With increasing levels of decentralised energy and falling battery costs, we expect to see significant deployment of distributed energy storage in each country, with the extent roughly proportional to the decentralisation index, though also influenced by electricity prices. At today's prices we expect less storage will be built in China and India than in Australia.

TRANSPORT

Expanding urbanisation by 2030 will continue to strain urban infrastructure across Asia. According to HSBC, emerging Asia will need US\$11 trillion in basic infrastructure investment between 2014 and 2030 and the finance will increasingly come from China. A decentralisation trend is evident in infrastructure delivery. This report briefly explores water infrastructure but concentrates on transport and urban mobility modes as well as integrated mobility services.

Growing cities can become constrained by transport congestion, and air quality is affected by vehicles. China, India and other countries in the region, already experience severe traffic and vehicle air pollution. Passenger transport in China has tripled in the last decade, and vehicle numbers are forecasted to quadruple again by 2030. Demand for transport in India will grow by 2.5 times by 2030. Recent trends in India show a preference for private vehicles over public transport; Growth in private cars simply cannot continue in already-congested and polluted cities - air quality in New Delhi is already worse than in Beijing. Furthermore, energy security reasons preclude unconstrained vehicle growth.

The future of mobility is likely, then, to be a combination of evolved light vehicle solutions with much more extensive public transport options to offer people

convenient, integrated mobility services. We are sceptical of predictions based on a single transport mode or technology; the future will be a combination of modes and technologies, made possible by advanced ICT and emerging mobility integrators. The future will be focussed on customer needs.

Light Vehicles

We expect capital cost parity of electrified vehicles (EV, hybrid, fuel cell) by 2025. Penetration rates may be as high as 50% by 2030 depending on the level of government support and the competitive reaction of the local car industry in each country. In total, for the Asian countries studied, which should represent the bulk of demand for electric vehicles in the region of interest, the production of electric cars, including plug-in hybrids, between now and 2030 should be approximately 75 million vehicles. The combination will be 55% in China, around 19% each for India and Japan respectively, and around 3% each in Australia and Korea.

It is uncertain whether this number of electrified vehicles can be reached in highly urbanised countries. Many cities will become constrained by congestion. The trends towards autonomous vehicles and car sharing may likely be encouraged by governments in order to increase the utilisation of vehicles and road capacity. People’s mobility needs are unaffected by transport technology, thus when congestion constrains vehicle numbers, there will be substitution into alternative modes of transport including walking, bicycles and public transport.

Public Transport

Congestion, air quality and climate concerns amid increasing urbanisation and population growth will encourage the growth of public mass transit over individual transport in and between the large Asian cities by 2030. This public transport will increasingly be electrified, with implications for growth in the associated electricity systems. Three transport modes are examined: high-speed (intercity) rail, urban metro rail and electric buses. For each, the China market determines at least 80% of the total regional market, and China’s technology will be exported and used elsewhere.

For high-speed rail, the Chinese domestic network will be by far the largest in the world by 2030 with a number of international links planned. We expect the domestic network to grow to around 40,000km by 2030, implying roughly 4,150 train sets. We predict an 11,000km Chinese urban rail network in 2030, entailing a fleet of 77,000 urban/subway railcars in 2030. The significant metro developments in India are an order of magnitude smaller than the Chinese plans, and the other countries of interest are smaller again. For electric buses we expect total production to 2030 of 1.14 million vehicles for China domestic use. The



BYD ebus fleet in Xi’an city of Northwestern China
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numbers anticipated for Korea (3,800 by 2020), India and the other countries are comparatively small, approximately 1.4 million vehicles for the entire region by 2030.

RESIDENTIAL BUILT ENVIRONMENT

Population and economic growth will drive increases in the number of dwellings, size of dwellings and electricity use per dwelling in the main countries of interest. There will be significant growth in China and India. Housing construction growth is also expected in the more stable, developed economies of Japan, Korea and Australia. In all countries there will be a drive towards energy efficiency.

APPLIANCES

Population and economic growth will drive a huge uptake in appliances in Asia. This will be accompanied by a drive towards appliance efficiency. Though the appliances will be less electricity intensive, the overall appliance demand will increase. The sharing economy may provide a slight restraint on the growth of small portable appliances such as hand tools, but not large appliances like HVAC and white goods. The number of new urban buildings provides an indication of the incremental appliance demand, particularly in China where urban buildings are already fully penetrated with HVAC and middle class consumer appliances.



2

INTRODUCTION

PURPOSE OF THE ROADMAP

The Copper Roadmap 2030 has been written to provide insights for a broad range of individuals from copper production through to technology development. This report will also provide benefit for the ICA and its member companies to inform planning, marketing (growth and defence) and industry engagement. The Roadmap provides strategic insights to shape decisions on future projects in Asia. Whilst no one can precisely predict the future, making plans based on a broad range of industry insights, observations, projections of demographic and economic changes and anticipated technology trends will put the copper industry in a stronger, more informed position than merely reacting to year-by-year, incremental changes to business as usual.

CONTEXT

Copper has historically been vital to industrialised human development in electricity, plumbing and communications. Development and economic growth have driven strong demand for copper. Aspects of this pattern of demand have changed as new materials

have replaced some traditional uses of copper, however as this research demonstrates, copper is still a crucial material for human development, and the rapid economic development in the Asian region has required huge volumes of copper.

FACTORS CONSIDERED IN THIS STUDY

Economic growth

- The growth of China and its evolution beyond the massive infrastructure and heavy industry-driven economic growth to the emerging services economy.
- Growth in India

Environmental factors

Since the industrial revolution, economic development has been powered by fossil fuels. Despite its effectiveness in providing energy that has met mankind's ever growing demand, science presently advises that the environmental impact of fossil fuel use has begun to alter the Earth's climate. The projected impacts of global climate change are far reaching and potentially catastrophic. The world's governments have therefore begun to respond by steering away from fossil fuel based energy systems. Phasing out the use of fossil fuels will lead to huge economic disruption but also significant opportunity. Fortunately, copper will be integral to renewable (pollution free) energy systems and many of the technologies that will use this clean electricity energy.

Technology and innovation

Largely driven by the change in energy systems, but also the ever-growing market for consumer electronic devices and electrical household equipment, the copper industry is well placed to benefit from the transition to the post-fossil fuel industrial era.

Past research

The Copper Roadmap 2030 work follows previous research undertaken by the Warren Centre for ICA in 2004 - *Building Construction Technology Roadmap*¹ - noting though that this earlier work had a narrower scope both technologically and geographically.

The project team also benefited from insights provided by ICA's in-country technical experts and head-office technologists in the USA.

Audience

This report has been written with the following audiences in mind:

- Copper Producers
- The ICA and its members
- Technologists
- Futurists
- Policy makers and planners.

Scope

The project examined the drivers of future copper use in Asia until 2030, focusing on residential built environment and associated energy and transport implications. The scope of the study was as follows:

Demographics and economics		Built environment	Energy	Infrastructure	Consumer Goods/ Services
Pop'n growth & ageing	GDP growth	Building wiring	EVs, EV charging, other Light Vehicles		
Urbanisation & relocation	Personal income spending, saving	HVAC	Centralised generation	Public transport	Appliances
Immigration/emigration	Consumer trends & preferences	Plumbing	Transmission & distribution	Telecoms networks	Mobile technology
National and socio-political factors		Building materials	Renewables	Water networks	ICT & e-Commerce
Climate impacts		Housing type preferences	Decentralised energy, storage		Decentralised manufacturing
Food/energy/water nexus					

The geographical scope of the report is illustrated below. For simplicity and due to relative impact and scale countries have been grouped into the following regions:

China	India	Japan	Korea	East Asia		Australia
China	India Sri Lanka Bangladesh	Japan	South Korea	Indonesia Vietnam Malaysia Singapore	Thailand Philippines Taiwan Cambodia, Laos, Burma etc	PNG Australia New Zealand

¹ *Building Construction Technology Roadmap*. (2004). Woolloomooloo, NSW: Copper Development Centre Australia & Warren Centre for Advanced Engineering.



3

METHODOLOGY: UNDERSTANDING DEMAND WITHIN THE COPPER SYSTEM

IDENTIFYING DRIVERS OF DEMAND

Demand for copper is intrinsic to its principal function as an electrical current carrying material. As a transmitter of energy, copper is a critical component of the modern industrial society. As copper is mined and refined it accumulates in the anthroposphere in buildings, infrastructure, transport, equipment and scrap. Copper consumption is therefore associated with growth in these applications. To forecast copper demand, analysts must identify what drives this growth and how applications impact copper demand.

Several of these drivers of demand may interact or overlap. This Roadmap covers each growth driver in a country-by-country analysis using the methods described

in this chapter. These analyses are contextualised by a review of government policy of each country and the insights, observations and expectations of experts consulted by the Study team (The Warren Centre).

MEGATREND DRIVERS

Megatrend drivers are the fundamental societal forces that create demand for copper-containing technologies.

Population

At the most fundamental level, demand is the sum of the copper consumption and utilisation by each person. By defining copper consumption per capita, population

is a reliable data source that can be used to project demand into the future.

Demographic Drivers

While population statistics are readily available, they are a complex sum of demographics. The geographical scope of this Roadmap comprises countries with growing, stagnant and even declining populations, including ageing populations. These trends significantly affect the per capita copper consumption and must be considered.

Economic Drivers

The economic performance of each demographic can be profiled by the gross domestic product (GDP) of the region. This is generally a good indication of industrial and social development. When combined with demographic statistics, GDP provides individual wealth (GDP per capita). Current research indicates that GDP per capita is correlated to copper demand in developing economies. However, in advanced economies there is a distinct decoupling, attributed to the growing in-use stocks of copper that accompany the construction of modern infrastructure.

Urbanisation

Urbanisation trends arise as a consequence of demographic and economic development. A higher proportion of a population living in large cities is accompanied by a higher copper intensity per capita. An urbanisation index is used to split the population of each country into urban and rural classifications, each of which is analysed with distinct copper consumption characteristics.

Decarbonisation

Following the December 2015 Paris Agreement, 195 countries agreed to legally binding carbon emission targets. To achieve these targets, many countries must retool their energy generation and distribution sectors with solar, wind and storage technologies and electrify transport. The copper intensity of each of these technologies combined with the volume of production determines contribution to copper demand in 2030.

MATERIAL DRIVERS

Material drivers are the applications of copper-containing technologies. Demand for these technologies directly creates demand for copper.

Infrastructure Drivers

- Rail and metro system
- Streetscapes and traffic lights
- Broadcasting and television network
- Telecommunications

- Electric power transmission and distribution
- Electric power generation
- Water supply and distribution

Transportation Drivers

- Automobiles
- Aircraft
- Civil transport vessels
- Railroad vehicles

Buildings Drivers

- Residential Buildings
- Commercial Buildings
- Industrial Buildings

Equipment Drivers

- Household Durables
- Commercial Equipment
- Industrial Machinery

OTHER FACTORS THAT AFFECT DEMAND

Demand Elasticity

New technologies may not contribute additively if total global consumption is constrained by supply or other economic pressures. Increased demand in one sector may cause a price pressure on other sectors. End consumers of copper do not usually buy pure copper, rather they buy electronic equipment or demand services that contain copper. Manufacturers or service providers can make economic decisions to reduce copper intensity if the market price is high. Copper demand is therefore somewhat elastic.

Perhaps counterintuitively, increased demand may also increase economies of scale of copper production, so while a short-term increase in demand may increase the price of copper, the long-term effect might be to lower copper prices.

The preceding discussion and analysis established that demand is part of a greater system, which can be modelled by a bottom-up analysis and that despite the geographical scope of this Roadmap, has global influences. To build a bottom up model we must define what drives demand.

Dematerialisation

The economic benefit of using less material applies to specific applications and to greater society alike. According to Gerst et al, this process, called dematerialisation, can occur in four ways: transition

3. Methodology: understanding demand within the copper system continued

in economies from agriculture to industrial to service-based, saturation of bulk markets for materials, material substitution, and technological change in the amount of material required per unit of service.²

UNDERSTANDING DEMAND WITHIN THE COPPER SYSTEM

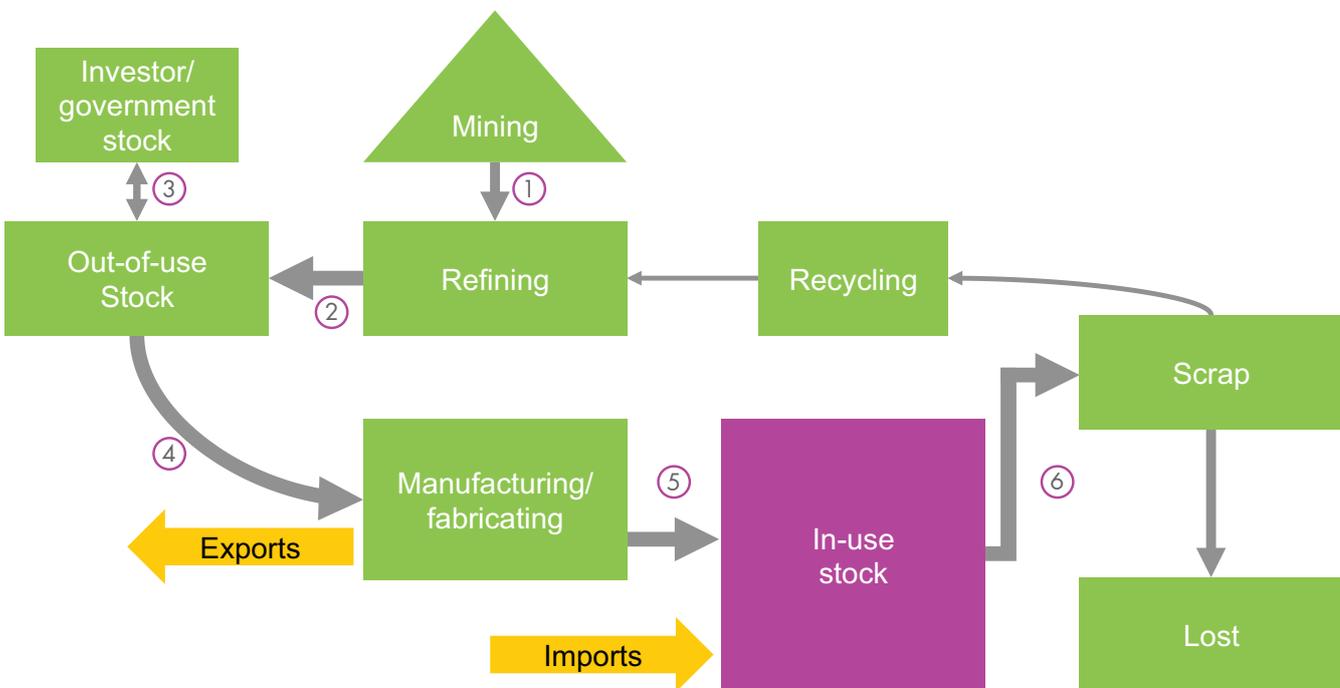
THE COPPER MATERIAL SYSTEM AND MARKET

Copper is both a base and precious metal, meaning that it is not only critical to industrialisation but the metal is also stockpiled and traded as a commodity.³ The flow of copper through the global system is driven by a complex

market mechanism. Copper is a limited resource, with a steady decline in ore grade accompanied by increasing mining and refining energy intensity.⁴

Despite this, copper demand continues to increase due to unabating economic, demographic and technological factors. Acting as a buffer between supply and demand, out-of-use or market stock copper provides time for the mining industry to meet demand. The price of copper is dictated by buyer competition for market stock.⁵ Since price is a function of both supply and demand, price is not used to forecast demand in this Roadmap.

Nevertheless, as this Roadmap aims to forecast copper demand, it is necessary to consider price as part of a complex system linking copper material flows through mining, refining, out-of-use (market) stock, manufacturing/fabricating, in-use stock, scrap and recycling.



Copper Material System (original image by The Warren Centre study team). In the Copper Material System, the demand for refined copper by each sector is represented by the arrow (4). Historical demand data was provided by the International Copper Association.

Definition of Terms:

Fabrication - the making of simple copper products such as pipes, wires and busbars.

Manufacturing - the making of complex equipment that contains copper components such as electric vehicles, appliances and solar PV.

² Gerst, M. D. (2009). "Linking Material Flow Analysis and Resource Policy via Future Scenarios of In-Use Stock: An Example for Copper." *Environmental Science & Technology* 43(16): 6320-6325.

³ Papp, J. F., et al. (2007). "Cr, Cu, Mn, Mo, Ni, and steel commodity price influences, version 1.1." US Geological Survey Open-File Report 1257: 50.

⁴ G.M. Mudd, W., Z., R. Memary S.A. Northey, D. Giurco, S. Mohr, L. Mason (2012). *Future Greenhouse Gas Emissions from Copper Mining: Assessing Clean Energy Scenarios*. CSIRO, Monash University, University of Technology, Sydney.

⁵ Sverdrup, H. U., et al. (2014). "On modelling the global copper mining rates, market supply, copper price and the end of copper reserves." *Resources, Conservation and Recycling* 87: 158-174.

FORECASTING METHODS

In order to forecast copper demand, it is necessary to model the *Copper Material System* and *Copper Market System* that drive material flow through the anthroposphere. Commodity flows such as these can be modelled using various methods of Material Flow Analysis (MFA).⁶ These are classified as retrospective/prospective and top-down/bottom-up.

In this chapter the merits of each method are discussed, and the data used to build the baseline demand are defined. This Roadmap employs a combination of the following methods:

Top down:

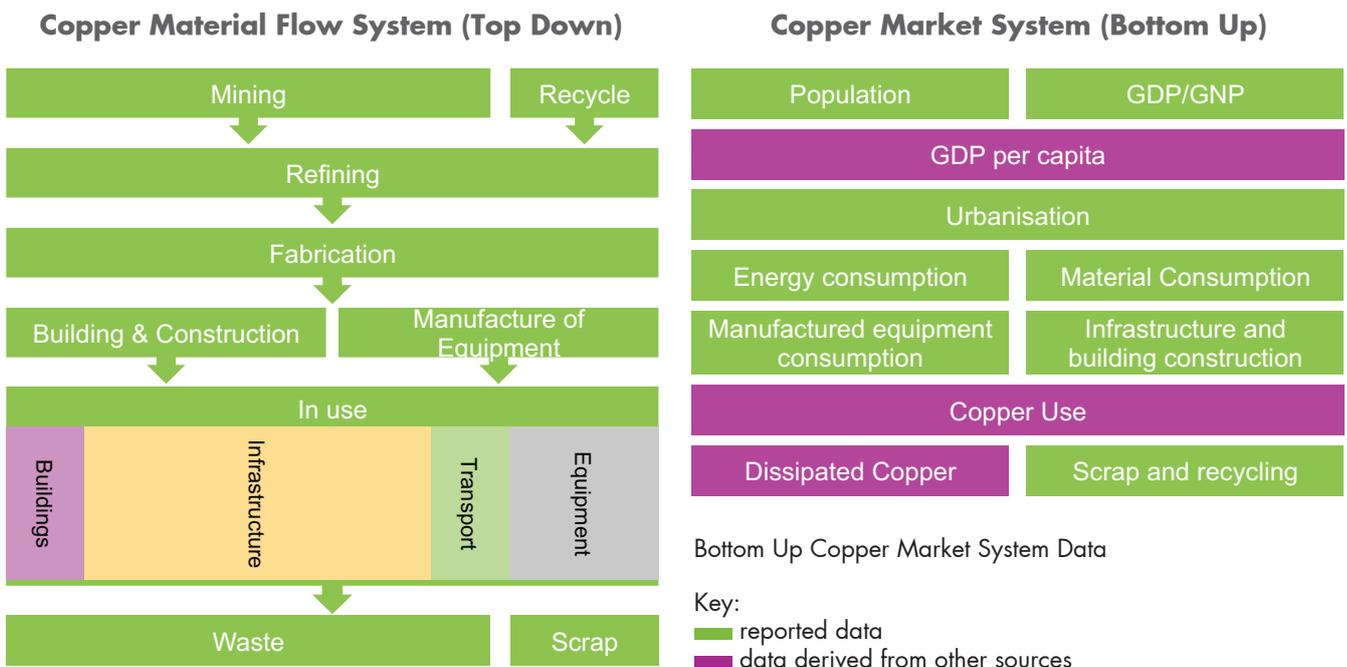
- Retrospective analysis of refined copper consumption
- Prospective analysis of demographic/economic indices

Bottom-Up

- Retrospective survey of in-use copper stock by geography
- Prospective analysis of major novel copper intensive technologies

In this report, the concept of top and bottom relate to the source of data within either the Copper Material Flow System or the Copper Market System (as shown below).

Forecasting requires the extrapolation of these models into the future. The most basic method is linear extrapolation. However, successive waves of innovation continue to bring exponential adoption of new technology, disrupting the market for incumbents.⁷ The 2030 Roadmap is based on a probabilistic approach incorporating numerical data and insights from experts.



Definition of Terms:

Copper Material Flow System - the flow of copper from the mine to end-use via refining, fabrication and manufacturing.

Copper Market System - the economic, demographic and technological drivers of copper demand.

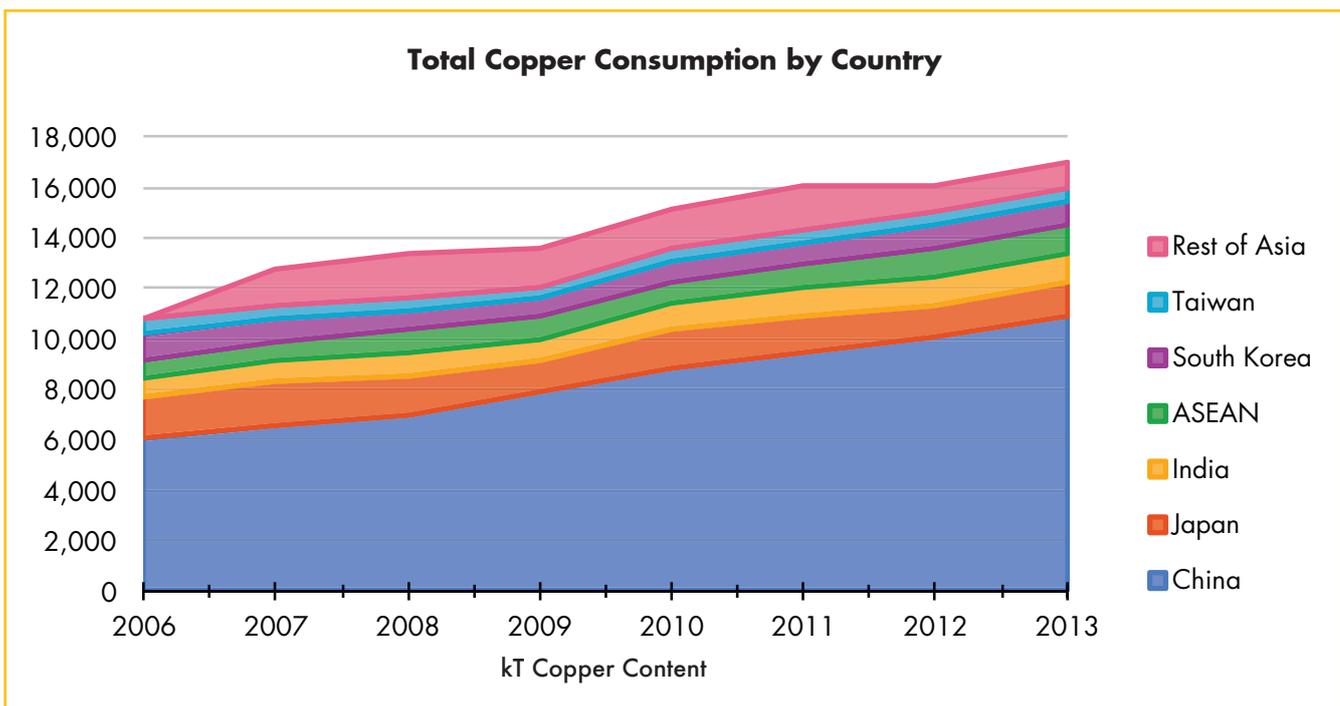
⁶ Müller, E., et al. (2014). "Modeling Metal Stocks and Flows: A Review of Dynamic Material Flow Analysis Methods." *Environmental Science & Technology* 48(4): 2102-2113.

⁷ Farmer, J. D. and F. Lafond (2016). "How predictable is technological progress?" *Research Policy* 45(3): 647-665.

TOP-DOWN METHOD: REFINED COPPER CONSUMPTION BY COUNTRY

Yearly consumption is approximately equal to the rate of increase of in-use copper stock. If data is readily available to describe refined copper output, it is possible to model changes to in-use stock, and therefore demand, via a top-down analysis of copper consumption.

The yearly copper consumption for each country within the geographical scope is presented for the years 2006 to 2013 (shown below). From this it is possible to extrapolate the data to half this time again, to 2017, with acceptable confidence. In the timeframe of this data, the only country with significant growth is China, with about 8% growth per year. The other major consumers of refined copper grow at less than 1% per year. This data provides little insight into geographical copper demand.



Refined copper consumption by country. Data: ICA/IWCC.

The refined copper demand within the Asian scope is just one part of the global Copper Material System and Market System, with supply and demand from other geographies also driving copper flows through the system. Refined copper demand is therefore quite far removed from the end-use of copper that provides the fundamental drive for demand and cannot inform how demand might change in the future. It also cannot account for copper that is consumed by a local manufacturing industry which then exports copper-containing products outside the Asian region. All countries that are net exporters of copper will exhibit high per-capita copper consumption when using data from this top-down method.

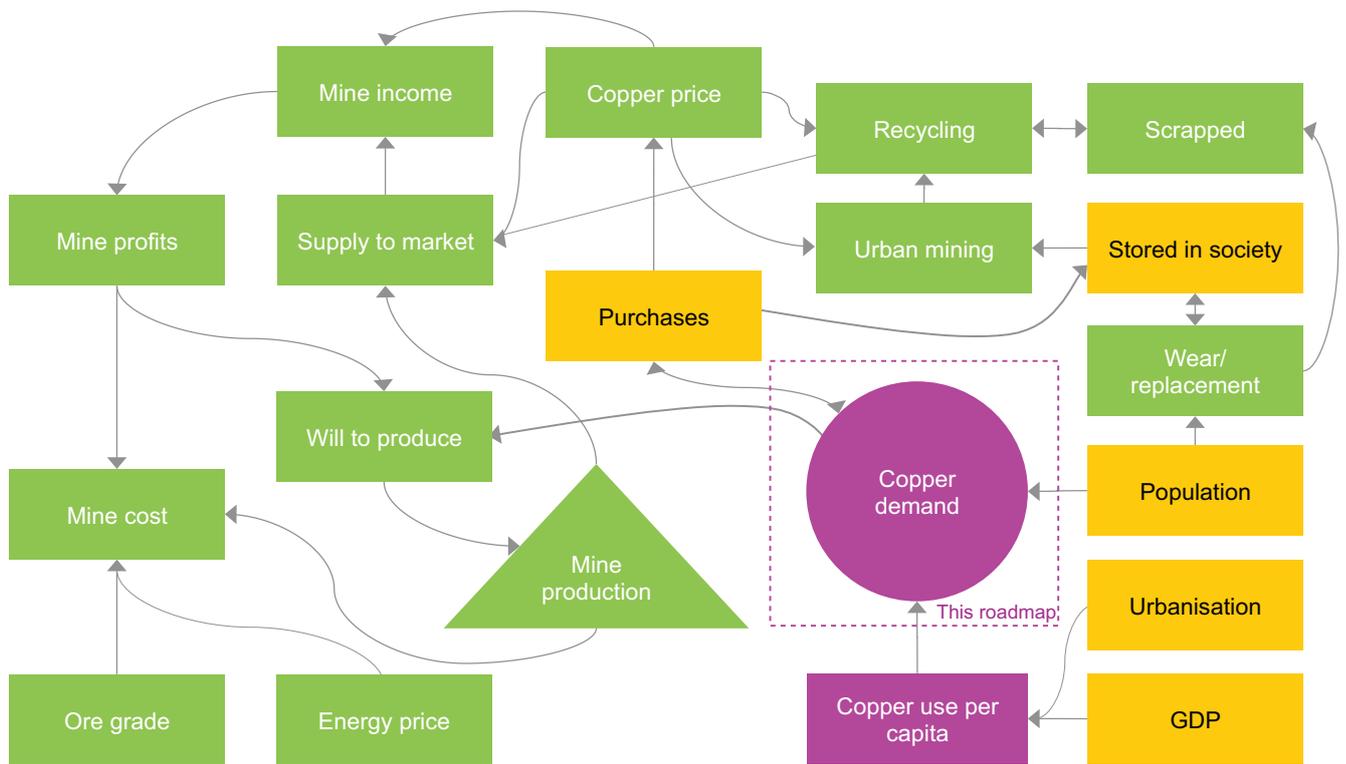
In addition to being a poor indicator of demand, this top-down analysis can give a misleading representation

of supply, or more specifically, the amount of refined copper entering the manufacturing and fabrication stage. This uncertainty arises from the increasing and uncertain proportion of refined copper coming from recycled scrap.

The balance of supply from mining and recycling is dictated by a complex market mechanism that works using price signals and cost factors. The potential for urban mining will increase as in-use stocks of copper increase. Since recycling consumes at most half the energy of primary production, the viability of copper recycling will become increasingly favourable.⁸ This relationship is described in the causal loop diagram for the Copper System, illustrated in the following diagram.

⁸ Agrawal, A. and K. K. Sahu (2010). "Problems, prospects and current trends of copper recycling in India: An overview." Resources, Conservation and Recycling 54(7): 401-416.

Figure 3.4: Causal loop diagram for copper system



Direction of arrow indicates positive relationship e.g. increased population causes increase in demand. Yellow box indicates data that is used in this report. Purple box indicates inferred data.

TOP-DOWN METHOD: DEMOGRAPHIC, ECONOMIC AND URBANISATION DATA

An alternative top-down method that utilises demographic, economic and urbanisation trends can be used to forecast copper demand. These are well researched indices within the field of macroeconomics that have acceptable confidence. Of these, population is the most fundamental copper demand driver. It is possible to derive a factor for the copper demand per capita, then couple population with this factor to forecast total copper demand for the region.

but decouples when per capita GDP reaches a certain point (2008 US\$15,000 in the Japanese case study).¹⁰ It is unclear whether this figure is applicable to other countries.

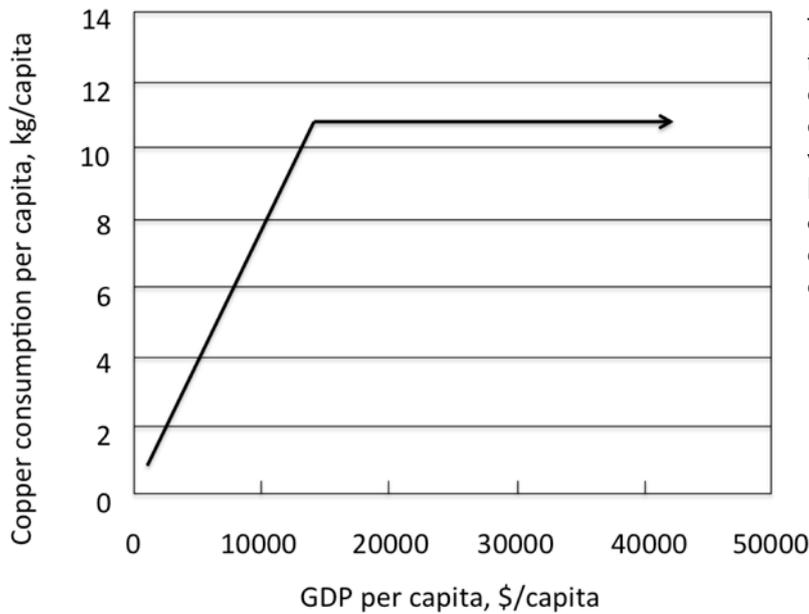
The decoupling could be a result of many factors, including the slowing of population growth, industrialisation and construction.

Unfortunately, this analysis method is complicated by changes in demography. As individual wealth of an individual increases, so too does demand for floor space, infrastructure, copper-containing goods and energy. These demands increase individual's consumption of copper. It has been demonstrated that copper consumption per capita is coupled with GDP per capita,

⁹ Graph Adapted from: Müller, E., et al. (2014). "Modeling Metal Stocks and Flows: A Review of Dynamic Material Flow Analysis Methods." Environmental Science & Technology 48(4): 2102-2113.

¹⁰ Halada, K., et al. (2008). "Decoupling status of metal consumption from economic growth." Materials transactions 49(3): 411-418.

3. Methodology: understanding demand within the copper system continued



The analysis must therefore acknowledge that demographic and economic indices alone are problematic indicators of copper demand due to their non-linear relationship with copper consumption. Indices will however provide valuable insight into copper demand prospects that cannot be extrapolated from historical copper demand data.

Decoupling of copper consumption from economic growth in Japan.

Source: Halada, K., et al. (2008). "Decoupling status of metal consumption from economic growth." *Materials transactions* 49(3): 411-418.

BOTTOM-UP METHOD: SURVEY OF IN-USE STOCK

This method analyses all applications of copper within a geographical region. While the method ignores all of the macroeconomic drivers, it provides an accurate assessment of the amount of copper in the anthroposphere. Combined with information of the lifespan of each copper application, this bottom-up method can provide information about material flows into and out of the anthroposphere. These drivers can be regarded as the microeconomic drivers of demand and will be referred to as micro-drivers.

A comprehensive survey of micro-drivers is an exhaustive task. Therefore, any such analysis will focus primarily on technology trends that significantly affect demand. This may include the phasing in (or out) of copper intensive technologies or changes in the copper intensity of existing technologies.

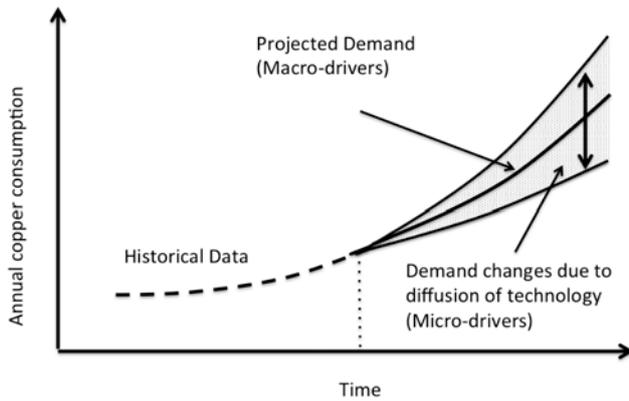
There are two major sources of information used to build this method's database. Predominantly used are surveys of in-use copper stocks that have been conducted to evaluate the prospects of urban mining¹¹ or developing recycle strategies¹². In addition to this are Life-Cycle Analyses (LCA) of manufactured goods that provide material composition and service life data.

Copper forecasts in this Roadmap will utilise these copper stock surveys and LCAs to deduce a copper factor. This factor will allow the analysis to forecast the volume of copper entrained in a specific use or technology. For example, the analyst might want to know how much copper demand will be generated by the construction of residential buildings. To do this, a sample of residential buildings must be surveyed whereby the floor area and copper content of the sample is measured. Using this information it is possible to deduce a "copper mass per floor area" factor. This information can be combined with census data that describes the floor area per capita to derive a "copper mass per capita" factor. Using population and demographic data the analyst can thereby forecast copper demand to 2030 associated with residential building construction.

This bottom-up method provides a good indication of which technologies will be major demand drivers, however it is important to acknowledge that it is difficult to account for overall copper demand by summing each driver. It is unlikely that total demand is sensitive to any one technology, however it is possible that unprecedented technologies such as distributed energy generation and storage may have significant impact. The relationship between macroeconomic and microeconomic models of copper demand is illustrated in the graph below.

¹¹ Wallsten, B., et al. (2015). "The economic conditions for urban infrastructure mining: Using GIS to prospect hibernating copper stocks." *Resources, Conservation and Recycling* 103: 85-97.

¹² Zhang, L., et al. (2015). "Understanding the Spatial and Temporal Patterns of Copper In-Use Stocks in China." *Environmental Science & Technology* 49(11): 6430-6437.



Relationship between macro- and micro-economic drivers of copper demand. Source: Inoue, Y., et al. (2012). Evaluating risks of copper depletion based on sustainability scenarios.¹³

BOTTOM-UP METHOD: TECHNOLOGY FORECAST

This method seeks to identify the most copper-intensive technologies to 2030. These technologies will meet the needs of 21st century Asia and may not have contributed at all to historical demand. These needs are associated with unprecedented ageing, congestion, mobility, communication, computing, transport, energy, food production and water scarcity.

In addition, the environmental, and now political, necessity of decarbonisation of Asian economies will drive the transition from fossil fuel to renewable energy, which requires the electrification of cities and transport. With this trend comes the diffusion of many copper-intensive technologies such as solar PV, wind, battery storage and electric vehicles. Many of these technologies were, until recently, negligible drivers of demand. The associated increase in copper demand is likely to test the elasticity of the market if supply cannot increase proportionally.

The Technology Forecast method transcends the geographical barriers of the Survey of In-Use Stock method. For example, the spatial distribution of power and storage technologies is likely to be similar to that of manufactured white goods. Their production is generally concentrated in major industrial countries but their use is global. For example, of the top fifteen manufacturers of solar PV, nine are based in China, where 78% of first generation silicone modules are produced.^{14 15}

APPLYING THE METHOD WITHIN THE ROADMAP SCOPE

The scope of this Roadmap is limited geographically to Asia, but within Asia are major importers of refined copper, manufacturers and exporters of copper-containing products, and importers of distributed energy technology. Therefore, each of the four methods described may overlap if the analyst were simply to add outputs together. For example, counting in-use manufactured goods in the geographical survey as well as in the technology forecast would effectively double count a portion of demand.

The demand for copper for any one country is also influenced by the performance of the manufacturing industry, which may export copper-containing products. This skews the per-capita copper data to give the impression that residents of net exporting countries consume more copper. This is often the opposite of expectations, since high net exporting countries may have global cost advantages due to cheap labour, but low wage domestic demography is associated with low copper intensity.

Manufacturing industries are sensitive to the global copper market, with higher prices and incentive to reduce the copper intensity of their products and therefore copper consumption. It is therefore difficult to forecast copper demand in the globalised manufacturing industry, and the reason why end-use, rather than manufacturing, is the focus of this Roadmap.

LEARNING FROM PREVIOUS WORK: 2004 BUILDING CONSTRUCTION TECHNOLOGY ROADMAP

Many of the technologies that were forecasted by the 2004 Report eventuated but did not increase demand for copper. These include the adoption of smart wiring and increased application of water harvesting systems. While each of the technologies sought to address contemporary issues such as rising energy prices and water scarcity, their ultimate success hinged on uncertainty associated with competing and converging technologies and environmental externalities.

¹³ Inoue, Y., et al. (2012). Evaluating risks of copper depletion based on sustainability scenarios. *Electronics Goes Green 2012+ (EGG)*, 2012.

¹⁴ Subtil Lacerda, J. and J. C. J. M. van den Bergh (2016). "Diversity in solar photovoltaic energy: Implications for innovation and policy." *Renewable and Sustainable Energy Reviews* 54: 331-340.

¹⁵ Kumar Sahu, B. (2015). "A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries." *Renewable and Sustainable Energy Reviews* 43: 621-634.



4

ECONOMIC & DEMOGRAPHIC DRIVERS

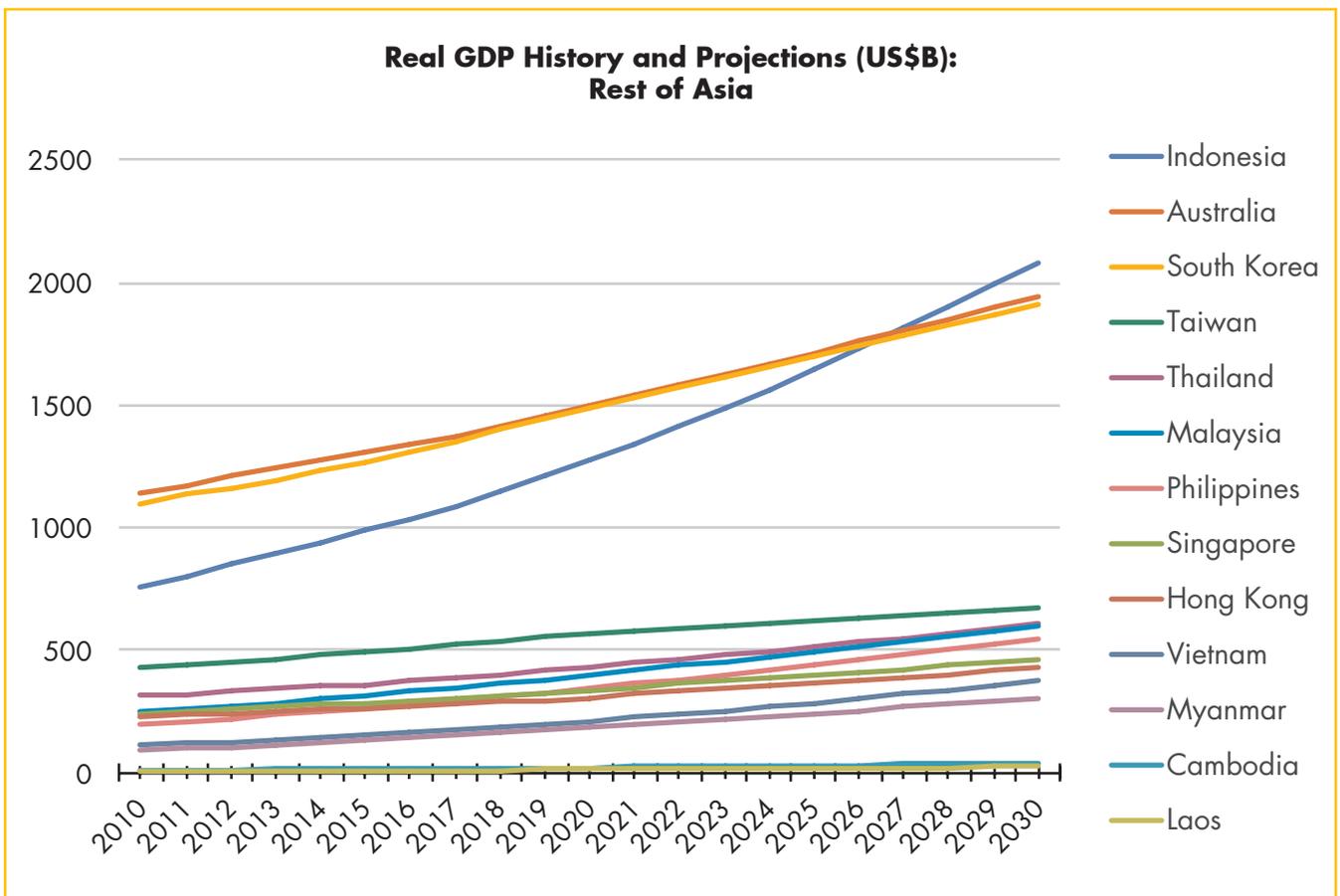
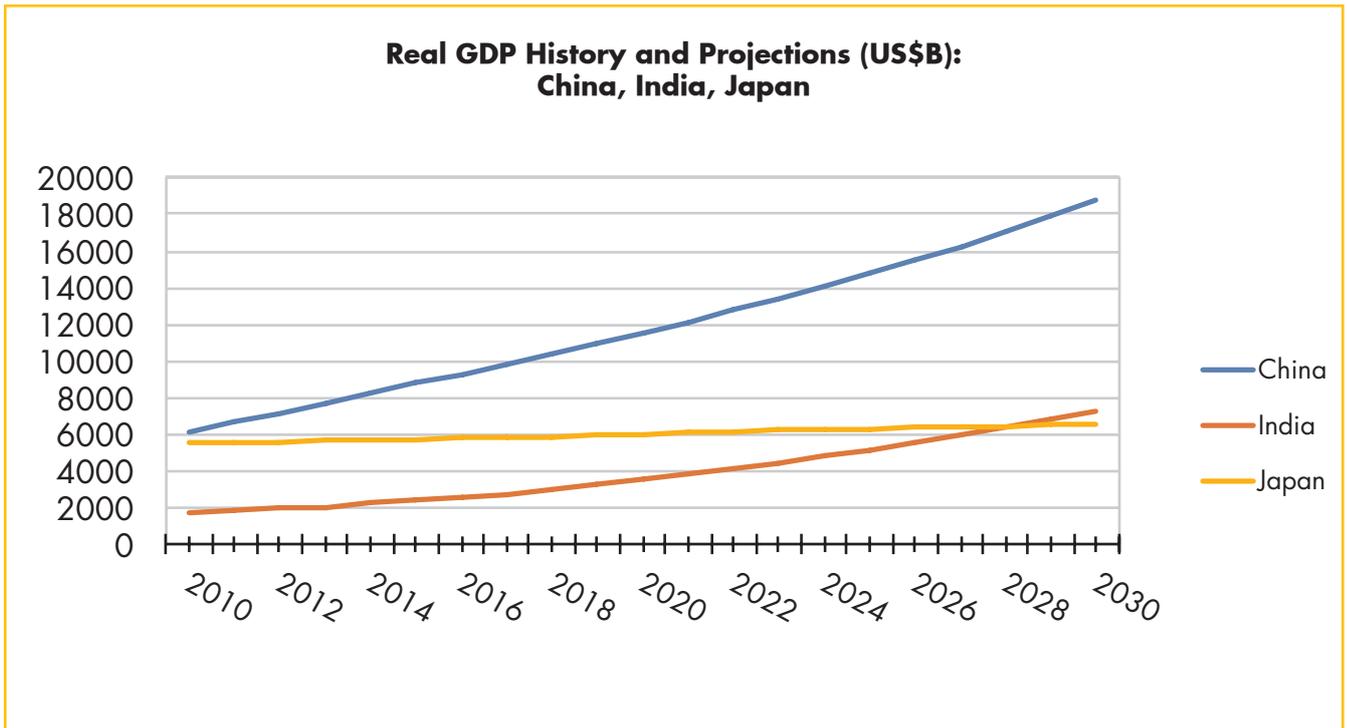
NATIONAL AND REGIONAL OVERVIEW

ECONOMIC GROWTH

The Asian countries of interest are unquestionably an engine of global growth. GDP is far from a complete metric of performance, but GDP gives some indication of relative national growth. The charts below are one projection of GDP growth made by the USDA. Based on this data set, the Asian countries of interest were

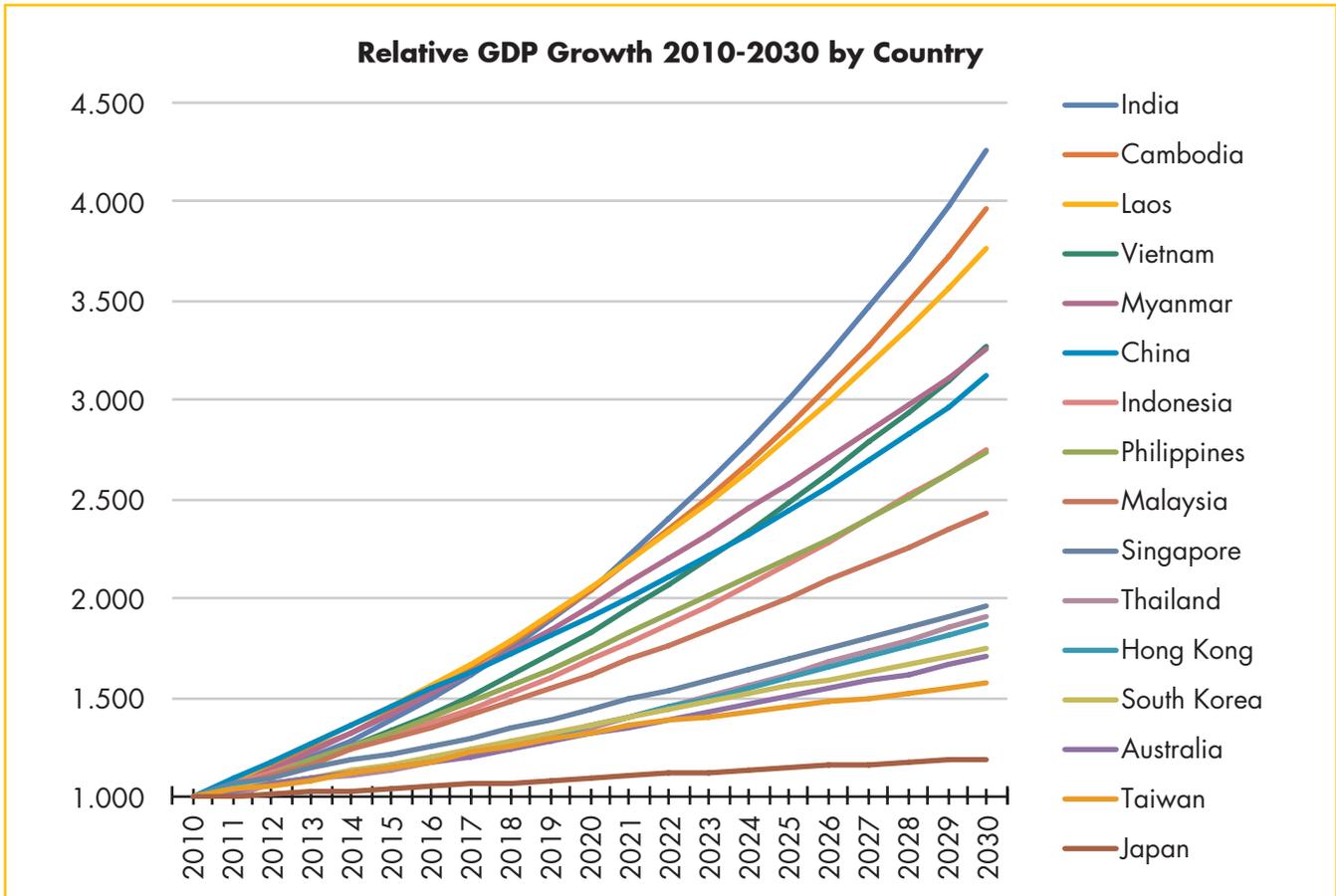
27.8% of the global economy in 2010 and will grow to be 36.4% of the global economy in 2030. The combined compound annual GDP growth of the Asian countries to 2030 is predicted to be 4.37% compared to 2.30% for the rest of the world.

¹⁶ Heerman, K. (Dec, 2015). *Projected Real Gross Domestic Product (GDP) and Growth Rates of GDP*, <http://www.ers.usda.gov/data-products/international-macroeconomic-data-set.aspx>

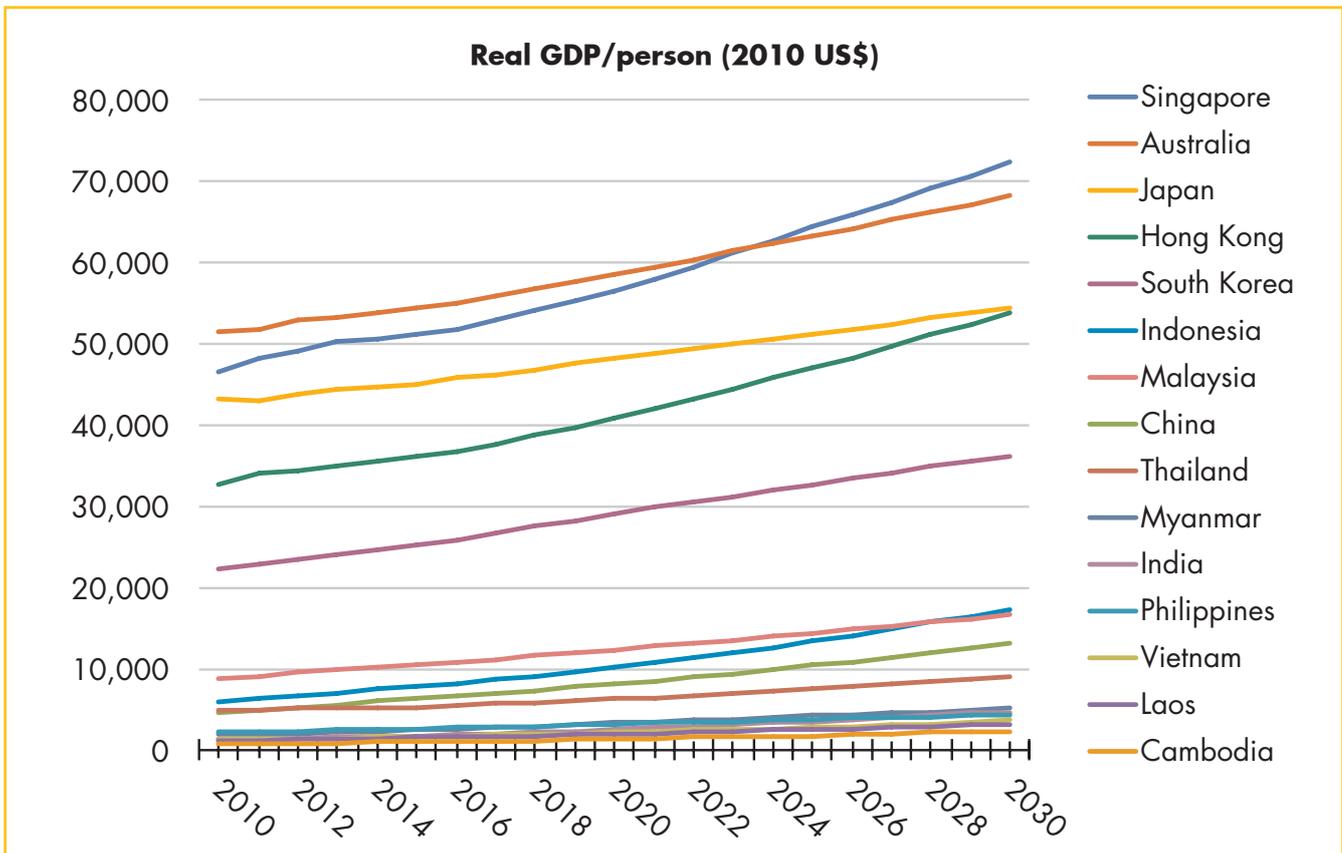


As it is difficult to sense the relative growth rates in the charts above, an alternate view of the same data is shown below, indexed to 2010 for each country.

4. Economic & Demographic Drivers continued



Standards of living will increase across the region, though unevenly according to country. The following chart projects GDP per head of population based on the USDA GDP data and UN population data .



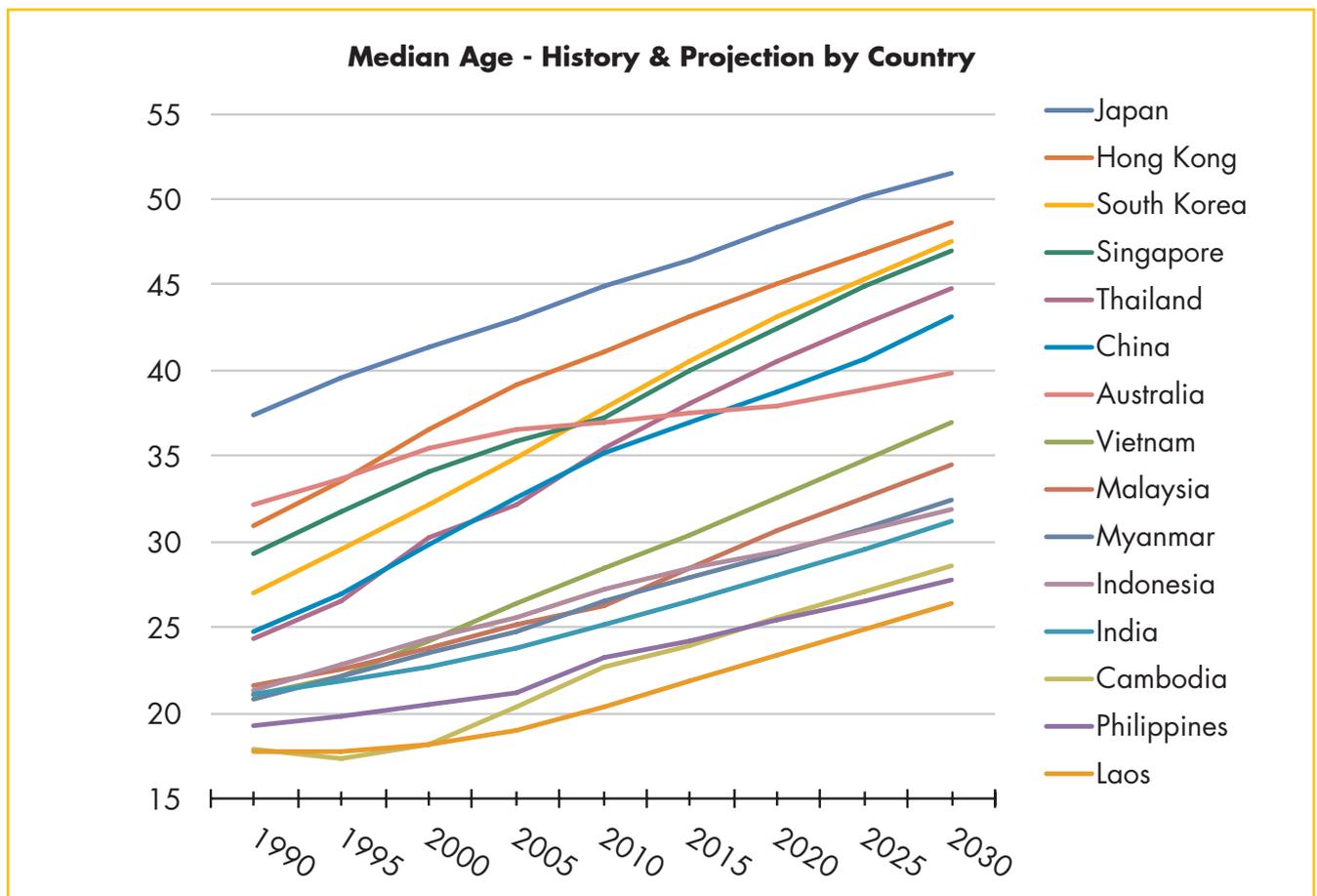
¹⁷ United Nations department of Economic and Social Affairs (2015), World Population Prospects, the 2015 Revision, un.org, <http://esa.un.org/unpd/wpp/>

With increasing per capita GDP and incomes, services become a larger part of each rising Asian economy, and manufacturing and primary industry become proportionally smaller. According to the Grattan Institute’s John Daley, due to the growing use of technology, Asian manufacturing will not reach as high a proportion of the economy as was seen in the countries which industrialised earlier. Per capita resource use tends to flatten as countries transition to

a service economy, according to CSIRO’s Paul Graham. The Asian middle class will grow significantly by 2030. Whether resource consumption will follow middle class growth depends on the evolution of social attitudes. Travers McLeod, CEO of the Centre for Policy Development, expects people’s attitudes towards sustainability and the protection of natural capital will have evolved significantly by 2030.

DEMOGRAPHICS

According to the Grattan Institute’s Professor John Daley, birth rates in much of Asia are “dropping rapidly and there’s not much immigration”. The Indian population continues to grow, but its 2014 growth rate of 1.22% was ranked 125th in the world.¹⁸ Hence many of the countries of interest show rapid aging as seen in the following chart:



Source: UN Median age data: history and medium projection¹⁹

Interestingly, Australia’s high immigration intakes lead to much slower growth than in all the other countries.

Population growth is explored in more detail in the following section.

¹⁸ World Bank (2015). *World Development Indicators*, http://data.worldbank.org/indicator/SP.POP.GROW?order=wbapi_data_value_2014+wbapi_data_value+wbapi_data_value-last&sort=desc

¹⁹ United Nations, Department of Economic and Social Affairs, Population Division (2015). *World Population Prospects: The 2015 Revision, DVD Edition*. <http://esa.un.org/unpd/wpp/>

MAJOR MOVEMENTS OF PEOPLE, ECONOMIC SHOCKS

Many of the countries of interest do not have skilled immigration pathways. New free trade agreements are starting to encourage a more systematic approach to labour movement, but pressures from unplanned migration including refugees are likely to put pressure on security and infrastructure. Climate impacts may increase the flow of people by 2030, and infrastructure could be further strained by extreme weather events and sea-level rise. The 2013 Fifth Assessment Report of the Intergovernmental Panel on Climate Change (AR5 IPCC) concluded that the global mean sea level will continue to rise at a rate very likely to exceed the rate of the past four decades.²⁰ Experts have recently estimated this to be 2.6 to 2.9 mm/year.²¹ Thus, a cumulative sea level rise may reasonably exceed 40mm by 2030. Likewise, economic shocks may result from major health events including pandemics, which occur infrequently, but regularly. Economies that are well prepared with good public health infrastructure will fare better than others. The emerging Asian economies are expected to be more exposed to the risks than the USA or Europe.

CONSUMER TRENDS AND PREFERENCES

Demand for goods is driven by people's need for solutions such as mobility, light, warmth/cooling, information, water and food. If a better means to solve a particular problem is presented, modern consumers exhibit little loyalty to the displaced product or service. Adoption of new solutions is typically not linear and is more influenced by social norms and attitudes than technical or economically rational thinking.

The Roadmap 2030 team discussed technology adoption with Katherine Teh-White, CEO of Futureye. She said adoption rates are largely influenced by the social maturity of issues i.e. the degree of public awareness acceptance of an issue which evolves over time in predictable stages. This is qualitative and emotional, not quantitative and rational. For example, she suggests that consumers in Asia have a growing awareness of sustainability issues which is starting to affect their buying behaviour; this will grow over time. She discussed how industries and companies in all sectors now need to consider reputational issues and plan to secure and maintain their "social licence to operate". Similarly, the Centre for Policy Development's Travers McLeod expects that the pressure to do more

with less will motivate companies to engage in a "race to the top" on sustainability and will help build the sharing economy.

In China ten years ago there was little public awareness of, or dissatisfaction with, air quality. Now air pollution is a major issue for people and a serious source of pressure and political risk for the government, which is responding quickly with measures that would have seemed unthinkable not long ago. Populations are increasing finding their voices, and that trend is expected to accelerate to 2030. In many developed nations a trend has been documented that today's young adults are generally less driven to gather material possessions than earlier generations, favouring experiences and services. An example is the falling rates of car ownership and people holding driver's licenses in the US, concurrent with the rise of car-sharing and e-hailing services.

Most governments globally have not historically felt the need to secure the support of the population when making major infrastructure decisions, for example when choosing electricity generation fuels. We believe that the need to maintain a social licence to operate will motivate governments and utilities to favour renewable and distributed renewable electricity generation.

Engagement of emerging Asian populations in online social media illustrates how digital media illuminates social concerns and creates pressure on governments to respond. A series of food safety scandals in China illustrate this. Contaminated, counterfeit and harmful baby formula incidents have occurred, notably the 2008 Sanlu incident reported to have caused six deaths and more than 250,000 illnesses when the chemical melamine was fraudulently added to milk products to boost dairy profits. Similar food safety incidents concerning "gutter oil" in 2010 and 2014 and the Huangpu pork scandal of 2013, illustrate rising concern for health and wellbeing, rising "voice" of the people and rising pressure, brought through digital media, for transparency and accountability from governments.

INTERDEPENDENCY

Many of the issues discussed in this report are highly interdependent. It is tempting but unhelpful to treat each issue independently and assume the outcome is the sum of the parts. For example, food quality concerns are interlinked with supply chain sustainability issues. A "systems" approach is needed to understand this interdependency; disruptions and shocks influence multiple parts of a system. Each country is affected by both local, grassroots issues and major macroeconomic

²⁰ IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf

²¹ Watson, C. S., White, N. J., Church, J. A., King, M. A., Burgette, R. J., & Legresy, B. (2015). Unabated global mean sea-level rise over the satellite altimeter era. *Nature Clim. Change*, 5(6), 565-568. doi:10.1038/nclimate2635

developments. Chief amongst these is the need to adapt to climate change, which impacts food, water, energy, transport, land use, security and health.

CLIMATE ADAPTATION

Climate change adaptation refers to actions taken in response to the changing climate, for instance altering building codes and standards to increase resilience in areas where extreme weather events are projected to increase. This is distinct from climate change mitigation, which seeks to reduce greenhouse gas emissions that are known to contribute to climate change, such as transitioning away from fossil fuels to renewable energy. Adaptation actions must be local as the impacts of climate change vary from region to region due to the local climate topography, coastal proximity to rising sea level and the built environment.

There is also a confluence of climate adaptation and mitigation where actions to reduce risk exposure to climate hazards simultaneously reduces emissions. For instance, distributed renewable energy systems are both resilient in the face of extreme climate events whilst at the same time generating zero-emission energy. Conversely, climate change impacts are already apparent and affecting renewable generation opportunities. For example, in China, rising temperatures may be causing erratic rainfall patterns, straining the Three Gorges Dam and causing both longer droughts in dry seasons and more intense floods in wet seasons.

Of note for this analysis is the fact that cities are in many cases taking the lead in adaptation. The C40 Cities Climate Leadership Group comprises more than eighty of the world's great cities. Just as the Roadmap has recorded that urbanisation is a key driver and indicator of economic activity, cities are proving to be central in the response to climate change. Large cities consume two thirds of the world's energy and generate over 70 per cent of global greenhouse gas emissions.²² City-level action is a sensible policy response. City-to-city international cooperation is an innovation trend that is likely to persist and expand in the future, affecting the Asian region.

Within the region of focus for the Copper Roadmap 2030, there are many cities which are members of the C40 network and therefore committed to climate change mitigation and adaptation.

- China: Beijing, Guangzhou, Hong Kong, Nanjing, Shenzhen, Wuhan
- Republic of Korea: Seoul, Changwon
- Japan: Tokyo, Yokohama
- India: Bengaluru, Delhi NCT, Jaipur, Kolkata, Mumbai

- Bangladesh: Dhaka
- Vietnam: Hanoi, Ho Chi Minh City
- Indonesia: Jakarta
- Philippines: Quezon City
- Singapore
- Thailand: Bangkok
- Australia: Sydney, Melbourne
- New Zealand: Auckland

The most significant implications for copper demand from adaptation policies and actions occur where increased resilience is designed and built into local energy systems. Whether this is due to increased network capacity and redundancy or due to the establishment of local renewable energy generation, storage and distribution, such investment decisions will require significant electrical equipment entailing significant copper opportunities.

NATIONAL AND REGIONAL INSIGHTS AND OVERVIEWS

During our interviews with the experts listed in the acknowledgements, our independent research of literature and our follow-on reviews from sources suggested by the experts, a number of insights were revealed. These insights on national and regional issues are collated for each of our countries of interest. Some are based on anecdotes and intuition, but given the strong intellect of the experts consulted, these insights may include wisdom that has not yet broken through to mainstream thinking.

China

The University of Sydney's Professor Hans Hendrichske, an expert in Chinese business and management, warns that it is a mistake to think of China as a single, uniform entity. China is composed of 34 provinces and regions with significant geographic, economic and social diversity. One must be wary of "one rule fits all" conclusions. Likewise, a number of our experts suggested that China's primary focus is on domestic, rather than regional or global issues.

The University of Sydney's Professor Tihomir Ancev, who is expert in environmental and resource economics, notes that China's recent "neck-breaking growth, sustained for such a long period, cannot be sustained without damage to the environment." He suggests, though, that reasonable rates of growth can still be maintained by developing with cleaner technologies. Indeed there are signs that this is underway, as discussed in later sections. Ancev notes that many countries in the past, for example the UK, have successfully transitioned from a high-pollution industrial economy to a much cleaner economy. UTS Business School Dean Roy

²² C40 Cities (2016), Ending Climate Change ends in the city, C40.org, <http://www.c40.org/ending-climate-change-begins-in-the-city>



Green spoke of Taiwan's example as a reasonable indication of future Chinese economic development. Low-cost production is no longer performed in Taiwan, and the island now aims instead to be a nimble "brains trust", moving fast up the value chain.

There is significant social change occurring in China. Travers McLeod, CEO of the Centre for Policy Development, notes the ageing trend discussed earlier and also advises that urbanisation and upward class mobility will reshape the domestic economy. Various experts noted the economic implications of 100 million or more people moving from rural to urban areas by 2020. As discussed previously, civil society groups are becoming active, and there is evidence of a growing sustainability awareness. University of Sydney law researcher Penelope Crossley cites, for example, recent instances of people resisting hydroelectric projects which would impact biodiversity.

Despite the recent relaxation of the one child policy, many think that the cost and difficulty of child-rearing are likely to deter many eligible couples from having two children, thus the policy change is not expected to create a quick reversal to the ageing trend. The proportion of working-age people (16 to 59 years old) declined from a peak of 74.5 per cent in 2010 to 66 per cent in 2014.²³ China seeks to avoid the "middle-income trap", or income inequality, which has affected many developing economies, by raising the

average per capita income to \$12,000 a year, double the 2010 level.

Climateworks's Amandine Denis emphasised the global importance of Chinese innovation. China already dominates the world market in many sectors including some of those of interest here or will dominate by 2030. The Chinese approach is a big lever when forecasting regional or global future outcomes. Straight-line projections based on today's practices are unlikely to be accurate, thus it is necessary to account for productivity improvements, for example lower resource use, dematerialisation, material changes, energy efficiency, etc.

Many noted China's acceptance of the need to act to mitigate climate change and simultaneously to succeed economically by doing so. Crossley considers that China aspires to be seen as a world leader on climate action. The ICA's Hal Stillman believes China holds the ambition of creating an ecological civilisation by minimising human ecological disturbance while growing economically and improving standards of living. Furthermore, China will export clean technology required by the rest of world.

India

Experts consistently advised us that India's development path will be a critically important factor. India has a number of ambitious goals on economic and social

²³ Moody, A. (6 November, 2015). There's a serious side to the shi-san-wu. China Daily. http://europe.chinadaily.com.cn/epaper/2015-11/06/content_22383710.htm

development. Many interviewees mentioned the “Affordable Housing for All by 2022” policy of the Indian Government. Professor Ancev noted the accompanying “intense electrification challenge” to provide reliable electricity supply to 300 million people with no power today. Another related policy is the Indian Government’s announced 100 Smart Cities Mission. These policies and ambitions are discussed in detail in later sections.

The GDP data presented above shows India as the fastest-growing of the countries of interest with a sustained growth rate of 7.5% on a massive base. The government aims for over 7% growth, though Tim Buckley of IEEFA suggests 7% is a reasonable assumption given high inflation (recently down from 10% to 5%) and interest rates (13% recently). Bureaucracy has historically slowed progress in India, and some interviewees discussed slow approvals of projects, but other experts were more bullish on the country’s ability to deliver in the current environment with strong leadership from the Prime Minister and Council of Ministers.

Japan

As can be seen from the previous data, Japan has the slowest growth of the countries of interest with the most severe population ageing. Yet it is a large, highly-advanced economy with high standards of living. Japan is undertaking an energy transition following the 2011 Fukushima nuclear accident. Already the most energy-efficient economy in the world²⁴, the nation provides interesting lessons and examples of what has been achieved in the Asian region.

Korea

Population growth was feared in Korea in the 1950s, but has since slowed to one of the lowest birth rates in the world. There are now concerns about how to pay for the rapidly ageing population. Professor Ki-Sung Kwak, Head of the Korean Studies Department at the University of Sydney, described Korea’s ageing population and said the government’s attempts to lift the birth rate are failing. He says that young people are increasingly delaying marriage. Immigration is growing with approximately one million immigrants in the total population of around 43 million, but even so Korea is forecasted to have one of the fastest-ageing populations in Asia. Professor John Daley, CEO of the Grattan Institute, also noted this trend and Korea’s low population growth rate.

Professor Kwak believes government policy is too focused on the single corporate model of the chaebol,

the Korean conglomerate business model. UTS Business School’s Professor Roy Green said the chaebol model has been successful, but may now be past its usefulness, due to lack of agility in many cases and noting in particular the adversarial approach to industrial relations. Unemployment is high, many jobseekers are overqualified for the available positions and a social safety nets are inadequate, leading to serious future economic issues. Professor Green says Korea is nimble and innovative, though it appears that the population may not have fully shared in the country’s economic success. Professor Kwak expects that situation to worsen by 2030 unless there is major reform.

Indonesia

Indonesia’s population of around 257 million dispersed on over 900 permanently inhabited islands is expected to grow almost 15% by 2030. The nation currently has 11% poverty and is aiming to reduce that to less than 4% by 2025.²⁵ The data above suggests that sustained economic growth of over 5% will make Indonesia the largest economy in ASEAN by 2030, also overtaking South Korea and Australia to be the fourth-largest among the countries of interest. A growing middle class and a goal to electrify all households by 2025²⁶ mean a significant increase in copper products demand. Global Infrastructure Hub CEO Chris Heathcote expects significant new infrastructure to be built, much of it via public-private partnerships (PPP), though, as is the case elsewhere in the region, governance and transparency can be obstacles to a PPP project structure.

Other ASEAN Countries

China’s influence is strongly felt in its neighbouring ASEAN countries, so outcomes in China will affect Southeast Asia as well, including in new infrastructure delivery. Some interviewees highlighted the key role of Chinese capital, particularly the new Asian Infrastructure Investment Bank, in developing infrastructure in the region. Professor Green suggested that attracting other foreign direct investment (FDI) will be important for many ASEAN countries and suggested some countries will follow the lead of Singapore in FDI strategies.

Australia

Australia’s population is small but its economy is relatively large in the context of the region to date. Trends beginning in the Australian market may be early indications of trends which will later affect the rest of the region. Australia has traditionally been treated as a regional pilot market by global businesses headquartered in Europe or the US. The rapid decentralisation of energy generation currently occurring in Australia has spurred the recent launch

²⁴ Vivoda, Vlado. “Japan’s energy security predicament post-Fukushima.” *Energy Policy* 46 (2012): 135-143.

²⁵ *Intended Nationally Determined Contribution - Republic of Indonesia*. (Sep, 2015), <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

²⁶ Uco W.R. Siagian, R. G. D., Iwan Hendrawan, Rizaldi Boer, Gito Emmanuel Gintings. (Sep, 2014). *Pathways to deep decarbonization - 2014 report; Indonesia chapter*, http://unsdsn.org/wp-content/uploads/2014/09/DDPP_2014_report_Indonesia_chapter.pdf

4. Economic & Demographic Drivers *continued*

of a number of residential battery storage products and services.

Australia has a more favourable demographic profile than most of Asia according to John Daley. Noting that 27% of Australians are immigrants, Daley says that no other country other than Israel has consistently attracted immigration rates as high as Australia. As noted above, Australia's median age is growing much more slowly than the other countries of interest.

Regional dynamics

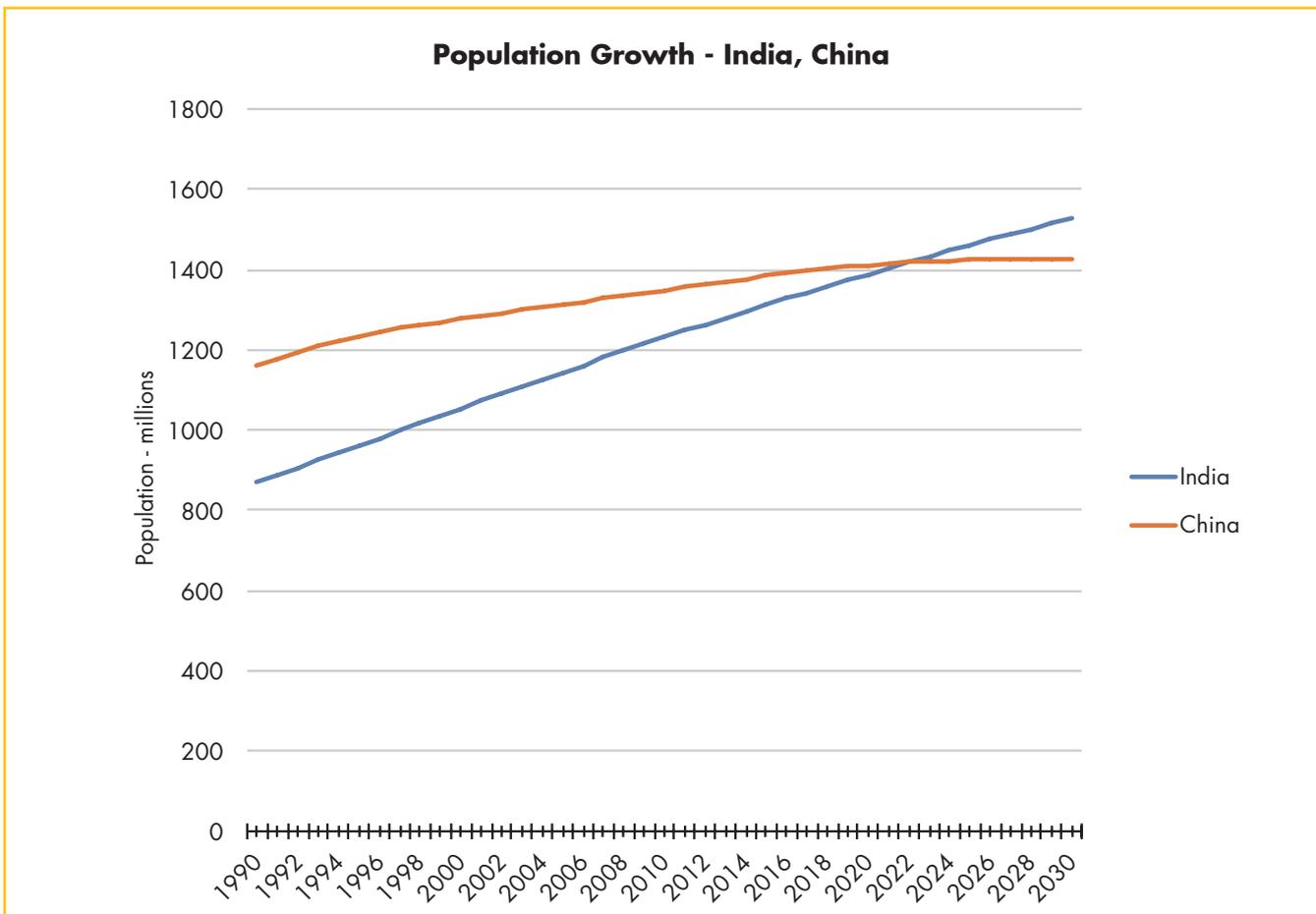
Diplomatic and trade relationships among the subject Asian nations are important to the analysis. Several new multilateral and bilateral trade agreements will influence regional trade, though Travers McLeod suggests these will be less relevant by 2030, replaced by raising standards for the compliance and certification

of products and services. McLeod expects a race to top on sustainability where manufacturers compete not only on lowest cost but also on lowest impact.

Several bilateral relations are important. Some experts mentioned that Korea-China relationships were warming while China's relations with North Korea worsen. China has investment plans for the Rason Special Economic Zone in North Korea which include a power line from China to ease acute electricity shortages there. Led by China's Commerce Ministry and Chinese firms, progress has been slower than hoped, and construction of the power line has not yet started. There are indications that South Korea may collaborate with China on a similar project. In the South China Sea, the Diaoyu Islands controversy involves a territorial dispute over petroleum rich islands and shallow waters among China, Taiwan and Japan.

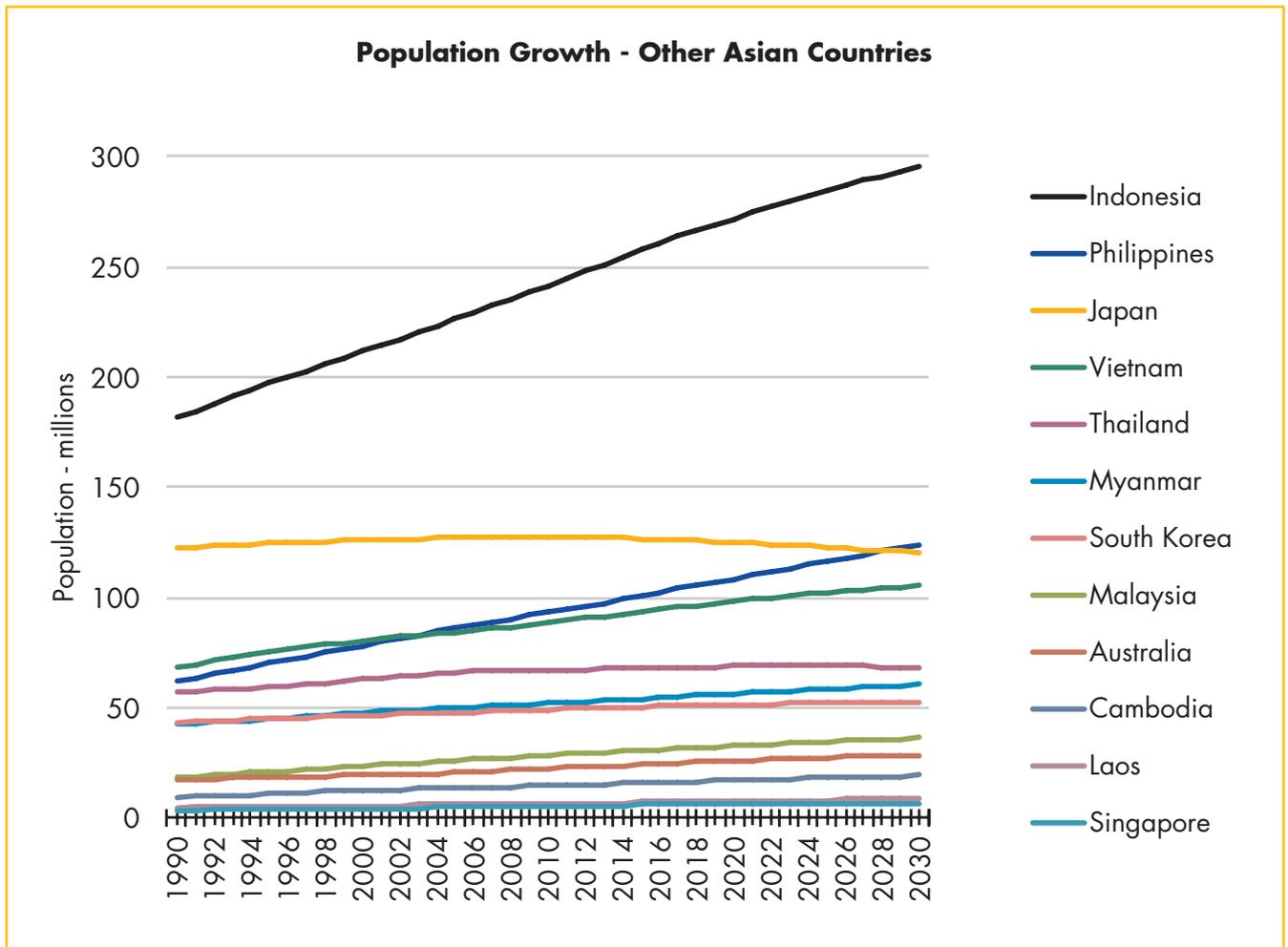
POPULATION GROWTH

Population growth in the Asia region is not uniform. United Nations forecasts²⁷ for population according to a medium growth scenario are shown in the graphs below for the key markets of China, India and the other countries in the Asian region.



Source: United Nations, Department of Economic and Social Affairs, Population Division (2015)

²⁷ United Nations, Department of Economic and Social Affairs, Population Division (2015). World Population Prospects: The 2015 Revision, DVD Edition. <http://esa.un.org/unpd/wpp/>



Source: United Nations, Department of Economic and Social Affairs, Population Division (2015)

The data shows that the East Asian nations (China, Japan, and Korea) are generally experiencing declining population growth and ageing populations. Japan's population is expected actually to decline, and Korea's population is expected to remain near today's level over the period to 2030. India and the ASEAN nations (Indonesia, Vietnam, Philippines, etc.) are generally growing in population with the fastest rates in India followed by Indonesia and the Philippines.

China's One Child Policy was relaxed in 2015 after 35 years as the nation's official population control and family planning rule. The policy is said to have prevented 400 million births, especially in urban centres.²⁸ The long-lasting effects of the policy are that

the overall population in China is ageing and that there is a labour shortage in some areas, and as observed in the previous section, the working age segment has declined from a peak of 75 per cent in 2010 to 66 per cent in 2014.²⁹ Although the change in policy permits an additional 90 million couples to have a second child, analysts do not forecast a turnaround in birth rates. Mu Guangzong, a Peking University demographics professor, predicts that the economic cost of having a second child is prohibitive for many and that most families will continue to maintain single child status as a cultural norm.³⁰ As shown in the chart above, continued low fertility rates should cause China's population to flatten and peak between 2025 and 2030 at just over 1.4 billion.

²⁸ Prospect Journal (2015), Too Little, Too Late: China's Future without the One Child Policy, Prospect Journal of international Affairs, November 13 2015, <http://prospectjournal.org/2015/11/13/too-little-too-late-chinas-future-without-the-one-child-policy/>

²⁹ Moody, A. (2015). There's a serious side to the shi-san-wu. China Daily, 6 November 2015, http://europe.chinadaily.com.cn/epaper/2015-11/06/content_22383710.htm

³⁰ Buckley, Chris. (2015) China ends One Child Policy Allowing Families Two Children http://www.nytimes.com/2015/10/30/world/asia/china-end-one-child-policy.html?_r=0

4. Economic & Demographic Drivers *continued*



Japan's Ministry of Health, Labor and Welfare reports flat population of about 125 million for the past 20 years and predicts significant rise in median age and a declining population.³¹

In Korea, population growth was feared in the 1950s but birth rates have slowed and are now at their lowest levels since official statistics have been recorded. The Korean birth rate is among the lowest in the world. The population is ageing at a pace unprecedented in human history, leading to concerns about how to fund this ageing population.³² While the causes are different from China, the trends across the three East Asian countries are similar.

Currently, the second most populous country behind China, India's population will continue to grow from 1.25 billion. Although birth rates are declining, infant mortality rates are falling even faster. The UN projects growth to over 1.5 billion by 2030 with continued growth for some decades thereafter, peaking at around 1.75 billion in the 2060s.

Indonesia has a population of 258 million and a growth rate of 1.28%.

Summary statistics

Population estimates and growth from various in-country and international sources may conflict, but the table below shows estimates from the United Nations Department of Economic and Social Affairs.³³

World rank	Country	Population (July 2015 est.)	Popn growth rate	Median age
1	China	1,376,049,000	0.52%	37.0
2	India	1,311,051,000	1.26%	26.6
5	Indonesia	257,564,000	1.28%	28.4
7	Pakistan	188,925,000	2.11%	22.5
9	Bangladesh	160,996,000	1.20%	25.6
11	Japan	126,573,000	-0.12%	46.5
13	Philippines	100,699,000	1.58%	24.2
15	Vietnam	93,448,000	1.12%	30.4
21	Thailand	67,959,000	0.38%	38.0
25	Myanmar	30,331,000	0.82%	27.9
28	Korea, South	50,293,000	0.48%	40.6
42	Nepal	28,514,000	1.18%	23.1
43	Malaysia	30,331,000	0.82%	28.5
51	Korea, North	25,155,000	0.53%	33.9
56	Australia	23,969,000	1.57%	37.5
57	Sri Lanka	20,715,000	0.50%	32.3

Note: Pakistan is outside the study scope

³¹ Desvaux et al, (2015). *The Future of Japan: reigniting productivity and growth*, McKinsey, http://www.mckinsey.com/~media/mckinsey%20offices/japan/pdf/future_of_japan_full_report_march_2015.ashx

³² The Wall Street Journal (2014), South Korea Birth-rate hits Lowest on Record, [blogs.wsj.com](http://blogs.wsj.com/korearealtime/2014/08/26/south-korea-birthrate-hits-lowest-on-record/), 26 August 2015, <http://blogs.wsj.com/korearealtime/2014/08/26/south-korea-birthrate-hits-lowest-on-record/>

³³ United Nations, Department of Economic and Social Affairs, Population Division (2015). *World Population Prospects: The 2015 Revision*, DVD Edition. CIA World Book data (06 Jan 2016, <http://esa.un.org/unpd/wpp/>.)

URBANISATION

WHAT IS URBANISATION?

The term urbanisation describes the population movement from rural settlements with low population density to large urban settlements with high population density. This population shift reflects the transition from predominantly agricultural economic activity to industrial and service-based economies. Urbanisation is an important indicator of economic development and therefore important to the analysis in the Copper Roadmap 2030 as it is a significant driver of demand for the consumption of goods and services.

When discussing urbanisation, it is important to distinguish between the *level* and the *rate* of urbanisation. The *level* of a nation's urbanisation refers to the percentage of the population living in urban settlements and is strongly linked to national income, while the *rate* of urbanisation, that is the rate at which the population is shifting from a rural to an urban setting, is not strongly linked to national income. An increase in automation of agriculture is also a driver of urbanisation, unless labour costs are very low, in which case investment in plant and equipment is less appealing.

Accompanying urbanisation is the phenomenon of centralisation. Centralisation is the concentration of populations in major cities. Centralisation is driven by the inevitable increase in services available when cities reach a critical mass. However, centralisation continues beyond the point of optimal capacity, as determined by infrastructure such as energy, water, housing, transport capacity and ecosystem services (water, air, biodiversity).

WHY DOES URBANISATION MATTER?

As observed by The Department of Economic and Social Affairs of the United Nations Secretariat³⁴, the level of urbanisation is observed to increase across groups of countries classified by the level of income. High income countries in 2014 display a level of urbanisation well over twice that in low income countries (80 per cent compared to 30 per cent). The UN Report into Urbanization (2014 Update) described the association between national income and the process of urbanisation as complex, noting that the causal relationship between the two is likely bidirectional and that effective planning and policies are needed to optimise urbanisation and economic development.

HOW DOES THE LEVEL OF URBANISATION IMPACT DEMAND FOR COPPER?

The link between the level of urbanisation and economic activity and consumption is well recognised. The International Association of Public Transport (UITP, France) states that, "Growing urbanisation leads to an increasing demand for transport, which requires a corresponding increase in mass transit supply in order to absorb it".³⁵ Urbanisation drives private spending and public investment, both of which require energy and materials.

According to the Reserve Bank of Australia, urban areas in China and India have fewer occupants per household and more floor space per capita than rural areas³⁶. Therefore the migration of people from rural to urban areas will drive demand for urban housing that is more copper intensive.



Busy Jodhpur

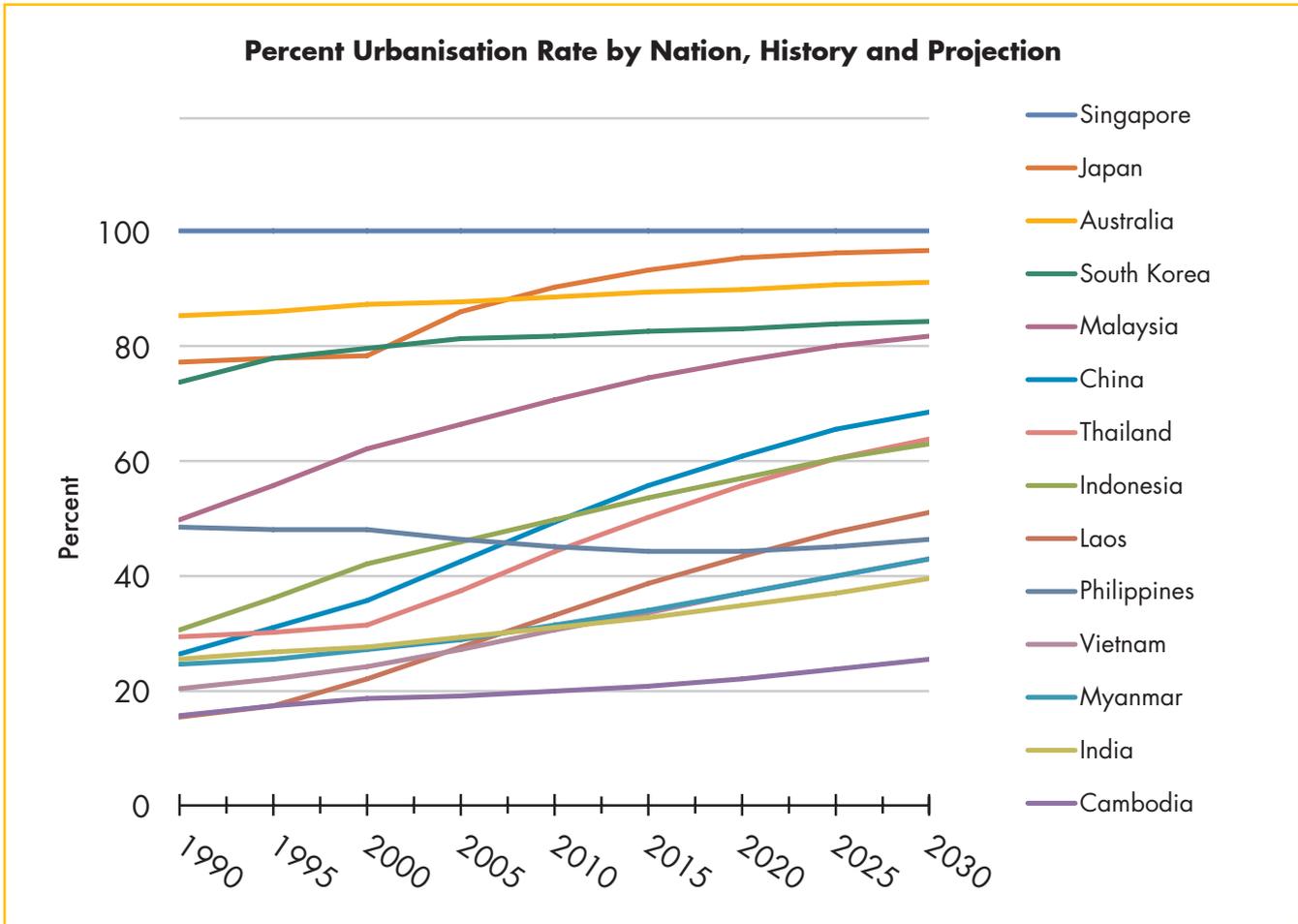
³⁴ "World Urbanization Prospects: The 2014 Revision, Highlights" (ST/ESA/SER.A/352) from <http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf>.

³⁵ *Public transport trends*. (2015). UITP, http://www.uitp.org/sites/default/files/cck-focus-papers-files/UITP_Trends_Exec_summary_12p.pdf

³⁶ D'Arcy, P. and A. Veroude (2014). "Housing Trends in China and India." RBA Bulletin 20. <http://www.rba.gov.au/publications/bulletin/2014/mar/pdf/bu-0314-7.pdf>

REGIONAL BREAKDOWN: KEY COUNTRIES

Country urbanisation data



Source: UN population projections³⁷

Urbanisation in Asia continues to increase following a steady rise since the middle of the 20th century, which saw the median level of urbanisation across the 51 countries of Asia (as defined by the UN) in 1950 grow from only 27 per cent to 57 per cent by 2014.

In 2014, seventeen countries in Asia were more than 75 per cent urban, including several of the region’s most populous countries, such as Japan (93 per cent urban) and the Republic of Korea (82 per cent urban). This trend of urbanisation is expected to continue with the United Nation projections indicating that by 2050 half of Asia’s countries will have levels of urbanisation greater than 72 per cent and 45 of the 51 countries (88 per cent) will be more than 50 per cent urban.³⁸

China

China’s population has grown to 1.4 billion people in 2014, 54 per cent of whom resided in urban settlements, and the shift to urban settlements continues. This is predicted to increase to a level of 60 per cent by 2020, which will involve an estimated 100 million people migrating to urban areas, an average of more than 13 million per annum. According to Yin and Chen³⁹ “there is strong empirical evidence that urbanization is correlated to GDP, and the urbanization level will increase as per capita GDP increases.” They go on to say that, “we assume the urbanization rate to be a function of per capita GDP”. So ongoing growth in the economy will result in continued urbanisation.

³⁷ United Nations, Department of Economic and Social Affairs, Population Division (2015). World Population Prospects: The 2015 Revision, DVD Edition. <http://esa.un.org/unpd/wpp/>

³⁸ United Nations, Department of Economic and Social Affairs, Population Division (2015). World Population Prospects: The 2015 Revision, DVD Edition. <http://esa.un.org/unpd/wpp/>

³⁹ “World Urbanization Prospects: The 2014 Revision, Highlights” (ST/ESA/SER.A/352) from <http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf>.

India

According to the United Nations, India is projected to “nearly double the size of its urban population between 2014 and 2050.”⁴⁰ The population of India has more than tripled since 1950 to nearly 1.3 billion, and the level of urbanization nearly doubled, reaching 32 per cent in 2014. Considering that approximately 300 million of the current population do not have access to affordable electricity, the pressure to deliver reliable electricity (and water and sewer) to the increasing urban population will be profound. In 2015, in response to the poor level of housing, the Indian Government has developed the ‘Affordable Housing for All by 2022’ policy.⁴¹ This will bring a further driver to urbanization, infrastructure and support services.

Japan

Unlike most Asian countries covered in this study, Japan is already considered highly developed and with a stable high level of urbanisation. Indeed, Japan is predicted to contract in terms of population. “In Japan, the urban population is projected to shrink by 12 million (10 per cent) between 2014 and 2050.” Yet over the same period, the UN projects that “in proportional terms, Japan is projected to have the largest rural population loss: the rural population in 2050 will be 71 per cent smaller than in 2014”.

Korea

Korea is one of the world’s most densely populated countries. By 2023, population density will reach 530 people per square kilometre. The population is expected to stabilize at around 52.6 million in the same year. Korea’s level of urbanisation is over 78 per cent. Most of this urban increase has been attributed to migration rather than to natural growth of the urban population.

Indonesia

Indonesia surpassed the 50 per cent level of urbanisation and, as of 2014 53 per cent of its 253 million inhabitants resided in urban settlements.



Severe air pollution in Beijing, China

⁴⁰ United Nations, Department of Economic and Social Affairs, Population Division (2015). World Population Prospects: The 2015 Revision, DVD Edition p56. <http://esa.un.org/unpd/wpp/>

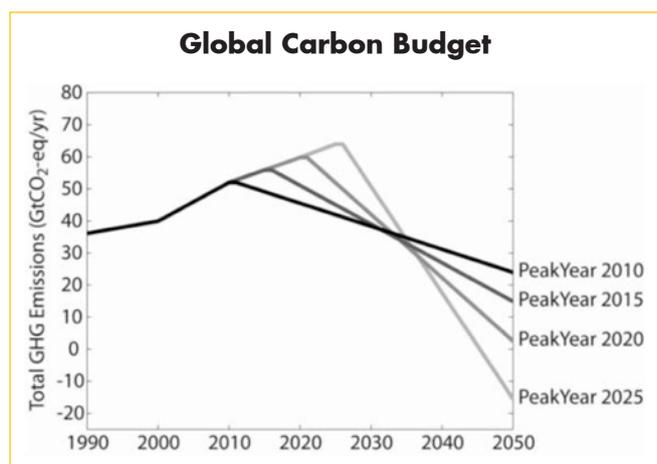
⁴¹ Government of India (2015) “Housing for All by 2022” Mission - National Mission for Urban Housing, Press Information Bureau, Government of India, 17 June 2015, <http://pib.nic.in/newsite/PrintRelease.aspx?relid=122576>

5

DECARBONISATION

DRIVERS OF DECARBONISATION

The need for economies to decarbonise is clear, though international agreement on the levels of carbon dioxide reduction needed from each country has been difficult and slow. With global agreement in 2011 on the need to restrict climate change to less than a 2 degrees Celsius increase in global temperature from pre-industrial times⁴² a global carbon budget is implied. For a 75% chance of avoiding 2°C warming, the global budget to 2050 is approximately 1500 billion tonnes of CO₂-e equivalents.⁴³ Various trajectories are possible to achieve this budget (see chart right), but earlier action is probably cheaper and more feasible than late adjustments.



Source: The Climate Institute; Operating in Limits: Defining an Australian Carbon Budget. March 2013. Used with permission.

⁴² UNFCCC (2014). "Durban: Towards full implementation of the UN Climate Change Convention." from http://unfccc.int/key_steps/durban_outcomes/items/6825.php.

⁴³ Jackson, E. (2013). "Operating in Limits: Defining an Australian Carbon Budget." from <http://www.climateinstitute.org.au/articles/publications/operating-in-limits.html>.

Current international climate negotiations are aimed at a fair allocation of that carbon budget among nations. On December 12, 2015, international negotiators representing 195 countries adopted the Paris Agreement to counteract climate change. The Paris Agreement paves a way for the decarbonisation process. Below is an indication of the position of the main countries of interest as expressed prior to the Paris conference and during the conference.

There are subtle differences in the pre- and post-conference positions. Coming into the conference the US and China had signalled strong commitments to GHG reductions. A key question was how much decarbonisation could be agreed for the Indian economy and similar poor, but rising, economies (Indonesia, Africa, etc). Perhaps the Paris Conference was especially focused on the question of what relative priority would be given to economic development and rise in standards of living for poorer economies versus the need for clean power generation. Indeed, a key negotiating uncertainty was how much the US and Europe would subsidise decarbonisation of India, Indonesia and other developing countries.

The pre-conference Intended Nationally-Determined Contributions (INDCs) indicate emissions reduction plans for 182 countries. Under the Paris Agreement these plans will become binding commitments. Emissions reduction progress will be reviewed in 2019, and then a global stocktake will be made in 2023 and every five years thereafter. The INDC commitments made so far are, in aggregate, far short of the collective action required to avoid dangerous climate change, so action must be increased considerably before 2030. The Paris process means deep decarbonisation pathways will be progressively developed for every country.

Aside from climate change, there are other significant drivers to reduce fossil fuel electricity generation. Air pollution diseases are scientifically linked to billions of dollars in health care costs especially related to coal combustion. Thermal power generation (coal, gas and nuclear) uses vast quantities of water. Much of developing Asia is experiencing water scarcity with many major river basins drought stressed. There is a concern about the impacts of continuing to grow thermal generation in these areas.⁴⁴ Harvard Business Review discusses the water-energy nexus noting that “water and energy are typically not priced to reflect their true scarcity, value or costs” and that “coordination and investment across energy and water infrastructure is

often lacking.”⁴⁵ Economists, engineers and governments are increasingly aware that integrated and holistic approaches to planning will be required for new energy projects to recognise social and environmental costs previously overlooked as externalities.

NATIONAL DECARBONISATION COMMITMENTS AND TARGETS

Most of the initial 2030 commitments (Intended Nationally-Determined Contributions) from the countries of interest exceed the carbon budget implied by the need to avoid dangerous climate change. It is therefore expected that the commitments must be progressively increased over time under the Paris process. China and India are the countries which can most influence the achievement of global climate change mitigation goals, and there is evidence to indicate they can over-achieve emissions reduction compared to the conservative 2015 INDCs. Indeed, Tim Buckley of The Institute for Energy Economics and Financial Analysis (IEEFA) suggested these two countries will lead the world in decarbonisation.

Five of the subject countries released an initial decarbonisation report late in 2015 as part of the Deep Decarbonisation Pathways Project of the UN Sustainable Development Solutions Network.⁴⁶ These reports each describe a national plan for deep decarbonisation by 2050 in line with the carbon budget implied by the need to avoid dangerous climate change and are summarised below. The thinking underpinning the DDPP plans in some cases is transformative, but in other cases the plans were an extension of current business as usual. Regardless of today’s targets and aspirations, we believe decarbonisation ambition will increase now that the Paris Agreement is completed and that nations will progressively commit to further actions to deliver a carbon budget performance consistent with no more than 2 degrees warming or possibly 1.5 degrees. It is recognised however that present post Paris optimism is exposed to complex global political forces. Global coordination depends on strong four-way cooperation among the EU, the USA, India and China. As of 2016 the EU is presently undergoing long term economic correction with significant migration challenges and continuous threats of Greek or British exit from the Union.

⁴⁴ Dubey, Sunita S. C. a. S. K. (October 2014). “Electricity for all in India” from

<http://www.vasudha-foundation.org/wp-content/uploads/Electricity-for-all-in-India-Why-Coal-is-not-always-king1.pdf>.

⁴⁵ Kevin Moss, D. F. (JANUARY 25, 2016). “Solving the Twin Crises of Energy and Water Scarcity.” Harvard Business Review. <https://hbr.org/2016/01/why-energy-and-water-scarcity-are-connected-challenges>

⁴⁶ Deep Decarbonisation Pathway Project (2015, Deep Decarbonisation – Countries, [deepdecarbonation.org](http://deepdecarbonization.org/countries/) <http://deepdecarbonization.org/countries/>)

5. Decarbonisation continued

President Obama's Clean Power Plan is under attack in the US Supreme Court, and the 2016 US Presidential election could result in reversal of US participation and leadership of the Paris process in much the same way that Kyoto was undermined by US domestic political changes. Given the extreme air pollution of challenges

facing Chinese and Indian we believe domestic political support in these two countries is durable. But financing India's transition to clean energy is certainly reliant on US and EU contribution. Political forces outside the Asian region may change transition within the region.

COUNTRY SUMMARIES

India

STATEMENTS AT COP21:

- Prime Minister Narendra Modi said developing countries are seeking ways to enjoy economic growth while protecting the Earth. Modi said that by 2030, India will reduce its greenhouse gas emissions by 33-35 percent from 2005 levels. He cited various means of attaining this goal, such as removing subsidies for fossil fuels, transforming cities and improving public transportation. Modi said, "Solar technology is evolving, costs are coming down, and grid connectivity is improving. The dream of universal access to clean energy is becoming more real. This will be the foundation of the new economy of the new century."⁴⁷

TARGETS:

- India has announced a target to achieve 40% renewables by capacity before 2030 (26-30% by generation) with a 33-35% reduction in emissions intensity.⁴⁸
- This target translates to 350GW of renewable capacity which is likely to mean 250GW of solar PV and 100GW wind power in 2030.⁴⁹
- India is aiming for 175GW of renewable energy installations by 2022, up from 36GW today. This is a tenfold increase in solar installation capacity to 100GW by 2022, trebling to 60GW of new wind farms, 10GW of biomass and 5GW of small scale, run-of-river hydroelectric power. These initiatives require an investment of over US\$200bn with new national legislative support currently proposed under the National Renewable Energy Act.⁵⁰
- If the challenging domestic 2022 renewable target is met, the 2030 fossil fuel-free target is likely to be exceeded.

- In September 2015, Energy Minister Goyal expressed aspirations for India to become the largest clean energy market in the next 10 years.⁵¹

DEEP DECARBONISATION PLAN HIGHLIGHTS:⁵²

- The plan concludes that deep decarbonisation by 2050 is feasible using known technologies and resources. Electricity is the sector key to decarbonisation. Vision and early action are vital.
- Regional cooperation is needed, but it is important to establish a domestic low-carbon industry.
- The Plan expressed 2050 annual carbon emissions of 2108Mt CO₂-e compared to 2010 emissions of 1497Mt and business as usual (BAU) 2050 estimate of 3157Mt. Emissions per capita in 2050 in the Sustainable scenario rise to 1.4t from a low 2010 level of 1.24t.
- The single largest contributor to Indian emissions is coal, and significant deployment of carbon capture and storage (CCS) will be needed to reach the forecast scenario.
- The high renewable electricity content needed would require mitigating risks associated with the stability of the transmission grid.
- In transport, a shift from oil to gas, electricity and biofuels is needed.
- In residential and commercial buildings there is a reduction in emissions intensity forecast, but an overall increase in energy use.
- The plan would also deliver favourable impacts on air quality and energy security as well as carbon emissions reductions.

⁴⁷ Puri, Ratul. (2016) story of Indian solar sector - matter of time & not whether, [economicstimes.indiatimes.com, http://articles.economicstimes.indiatimes.com/2016-01-13/news/69735441_1_energy-consumption-indian-government-renewable-energy](http://articles.economicstimes.indiatimes.com/2016-01-13/news/69735441_1_energy-consumption-indian-government-renewable-energy)

⁴⁸ India's intended nationally determined contribution: working towards climate justice. (Oct, 2015). <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

⁴⁹ Sethi, N. (22 Sep, 2015). India's energy mix to have 40% renewable sources by 2030. *Business Standard*. http://www.business-standard.com/article/economy-policy/india-s-energy-mix-to-have-40-renewable-sources-by-2030-115092200057_1.html

⁵⁰ Buckley, T. (Aug, 2015). *India's Electricity-Sector Transformation*. <http://ieefa.org/wp-content/uploads/2015/08/IEEFA-Indian-Electricity-Sector-Transformation-August-2015.pdf>

⁵¹ The Economic Times (2015) Energy Minister Piyush Goyal urges US to invest in clean energy market in India, [economicstimes.indiatimes.com, http://articles.economicstimes.indiatimes.com/2015-09-21/news/66760829_1_renewable-energy-energy-development-welspun-energy](http://articles.economicstimes.indiatimes.com/2015-09-21/news/66760829_1_renewable-energy-energy-development-welspun-energy)

⁵² P.R. Shukla, S. D., Minal Pathak, Darshini Mahadevia, and Amit Garg. (Sep, 2015). *Pathways to deep decarbonization in India*, http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_IND.pdf



**Solar Energy Demonstration,
Sonsa Village, India.**
CC BY NC-ND-2.0

INITIAL NATIONALLY-DETERMINED CONTRIBUTION BY 2030 UNDER PARIS AGREEMENT⁵³ (HIGHLIGHTS):

- To put forward and further propagate a healthy and sustainable way of living based on traditions and values of conservation and moderation.
- To adopt a climate friendly and a cleaner path than the one followed so far by other nations at corresponding level of economic development.
- To reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from 2005 level.
- To achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030 with the help of transfer of technology and low cost international finance including from Green Climate Fund (GCF).
- To build capacities, create domestic framework and international architecture for quick diffusion of cutting edge climate technology in India and for joint collaborative research and development (R&D) for such future technologies.

China

STATEMENTS AT COP21:

- Summary by World Resources Institute's Jennifer Morgan⁵⁴: "President Xi showed his resolve to address climate change and reach a strong agreement with all countries taking action. His comments show that China is ready to step into a pivotal role in reaching common ground on key issues in Paris. Xi embraced China's role of the largest emerging economy to help developing countries to tackle climate change via South-South cooperation, providing financial, technological and capacity-building support." President Xi also said, "The Paris conference is not the finishing line, but a new starting point."

TARGETS:

- Experts interviewed estimated that China is aiming for 60% renewable energy by 2030 (30% without hydroelectricity). Xinhua quotes a senior government official as saying installation of solar PV alone will reach 150GW peak capacity by 2020.⁵⁵

⁵³ India's Intended Nationally Determined Contribution: Working Towards Climate Justice. (Oct, 2015). <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

⁵⁴ Xinhuanet (2015) Spotlight: China stands as constructive player in global fight against climate change, news.xinhuanet.com, http://news.xinhuanet.com/english/2015-12/11/c_134907291.htm

⁵⁵ China's PV power capacity to hit 150 gigawatts by 2020. (13 Oct, 2015). Xinhua, http://news.xinhuanet.com/english/2015-10/13/c_134710495.htm

5. Decarbonisation continued



EV taxi in China
(CCO 1.0)

- An April 2015 report from China's Energy Research Institute of the National Development and Reform Commission, "China 2050 High Renewable Energy Penetration Scenario and Roadmap Study"⁵⁶, forecasts fossil generation will be only 9% by 2050 to be replaced by 2700GW PV and 2400GW wind capacity installed. Their interim forecast for 2030 is 1100GW and 1050GW respectively. Given that China is already successfully diversifying away from thermal power generation far faster than expected, this ERI scenario has considerable credibility.
- The same source says that in 2050 renewables will be 62% of electricity generation and that energy efficiency is targeted to be 90% higher by 2050.
- Clean technologies such as wind, solar and EVs are intended to become the new economic growth and export engines, together representing 6.2% GDP and 12M jobs by 2050 (3.9% GDP by 2030).⁵⁷
- A low-carbon pathway is largely consistent with China's domestic interest and requires a strong policy response.
- Three main initiatives are discussed: replace coal burning with electricity in the industrial sector; penetration of electric cars; and carbon capture, utilisation and storage (CCUS).
- Gradual change in emphasis from emissions intensity to overall emissions.

INITIAL NATIONALLY-DETERMINED CONTRIBUTION BY 2030 UNDER PARIS AGREEMENT⁵⁹ (HIGHLIGHTS):

- To achieve peak carbon emissions around 2030 with best efforts to peak early.
- To reduce carbon emissions per unit of GDP by 60% to 65% from 2005 levels.
- To increase the share of non-fossil fuels in primary energy consumption to around 20%.

DEEP DECARBONISATION PLAN⁵⁸ HIGHLIGHTS:

- Action on climate change is no longer regarded as a cost but an opportunity to help deliver the social economic objectives of better growth, better environment and better energy infrastructure.

⁵⁶ Energy Research Institute, NDRC (Apr, 2015). *China 2050 High Renewable Energy Penetration Scenario and Roadmap Study*, <http://www.efchina.org/Reports-en/china-2050-high-renewable-energy-penetration-scenario-and-roadmap-study-en>

⁵⁷ WAN, L. (November 2015). *Overview of Renewable Energy in China Policy Strategy and Priority of New and Renewable Development*. Paper presented at the APEC NEW AND RENEWABLE ENERGY TECHNOLOGIES EXPERT GROUP, 45th Meeting. <http://www.egnret.ewg.apec.org/meetings/egnret45/economy%20presentation/%5BChina%5D%20APEC%20EGNRET%2045%20Meeting%20China%2020151116.pdf>

⁵⁸ Qiang Liu, Y. C., Chuan Tian, Xiaoqi Zheng, Fei TENG, Alun GU, Xi YANG, Xin WANG. (Sep, 2015). *Pathways to deep decarbonization in China*. http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_CHN.pdf

⁵⁹ Wei, S. (30 June, 2015). *Intended nationally determined contribution - Enhanced Actions on Climate Change*, <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

Indonesia

STATEMENTS AT COP21:

- President Joko Widodo⁶⁰ voiced his country's commitment to reduce emissions by 29 percent below business as usual by 2030 through measures such as:
 - Reallocating fuel subsidies
 - Increasing renewable energy sources to 23 percent of the national energy mix by 2025
 - Converting waste into energy
 - Establishing a moratorium on issuing permits for peat land use.

The President said, "The Paris agreement must reflect equity and fairness. It must be legally binding, long term, ambitious, and must not impede development in developing countries. All parties must contribute more in mitigation and adaptation efforts." Widodo also emphasised the importance of developed countries mobilising \$100 billion in climate finance by 2020, a number which should increase over the years.

TARGETS:

- From 2014 Deep Decarbonisation Report⁶¹: 63% of Indonesia's emissions are from land use change, peat fires and forest fires. Combustion of fossil fuels is 19%. Indonesia's Goal is 26% reduction by 2020 against the business-as-usual scenario (extrapolated from 2010 at 2000-2010 rate).
- Indonesia's mixed energy use policy specifies that at least 23% energy will come from new and renewable sources by 2025.⁶²

INITIAL NATIONALLY-DETERMINED CONTRIBUTION BY 2030 UNDER PARIS AGREEMENT⁶³ (HIGHLIGHTS):

- Unconditionally 29% against the business-as-usual scenario by 2030 which is a level of 2046Mt CO₂-e.
- Conditional on support from international cooperation (technology development and transfer, capacity building, payment for performance mechanisms, technical cooperation and access to financial resources): 41% reduction against BAU.

Japan

STATEMENTS AT COP21:

- Prime Minister Shinzo Abe said, "We'll achieve [the goal] without sacrificing economic growth. We'll further improve Japan's strength [in the battle against global warming] and keep playing a leading role in the international community." He said the agreement was "fair" and that Japan would implement it as a "top priority issue for the Cabinet."⁶⁴

TARGETS:

- Japan is already the most energy efficient economy in the world.⁶⁵
- Japan will reduce industrial GHG emissions by 3.8% below fiscal year 2005 levels by 2020 including use of forestry management credits.⁶⁶
- Renewables will provide 22-24% of electricity by 2030.⁶⁷

DEEP DECARBONISATION PLAN⁶⁸ HIGHLIGHTS:

- 80% decarbonisation goal by 2050 while reducing nuclear electricity generation.
- Two prongs: energy-efficient technologies and low-carbon technologies, including CCS (for coal but mainly for gas) and renewables.
- Three scenarios are proposed: one with little CCS, one with no nuclear and the third a mixed scenario.
- The main driver of 2050 emissions reductions is a halving of final energy demand, largely due to efficiency measures.
- Emission reductions of 84% are possible in all three scenarios, with fossil fuel consumption decreasing by 60% from 2010 levels in each.
- Renewables make up 49% of the total primary energy supply in the limited CCS scenario and 35% in the others.
- Electric vehicles in the transport sector and heat pumps in the buildings sector (water heaters and air conditioners) will play important roles in electrifying energy demand in Japan.

⁶⁰ Joko Widodo, H. E. (2015) Statement the President of the Republic of Indonesia, 21th Conference of the Parties to the UNFCCC Paris, France, 30 November 2015 https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/cop21_cmp11_leaders_event_indonesia.pdf

⁶¹ Ucook W.R. Siagian, R. G. D., Iwan Hendrawan, Rizaldi Boer, Gito Emmanuel Gintings. (Sep, 2014). *Pathways to deep decarbonization - 2014 report; Indonesia chapter*, http://unsdsn.org/wp-content/uploads/2014/09/DDPP_2014_report_Indonesia_chapter.pdf

⁶² *Intended Nationally Determined Contribution - Republic of Indonesia*. (Sep, 2015), <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

⁶³ ibid

⁶⁴ Japan Times (2015) Abe says Japan will not sacrifice growth as world agrees to combat climate change, [japantimes.co.jp](http://www.japantimes.co.jp/news/2015/12/13/national/abe-says-japan-will-not-sacrifice-growth-world-agrees-combat-climate-change/#.Vsaj3seO68U)

⁶⁵ Vivoda, Vlado. "Japan's energy security predicament post-Fukushima." *Energy Policy* 46 (2012): 135-143.

⁶⁶ <http://climateactiontracker.org/countries/japan.html>

⁶⁷ Dewit, A. (Oct, 2015). Japan's Bid to Become a World Leader in Renewable Energy, <http://www.globalresearch.ca/japans-bid-to-become-a-world-leader-in-renewable-energy/5480274>

⁶⁸ Kainuma, M., Toshihiko Masui, Ken Oshiro, Go Hibino (Sep, 2015). *Pathways to deep decarbonization in Japan*, http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_JPN.pdf

5. Decarbonisation continued

INITIAL NATIONALLY-DETERMINED CONTRIBUTION BY 2030 UNDER PARIS AGREEMENT⁶⁹ (HIGHLIGHTS):

- Reduction of 26.0% by fiscal year 2030 compared to financial year (FY) 2013 (25.4% reduction compared to FY 2005).

Korea

STATEMENTS AT COP21:

- President Park Geun-hye said Korea will spearhead a force to reduce carbon emissions and seeks to reduce its own emissions by 37 percent.⁷⁰ Korea unveiled its strategy to nurture new energy industries through an open consumer market.

TARGETS:

- Background: An emission trading scheme (ETS) was launched in 2015 covering 68% of national emissions.⁷¹
- 30% national GHG reduction from business-as-usual projection by 2020 (pledge to UNFCCC).⁷²

INITIAL NATIONALLY-DETERMINED CONTRIBUTION BY 2030 UNDER PARIS AGREEMENT⁷³ (HIGHLIGHTS):

- 37% reduction from business-as-usual projection by 2030 (850.6MtCO₂e).

Australia

Statements at COP21: Prime Minister Malcolm Turnbull emphasised Australia's support for a truly global climate agreement that will drive humanity's capacity for inventiveness and a new wave of technological advances.⁷⁴ "From Australia, we come with confidence and optimism ... We don't doubt the implications of the science or the scale of the challenge ... Above all we don't doubt the capacity of humanity to meet it. Impacts of global warming are already being felt and will

continue to be even when we reach a global net of zero emissions. Adaptation is equally important, and there too, innovation is key. Some of the most vulnerable nations are our Pacific neighbours, and we're helping them build resilience through practical action. Our agreement must provide common platform for action. Australia isn't daunted by the challenges ... We're confident with our collective leadership ... We will, in common cause, secure our future."

TARGETS:

- 2020 emissions 5% below 2000 levels (same as 13% below 2005); 15%-25% below 2000 levels by 2020 under different conditions of a global agreement that stabilizes GHG levels.⁷⁵
- 33,000GWh annual new renewable energy generation by 2020 (~23%).⁷⁶
- Developing national energy productivity target of 40% improvement by 2030 on 2015 levels.⁷⁷

INITIAL NATIONALLY-DETERMINED CONTRIBUTION BY 2030 UNDER PARIS AGREEMENT⁷⁸ (HIGHLIGHTS):

- An economy-wide target to reduce greenhouse gas emissions by 26 to 28 per cent below 2005 levels by 2030.
- In 2017-2018 the Australian Government will undertake consultation to determine further post-2020 domestic emissions reduction policies. The government will ensure that policies used in the post-2020 period are efficient and complementary with one another and are appropriately calibrated towards achieving Australia's 2030 target. As a part of this process, the government will consider a potential long term emissions reduction goal for Australia, beyond 2030, taking into account international trends and technology developments.

⁶⁹ United Nations Framework Convention on Climate Change, (2015) *Submission of Japan's Intended Nationally Determined Contribution, July 2015*, <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

⁷⁰ United Nations Framework Convention on Climate Change (2015) Remarks at the Climate Summit - President Park Geun-hye, 30 November 2015. Paris, https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/cop21cmp11_leaders_event_rep_korea.pdf.

⁷¹ *Korea Emissions Trading Scheme*. (Feb, 2016), https://icapcarbonaction.com/en/?option=com_etsmap&task=export&format=pdf&layout=list&systems%5B%5D=47

⁷² Centre for Climate and Energy Solutions (2016) 2020 Country Emissions Targets, C2es.org, <http://www.c2es.org/international/history-international-negotiations/2020-targets>

⁷³ United Nations Framework Convention on Climate Change (2015) *Intended Nationally Determined Contribution: Republic of Korea*, 30 June, 2015. <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

⁷⁴ Turnbull, M. (2015) 2015 United Nations Climate Change Conference speech, [malcolmturnbull.com.au](http://www.malcolmturnbull.com.au/media/2015-united-nations-climate-change-conference-speech), <http://www.malcolmturnbull.com.au/media/2015-united-nations-climate-change-conference-speech>

⁷⁵ <http://www.c2es.org/international/history-international-negotiations/2020-targets>

⁷⁶ Australian Government Department of the Environment (2016) The Renewable Energy Target (RET) scheme, [environment.gov.au](http://www.environment.gov.au/climate-change/renewable-energy-target-scheme), <https://www.environment.gov.au/climate-change/renewable-energy-target-scheme>

⁷⁷ *National energy productivity plan 2015-2030*. Dec, 2015, Commonwealth of Australia <https://scer.govspace.gov.au/files/2015/12/National-Energy-Productivity-Plan-release-version-FINAL.pdf>.

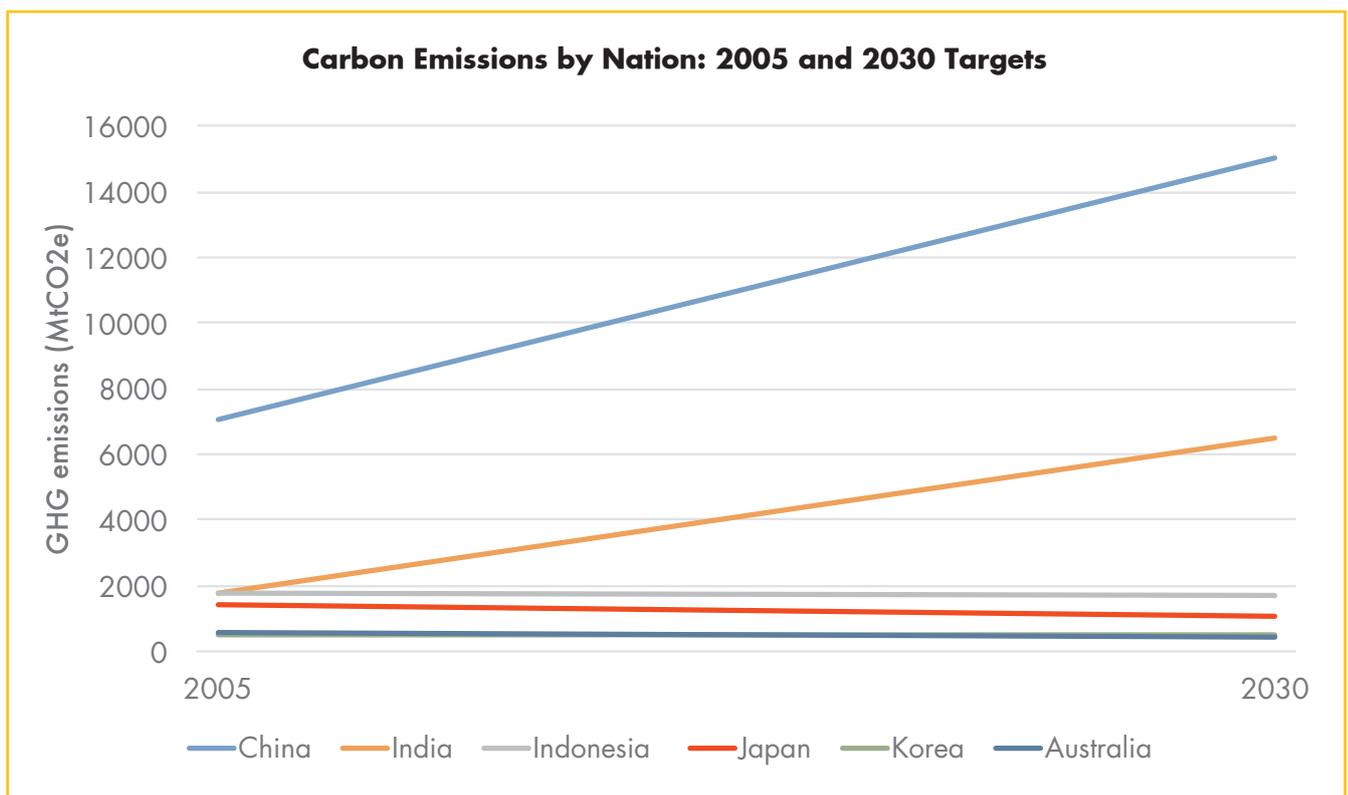
⁷⁸ *Australia's Intended Nationally Determined Contribution to a new Climate Change Agreement*. (August 2015), <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

DEEP DECARBONISATION PLAN⁷⁹ HIGHLIGHTS:

- Concludes Australia can achieve net zero emissions by 2050, using technologies available today, while maintaining economic prosperity and similar GDP growth rates to the last five years.
- Australia can achieve per capita energy emissions of 3tCO₂-e by 2050.
- Action comprises a halving of the energy intensity of GDP, a doubling of the share of electricity in final energy from 22% to 46% and an increase in overall electricity demand by 2.5 times from 2012 to 2050.
- Renewables are at least 71% of generation by 2050 with solar the dominant technology. One scenario includes 27% nuclear generation and another has a slightly higher level of generation from gas and black coal with CCS.
- High levels of renewables are handled by a range of measures including inter-regional trading, flexible generation (gas and renewable), battery storage and demand management as a last resort.

SUMMARY OF NATIONAL CLIMATE POLICY GOALS

The following chart shows 2005 GHG emissions and emissions per capita for each of the main countries of interest along with their 2030 goals per the INDCs submitted:



Sources: United Nations Framework Convention on Climate Change (2015)⁸⁰, Carbon Brief (2015)⁸¹, Climate Action Tracker (2015)⁸² and Warren Centre Analysis.

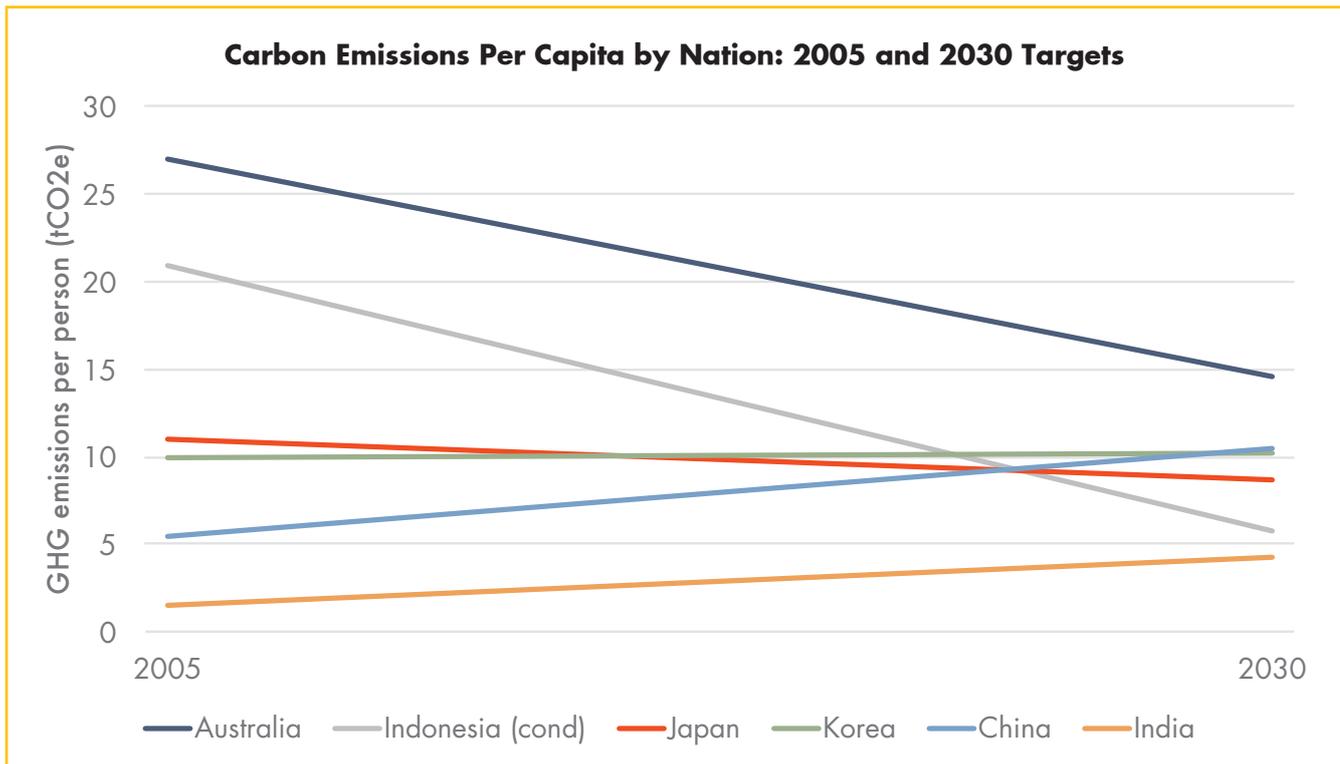
⁷⁹ Denis, A. et al (Oct 2015). *Pathways to deep decarbonization in Australia*, <http://deepdecarbonization.org/countries/#australia>

⁸⁰ United Nations Framework Convention on Climate Change (2015), INDC's as communicated by Parties, <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>

⁸¹ Carbon Brief (2015) Analysis: Indi's climate pledge suggests significant emissions growth up to 2030, [carbonbrief.org, http://www.carbonbrief.org/indias-indc](http://www.carbonbrief.org/indias-indc)

⁸² Climate Action Tracker (2015) Rating Countries, [climateactiontracker.org, http://climateactiontracker.org/countries/](http://climateactiontracker.org/countries/)

5. Decarbonisation continued



Sources: as above, UN population data and projections,⁸³ and The Warren Centre analysis

IMPLICATIONS FOR COPPER

The three main strategies undertaken by national governments to achieve decarbonisation targets are:⁸⁴

- a shift from fossil fuel to renewables in the power sector;
- increased electrification in sectors including building and transport; and
- enhanced energy efficiency.

All are generally positive for copper and will be explored in detail in the following sections of this report.

IMPACT OF CARBON PRICING ON COPPER DEMAND

As the Paris Agreement is implemented, many countries are likely to institute carbon pricing or cap-and-trade schemes. Copper production is energy-intensive, but, perhaps counter-intuitively, carbon pricing could be a competitive advantage for copper.

Early in Australia's considerations to implement carbon pricing in 2008-2011, debates focussed on the prospect of "carbon leakage".⁸⁵ If carbon pricing is not uniform across international boundaries, carbon-intensive activities and industries will relocate from countries with carbon pricing to those with no carbon price. One effect of the Paris Agreement may be growing adoption of uniform carbon pricing around the world. Among the key provisions of the Paris agreement⁸⁶ was a new mechanism to ensure that carbon emissions reductions are "real, measurable and long-term", a provision that gives investors and the private sector a strong signal to

⁸³ United Nations, Department of Economic and Social Affairs, Population Division (2015). World Population Prospects: The 2015 Revision, DVD Edition. <http://esa.un.org/unpd/wpp/>

⁸⁴ Deep Decarbonisation Pathways Project (2016) Questions and Answers, [deepdecarbonization.org](http://deepdecarbonization.org/questions-answers/), <http://deepdecarbonization.org/questions-answers/>

⁸⁵ Haywood, C. (2011). Carbon Leakage—The First Mover Disadvantage: Australia's Trade-Related Assistance Measures for Emissions-Intensive, Trade-Exposed Industries. *Review of European Community & International Environmental Law*, 20(1), 78-90.

⁸⁶ United Nations Framework Convention on Climate Change (2015), adoption of the Paris agreement Proposal by the President Draft decision -/CP.2, United Nations, [unfccc.int](https://unfccc.int/resource/docs/2015/cop21/eng/109.pdf), <https://unfccc.int/resource/docs/2015/cop21/eng/109.pdf>

begin to shift their portfolios toward lower-carbon assets. The Paris Agreement aspires to facilitate implementation of more uniform carbon pricing and carbon market regimes to avoid international relocation of carbon-intensive industries. About 40 countries and over 20 regions, states and cities, representing about 12 percent of global greenhouse gas emissions, have already implemented mechanisms to price carbon. China is running seven pilot carbon pricing schemes and plan a nationwide scheme which may be launched by the end of 2016 and fully implemented in 2019.⁸⁷

According to the International Council on Mining and Metals (ICMM), the carbon intensity of copper production ranges from 1.25 to 6tCO₂-e per tonne of copper with most estimates in the range of 3-4.5tCO₂-e/t.⁸⁸ Generally the emissions are split roughly evenly between the mining and processing stages of copper production. Aluminium, in comparison, has a best-practice carbon intensity 2-3 times higher, at around 10tCO₂-e per tonne of primary production, 55% of which is due to the electricity emissions from the electrolysis process. There is significant variation depending on the carbon intensity of the electricity supply. Nature Climate Change⁸⁹ indicates that China's aluminium ingot production creates 68.4tCO₂-e/t, almost seven times the level in the EU. That EU figure is probably a combination of coal, solar, wind and nuclear electricity. The China CO₂-e efficiency reflects chemical process inefficiencies, thermal energy inefficiencies and poor efficiency of Chinese coal electricity.

This is significant as the majority of copper demand in our forecast is in China and, as discussed above, a carbon price will soon be implemented in China affecting metal production. Assuming a carbon price in 2030 is an average US\$30/tCO₂-e, copper can expect a cost increase at current levels of Chinese carbon intensity of around US\$150/tonne or around 3%. Best-practice aluminium would have an equivalent cost increase of \$300/tonne or roughly 20%. Current levels of Chinese carbon intensity, aluminium would be subject to a cost increase of over US\$2,000/tonne or 133%.

In a carbon-constrained world the apparent cost advantage of aluminium is heavily eroded. Of course decarbonising the electricity supply, which we forecast will gradually occur, will close the carbon-intensity gap between the two metals and the price signal should drive improved efficiency in production, as intended,

and perhaps the substitution of best-practice imported aluminium. However we expect copper to remain carbon-advantaged in all scenarios, particularly if carbon prices increase over time.

Carbon pricing will likely "shock" the aluminium industry, and governments in China, Indonesia and developing countries may take actions to protect domestic aluminium producers as was observed in Australia in 2007 to 2011.⁹⁰ When carbon pricing was instituted in Australia in 2011, the impact of the full carbon price on aluminium production in 2013 imposed a cost premium of over 15%. This was reduced to around 2% after government assistance to Emissions-Intensive, Trade-Exposed (EITE) industries. The impact of the same carbon price on copper production was a cost premium around 2.8% which reduced to around 0.2% after EITE assistance. Had the Australian carbon price been implemented undiluted, despite copper costs being slightly higher, the competitive advantage of copper over aluminium would have been much greater. Carbon pricing policy and government subsidies to affected industries could significantly change the economics of technical substitution between aluminium and copper at the global level and within individual countries' taxation, environmental and home industry EITE protection policies.

According to the Grattan Institute's CEO, Professor John Daley, carbon pricing generally works more effectively than forecasted to encourage producer substitution. In response to the price signal, early innovation occurs which includes substitution away from carbon-intensive materials and processes. Widespread adoption of uniform carbon pricing could be favourable for copper against its main competing material, aluminium. Industry assistance from government to relieve the additional carbon cost burden, would appear to dampen copper's competitive advantage.

In conclusion, based on the implications for production costs and competitive advantage over aluminium substitution, uniform and undiluted carbon pricing policy in the jurisdiction in which copper and aluminium are both produced (China and Australia in the Asia region), could potentially advantage copper production. Noting that many copper producers are also engaged in the industries of coal, aluminium, petroleum/gas and uranium, the carbon pricing and EITE issues are quite complex, politically-charged and worthy of significant further study.

⁸⁷ Alexandre Kossoy, G. P., Klaus Oppermann, Nicolai Prytz, Noémie Klein, Kornelis Blok, Long Lam, Lindee Wong, Bram Borkent. (Sep 2015). *State and Trends of Carbon Pricing 2015*, <http://www.worldbank.org/content/dam/Worldbank/document/Climate/State-and-Trend-Report-2015.pdf>

⁸⁸ Cooper, J. D. a. S. (April, 2013). *The cost of carbon pricing: competitiveness implications for the mining and metals industry*, <http://www.icmm.com/page/92375/the-cost-of-carbon-pricing-competitiveness-implications-for-the-mining-and-metals-industry>

⁸⁹ Liu, Z., Davis, S. J., Feng, K., Hubacek, K., Liang, S., Anadon, L. D., . . . Guan, D. (2016). Targeted opportunities to address the climate-trade dilemma in China. *Nature Clim. Change*, 6(2), 201-206. doi:10.1038/nclimate2800

⁹⁰ Cooper, J. D. a. S. (April, 2013). *The cost of carbon pricing: competitiveness implications for the mining and metals industry*, <http://www.icmm.com/page/92375/the-cost-of-carbon-pricing-competitiveness-implications-for-the-mining-and-metals-industry>

6

ELECTRICITY SYSTEM

COUNTRY AND REGIONAL OVERVIEWS

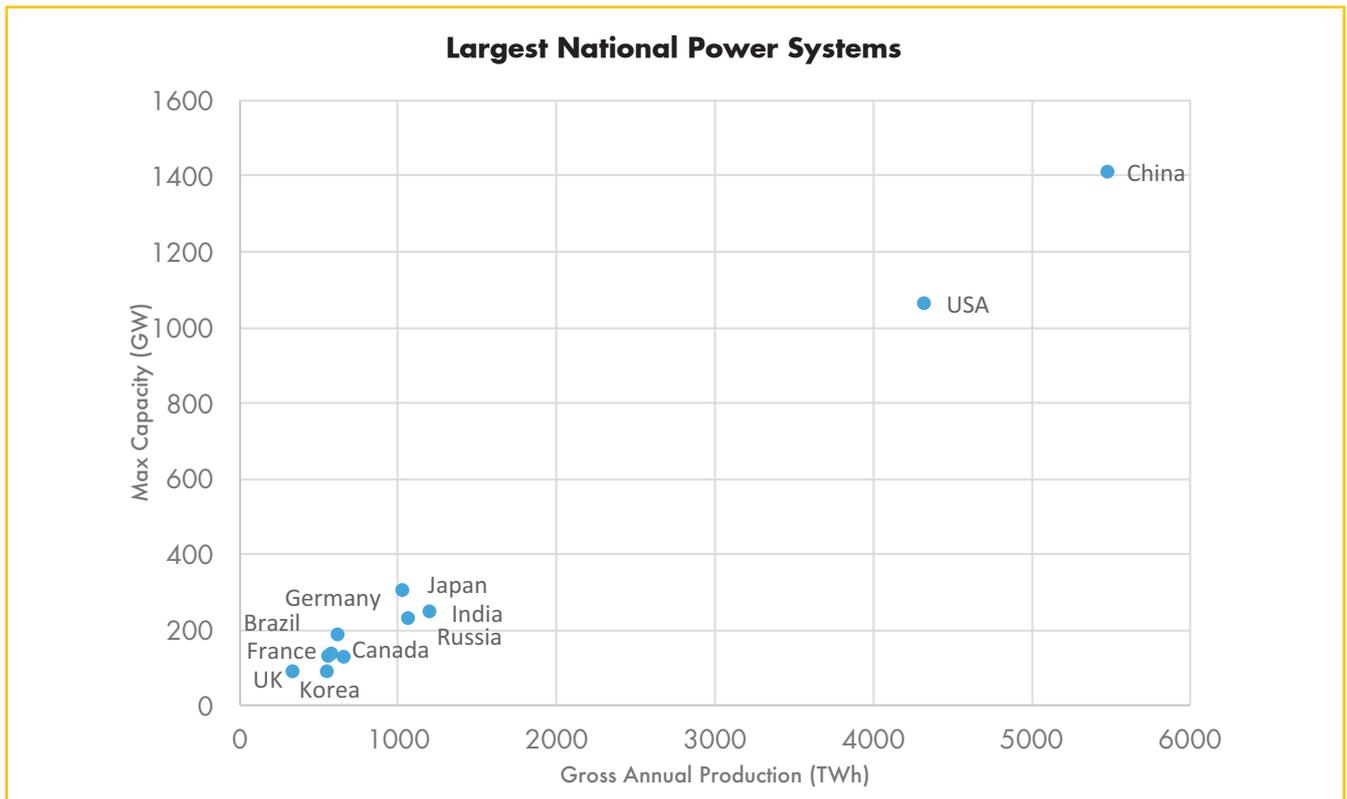
ASIAN DEMAND GROWTH

The Asian region is predicted to represent around 43% of world electricity demand by 2035 according to the ADB.⁹¹

Asian countries of interest include four of the top twenty power markets in the world ranked by installed capacity, see chart below. The top five are dominated by Asia, as follows:

- China: 1st, 1413 GW installed capacity
- Japan: 3rd, 303 GW installed capacity
- India: 4th, 236 GW installed capacity

⁹¹ Jong Ho Hong, C. K., and Heeyoung Shin. (Sep, 2014). *Power Sector in Developing Asia: Current Status and Policy Issues*. <http://www.adb.org/sites/default/files/publication/42879/ewp-405.pdf>

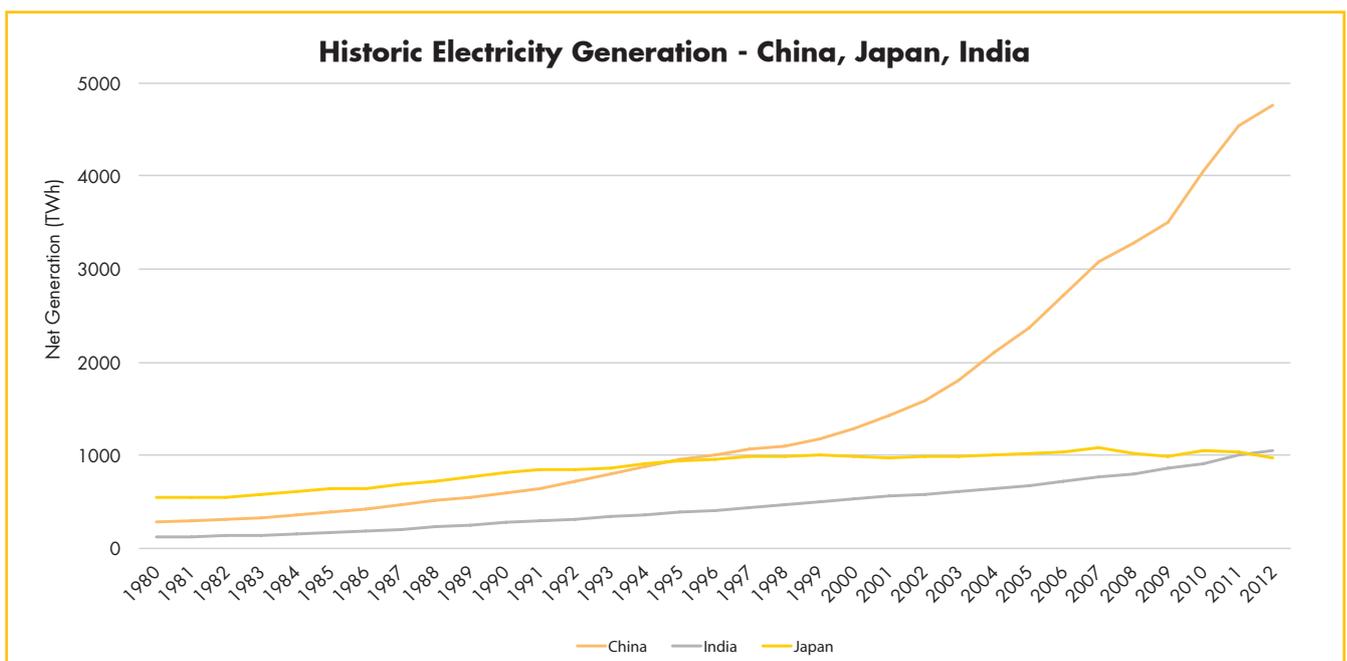


Source: Jong Ho Hong, C. K., and Heeyoung Shin. (2014).

Generation rankings closely track installed capacity as shown below. In terms of electricity generation, the 2014 global top ten include:

- China: 1st, 5472 TWh
- India: 3rd, 1194 TWh
- Japan: 5th, 1025 TWh
- Korea, 10th, 545 TWh

Growth trends in electricity generation among the Asian countries of interest since 1980 are shown below.

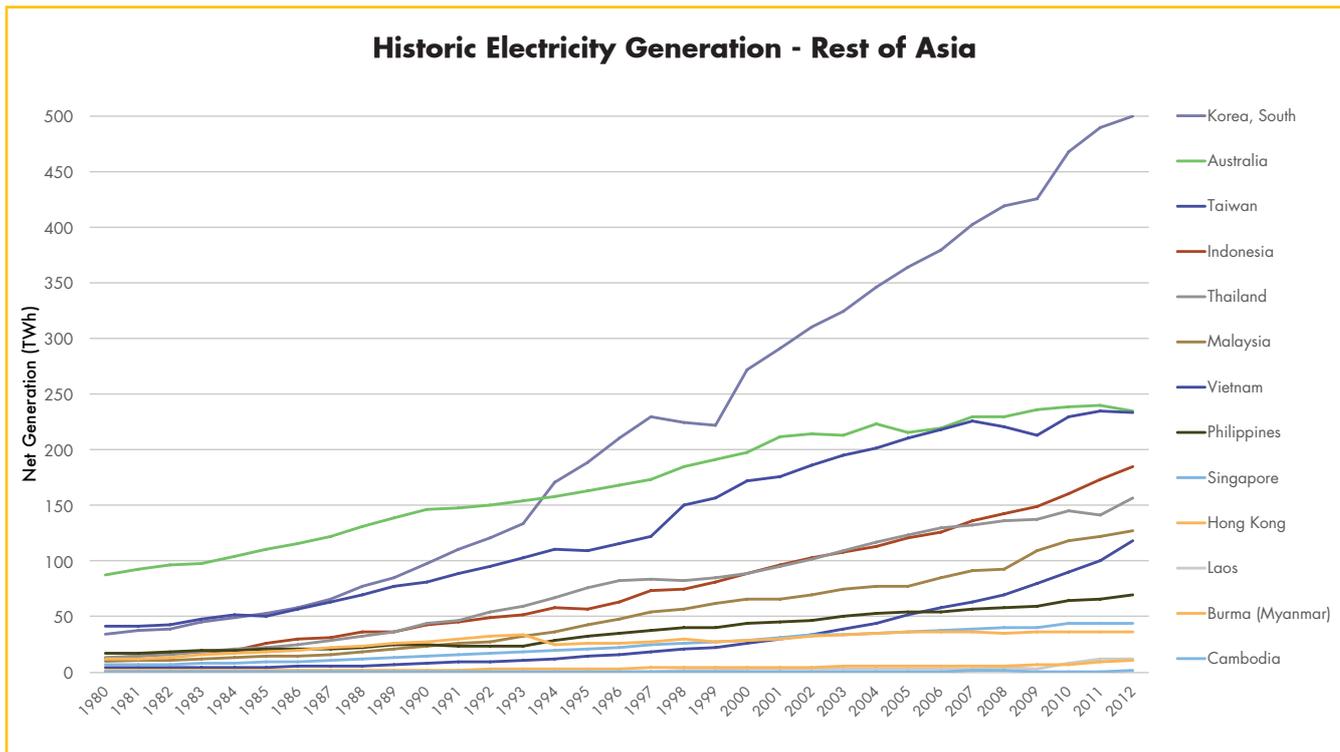


Source: OECD/IEA⁹², EIA⁹³

⁹² OECD (2015) Electricity Information 2015. Paris, OECD, IEA. <http://www.oecd-ilibrary.org/docserver/download/6115151e.pdf?expires=1456356826&id=id&accname=ocid195150&checksum=3187DC00AD478CA33CC9E978049550F5>

⁹³ US Government, Energy Information Administration, EIA Beta, <http://www.eia.gov/beta/international/>

6. Electricity System continued



Source: EIA⁹⁴

In 2030, generation in China and India is predicted to more than double. Their national power systems will remain two of the three largest globally by a considerable margin, with estimated annual generation of 11,860TWh and 2,760TWh respectively. Within the Asian countries of interest, it is predicted that at least Vietnam and Indonesia will join the top twenty countries globally in terms of generation.

Developments in the large Asian power markets over the next fifteen years will be an important driver of global copper use. The following sections give an overview of the current situation and likely developments in the power sector for each of the main countries of interest.

COUNTRY OVERVIEWS

India

India is currently the world's third largest electricity market with the fastest growth rate of the top ten global electricity markets.⁹⁵ It is also now the third largest greenhouse gas emitter⁹⁶ with a power sector in rapid transition.

The Indian electricity sector is a small, but growing, part of the nation's overall energy demand. The share of electricity in energy demand was 15.6% in 2011-12 and is expected to grow to 20.6% by 2030. For example, some estimates indicate that two-thirds of residential energy will still be supplied from biomass by 2030. The residential electricity load is forecasted to be around 38% of the total electricity load by 2030.⁹⁷

As discussed in the previous section, India's increasing urbanisation, its pattern of urbanisation, and the nation's goal of electrification of all households by 2022 combined with rising income levels in both urban and rural areas will drive residential electricity demand and an associated demand for electrical appliances. The Indian government program of Affordable Housing for All by 2022⁹⁸ underpins electricity demand growth.

⁹⁴ US Government, Energy Information Administration, EIA Beta, <http://www.eia.gov/beta/international/>

⁹⁵ EIA (2016) International Country Selection, [eia.org, https://www.eia.gov/beta/international/analysis.cfm](https://www.eia.gov/beta/international/analysis.cfm)

⁹⁶ Friedrich, J. Ge, M. and Damassa, T., (2015) Infographic: What Do Your Country's Emissions Look Like?, World Resources Institute, <http://www.wri.org/blog/2015/06/infographic-what-do-your-countrys-emissions-look>

⁹⁷ NITI Aayog (2015). A Report on Energy Efficiency and Energy Mix in the Indian Energy System (2030): Using India Energy Security Scenarios, 2047. http://niti.gov.in/mgov_file/Energy_Efficiency.pdf

⁹⁸ Government of India (2015) "Housing for All by 2022" Mission - National Mission for Urban Housing, Press Information Bureau, Government of India Cabinet, 17 June 2016, <http://pib.nic.in/newsite/PrintRelease.aspx?relid=122576>

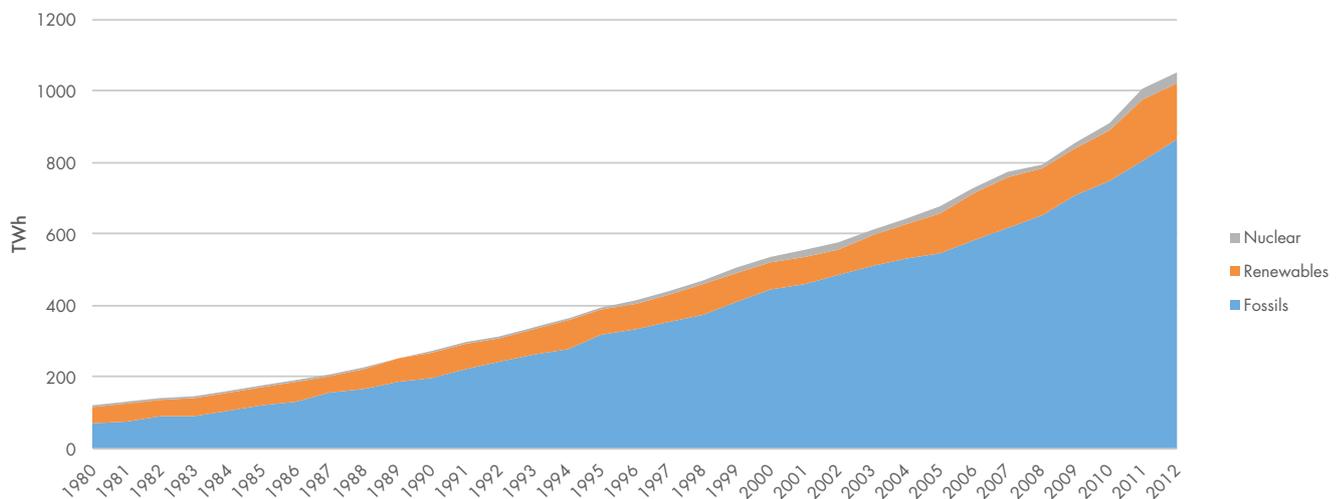
India's electricity consumption per capita today is one third of China's and one thirteenth of US levels. To achieve the government's development goals, approximately 15-20GW of new generation capacity per annum is needed until 2035.⁹⁹ Using business-as-usual generation trends, even with a moderate mix of renewables, India's electricity sector greenhouse gas emissions will double by 2035.¹⁰⁰ India has announced targets to decarbonise its economy while balancing economic growth and improving standards of living for its vast and rapidly growing population. The UN Deep Decarbonisation Pathways Project (DDPP) offers a path of transition consistent with avoiding dangerous climate change, and the Indian approach is discussed in the decarbonisation section which follows.

Assuming a constant 7% economic growth rate, electricity demand is predicted to grow approximately 250% from a 2012 baseline to over 2700TWh by 2030.¹⁰¹ Although power plant construction is the main means to supply the massive increase in generation and grid capacity, a sizeable portion of the task could actually be achieved by reducing network losses and increasing end use energy efficiency. Currently India has the highest grid loss rates in the world, averaging 26%.¹⁰² Energy Minister Piyush Goyal is pushing hard for distribution sector reform and for increased energy efficiency.

The Indian government has initiated a radical transformation of the Indian coal, renewable energy, power generation and electricity distribution sectors. Energy Minister Goyal has set extremely ambitious targets to increase Indian energy supply, including adding 175GW of renewable energy installation by 2022, a US\$50 billion modernisation of the electricity grid and a target that would more than double India's domestic coal production. MIT described these initiatives as "the world's most aggressive low-carbon capacity building program"¹⁰³. Renewables are currently 13% of capacity, but the government is aiming for 40% by 2030 which equates to around 275GW renewable capacity. This is discussed in further detail in the Decarbonisation section.

India is predicted to increase domestic coal production from 660Mt per year to 1500Mt by 2020.¹⁰⁴ Energy security is the main driver for this increase. Coal currently provides 70% of India's electricity. There are significant prospects to increase the efficiency of current coal and gas burning systems. For example, the Government has a goal to increase utilisation of existing coal plants from 60% to 75%. A coal tax has raised US\$2.6 billion, but the funds have not yet been spent on efficiency programs or projects. Tim Buckley of IEEFA says, "It is now clear that electricity generation sourced from a new imported coal fired power plant in India is immediately more

India: Electricity Generation by Primary Fuel 1980-2012



⁹⁹ Martin, R. (Nov, 2015). India's Energy Crisis. MIT Technology Review 118/6
<https://www.technologyreview.com/s/542091/indias-energy-crisis/>

¹⁰⁰ P.R. Shukla, S. D., Minal Pathak, Darshini Mahadevia, and Amit Garg. (Sep, 2015). *Pathways to deep decarbonization in India*.
http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_IND.pdf

¹⁰¹ NITI Aayog (2015). A Report on Energy Efficiency and Energy Mix in the Indian Energy System (2030): Using India Energy Security Scenarios, 2047. http://niti.gov.in/mgov_file/Energy_Efficiency.pdf

¹⁰² World Bank (2016) World Development Indicators, The World Bank, 1960 – 2015, last updated 17-Feb-2016, <http://data.worldbank.org/data-catalog/world-development-indicators/>

¹⁰³ Martin, R. (Nov, 2015). India's Energy Crisis. MIT Technology Review 118/6
<https://www.technologyreview.com/s/542091/indias-energy-crisis/>

¹⁰⁴ *Coal and thermal power generation Background note for National Energy Policy 2015. (2015)*. Retrieved from www.prayaspune.org/.../651_dc898aaece9aac4a19ba0d6cf63c5e7e.html.

6. Electricity System continued

expensive than utility scale solar.” He predicts significant corporate support for the Government’s renewable energy goals and cites a recent private sector Power Purchase Agreement for utility-scale solar PV agreed by the Government with SunEdison for a 25-year term with price fixed at a flat Rs4.63/kWh (US7.1c/kWh) for the output of a 500MW PV project in Andra Pradesh.¹⁰⁵ In January 2016 the Rajasthan government agreed a PPA with Finnish group Fortum Energy at Rs4.34/kWh (US6.5c/kWh) for a 70MW solar PV plant.¹⁰⁶ These PPA prices are fixed for 25 years, meaning there is year-on-year price deflation locked for a long period in real terms without any fuel price risk. There were fears that these conditions may deter potential project financiers, but investors appears not to have been frightened. Softbank, for example, is reportedly planning to invest US\$20 billion on PV projects in India.¹⁰⁷

The high forecast penetration of renewables could create a very different network to today’s, yielding high penetration of decentralised energy resources incorporated with battery storage. While the grid already reaches within a few kilometres of most of the population, grid investment has not kept pace with generation investment, and there are at least 15,000 villages with little or no access to electricity.¹⁰⁸ Substantial investment in the low-voltage distribution network is needed to ensure stability. India is working towards a single national transmission network with a cumulative capacity of about 250 GW. The southern grid will merge with the already synchronised grids of the northern, eastern, western and north-eastern regions grid. The Government estimates that an investment of nearly US\$8 billion is needed to strengthen and develop transmission infrastructure for renewable power capacity additions planned during the next five years, part of a planned \$50 billion grid investment by 2025. This includes \$15 billion on nine new high-capacity transmission links including HVDC transmission projects to connect the major renewable generation regions with load centres. For example, ABB is building an 8GW-capacity HVDC transmission line over 1700km connecting hydroelectric power resources in the north-eastern state of Assam to the western city of Agra.¹⁰⁹ Western finance may be needed to fund the

necessary grid investment which looks more likely following the 2015 Paris Agreement.

Today’s Indian electricity system is actually five separate regional grids, often haphazard and improvised, with limited interconnection and unreliable interconnection switching and control between regional grids. The systems suffer high technical and commercial losses, discussed elsewhere, with grid losses in some areas at 50%. Rolling brownouts are common in most cities. The distribution utilities who run the system are unprofitable, some to the point of bankruptcy with two government bail-outs required since 2002. Accusations of corruption are common.¹¹⁰ MIT suggests the utilities have so far ignored mandated minimum renewable requirements amongst other deficiencies. Part of the root cause of the utilities’ problems is that state and local governments force utilities to sell electricity below cost and to provide free power to farmers. MIT says utility reform, including privatisation, independence, and terminating subsidies, is necessary for the Indian Government’s transformative goals to have any chance of success.

There is evidence that such reform is underway. The government’s 5-year Uday reform scheme provides federal funding to utilities in return for restructuring.¹¹¹ The government aims to reduce transmission and distribution losses from a recent high of over 26% nationally to 15% by 2018 (possibly optimistic) and to an internationally-competitive 9.9% by 2030. The Indian Government has committed US\$6.4 billion for the segregation of rural feeders so rural villages can be billed for electricity use while keeping electricity free or highly subsidised for agricultural users.¹¹² Such a policy seems unnecessary duplication which fails to address the fundamental problem of subsidised energy that leads to energy inefficiency and a lack of incentive for utilities to invest. As indicated, perhaps further economic reforms will be necessary as the Indian economy modernises and adapts to market needs.

For many villages and remote facilities with limited or no electrical connection, solar micro grids appear more practical than a “last mile” grid connection. As an example, in January 2016 Energy Minister Goyal announced a

¹⁰⁵ Buckley, T., S., J (November, 2015). India’s Electricity Sector Transformation: Global Capacity Building, Institute for Energy Economics and Financial Analysis.

http://ieefa.org/wp-content/uploads/2015/11/IEEFA-India-Electricity-Sector-Transformation_Global-Capacity-Building_11112015.pdf

¹⁰⁶ Upadhyay, A. (2016) Coal plant developer Rattan India Power switches to solar for site in Punjab, 29 January 2016, LiveMint.com, <http://www.livemint.com/Companies/eQLRrel4a1KL7vtAg9IM/Coal-plant-developer-RattanIndia-Power-switches-to-solar-for.html>

¹⁰⁷ [http://www.ey.com/Publication/vwLUAssets/EY-power-transactions-and-trends-q2-2015/\\$FILE/EY-power-transactions-and-trends-q2-2015.pdf](http://www.ey.com/Publication/vwLUAssets/EY-power-transactions-and-trends-q2-2015/$FILE/EY-power-transactions-and-trends-q2-2015.pdf)

¹⁰⁸ Kohli, N. (2016) The loss of power, The Economic Times, TimesofIndia.com, <http://economictimes.indiatimes.com/new-sections/energy/the-loss-of-power/lifenologyshow/44083310.cms>

¹⁰⁹ ABB (2016) Will supply electricity to serve 90 million people, news.abb.com, <http://new.abb.com/systems/hvdc/references/north-east-agra>

¹¹⁰ Martin, R. (Nov, 2015). India’s Energy Crisis. MIT Technology Review 118/6 <https://www.technologyreview.com/s/542091/indias-energy-crisis/>

¹¹¹ Bharat, U (2015) Towards Ujwal Bharat UDAY: The Story of Reforms, Ministry of Power, Coal and New & Renewable Energy, http://powermin.nic.in/upload/pdf/Power_Sector_Reforms.pdf

¹¹² Bhawam, S, S and Marg, R. (2014) Offician Memorandum, Ministry of Power, Government of India, http://powermin.nic.in/upload/pdf/Deendayal_Upadhyaya_Gram_Jyoti_Yojana.pdf

US\$11 billion investment to deploy 30 million solar irrigation pumps for farmers over the next three to four years with annual savings on existing farm subsidies modelled at US\$3 billion.¹¹³ Distributed energy clearly has enormous potential in India, and this is discussed in detail in a later section. The 2030 energy system, therefore will be a balance of centralised and decentralised assets. Mixed forecasts are provided in a later section.

Our demand projections for India in 2030 of 2600TWh generation supplied by 610GW of generation capacity are a combination of forecasts from a range of sources.
114 115 116

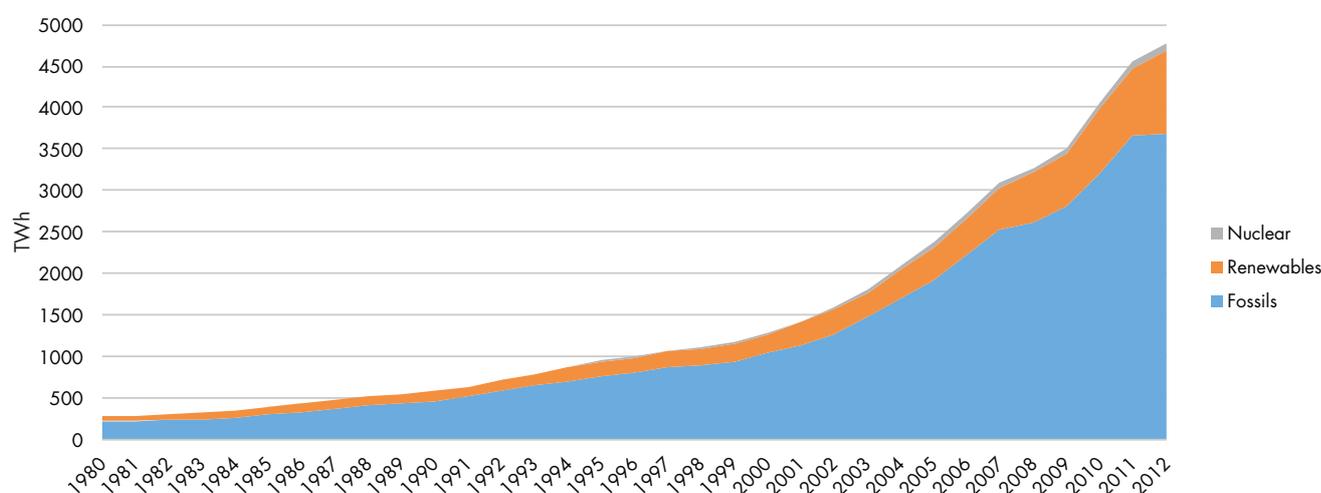
China

China is already the largest electricity market in the world and is likely to remain so for the foreseeable future. Rapid growth in power demand, shown below, has resulted in an unprecedented expansion of generation and transmission capacity in a relatively short period. The electrification level has increased from 7.7% in 1980 to 20% in 2008 while demand increased 12-fold to 3660TWh over a similar period and generation capacity grew by the same factor to

864GW.¹¹⁷ Annual capacity additions since 2004 have ranged from 50-100GW, equivalent to the entire grids of Australia at the lower end and the UK at the upper end of the range. Grid investment has kept pace with generation, and losses are now around 7%, comparable with most other nations.¹¹⁸ Retail prices range from 0.48-0.68RMB/kWh (US7.5-10.7c/kWh), comparatively low and, unusually, lower for residential than for commercial and industrial customers.¹¹⁹

Generation development has favoured coal as a fuel, and China is by far the largest global coal consumer. However China has recently seen a decoupling between electricity demand growth and economic growth, and there are now signs of slowing electricity demand growth. Growth in 2015 was just 0.5% to a total 5500 TWh, much reduced from the steep growth earlier this century. Heavy industry's consumption fell 1.9% while service sector electricity consumption grew 7.5% and household consumption grew 5%. China appears to be starting a transition away from heavy industry as have most advanced economies.¹²⁰ China is rapidly improving energy efficiency and has a 90% improvement goal by 2050.¹²¹

China: Electricity Generation by Primary Fuel 1980-2012



¹¹³ Chandra Prasad, G. (2016) Govt to invest in scheme to check power wastage in farm sector, 19 January 2016, LiveMint.com, <http://www.livemint.com/Politics/XznSUqjON4rhD3xiCNTV1K/Govt-to-invest-in-scheme-to-check-power-wastage-in-farm-sect.html>

¹¹⁴ NITI Aayog (2015). A Report on Energy Efficiency and Energy Mix in the Indian Energy System (2030): Using India Energy Security Scenarios, 2047. http://niti.gov.in/mgov_file/Energy_Efficiency.pdf

¹¹⁵ India's intended nationally determined contribution: working towards climate justice. (Oct, 2015). <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

¹¹⁶ Tuli, Khera (Jan, 2014). *India: Towards Energy Independence 2030*. McKinsey&Company. http://iitbaa-gbf.com/wp-content/uploads/2015/08/India_Towards_energy_independence_2030.pdf

¹¹⁷ Yuan, J., Xu, Y., & Hu, Z. (2012). Delivering power system transition in China. *Energy Policy*, 50, 751-772. doi:<http://dx.doi.org/10.1016/j.enpol.2012.08.024>

¹¹⁸ The World Bank (2016) World Development Indicators, data.worldbank.org, <http://data.worldbank.org/data-catalog/world-development-indicators/>

¹¹⁹ Zhang, F., et al. (2015). "Analysis of distributed-generation photovoltaic deployment, installation time and cost, market barriers, and policies in China." *Energy Policy* 81: 43-55. <http://www.sciencedirect.com/science/article/pii/S0301421515000737>

¹²⁰ Buckley, T. (2016) New china data shows an 'entirely beleaguered' seaborne market, *Institute for energy economics and financial analysis*, <http://ieefa.org/chinas-love-for-coal-and-coal-imports-and-longstanding-affair-with-heavy-emissions-rapidly-coming-off-the-boil/>

¹²¹ D'amato, i. (2015) China could limit emissions by 2025, lead clean revolution by 2050, <http://www.theclimategroup.org/what-we-do/news-and-blogs/china-could-limit-emissions-by-2025-lead-clean-revolution-by-2050/>

6. Electricity System *continued*

The rapid expansion of fossil fuel generation, non-electricity industrial combustion of coal and steep growth in petroleum vehicle count have created significant air pollution, worst in the largest industrial cities, but also affecting rural areas and extending over borders to other countries. The Grattan Institute's John Daley estimates that the Chinese Government's biggest political issue is now air pollution. In late 2015, thick smog blanketed a 530,000 square kilometre area in northern China and AQI readings reached record highs exceeding 1200 in Shenyang after central heating was turned on for winter.¹²² The Thirteenth Five-Year Plan (2016-2020) includes a goal to establish a nationwide, real-time online environmental monitoring system and an emissions permit system that will cover companies with static pollution sources.¹²³ Xu Lin, director of the NDRC Development Planning Department, said at an April 2015 press conference that as well as promoting China's transition to a high-income economy and emphasizing quality of economic growth instead of GDP growth, that strengthening energy efficiency and environmental protection efforts will be a key focus.¹²⁴

There are signs that China is now acting with the dual objective of reducing local pollution and overachieving on the national climate commitments made prior to the climate talks in Paris. Climate Tracker's Anthony Hogley says China has the biggest renewable energy program in the world with an installed renewable energy capacity greater than the rest of the world combined. "I would expect by 2050 China would be one of the cleanest industrial economies in the world, and it will be driven by 21st century energy technology, not 20th century technology," Hogley suggests.

Many experts suggest that while the acceleration in coal generation may now be waning, in absolute terms coal combustion will continue to grow and may continue to do so until 2030. However record low coal power utilisation rates of 53.7% in 2014 and 49.4% in the first half of 2015 are already undermining the profitability of even the newest coal-fired power plants and affecting the business case for new coal power.¹²⁵ With electricity demand forecasted to grow by only 3-4% in 2016, equivalent to 40-55GW generation capacity, and the forecasted addition of 65GW additional zero-carbon electricity capacity during the year, coal

consumption is forecasted to fall again in 2016.¹²⁶ Some Government presentations show coal generation peaking in 2020, well ahead of international commitments, but there is building evidence that it may have already peaked; this is discussed in the following section.

China has certainly been rapidly diversifying away from its historic reliance on coal-fired generation, having undertaken a significant and sustained investment program in wind, solar, hydro, nuclear and gas-fired power generation. China recently lifted its expected 2020 solar installation target by 50% from 100GW to 150GW, and hydroelectricity capacity additions could exceed 20GW annually this decade. China is already the largest wind power market globally by a factor of almost two with 145GW installed at the end of 2015. The country also forecasts to commission over 20GW of new nuclear facilities prior to 2020. In 2015 alone China installed over 30GW of new wind capacity and over 16GW of solar PV.¹²⁷ Dean Economou, formerly of NICTA, suggests that this transition is not just for domestic reasons and that China's long-term strategy is to be the premier renewables exporter globally. China already dominates global solar PV manufacturing. The Thirteenth FYP shows wind, solar and electric vehicles becoming new economic growth engines producing 3.9% of GDP by 2030 and 6.2% of GDP with 12 million jobs by 2050.¹²⁸

China has excellent renewable resources in a diverse range of regions. However there is evidence that renewables projects have in some cases have been allocated to regions on a political basis rather than based on renewable resources. University of Sydney law researcher Penelope Crossley says up to a third of wind projects have been built, but not yet connected. There may be some energy storage required to balance high levels of intermittent renewables in future.

Transmission and distribution are controlled by two state-owned transmission and distribution companies: State Grid and Southern Grid. State Grid is an important force shaping the Chinese power system and has constructed a number of ultra-high-voltage (UHV) transmission lines (both AC and DC) to connect major generation and load centres. University of Sydney Professor and Head of the Electrical Engineering School

¹²² Liu, C 2015, The Nanfang, Pollution In Northern China Is Bad, Crazy Bad, thenangang.com, <https://thenangang.com/beijing-air-pollution-year-high-govt-claims-pollution-reduction-achieved/>

¹²³ China Daily (2015) 'Highlights of proposals for China's 13th Five Year Plan', ChinaDaily.com, http://www.chinadaily.com.cn/china/2015cpcplenarysession/2015-11/03/content_22361998.htm

¹²⁴ The US-China Business Council 2014 <https://www.uschina.org/ndrc-prepares-next-five-year-plan-focuses-quality-over-quantity>

¹²⁵ Buckley, T. (August, 2015). India's Electricity-Sector Transformation, Institute for Energy Economics and Financial Analysis. <http://ieefa.org/wp-content/uploads/2015/08/IEEFA-Indian-Electricity-Sector-Transformation-August-2015.pdf>

¹²⁶ Institute for Energy Economics and Financial Analysis 18 January 2016 "New China Data Shows an 'Entirely Beleaguered' Seaborne Market" <http://ieefa.org/chinas-love-for-coal-and-coal-imports-and-longstanding-affair-with-heavy-emissions-rapidly-coming-off-the-boil/>

¹²⁷ Institute for Energy Economics and Financial Analysis 20 January 2016 "China Delivers a World Record Wind Installs in 2015; India Announces Another Record Low Solar Tariff" <http://ieefa.org/china-delivers-a-world-record-wind-installs-in-2015-while-india-announces-another-record-low-solar-tariff/>

¹²⁸ Energy Research Institute, NDRC (Apr, 2015). *China 2050 High Renewable Energy Penetration Scenario and Roadmap Study*, <http://www.efchina.org/Reports-en/china-2050-high-renewable-energy-penetration-scenario-and-roadmap-study-en>

Joe Dong notes that presently the Chinese grid is highly centralised and that State Grid has aspirations to build a Supergrid supplying neighbouring countries as well as domestic loads. This is discussed in more detail in a following section.

China's approach to the power system has to date been a highly centralised one. There are now pilots of decentralised generation in some cities and increasing government policy support for rooftop solar PV systems, but uptake has been slow so far, and the massive investment in the central system will likely keep decentralised energy solutions to a small part of the overall picture. This is discussed in detail in a following section.

Our demand projection for China in 2030 is drawn from the high renewables scenario of NDRC's Energy Research Institute¹²⁹ who expect 11,866TWh generation supplied by 3929GW of generation capacity.

Other nations

Due to their relative size and economic impact, the current analysis is concentrated on China and India. This section briefly reviews the ASEAN nations, Japan, Korea and Australia. Those countries with less than 50TWh current electricity demand are not reviewed.

Japan

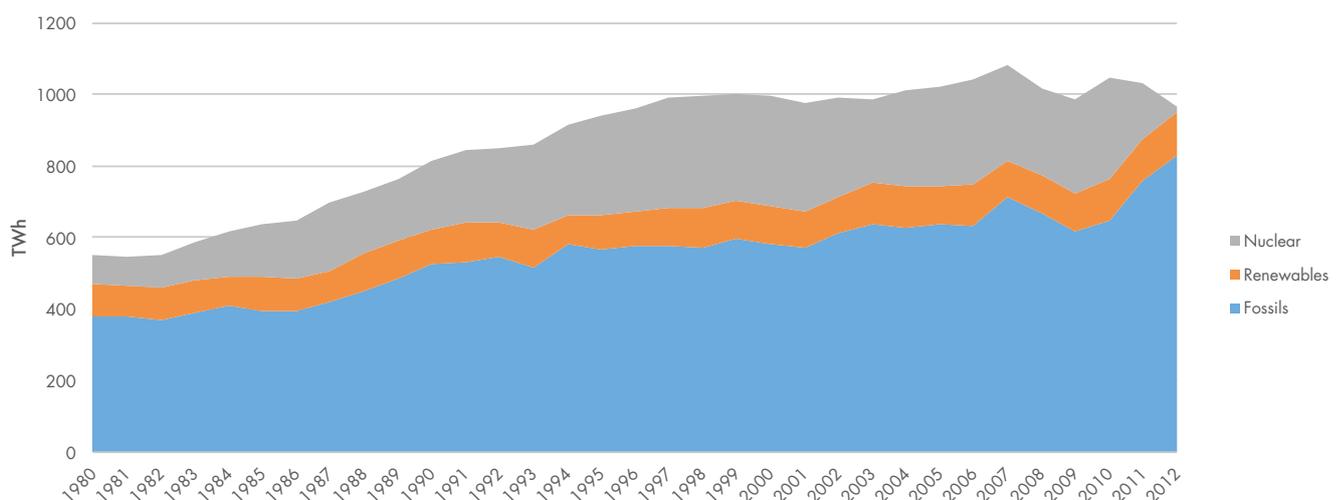
Japan is the 5th largest electricity market globally. The Japanese economy is characterized by low domestic reserves of fossil fuels which makes it highly dependent

upon imports with energy security a long-term issue. Japan currently has two separate, non-interoperable network systems: a 50Hz system in the east and a 60Hz system in the west.

After the first oil shock, Japan's energy policy focused on three pillars: energy security, environmental protection and economic efficiency. Energy supply was diversified and focused upon nuclear, liquefied natural gas and imported coal. The focus on energy security and climate change has favoured the development of renewables and the domination of nuclear power which was a critically important energy source until the Fukushima Daiichi accident in 2011.

Japan has acted to reduce nuclear power generation since Fukushima with a sharp increase in fossil fuel generation since 2011. Foreign ownership restrictions have been lifted for power system assets, and generous feed-in tariffs have been introduced to incentivise new renewable capacity, though there are doubts about the capacity of the grid to accept further distributed renewables on top of the 7GW already deployed. The large-scale renewable resources are unevenly distributed and generally not close to major demand centres.¹³⁰ Japan, though, has a goal to become a leader in renewable energy¹³¹, and renewables have the double benefit of improving energy security by increasing domestic-sourced primary energy from its current 4%. We expect grid investment to allow increased renewables penetration and for energy storage and coordinated use of distributed assets like smart inverters to improve network stability.

Japan: Electricity Generation by Primary Fuel 1980-2012



¹²⁹ Energy Research Institute, NDRC (Apr, 2015). *China 2050 High Renewable Energy Penetration Scenario and Roadmap Study*, <http://www.efchina.org/Reports-en/china-2050-high-renewable-energy-penetration-scenario-and-roadmap-study-en>

¹³⁰ US Government, Energy Information Administration, EIA Beta Country Information - Japan, <http://www.eia.gov/beta/international/>

¹³¹ Dewit, A. (Oct, 2015). Japan's Bid to Become a World Leader in Renewable Energy, <http://www.globalresearch.ca/japans-bid-to-become-a-world-leader-in-renewable-energy/5480274>

6. Electricity System continued

A report by the Ministry of Economy, Trade and Industry (METI) predicts that total energy demand in Japan will increase about 4% from 940 TWh in 2013 to 980.8 TWh in 2030.¹³² Japan's submission to the Paris Agreement (Intended Nationally-Determined Contribution or INDC)¹³³ process shows a slightly higher 2030 load of 1065TWh based on higher degrees of electrification of transport and building services. Although there is a 9% difference in the two estimates, both confirm expectations that Japan will continue to experience relatively low power generation growth following the trend of the past two decades.

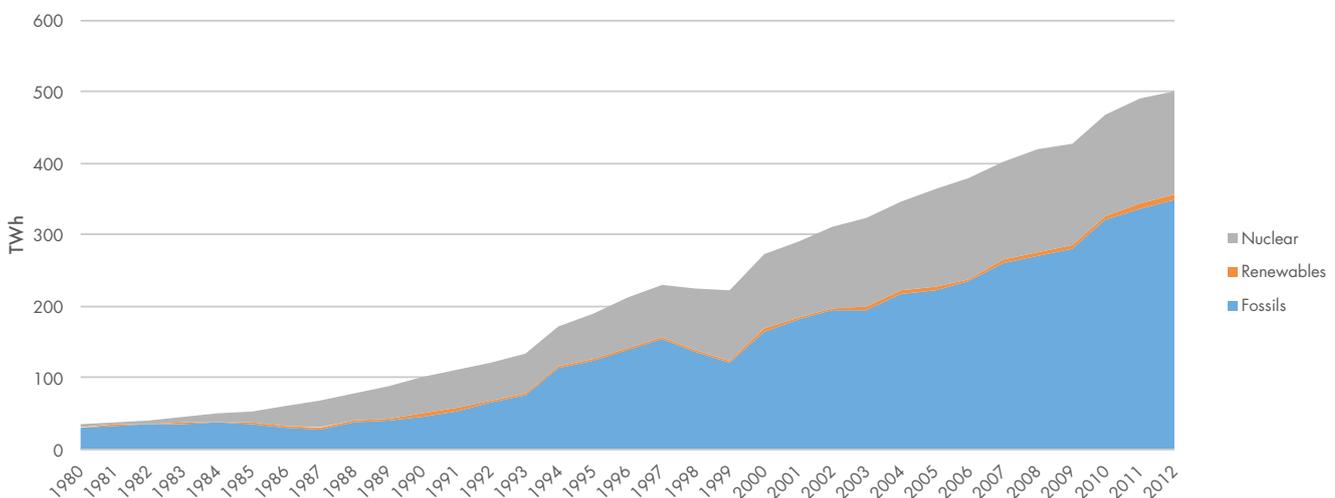
Korea

The total electricity generating capacity of Korea quadrupled over the past 22 years from 21 GW in 1990 to 81.8 GW in 2012. Coal-fired power plants constitute the largest portion of capacity (25.1 GW), followed by gas-fired plants (21.9GW, mostly combined-cycle plants) and nuclear (20.7GW). The remainder of generating capacity is comprised of hydro (6.4GW of which 4.7GW are pumped-storage hydroelectric plants used to store energy for use during times of peak power demand), oil-fired capacity (5.3GW) and a very small amount of capacity based on non-hydro renewable energy sources.¹³⁴

The 7th basic long-term power development plan of electricity supply and demand was released by the Ministry of Education, Science and Technology in July 2015 and predicts electricity demand to increase 2.2% annually to 2029, reaching 657 TWh.¹³⁵ Aggressive conservation measures are predicted to limit peak generation requirements at 112 GW. Extrapolating this level of growth a further year we predict a 2030 forecast of 671 TWh.

There are differing views about the strategic approach to provide generation capacity to meet this demand. Bloomberg New Energy Finance says Korea's power outlook "is highly uncertain as the government has not created an achievable long-term energy plan. It aims to increase coal capacity, but it has a target to reduce the country's emissions 19% below 2010 levels by 2020. In addition, it aims to reduce the share of nuclear, but is expecting less LNG-fired generation and does not have an effective renewable policy in place that will accelerate development similar to for example Japan and China".¹³⁶ In the Target scenario of the National Energy Basic Plan, the share of nuclear and renewable energy rises to 39.5% in 2030 with renewables providing 11% capacity.¹³⁷ Korea's INDC notes government support for new renewables capacity and suggests an obligation on power generators to supply a portion of electricity from renewable sources.¹³⁸

Korea: Electricity Generation by Primary Fuel 1980-2012



¹³² Nuclear Information Centre 4 June 2015 <http://www.nicenter.org.tw/modules/news/article.php?storyid=624>

¹³³ *Submission of Japan's Intended Nationally Determined Contribution (July 2015)*, <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

¹³⁴ Woo Jin Chung, "Update on ROK Energy Sector and Energy Policies", NAPSNet Special Reports, July 21, 2014, <http://nautilus.org/napsnet/napsnet-special-reports/update-on-rok-energy-sector-and-energy-policies/>

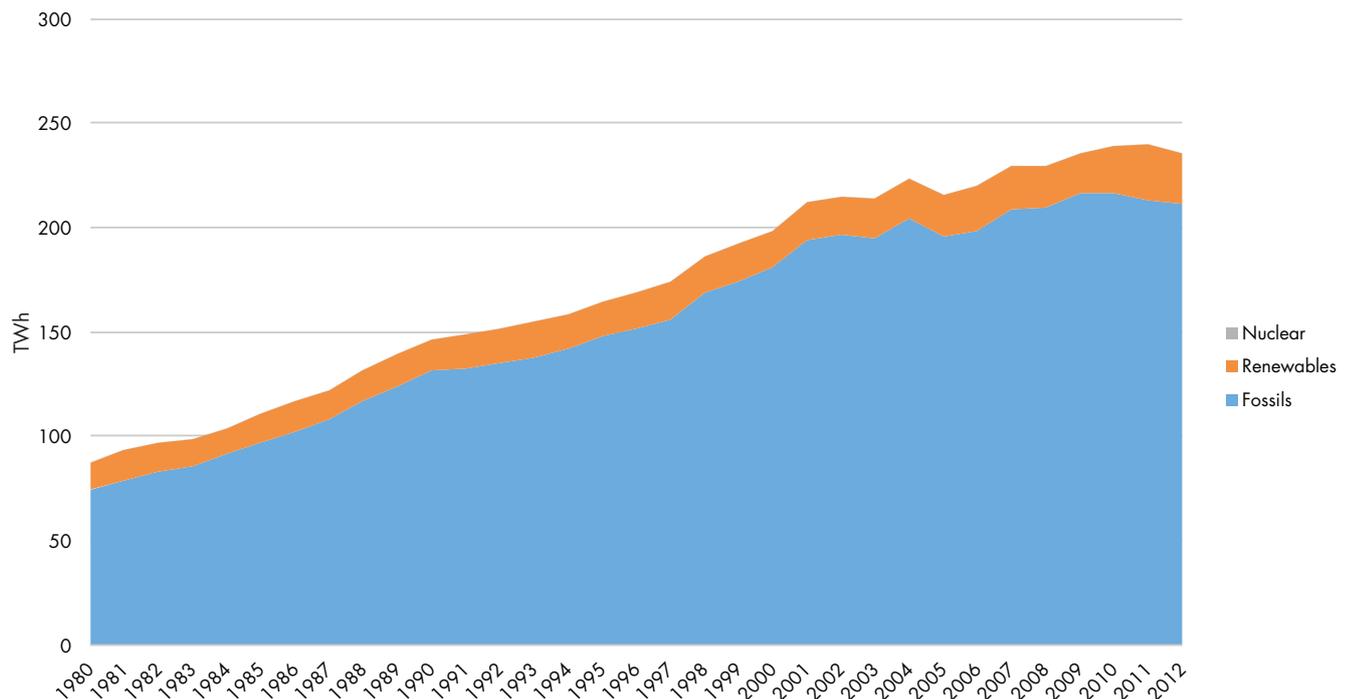
¹³⁵ World Nuclear Association January 2016 <http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx>

¹³⁶ June, 2014. 2030 MARKET OUTLOOK - Asia Pacific, Bloomberg New Energy Finance. <http://www.metering.com/wp-content/uploads/2015/03/bnefwhitepaper.pdf>

¹³⁷ Woo Jin Chung, "Update on ROK Energy Sector and Energy Policies", NAPSNet Special Reports, July 21, 2014, <http://nautilus.org/napsnet/napsnet-special-reports/update-on-rok-energy-sector-and-energy-policies/>

¹³⁸ *Intended Nationally Determined Contribution: Republic of Korea*. (30 June, 2015), <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

Australia: Electricity Generation by Primary Fuel 1980-2012



Australia

Electricity in Australia is supplied in the Eastern states, South Australia and Tasmania via the National Electricity Market (NEM). In the Perth region there is the Southwest Interconnected System which operates fundamentally differently to the NEM. Elsewhere electricity is supplied via local generation of varying scale. Darwin, Alice Springs, remote towns and most islands are isolated systems. Due to the remarkably high penetration of coal power, including significant capacity using brown coal, and inefficient coal power generation plants, Australia has the most carbon-intensive electricity in the developed world.¹³⁹ Comparatively low power prices have limited efficiency incentives, and Australian end use energy efficiency is lower than the OECD average.¹⁴⁰

The Australian energy sector is undergoing a disruptive transition. Formerly a stable, centralised system with monopoly regulated networks and steady, predictable demand growth, the Australian system is changing to a massively decentralised system with dynamic two-way flows, demand side participation, distributed generation and eroding demand with emerging competitors.

Electricity use has historically grown with GDP and population. Electricity demand forecasting in Australia has long assumed that growth and demand are coupled, and this was reasonably accurate until around the 1990s. However demand peaked in 2009 and has declined since. At the same time, during the period 2010-15 Australian network operators spent over A\$46 billion on augmenting the networks for demand growth¹⁴¹ which was the major contributor to a doubling in retail electricity prices in most states. Higher costs accelerated residential and business energy efficiency efforts and the deployment of rooftop solar PV; Australia now has the highest proportion of PV of any country.¹⁴²

Australia will need to undertake significant change to decarbonise its electricity supply and remain internationally competitive in a carbon-constrained world. It has had a renewable energy target since 2000 which is currently set at 33TWh by 2020, forecast to be around 23% of demand then.¹⁴³ Australia had a carbon price mechanism in place for the period July 2012 to June 2014. Power sector emissions dropped notably during this period, but have begun

¹³⁹ Australian Government "Garnaut Climate Change Review" 2010 http://www.garnautreview.org.au/pdf/Garnaut_Chapter7.pdf

¹⁴⁰ Australian Academy of Technological Sciences and Engineering "Energy Action Statement" December 2014 <https://www.atse.org.au/Documents/policy/doubling-australias-energy-productivity.pdf>

¹⁴¹ Dunstan, C. & Langham, E. 2010, Close to Home: Potential Benefits of Decentralised Energy for NSW Electricity Consumers, prepared by the Institute for Sustainable Futures, University of Technology, Sydney for the City of Sydney, November 2010. http://cfsites1.uts.edu.au/find/isf/publications/dunstanlangham2010closetohome.pdf?_ga=1.197331815.972346035.1456379507

¹⁴² Energy Supply Association of Australia (Australian Energy Council) "Australia's Household Energy Use" as at 24 Feb 2016 http://www.esaa.com.au/media/australia_the_world_leader_in_rooftop_solar_daylight_second_1_1_1_1

¹⁴³ Australian Government Department of the Environment "Renewable Energy Target Scheme" 2015 <https://www.environment.gov.au/climate-change/renewable-energy-target-scheme>

6. Electricity System *continued*

to rise again since. The Climate Institute's CEO John Connor says the future of Australia's generation sector "is all about policy for coal plant closure; we'll still be largely coal-powered in 2030 without intervention".

Australia has excellent renewable energy resources for both centralised and decentralised generation. The nation's solar resource is regarded as the best in the world, and new wind generation is already cheaper than new coal generation even given Australia's vast resources of easily-accessible coal. University of Sydney Electrical Engineering expert Dr Gregor Verbic believes concentrated solar thermal makes sense in Australia, but needs large capital investment and is still expensive.

Decentralisation of the power system will play an important role determining the 2030 situation in Australia. The Grattan Institute's John Daley said he expected significant growth of decentralised energy, and CSIRO's Paul Graham said distributed energy resources (DERs) would replace the whole generation stock with DERs over time (though well beyond the 2030 timeframe). Graham says Australia has every renewable choice available and will likely gravitate to renewables and storage.

Three of the four scenarios in CSIRO's Network Transformation Roadmap report of December 2015¹⁴⁴ show grid electricity demand in 2030 at around 200TWh, with the fourth lower near 160TWh. All show the impact of an increasingly distributed energy system. We have adopted the 200TWh forecast.

ASEAN generally

Almost all the ASEAN member countries are planning to develop nuclear power plants in the near future but also have considerable renewable energy potential such as geothermal (Indonesia and Philippines), high solar radiation (between 3 - 5 kW/m²/day), biomass and hydro.¹⁴⁵ Other sources include IEA's World Energy Outlook 2015¹⁴⁶ and 2013¹⁴⁷ reports and the EIA.¹⁴⁸ In making electricity demand forecasts Utama assumes a linear relationship with GDP and population which appears to underestimate opportunities for energy

efficiency, which World Energy Outlook describe as huge, and decentralised energy, so likely overestimate demand. Demand forecasts are presented in the individual country summaries below.

There is some international electricity interconnection within ASEAN, and sixteen further interconnection projects are proposed to build an ASEAN Power Grid.¹⁴⁹ These include undersea links from the Malaysian mainland to Borneo and from Borneo to the Philippines. These are the existing international interconnection links:

- Malaysia-Singapore 450MW
- Thailand-Malaysia 380MW
- Thailand-Laos 2.1GW
- Laos-Vietnam 248MW
- Vietnam-Cambodia 170MW
- Thailand-Cambodia 100MW

The priority upcoming projects include:

- West Kalimantan-Sarawak (i.e. within Borneo) 230MW (2015)
- Malaysia-Sumatra 600MW (2015)

though actual delivery progress on ASEAN projects is often slower than planned.

It is worth also discussing hydropower projects on the SE Asian mainland, as these affect multiple countries. Laos and Myanmar have abundant hydro resources, and there are major plans for over 70 new dams on Mekong and tributaries in Laos, Cambodia and Vietnam.¹⁵⁰ Cambodia has historically relied on imported oil generation. New hydro capacity may convert the country into an energy exporter. Although, this seems very positive for the growth of renewable energy in the region, these developments come with significant environmental effects on the river and people living near it. The Mekong's flow is reportedly already 10% reduced, half the sediment no longer reaches the sea, and there are food security impacts on rice yields and fishing. Twenty percent of the world's rice crop is grown in the Mekong delta.¹⁵¹

¹⁴⁴ CSIRO and Energy Networks Association 2015, *Electricity Network Transformation Roadmap: Interim Program Report*. http://www.ena.asn.au/sites/default/files/roadmap_interim_program_report.pdf

¹⁴⁵ N. Agya Utama, K. N. I., Tetsuo Tezuka (2012). "Power Generation Optimization in ASEAN by 2030." *Energy and Power Engineering* 4: 226-232. <http://dx.doi.org/10.4236/epe.2012.44031>

¹⁴⁶ International Energy Association "Energy and Climate Change Report" 2015 <https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf>

¹⁴⁷ International Energy Agency "World Energy Outlook" 2013 <http://www.worldenergyoutlook.org/weo2013/>

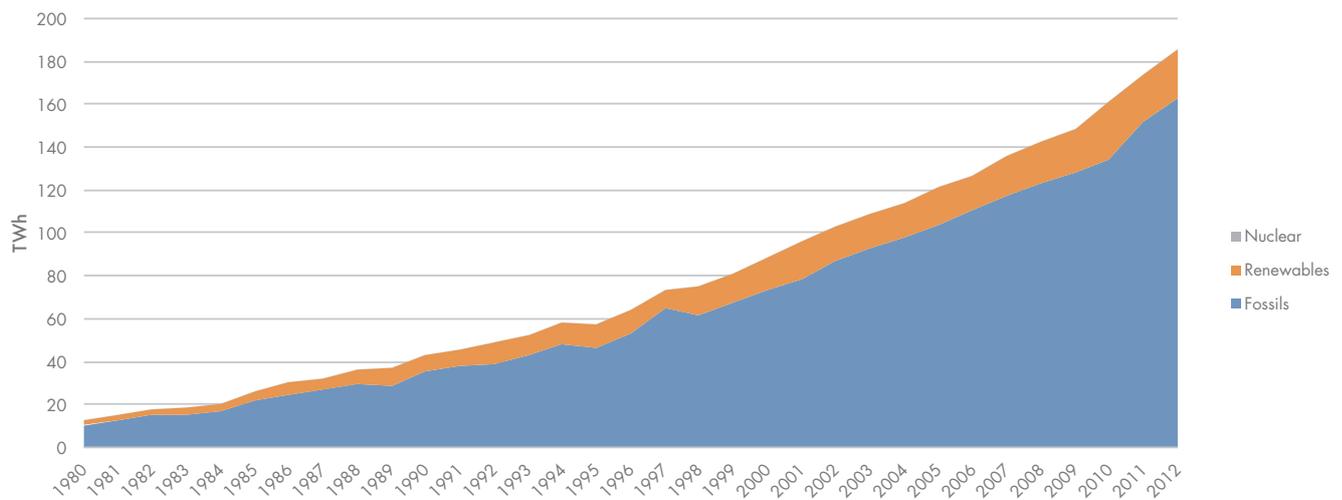
¹⁴⁸ US Government, Energy Information Administration, EIA Beta, <http://www.eia.gov/beta/international/>

¹⁴⁹ International Energy Association "ASEAN Power Grids Interconnection Projects for Energy Efficiency and Security Supply" November 2013 http://www.iea.org/media/training/bangkoknov13/session_1c_hapua_asean_perspectives.pdf

¹⁵⁰ Economic Consulting Associates (June 2010). The Potential of Regional Power Sector Integration Greater Mekong Subregion (GMS): Transmission & Trading Case Study. ESMAP Briefing Note 004/10. <https://openknowledge.worldbank.org/bitstream/handle/10986/17506/773070v40ESMAP0ter0Mekong0Subregion.txt?sequence=2&isAllowed=y>

¹⁵¹ Vidal, J. (Nov, 2015). Mekong: a river rising. *The Guardian*. <http://www.theguardian.com/environment/ng-interactive/2015/nov/26/the-mekong-river-stories-from-the-heart-of-the-climate-crisis-interactive>

Indonesia: Electricity Generation by Primary Fuel 1980-2012



Indonesia

Indonesia is the largest energy user in ASEAN and has significant resources of coal. It is a major coal exporter. Growth in generation has not kept pace with demand, leading to power shortages in grid-connected areas and limited growth in electrification which was 78% in 2014.¹⁵² Eastern Indonesia trails the rest of the country with only 43% electrification in West Papua. Per capita electricity consumption is low at 660kWh per person per year, and just 12% of final energy is currently delivered as electricity. Prices are kept artificially low by subsidy resulting in poor energy efficiency, and energy growth currently exceeds GDP growth.¹⁵³

Indonesia had around 51GW generation in 2013 with 88% fossil fuel, 8% hydro and 7% geothermal capacity.¹⁵⁴ ¹⁵⁵ The nation has been rapidly adding coal generation to increase the electrification rate. Indonesian fossil fuel power-plants are heavily subsidised, making it difficult for other forms of generation to displace them.¹⁵⁶ Utama et al forecast a 2030 energy mix of 52% coal, 29% gas and 13% geothermal, though hydro could be a much larger share if plans to generate in West Papua with a HVDC subsea link to the western islands eventuate.

The government regulates power prices below the costs of monopoly utility PLN but has recently raised prices. It aims to stimulate the addition of 35GW new generation by 2019, largely from foreign investment, 20GW forecasted to be coal power. Indonesia has a goal to reduce energy intensity by 1% each year until 2025 and to increase the share of “new and renewable” energy to 23% by 2025 and 31% by 2050. It aims to increase household electrification to 99% by 2020 and 100% by 2025.¹⁵⁷

Indonesia’s Deep Decarbonisation Plan report expects remote communities to be electrified with PV and micro hydro rather than by network connection. At the centralised level this plan accentuates the need to reduce the share of oil and coal by increasing gas generation, renewables and nuclear. It also suggests the introduction of carbon capture and storage so local coal can still be used. The plan forecasts that electricity’s share of final energy will increase to 35% in 2050. The report forecasts 2030 demand around 450TWh in all three scenarios.

¹⁵² Ucock W.R. Siagian, R. G. D., Iwan Hendrawan, Rizaldi Boer, Gito Emmanuel Gintings. (Sep, 2014). *Pathways to deep decarbonization - 2014 report; Indonesia chapter*, http://unsdsn.org/wp-content/uploads/2014/09/DDPP_2014_report_Indonesia_chapter.pdf

¹⁵³ US Energy Information Administration Indonesia Overview as at 7 October 2015 <https://www.eia.gov/beta/international/analysis.cfm?iso=IDN>

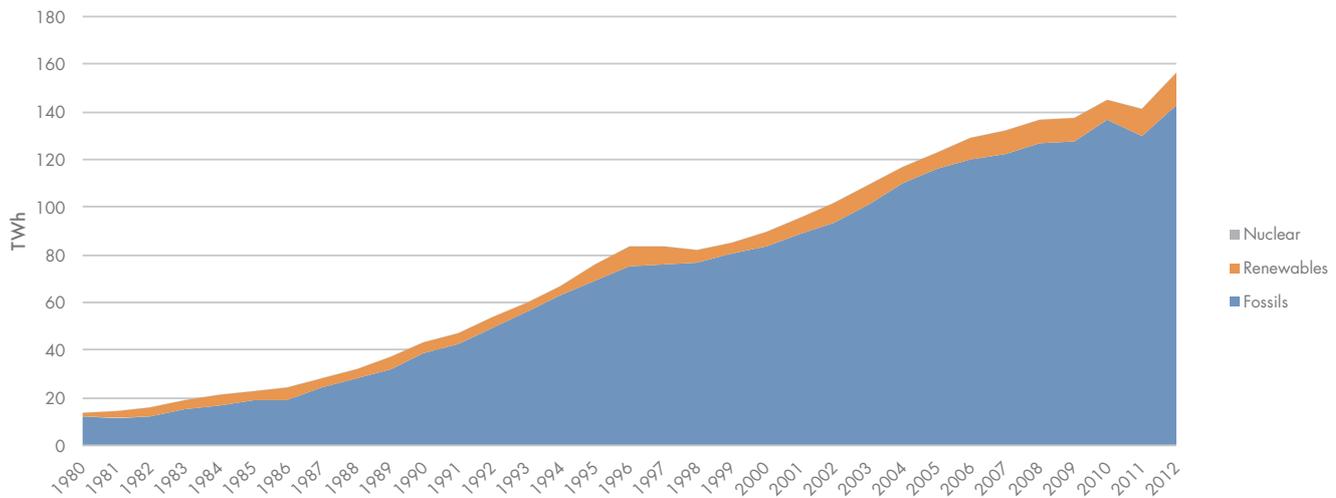
¹⁵⁴ US Energy Information Administration Indonesia Overview as at 7 October 2015 <https://www.eia.gov/beta/international/analysis.cfm?iso=IDN>

¹⁵⁵ Ucock W.R. Siagian, R. G. D., Iwan Hendrawan, Rizaldi Boer, Gito Emmanuel Gintings. (Sep, 2014). *Pathways to deep decarbonization - 2014 report; Indonesia chapter*, http://unsdsn.org/wp-content/uploads/2014/09/DDPP_2014_report_Indonesia_chapter.pdf

¹⁵⁶ N. Agya Utama, K. N. I., Tetsuo Tezuka (2012). “Power Generation Optimization in ASEAN by 2030.” *Energy and Power Engineering* 4: 226-232. <http://dx.doi.org/10.4236/epe.2012.44031>

¹⁵⁷ US Energy Information Administration Indonesia Overview as at 7 October 2015 <https://www.eia.gov/beta/international/analysis.cfm?iso=IDN>

Thailand: Electricity Generation by Primary Fuel 1980-2012



Thailand

Thailand is the second-largest energy user in ASEAN, and its power sector developed fast in the 1980s and the early 1990s. It has limited traditional energy resources and has been heavily dependent on fuel imports, consequently Thailand now aims to diversify generation and import electricity as well as fuel. 2011 peak demand was around 26GW dominated by gas power. Two commercial nuclear reactors have been planned since 2007 though progress has stalled since the Fukushima Daiichi accident.

Thailand has goals to reduce energy intensity by 25% by 2030 and 30% by 2036 compared with 2010 through removal of fossil-fuel subsidies and accelerated energy efficiency improvements, and for renewables to reach 20% of power generation.¹⁵⁸ Thailand has an energy efficiency revolving fund and an ESCO fund to help finance energy efficiency projects.¹⁵⁹

Power generation capacity is to be increased to 71 GW in 2030, with a gradual reduction in the share of natural gas and introduction of nuclear power from 2026. Thailand aims to increase the share of renewable energy in final consumption to 25% by 2021 and to reduce energy intensity by 25% by 2030 compared with 2005 levels.¹⁶⁰ The Thai Ministry of Energy 2012 Power Development Plan forecasts 2030 demand at 347TWh.¹⁶¹

Thailand intends to use international interconnection for 6.6GW capacity by 2030 though recognises the disadvantages of this approach in system security, transmission losses and loss of local skills.¹⁶² It has interconnection MoUs with:

- Laos for 7GW, delivered 2.1GW, PPA signed for another 3.3GW
- Myanmar for 1.5GW starting 2018
- Malaysia, delivered 0.4GW, potential +0.9GW
- China 3GW, earliest 2019
- Cambodia 1.9GW potential, no current plans

Malaysia

Malaysia is the third largest energy consumer in ASEAN with relatively high per capita consumption. Capacity in 2011 was 26GW comprised of around 13GW gas, 6GW coal and 5GW renewables including 2GW hydro. The 10th Malaysia Plan emphasises energy security and economic efficiency along with environmental and social considerations. The ERIA power sector forecasts show generation growing to 34GW in 2030.

Malaysia has a goal to increase renewable capacity to achieve 985 MW of installed renewable power capacity by 2015, contributing 6% of generation, rising to 2GW (13%) in 2020 and 4GW by 2030. It

¹⁵⁸ International Energy Agency "World Energy Outlook" 2013 <http://www.worldenergyoutlook.org/weo2013/>

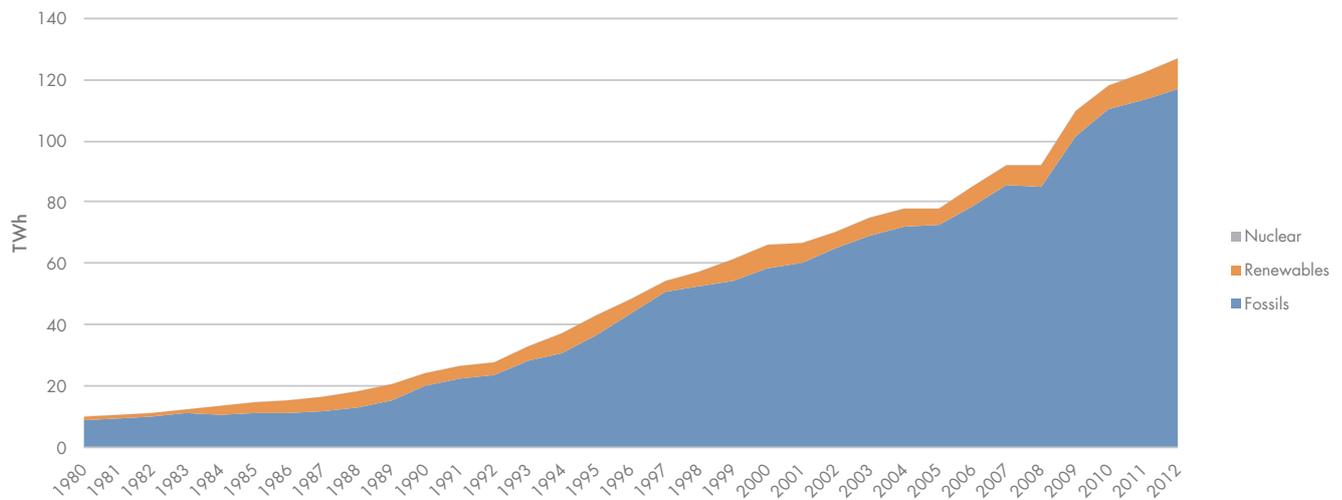
¹⁵⁹ Centre for Clean Air Policy "Thailand's Energy Conservation Fund" October 2012 http://ccap.org/assets/Thailand-Energy-Conservation-ENCON-Fund_CCAP-Oct-2012.pdf

¹⁶⁰ Centre for Clean Air Policy "Thailand's Energy Conservation Fund" October 2012 http://ccap.org/assets/Thailand-Energy-Conservation-ENCON-Fund_CCAP-Oct-2012.pdf

¹⁶¹ Fungtammasan. B. (2016) 'Thailand: Energy Outlook and the Contribution of JGSEE', The Joint Graduate School of Energy and Environment (JGSEE) and Center for Energy Technology and Environment (CEE), King Mongkut's University of Technology Thonburi, Bangkok, Thailand, SEE Forum, <http://www.seeforum.net/countryreport/thailand.html>

¹⁶² http://www.iea.org/media/training/bangkoknov13/session_9b_egat_bilateral_interconnection.pdf

Malaysia: Electricity Generation by Primary Fuel 1980-2012



also plans a 10% reduction in energy intensity by 2030 compared to business-as-usual. Nuclear power is seen as a longer term option. Malaysia plans to reduce CO₂-e emissions intensity of GDP by up to 40% compared with 2005 levels by 2020, contingent upon technology transfer and financial support from developed countries.

Utama et al¹⁶³ quote a Malaysian plan for electricity demand to increase to 274 TWh by 2030. They suggest renewables will be the best development option for Malaysia predicting lower costs than for fossil fuel power with a 2030 energy mix forecast of 43% hydro and 29% each of solar and biomass.

Another Malaysia 2030 demand forecast from Tan et al¹⁶⁴ is 316TWh which appears to be more likely. We have adopted the Tan demand forecast.

Vietnam

Vietnam has significant renewable and fossil energy resources and is developing nuclear. It has the fastest-growing electricity demand of all the ASEAN economies with growth currently 12%. It is likely to become the largest ASEAN electricity user by 2030, though will likely rely more on imports to ensure supply at that level of demand.

2015 generation capacity was around 40GW: 33% hydro, 25% gas, 36% coal, with a small level of power imports. Load in 2015 had grown to 170TWh. Presently it is cheaper for Vietnam to import from China than to replace thermal plant. Going forward the relative economics of local centralised and decentralised energy compared to imports will determine the future shape of the electricity system. There are two interconnectors to China (Yunnan) for import with a third planned, and one to Cambodia (Phnom Penh) for export with another planned as well as a new interconnector to Laos.¹⁶⁵

A competitive generation market since 2011, Vietnam now plans to reduce energy consumption relative to business as usual by 5% to 8% by 2015 and 8-10% by 2020. It will increase the share of renewables in electricity generation to 4.5% by 2020 and 6% by 2030, and develop 10.7 GW of nuclear power capacity by 2030. It plans to cut CO₂-e emissions intensity by 8-10% by 2020 compared with 2010 levels.¹⁶⁶ Vietnam aims to reach 100% electrification of rural households by 2020.¹⁶⁷

Vietnam should reach 75GW of generation capacity by 2020 and double again to 150 GW by 2030 by encouraging private investment in the power sector.

¹⁶³ N. Agya Utama, K. N. I., Tetsuo Tezuka (2012). "Power Generation Optimization in ASEAN by 2030." *Energy and Power Engineering* 4: 226-232. <http://dx.doi.org/10.4236/epe.2012.44031>

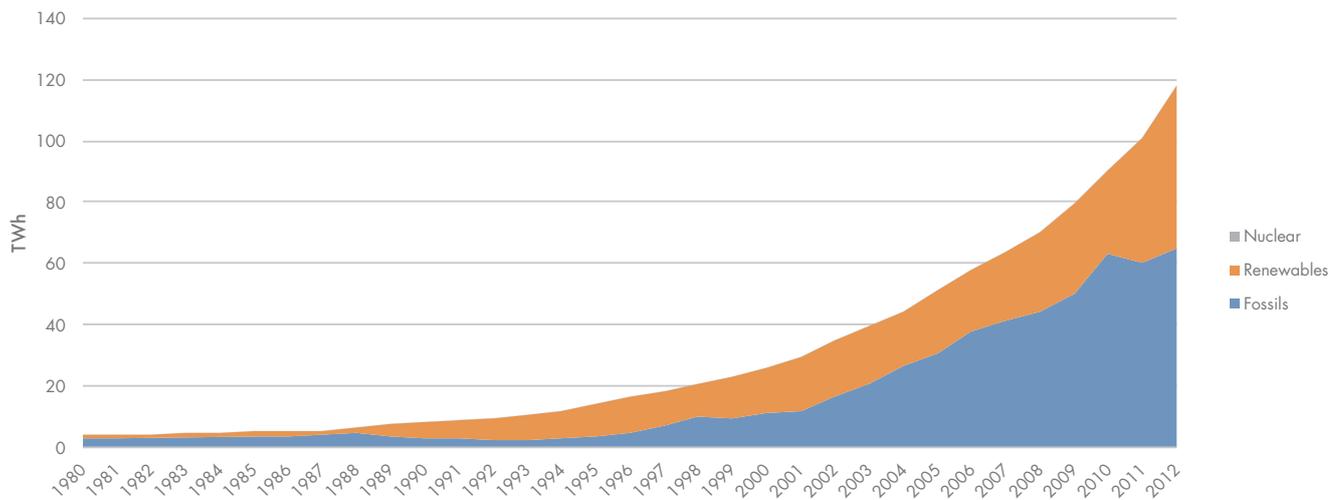
¹⁶⁴ Tan C.S., Maragatham. K. a. Leong. Y. P. (2013). "Electricity energy outlook in Malaysia." *Earth and Environmental Science* Vol. 16, 012126. (IOP Conf. Series). <http://iopscience.iop.org/article/10.1088/1755-1315/16/1/012126>

¹⁶⁵ US Energy Information Administration Indonesia Overview November 2014 <http://www.eia.gov/beta/international/analysis.cfm?iso=VNM>

¹⁶⁶ Anne Zimmer Michael Jakob, J. S. (2013). What motivates Vietnam to strive for a low-carbon economy? – An explorative case study on the drivers of climate policy in a developing country. International Conference on Public Policy, Potsdam Institute for Climate Impact Research. www.icpublicpolicy.org/IMG/pdf/panel_46_s2_zimmer.pdf

¹⁶⁷ Mayer Brown JSM, "Vietnam Power Development Plan for the 2011-2020 Period" September 2011 <https://m.mayerbrown.com/Files/Publication/7eb02f45-1783-4f14-8565-bf5120e1ea08/Presentation/PublicationAttachment/5dcbbea1-2d9f-42ae-8cbd-dab-97456c4c5/11556.pdf>

Vietnam: Electricity Generation by Primary Fuel 1980-2012



Total 2030 demand is forecasted at 615TWh according to EIA. Another forecast expects 548TWh by 2030,¹⁶⁸ and there are a wide range of other scenarios in government with other forecasts showing demand from as low as 400TWh to as high as 830TWh. We have adopted a mid-level scenario of 572TWh.

Philippines

The Philippines is already the world’s second largest geothermal producer, and increasing electricity demand requires power sector expansion. Generation capacity in 2010 was a little over 16GW comprised of 5GW coal, 3GW oil and diesel, 3GW gas, 3.4GW hydro and 2GW hydro. Household electrification rates are around 70%.^{169 170} The Philippine Energy Plan (PEP 2012-2030)¹⁷¹ has measures including securing energy security through expanded use of renewables as well as developing coal and oil resources.

Utama et al¹⁷² quote a Philippines 2030 plan which shows 34% low-carbon energy. They suggest geothermal in the Philippines looks cheaper than fossil fuels or nuclear, and they instead forecast a 2030 energy mix of 63% geothermal, 18% hydro and 17% coal.

The Philippines government aims for energy savings equivalent to 15% of annual final demand relative to BAU by 2020 and to triple the installed capacity of renewables power generation to 15GW by 2030 with most of the growth from geothermal and hydropower. The nation plans to increase the household electrification rate to 90% by 2017 with 100% electrification of small townships due to have occurred in 2015. The Philippines is suited to inter-island transmission, perhaps sub-sea HVDC, though the economics of local generation will determine whether that is economic.

The IEA projects an increase of generation capacity from 16GW in 2011 to 29GW in 2030 with an expanded grid interconnecting all major islands.¹⁷³ The ERIA power sector forecasts show generation growing to almost 33GW in 2030.¹⁷⁴ The Government’s 2030 plan shows a demand of 149TWh which we have adopted.

Singapore

Singapore’s generation capacity in 2010 was 12.3 GW, primarily gas- and oil-fired. According to the IEA, key strategies going forward include diversification of energy supplies, enhancing infrastructure and systems,

¹⁶⁸ National Energy Institute of Vietnam “Briefing on the adjustment of the National Power Development Plan 2011 – 2020 Vision 2030 (PDP7)” May 2014 <http://www.gms-eoc.org/uploads/resources/435/attachment/SEA-PDP7-Adjustment-2011-2020-Vision.pdf>

¹⁶⁹ Somani et al (2013). *The Energy Report Philippines: Growth and Opportunities in the Philippine Electric Power Sector 2013-2014 Edition*. www.kpmg.com/global/en/.../documents/energy-report-philippines.pdf

¹⁷⁰ US Energy Information Administration Indonesia Overview December 2014 <http://www.eia.gov/beta/international/analysis.cfm?iso=PHL>

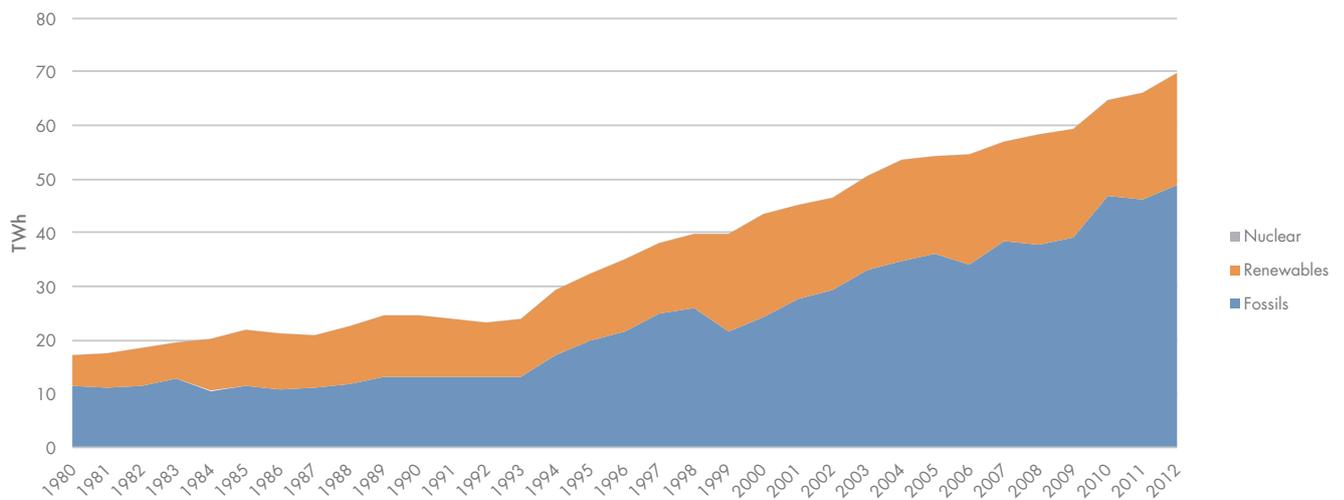
¹⁷¹ Republic of the Philippines Department of Energy “2012 – 2030 Energy Plan” <http://www.doe.gov.ph/policy-and-planning/philippine-energy-plan>

¹⁷² N. Agya Utama, K. N. I., Tetsuo Tezuka (2012). “Power Generation Optimization in ASEAN by 2030.” *Energy and Power Engineering* 4: 226-232. <http://dx.doi.org/10.4236/epe.2012.44031>

¹⁷³ International Energy Agency “Energy and Climate Change Report” 2015 <https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf>

¹⁷⁴ Working Group for the “Study on Effective Investment of Power Infrastructure in East Asia through Power Grid Interconnection” (2013), ‘Power Infrastructure Developing Plan in Each Country’, in Kutani, I. (ed.), *Study on Effective Investment of Power Infrastructure in East Asia through Power Grid Interconnection*. ERIA Research Project Report 2012-23, pp.6-56. http://www.eria.org/RPR_FY2012_No.23_chapter_2.pdf

Philippines: Electricity Generation by Primary Fuel 1980-2012



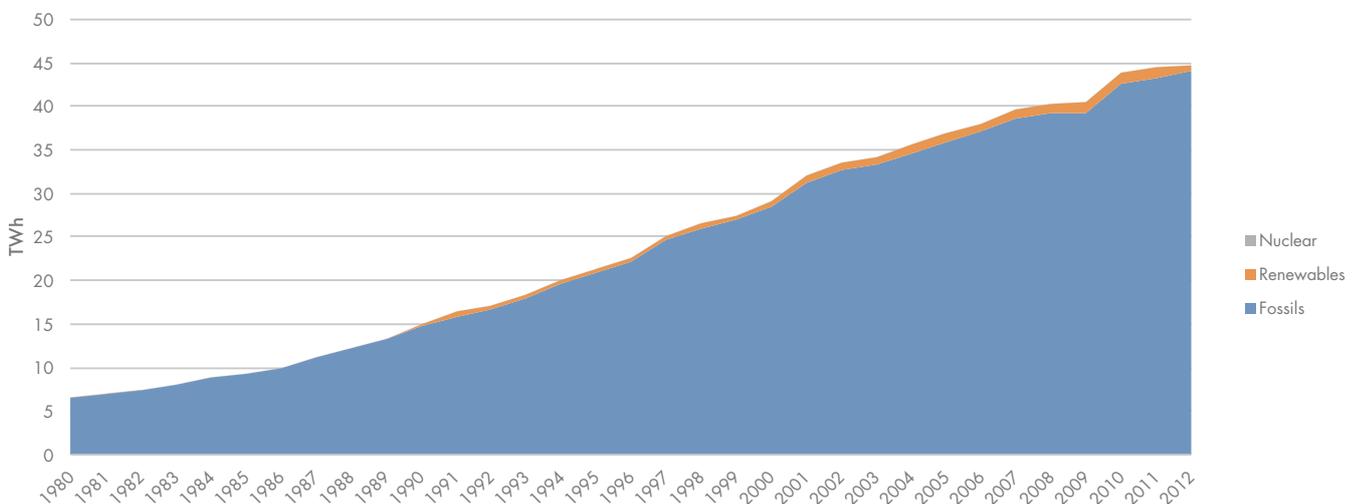
improving energy efficiency, strengthening the green economy while ensuring competitive energy pricing.¹⁷⁵

levels.¹⁷⁷ It aims to have 5% of peak electricity demand supplied from renewable energy sources by 2020.¹⁷⁸

Singapore plans to reduce energy intensity by 35% by 2030 from 2005 levels¹⁷⁶ and to reduce GHG emissions intensity by 36% by 2030 from 2005

The ERIA power sector forecasts show generation growing to 16.5GW in 2030, supplying demand of around 71GWh.¹⁷⁹

Singapore: Electricity Generation by Primary Fuel 1980-2012



¹⁷⁵ International Energy Agency "South East Asia Energy Outlook Report" 2015 https://www.iea.org/publications/freepublications/publication/WEO2015_SouthEastAsia.pdf

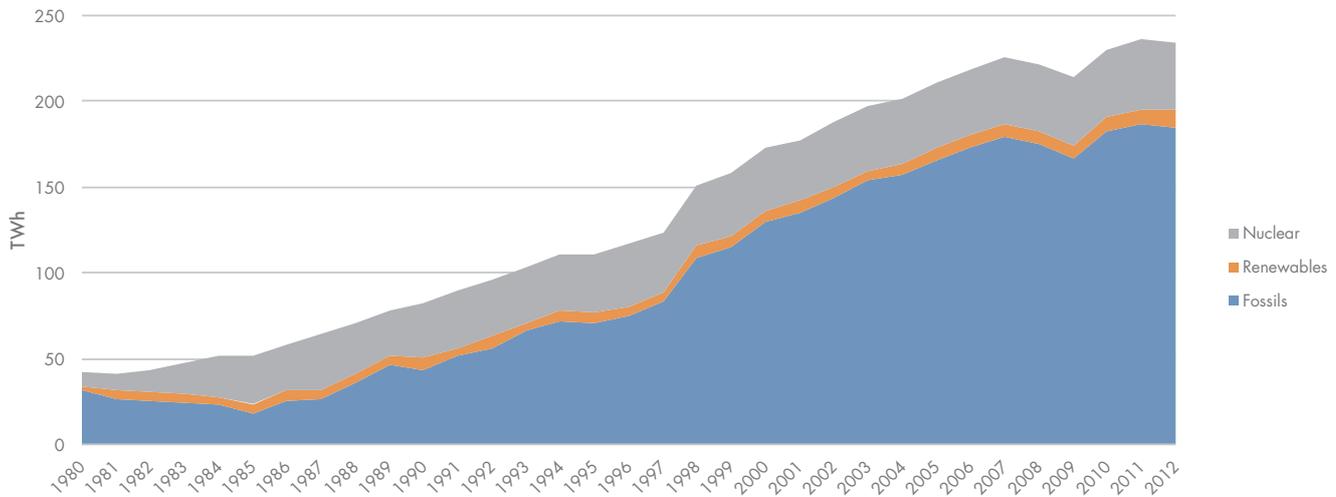
¹⁷⁶ Singapore Government Energy Market Authority "Update on Singapore's Energy Efficiency measures to contribute to APEC's 45% Energy Intensity Reduction Target - Presentation to 43rd APEC Expert Group on Energy Efficiency & Conservation Meeting" April 2014 www.egeec.apec.org/dmsdocument/472

¹⁷⁷ Climate Action Tracker Singapore Report <http://climateactiontracker.org/countries/singapore.html>

¹⁷⁸ Singapore Government National Climate Change Secretariat "The Straits Times: S'pore powers towards energy target with new solar projects" From the Singapore Press Holdings October 2014 <https://www.nccs.gov.sg/news/straits-times-spore-powers-towards-energy-target-new-solar-projects>

¹⁷⁹ Working Group for the "Study on Effective Investment of Power Infrastructure in East Asia through Power Grid Interconnection" (2013), 'Power Infrastructure Developing Plan in Each Country', in Kutani, I. (ed.), Study on Effective Investment of Power Infrastructure in East Asia through Power Grid Interconnection. ERIA Research Project Report 2012-23, pp.6-56. http://www.eria.org/RPR_FY2012_No.23_chapter_2.pdf

Taiwan: Electricity Generation by Primary Fuel 1980-2012



Taiwan

Taiwan imports 97.5% of its energy, which is vital to its rapidly industrialising economy. Per capita electricity consumption is high at 10,424kWh (in 2012). Energy demand grew at 3.5% per year over 1992-2012, and in 2012 half the demand was for electricity. Over that period, LNG imports grew eight-fold, mostly for electricity. Coal (47% share), natural gas (29% share), and nuclear power (16% share) make up the bulk of the island’s generation mix.¹⁸⁰

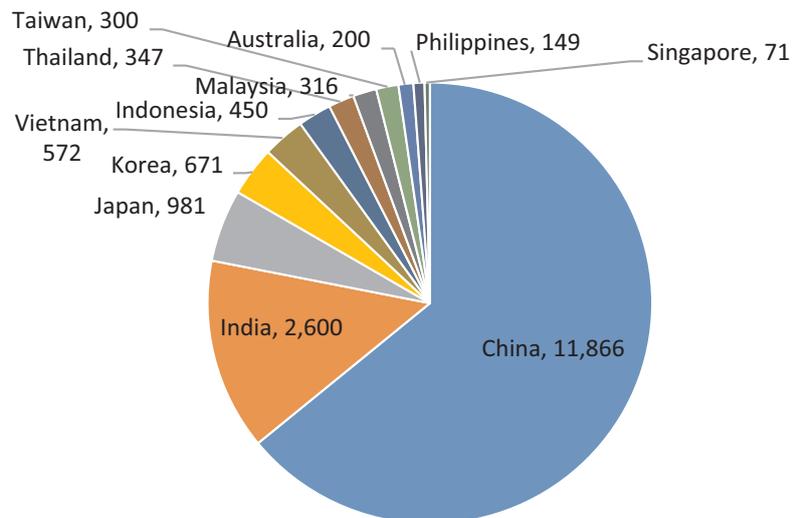
Generating capacity in 2012 was 48.4GW, with 17.4GW coal, 15.9GW LNG, 5.1GW nuclear, 4.7 GW hydro (including pumped storage), 0.57GW wind and 0.22GW solar. There has been a concerted program to develop capacity under the Renewable Energy Development Act of 2009, and by the end of 2013, 3.76GW was installed. The Ministry of Economic Affairs (MOEA) target is 9.95 GWe by 2030.¹⁸¹

Taiwan’s Industrial Technology Research Institute (ITRI) forecasts 2030 demand of 300TWh.¹⁸²

NATIONAL ELECTRICITY DEMAND FORECAST SUMMARY

Despite improvements in energy efficiency, the combination of population growth, increased rates of electrification and new electric loads will create considerable electricity demand growth in Asia by 2030. Consolidating the 2030 demand forecasts for each country, the 2030 electricity demand for the countries of interest is a little over 18,500TWh in total, aggregated as follows:

2030 Electricity Demand by Country (TWh)

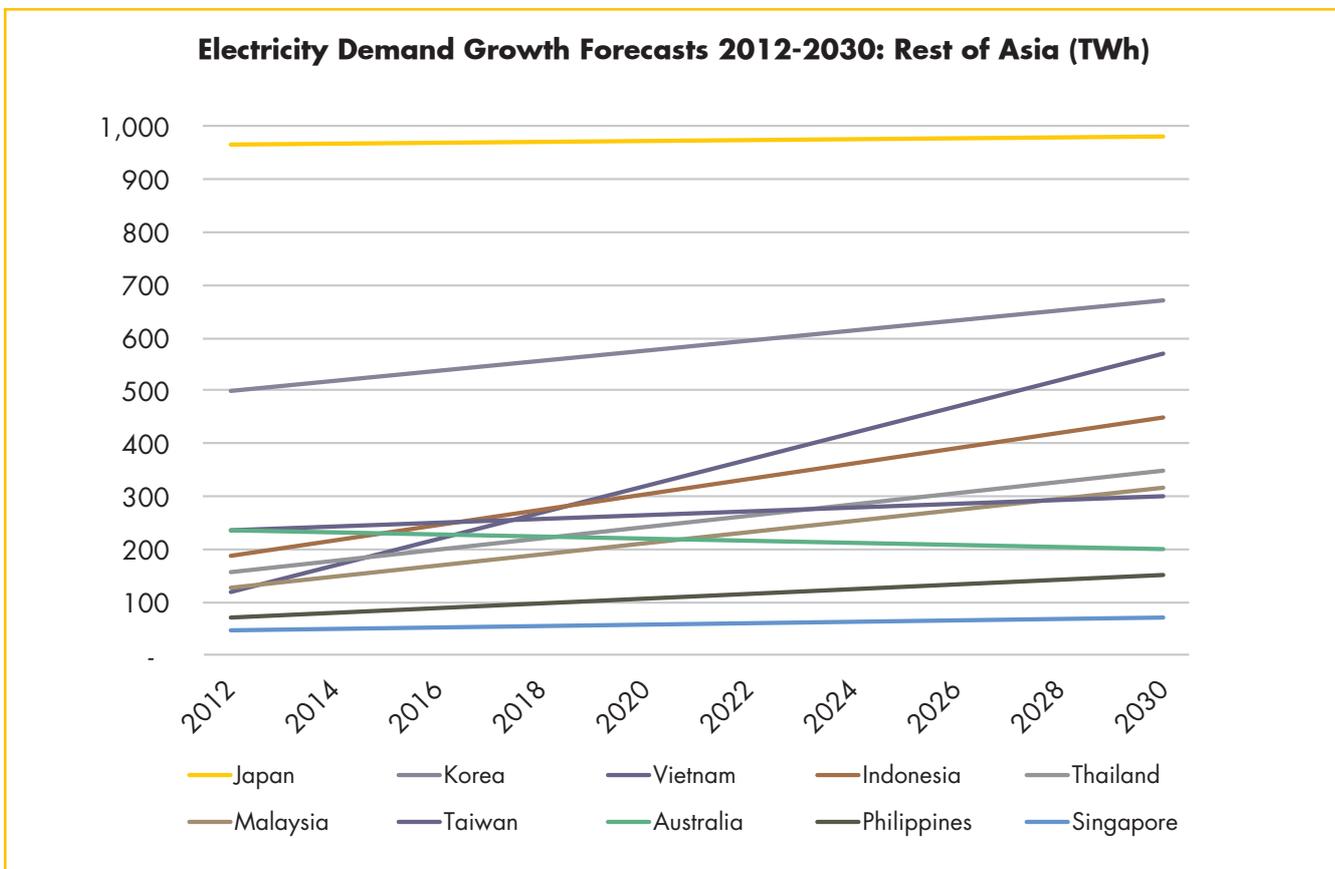
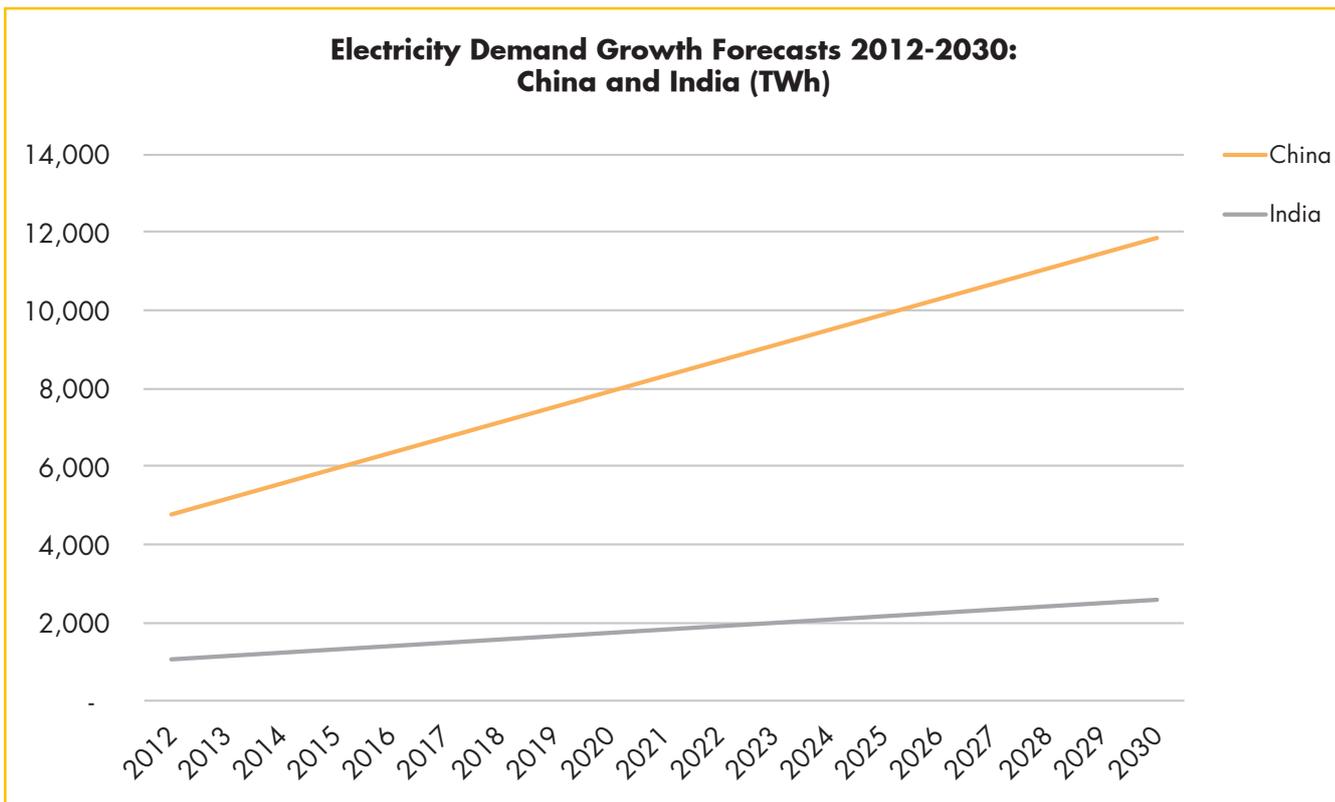


¹⁸⁰ US Energy Information Administration Taiwan Overview September 2015, <https://www.eia.gov/beta/international/analysis.cfm?iso=TW>

¹⁸¹ World Nuclear Association January 2016 <http://www.world-nuclear.org/info/country-profiles/others/nuclear-power-in-taiwan/>

¹⁸² Industrial Research Technology Institute Taiwan “Presentation on the The development and applications of the Taiwan 2050 Calculator” October 2015 http://www.digitimes.com.tw/seminar/itri_20150210/pdf/0210_final/0210-B.pdf

The charts below show the growth from 2012 actual demand to the forecast 2030 levels:



Analysis concentrates mainly on China and India in the following sections.

SOUTH-EAST ASIAN OR GLOBAL SUPERGRID

President and CEO of State Grid Corporation of China, Liu Zhenya, is the author of the book *Global Energy Interconnection*.¹⁸³ In this publication and elsewhere^{184 185}, Liu states the case to create a global Energy Internet and Interconnection (GEI) based on Ultra High Voltage AC and DC transmission links and smart grid technology to provide a secure means of promoting clean, cost-effective and sustainable energy. Liu discusses UHV DC (ultra-high-voltage direct current transmission) technology which “with overhead lines may be adopted [for connecting arctic wind bases to China], while UHV DC submarine cables may be used to support transmission to Japan and S Korea”. For connecting solar in NW Australia to SE Asia, he suggests “UHV submarine cables ~500km long to land on Indonesia, then onshore to Jakarta, a short distance undersea to Thailand via Singapore and Malaysia.” This latter line would be over 6000km, beyond the maximum distance for current 1100kV UHV DC, consequently Liu suggests innovation would be needed to realise it.

This is an important and potentially game-changing idea. The capital expenditure would be enormous and it would require serious long-term international cooperation. This concept moves strongly against the trend towards decentralisation of power systems, discussed in a following section.

There are a number of existing and planned international interconnections in Southeast Asia as discussed above, and China already exports power to Vietnam and a link to Thailand is being constructed. India has a single international connector to the Bhutan mega hydro project. There are only two international interconnections in Northeast Asia: one from China to Mongolia and the other recently built from Busan in South Korea to Japan. Various others are planned, including an interconnector between Mongolia to Japan and one between China and North Korea. University of Sydney law researcher Penelope Crossley suggests that while there are precedents of internationally interlinked power systems, particularly in the EU, Northeast Asia is different in that it does not have a strong body to share standards and technical information to ensure a common, coordinated approach. China’s diplomatic approach is generally bilateral. Some experts suggest China may not have the political will to secure the multi-lateral support needed for a truly regional or global interconnected system. Additionally, China also

benefits from the sale of decentralised energy equipment. Certain actors may be ambivalent if the future emerges to be less centralised than envisioned by State Grid.

Such international agreement would be a reversal of the recent experience of trade disputes, particularly around renewable technology. Most countries in the region have local content requirements (officially or unofficially) and a local partner. Perhaps new Free Trade Agreements planned and enacted may support international interconnection, but we think there is a low probability of a major regionally-interconnected power system being in place by 2030.

IMPLICATIONS FOR COPPER

There will be an enormous growth in power generation, transmission, distribution and residential electrification in Asia by 2030. This is clearly positive for copper and should drive significant copper demand throughout global supply chains, not just within the countries themselves. China is increasingly a major part of those supply chains. The main elements of this growth and the combination of technologies likely will be explored further in the following sections.

The proposed ASEAN undersea links would drive copper demand, but we are doubtful whether they will proceed given the decentralisation of energy expected in each country by 2030. Likewise, we are dubious about the prospects of the international supergrid proposed by China’s State Grid. Some interconnections already exist, and there will certainly be additions, but we suspect that in many cases nations will be reluctant to be dependent on a larger neighbour for power when local energy systems are becoming more commercially viable. Even if connections do proceed, the majority of long-distance transmission lines will be above-ground with aluminium conductors.

DECARBONISATION OF ELECTRICITY THE GLOBAL SHIFT FROM COAL TO RENEWABLES

Despite repeated forecasts from the IEA and others that coal will remain the dominant primary energy source globally for the foreseeable future, 2015 saw a continuing global move away from the fuel. This is particularly relevant to Asia as the five largest importers of coal are, in order: China, Japan, Korea, India and Taiwan.¹⁸⁶

¹⁸³ Liu, Z. (2015). *Global Energy Interconnection*, 1st Edition, Academic Press.

¹⁸⁴ State Grid Corporation of China “*Workshop on Technologies and Equipment for Global Energy Interconnection Held in Chicago, US*” November 2015 <http://www.sgcc.com.cn/ywlm/mediacenter/corporatenews/11/330171.shtml>

¹⁸⁵ China Daily 25 January 2016, “*Global Energy ‘Internet’*” http://www.chinadaily.com.cn/opinion/2016-01/25/content_23226651.htm

¹⁸⁶ IndexMundi, Coal Imports by Country (2015), <http://www.indexmundi.com/energy.aspx?product=coal&graph=imports&display=rank> accessed Feb, 2016

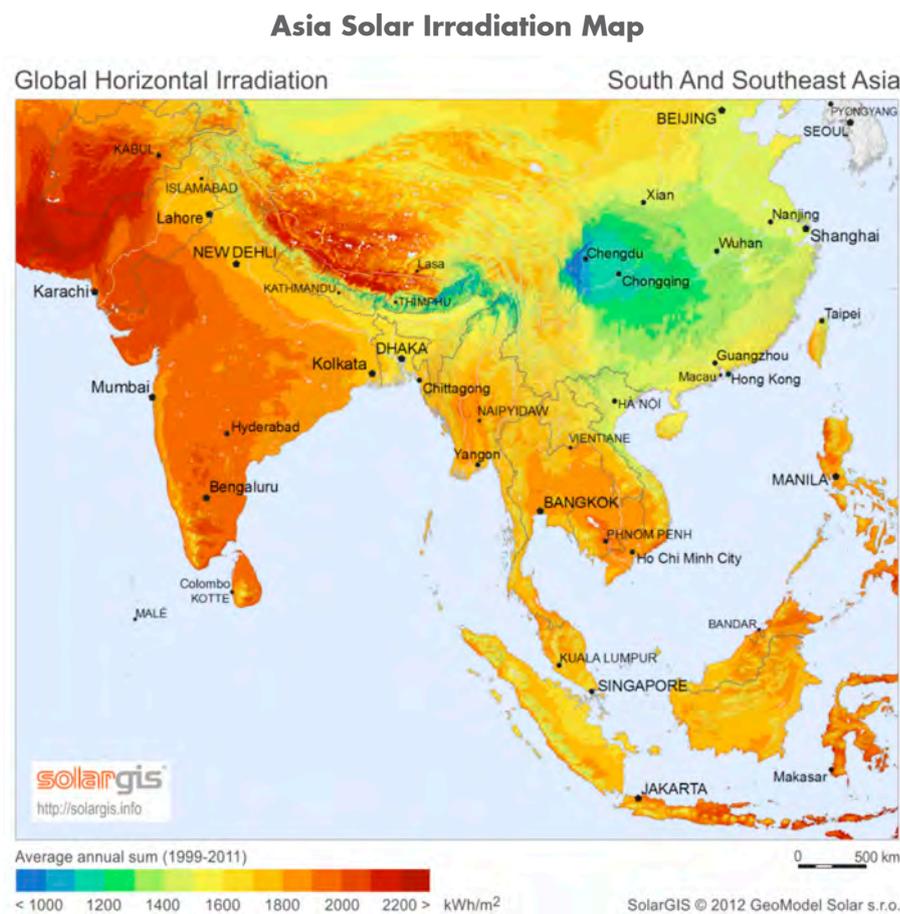
Some experts interviewed suggested that, while China is seeing a decline in the rate of growth of coal consumption, overall consumption will continue to increase for some time. The evidence suggests, however, that absolute coal consumption, in China and globally, has peaked in the past two years and is already declining. According to Analyst Tim Buckley of IEEFA, thermal coal import demand is now in decline: "History could well record 2013-2014 as showing that China coal production and consumption peaked, international coal imports peaked, and global consumption of coal peaked as well."¹⁸⁷ Latest figures show 2015 Chinese coal consumption was down 5% and coal imports down 35% year on year. China recently announced

the closure of 1000 coal mines in 2016 and has imposed a 3-year moratorium on new coal mines.¹⁸⁸ India is unlikely to import coal at scale in the future as, according to Buckley and as noted earlier, electricity generated from a new imported coal-fired power plant is now "materially more expensive than the cost of utility-scale solar, hydro, wind or gas-fired power, and double the cost of domestic coal-fired power generation."

While macroeconomic forces also affect coal prices, strong declines on coal prices may confirm these trends. Export coal prices have fallen steadily from a peak in January 2011 of over US\$140 to less than US\$56 in October 2015.¹⁸⁹

REGIONAL RENEWABLE RESOURCES

The potential for wind and solar generation clearly varies by region, and countries are planning their mix of decarbonisation technologies accordingly. The following charts indicate the main renewable resources in our region of interest.



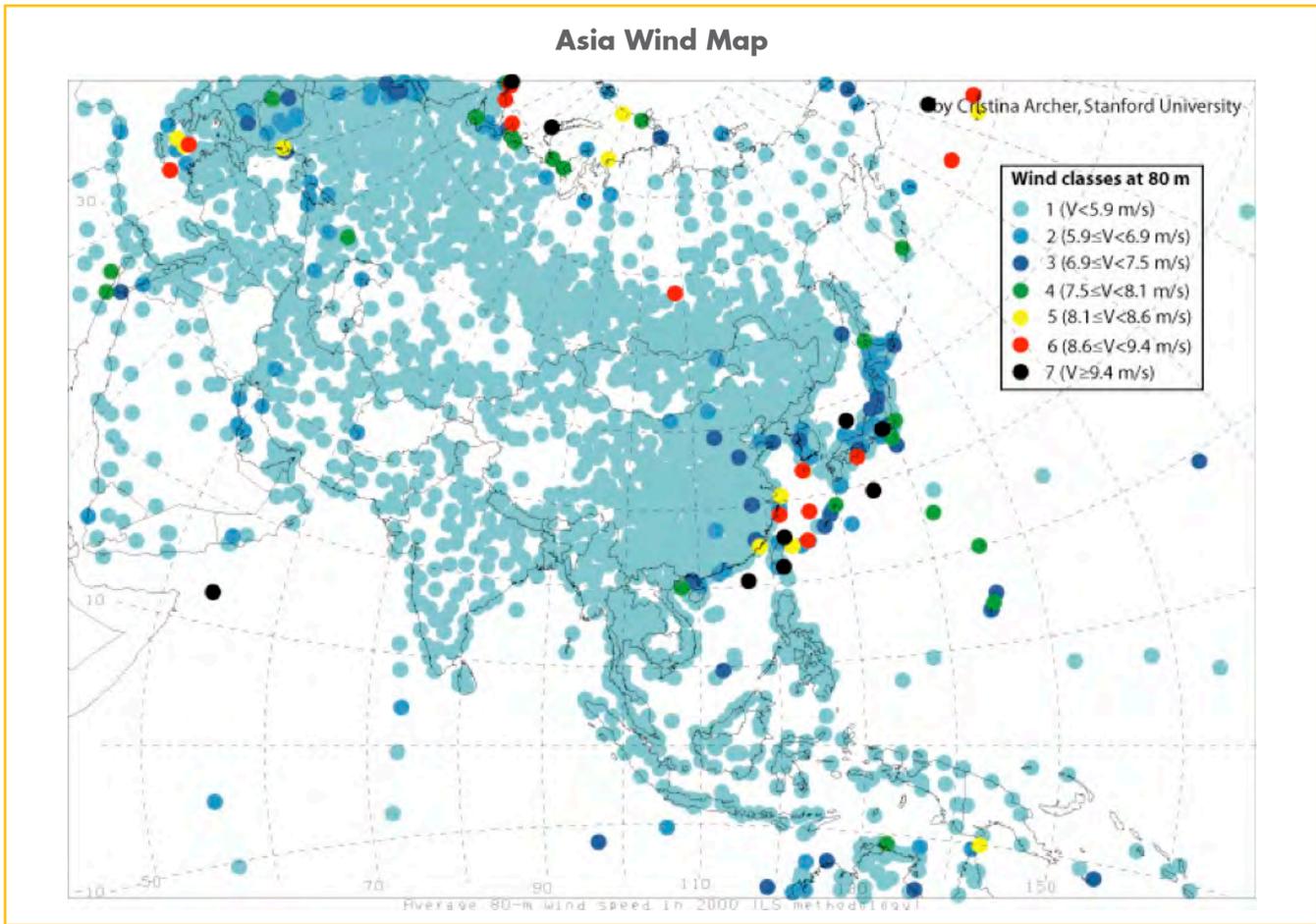
Source: SolarGIS © 2016 GeoModel Solar¹⁹⁰

¹⁸⁷ Buckley, T (2015) 'Past Peak Coal in China, Institute for Energy Economics and Financial Analysis (IEEFA), http://ieefa.org/wp-content/uploads/2015/11/IEEFA_Peak-Coal_November-2015.pdf

¹⁸⁸ Williams-Derry, C. (2016) Five Facts about Declining Coal Markets, , Institute for Energy Economics and Financial Analysis (IEEFA), <http://ieefa.org/commentary-five-facts-about-declining-coal-markets/>

¹⁸⁹ IndexMundi (2016), Aussie Mining Boom 2016, <http://www.indexmundi.com/commodities/?commodity=coal-australian&months=60>

¹⁹⁰ SolarGIS © 2016 GeoModel Solar, used with permission.



Source: Archer, C., and Jacobson, M. (2005) Evaluation of global wind power, *Journal of Geophysical Research*, Department of Civil and Environmental Engineering, Stanford University, Stanford, California, USA, Vol. 110, D12110, doi:10.1029/2004JD005462

IMPACT ON COPPER OF INCREASING LEVELS OF RENEWABLES

Renewable energy generation is more copper intensive than non-renewable energy, with estimates of the factor ranging from four to twelve times.^{191 192 193} While conventional power requires approximately one tonne of copper per installed MW, renewable technologies such as wind and solar require much more copper per installed MW. According to Harmsen et al,¹⁹⁴ "Given that virtually all renewable energy is found in a far more diffuse form than fossil fuels, it requires a multitude of installations to extract it. This, in turn, means an increasing material intensity for the worldwide renewable energy supply system compared to the current system".

Despite having a low copper intensity, in 2010 coal and gas generation commanded 68% of copper stocks in the electricity generation sector due to their market dominance, with wind and solar at 6% and 10% respectively.¹⁹⁵ According to Elshkaki and Graedel from the Centre for Industrial Ecology, Yale University, the growth in wind and solar will be accompanied by a shift in copper distribution within the electricity sector. By 2030, they say, coal and gas will represent 37% of the in-use copper stocks of the electricity generation industry, while wind and PV solar will increase to 24% and 25% respectively. Grouping this distribution into renewables and fossil fuels highlights the significance of renewable energy technologies to copper demand.

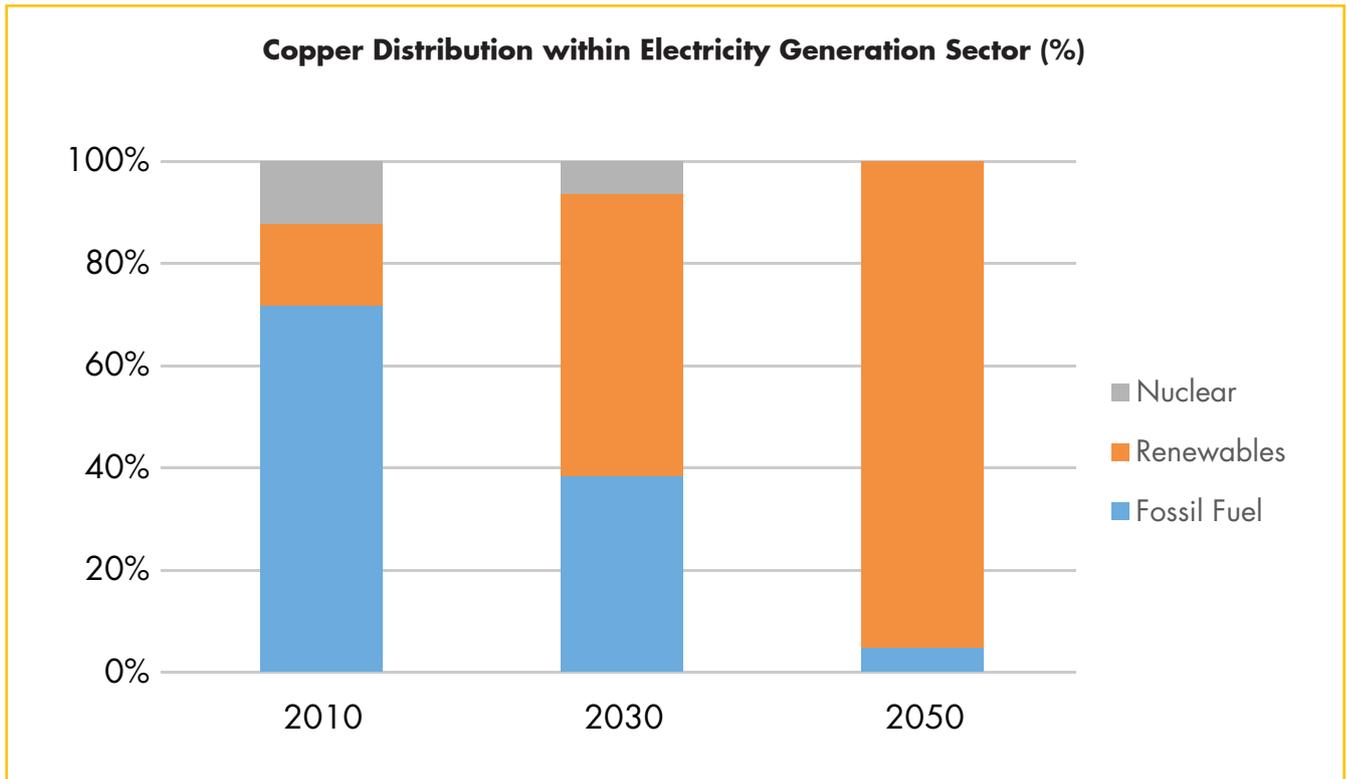
¹⁹¹ Copper Alliance (2016), *Copper's Contributions to Sustainable Development*, <http://copperalliance.org/app/>

¹⁹² Creara Energy Expert (2015) *Estimating Infrastructure Requirements for a Near 100% Renewable Electricity Scenario in 2050*, the Leonardo Institute, <https://www.scribd.com/doc/294693758/32/References>

¹⁹³ Perez et al (2014). *PV Grid Parity Monitor: Commercial Sector*. 1st issue. Eclareon.

¹⁹⁴ Harmsen, J. H. M, Rose, A. L. and Kumar Patel, M. (2013). "The impact of copper scarcity on the efficiency of 2050 global renewable energy scenarios." *Utrecht University, Copernicus Institute of Sustainable Development, The Netherlands Energy (Impact Factor: 4.84)*. 02/2013; 50(1):62-73. DOI: 10.1016/j.energy.2012.12.006 . https://www.researchgate.net/publication/257177056_The_impact_of_copper_scarcity_on_the_efficiency_of_2050_global_renewable_energy_scenarios

¹⁹⁵ Elshkaki, A. and T. E. Graedel (2013). "Dynamic analysis of the global metals flows and stocks in electricity generation technologies." *Journal of Cleaner Production* 59:260-273. DOI: 10.1016/j.jclepro.2013.07.003 https://www.researchgate.net/publication/260037380_Dynamic_analysis_of_the_global_metals_flows_and_stocks_in_electricity_generation_technologies



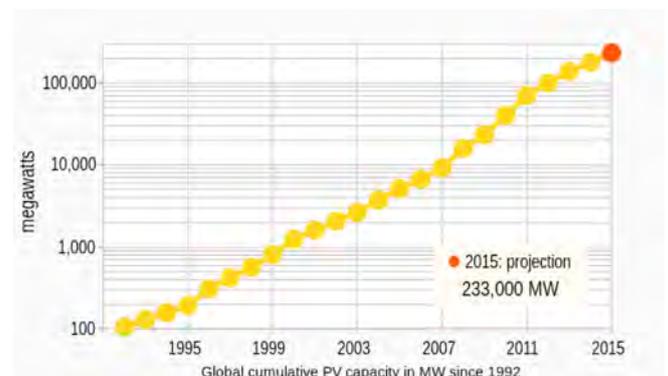
Source: Data from "Dynamic analysis of the global metals flows and stocks in electricity generation technologies," 2013.¹⁹⁶

Photovoltaics

The usage of copper in photovoltaic (PV) systems is substantial, averaging around 4-5 tonnes per MW or higher if ribbons (conductive strips to connect individual PV cells) are considered.¹⁹⁷ Copper is used in wires that interconnect PV modules, earthing grids, DC cables that connect PV modules to inverters, AC cables that connect inverters to metering systems and protection cabinets, communication cables, inverters/power electronics, ribbons, and transformer windings.

Copper used in photovoltaic systems in 2011 was estimated to be 150 kt. Cumulative copper usage in photovoltaic systems through 2011 was estimated to be 350 kt.¹⁹⁸ Cumulative worldwide deployment of PV capacity in 2011 was around 70GW¹⁹⁹, and PV capacity has approximately tripled since then.²⁰⁰ Forecasts by the IEA and long-term energy sector

analysts have continually underestimated the growth of PV capacity, projecting linear uptake while the history to date is one of exponential growth.



Source: Exponential growth-curve on a semi-log scale of worldwide installed photovoltaics in megawatts since 1992²⁰¹

¹⁹⁶ Elshkaki, A. and T. E. Graedel (2013). "Dynamic analysis of the global metals flows and stocks in electricity generation technologies." *Journal of Cleaner Production* 59:260-273. DOI: 10.1016/j.jclepro.2013.07.003 https://www.researchgate.net/publication/260037380_Dynamic_analysis_of_the_global_metals_flows_and_stocks_in_electricity_generation_technologies

¹⁹⁷ Creara Energy Expert (2015) Estimating Infrastructure Requirements for a Near 100% Renewable Electricity Scenario in 2050, the Leonardo Institute, <https://www.scribd.com/doc/294693758/32/References>

¹⁹⁸ Creara Energy Expert (2015) Estimating Infrastructure Requirements for a Near 100% Renewable Electricity Scenario in 2050, the Leonardo Institute, <https://www.scribd.com/doc/294693758/32/References>

¹⁹⁹ International Renewable Energy Agency Solar Photovoltaics Technology Brief E11 – January 2013 IEA-ETSAP and IRENA, <https://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E11%20Solar%20PV.pdf>

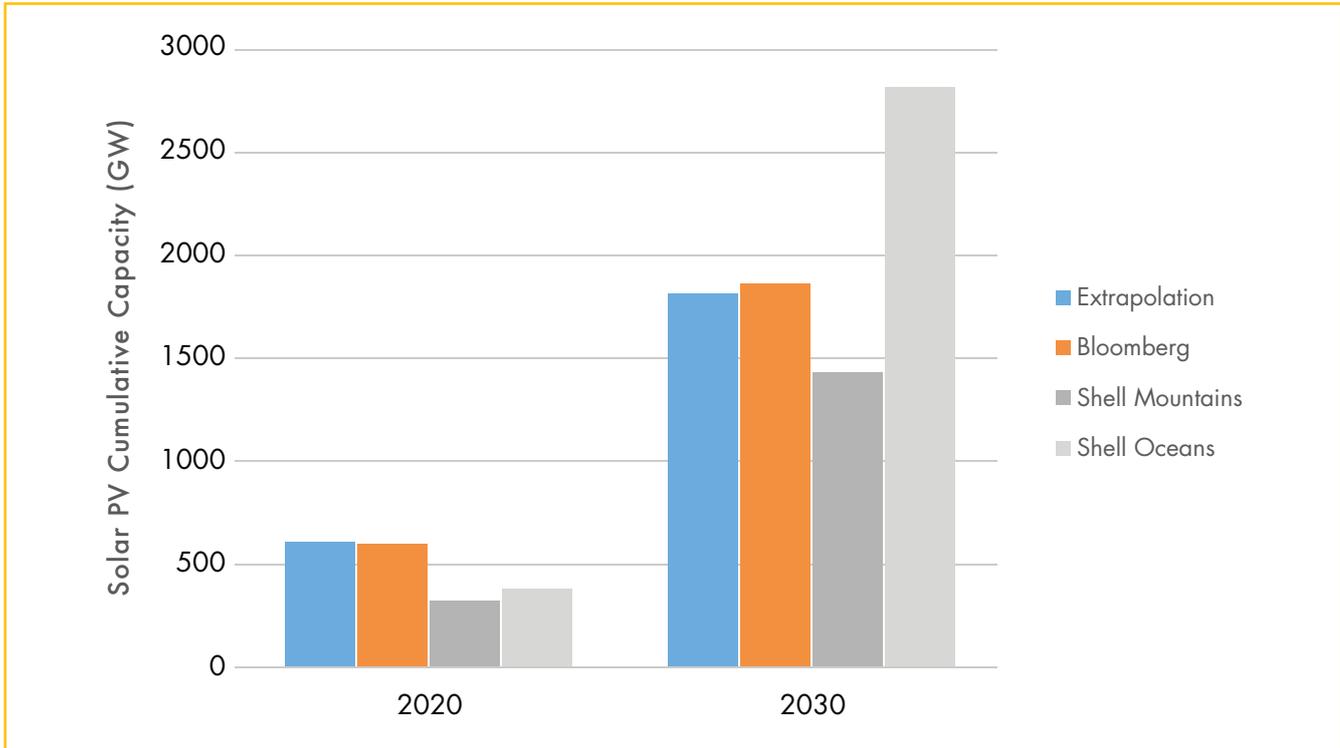
²⁰⁰ Beetz, B. (2015) Global installed PV capacity to reach 200 GW soon, says German solar association, *PV Magazine*, http://www.pv-magazine.com/news/details/beitrag/global-installed-pv-capacity-to-reach-200-gw-soon-says-german-solar-association_100020060/#axzz41JSt31Oy

²⁰¹ Exponential growth-curve on a semi-log scale of worldwide installed photovoltaics in megawatts since 1992, (2014), https://en.wikipedia.org/wiki/Growth_of_photovoltaics#/media/File:PV_cume_semi_log_chart_2014_estimate.svg

6. Electricity System continued

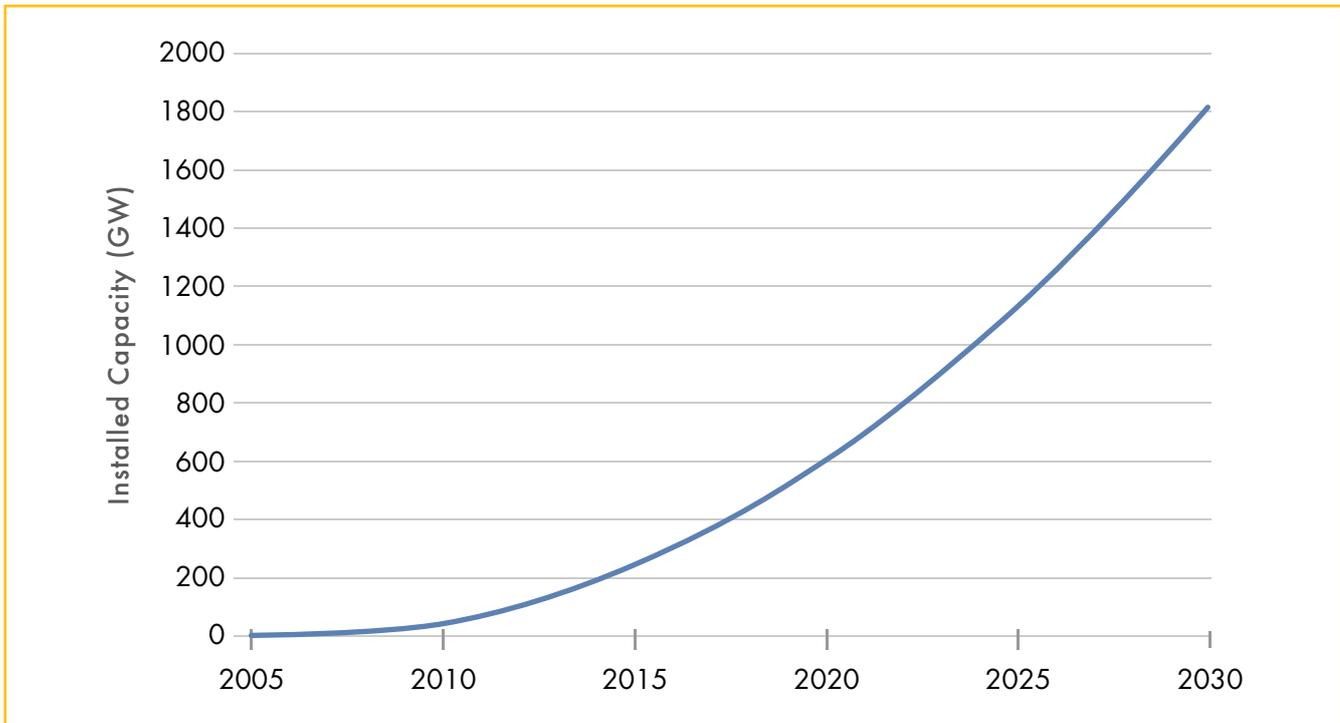
The national targets and commitments discussed in section 5, coupled with the availability of cost-effective energy storage, are expected to drive a further massive

increase in the sector by 2030. Adam Whitmore forecasts over 1800GW by 2030²⁰² and notes other similar and higher forecasts from Shell and Bloomberg.



Source: One Climate Policy²⁰³

These forecasts imply a PV cumulative deployment chart as shown below:



Source: One Climate Policy²⁰⁴

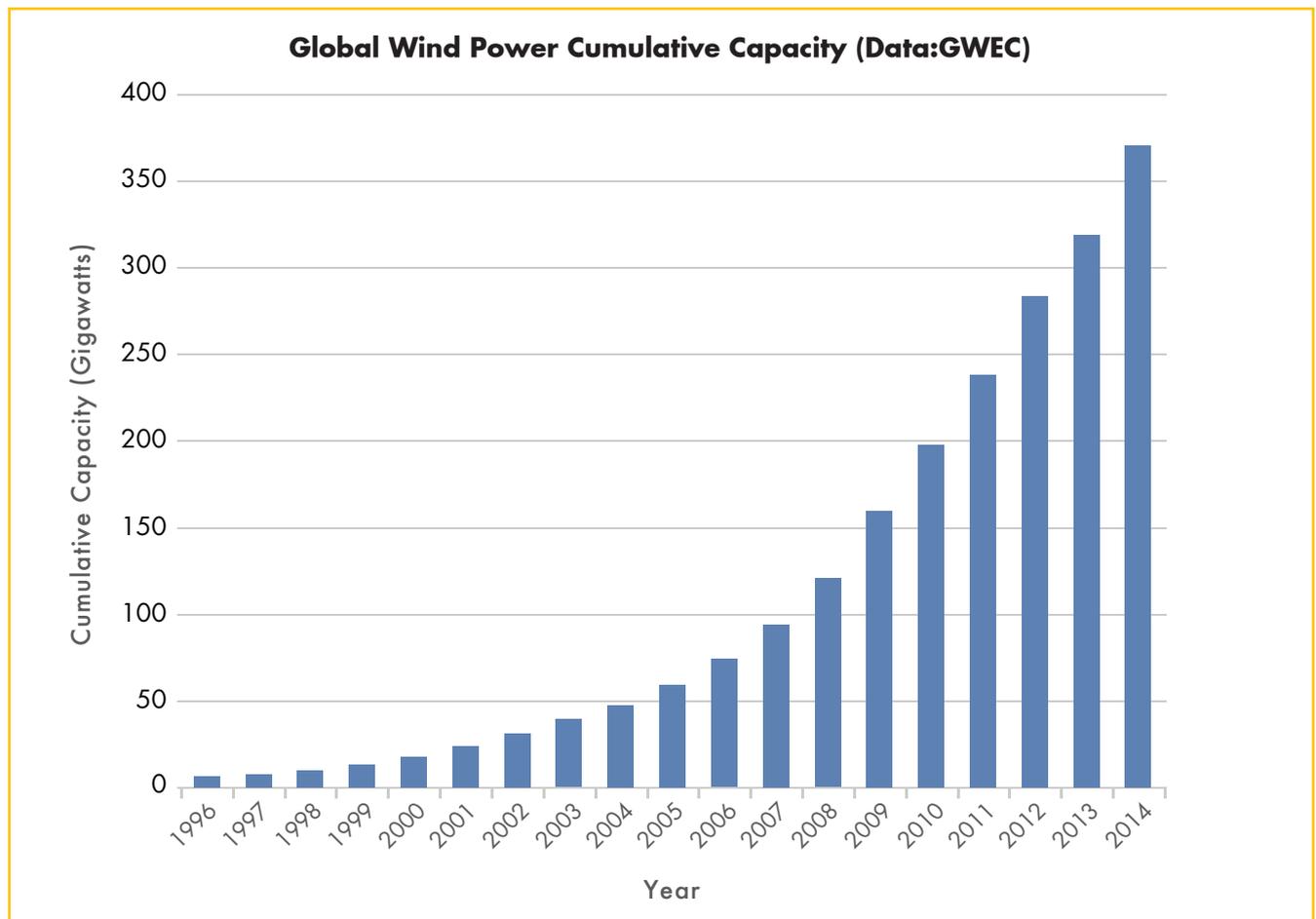
²⁰² ²⁰³ ²⁰⁴ One Climate Policy, Extrapolating deployment trends for solar PV, 27 June 2015, [blog], <https://onclimatechange.org.wordpress.com/2015/03/25/extrapolating-deployment-trend-for-solar-pv/>

Given that the 2030 commitments and targets from China and India alone imply over 1300GW, this forecast seems reasonable, even conservative. Using the factors from Harmsen²⁰⁵, the combined 2030 Chinese and Indian solar PV installed base would represent 6.5 million tons of copper.

Wind generation

Copper is an important conductor in wind power generation. Copper is used mainly in generators (stator

and rotor windings), gearboxes, transformers/inverters and cables and to a lesser extent in auxiliary motors, cooling systems and power electronics. Kundig²⁰⁶ estimates that the amount of copper used for wind energy systems in 2011 was 120kt. The cumulative amount of copper installed through 2011 is estimated to be 714kt.²⁰⁷ Cumulative worldwide deployment of wind capacity in 2011 was 238GW and capacity has almost doubled since to be around 432GW at the end of 2015.²⁰⁸



Source: Global Wind Energy Council (Global Wind Energy Outlook 2014)

The Global Wind Energy Council²⁰⁹ estimates 2030 capacity at between 964GW and 1934GW. Using their middle estimate (Moderate Scenario) gives a 2030 installed base of 1480GW, which seems conservative given that the 2030 commitments and

targets from China and India alone imply over 1200GW of wind capacity. Using the factors from Kundig,²¹⁰ the combined 2030 Chinese and Indian wind energy installed base would represent 3.6 million tons of copper.

²⁰⁵ Harmsen, J. H. M., et al. (2013). "The impact of copper scarcity on the efficiency of 2050 global renewable energy scenarios." *Energy* 50(1): 62-73. https://www.researchgate.net/publication/257177056_The_impact_of_copper_scarcity_on_the_efficiency_of_2050_global_renewable_energy_scenarios

²⁰⁶ BBF Associates and Kundig (2011). Market Study: Current And Projected Wind And Solar Renewable Electric Generating Capacity And Resulting Copper Demand. www.copper.org/about/pressreleases/pdfs/wind_solar_study.pdf

²⁰⁷ IMF. (2013). *In Our Hands, Earth's Precious Resources*: INTERNATIONAL MONETARY FUND.

²⁰⁸ Global Wind Energy Council (GWEC) (2016), Global Wind Statistics 2015, GWEC, Belgium, http://www.gwec.net/wp-content/uploads/vip/GWEC-PRstats-2015_LR_corrected.pdf

²⁰⁹ Global Wind Energy Council (GWEC) (2016), Global Wind Energy Outlook: 2000 gigawatts by 2030, GWEC, Belgium, <http://www.gwec.net/publications/global-wind-energy-outlook/global-wind-energy-outlook-2014/>

²¹⁰ BBF Associates and Kundig (2011). Market Study: Current and Projected Wind And Solar Renewable Electric Generating Capacity And Resulting Copper Demand. www.copper.org/about/pressreleases/pdfs/wind_solar_study.pdf

Future Technological Innovations

In addition to projecting forward current technologies, it is important to take into account likely and possible technology changes in the key renewable technologies by 2030. On solar PV, incremental changes are expected in technologies to 2030, but since much of the copper is in the wiring and inverter we expect copper content to remain roughly steady. However in wind there are some likely developments worth considering, in particular the prospect of superconducting generators.

Superconducting materials can be used for generator windings that are more powerful, lighter and more compact than copper-based alternatives. These technologies allow more power to be generated from an individual turbine, allowing turbines to reach 10MW capacity or higher. They are also constructed of more readily available and lower-cost materials than permanent-magnet-based generators. Turbine manufacturers including GE are searching for alternatives to rare earth generator materials due to cost and security of supply issues. A lower generator mass has major system benefits, including a lighter – and thus less expensive – tower, and reduced installation costs through the use of smaller cranes and offshore vessels.

These generators have yet to be commercialised however several prototypes have demonstrated that construction of such machines is possible²¹¹ and indicate that torque densities of two to three times those of permanent magnet machines can be achieved. According to Jensen,²¹² “The first practical superconducting wires consisted of filaments of the NbTi or Nb3Sn alloy embedded in a matrix of copper giving a round wire with a diameter of the order 1 mm. They were introduced around 1960 and still remain the working horse of the Magneto Resonant Imaging (MRI) industry, NMR spectrometers, accelerator magnets, and fusion experiments. More general power applications such as cables, transformers, and electrical machines are challenged by the dominating presence of available non-superconducting alternatives. This might not be the case for very large wind turbine generators (+10 MW), where current non-superconducting technology might be insufficient due to cost and weight constraints. Superconducting high torque machines could become commercially attractive, provided that the cost and production capacity of the superconductors are improved. Generator manufacturers that are active in the wind sector are preparing for the technology leap that might be necessary for large-scale offshore

turbines. There are a large number of challenges associated with employing superconductors in wind turbine generators. These challenges are easily met in collaboration between wind turbine manufacturers, wind farm developers/operators, and superconducting wire manufacturers. It is, however, unclear whether the future generators will converge towards only one superconducting technology or whether all three alternatives: LTS, HTS, and MgB2 will be seen in the future.”

This development will eventually be a threat to copper, particularly for the emerging large-turbine segment of the wind market, but is some time away from being commercial reality. The impact by 2030 is expected to be minor and to some extent offset by copper gains should the competing “Twistact” generator technology, patented and under development by Sandia,²¹³ be commercialised.

CENTRALISED AND DECENTRALISED ENERGY BALANCE OF CENTRALISED AND DECENTRALISED ENERGY

Electricity is transported from source of generation to point of use by the transmission and distribution systems, referred to as the grid and the network respectively. However, local energy generation and distribution systems are emerging which will change the balance of centralised and decentralised energy. This will vary by country.

TRENDS IN TRANSMISSION AND DISTRIBUTION

The typical architecture on today’s energy transmission and distribution systems is little changed from the late 19th century. The first three-phase alternating current transmission line was commissioned in Germany in 1891.²¹⁴

Generally, electricity is generated at a central location close to a fuel source, then transported via high voltage transmission lines to electricity distributors, who deliver it via medium and low voltage distribution networks to homes and businesses. Substations step up generated voltage for transmission and step down the voltage between the transmission grid and the distribution network and within the distribution network. Because

²¹¹ S. Kalsi, (2011) Applications of High Temperature Superconductors to Electric Power Equipment, Wiley-IEEE Press, ISBN: 978-0-470-16768-7

²¹² B. B. Jensen, N. Mijatovic, and A. B. Abrahamsen, “Development of superconducting wind turbine generators,” *J. Renewable Sustainable Energy*, vol. 5, Mar. 2013, Art. ID. 023137. <http://scitation.aip.org/content/aip/journal/jrse/5/2/10.1063/1.4801449>

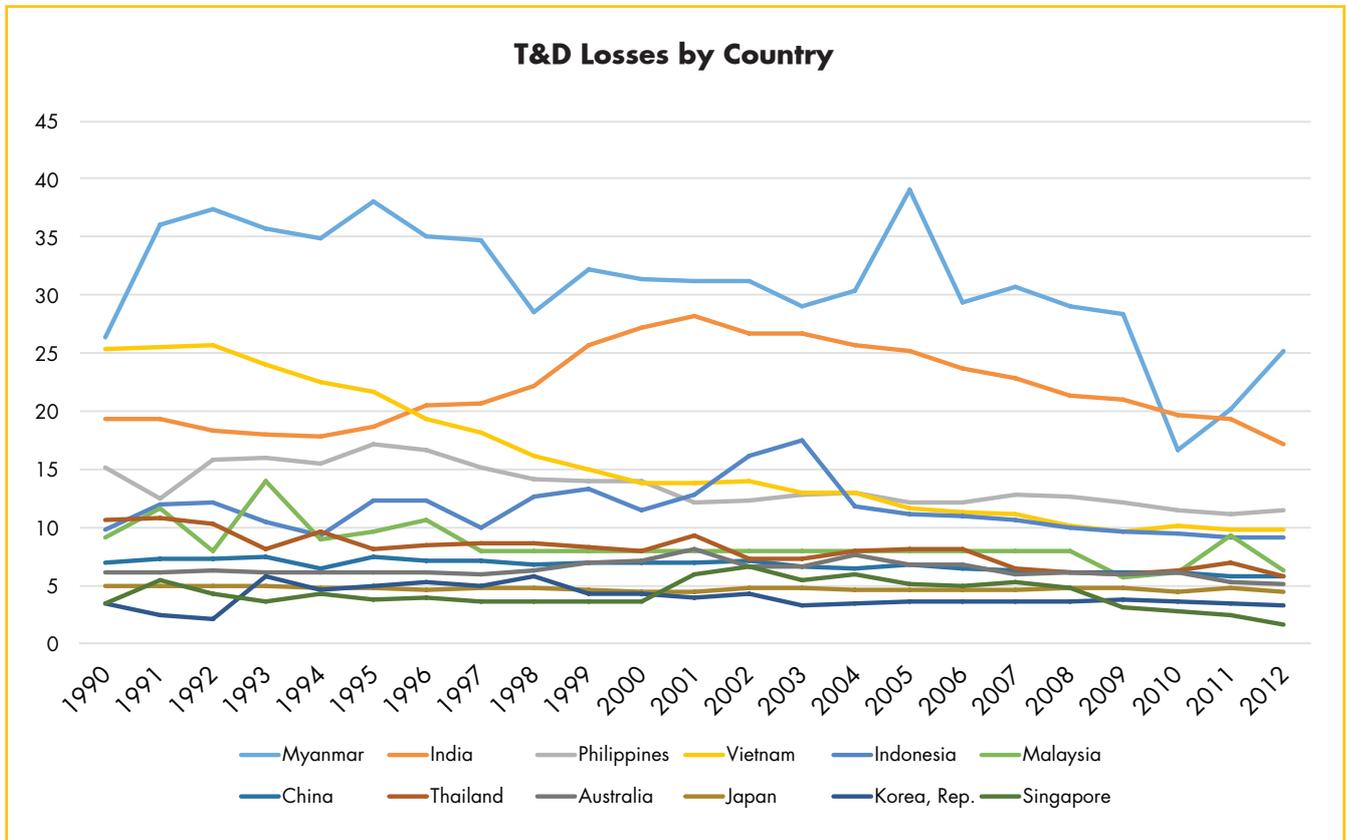
²¹³ Sandia National Laboratories (2015) Sandia’s Energy Program Wins Two Federal Laboratory Consortium 2015 Awards, Sandia, Energy and Climate, <http://energy.sandia.gov/sandias-energy-program-wins-two-federal-laboratory-consortium-2015-awards/>

²¹⁴ Edison Tech Centre, Lauffen to Frankfurt 1891 - The beginning of modern electric power in the world, <http://www.edisontechcenter.org/LauffenFrankfurt.html>

storage of energy at scale has been impractical, transmission and distribution systems are needed to balance supply and demand in real time.

While there are economies of scale in centralised generation and it is generally more cost-effective to

transport electricity than the generating fuel, there can still be significant energy losses in transmission and distribution systems. The following chart shows the losses in the transmission and distribution systems of our countries of interest, including “commercial” losses due to illegal connections.



Source: World Bank²¹⁵

Implications of Renewables for Transmission

Centralised renewable projects need more grid per unit of delivered energy than centralised fossil generation due to their intermittent nature. This implies that the massive deployment of large scale renewables predicted in China and India in the previous section will have a multiplier effect on the grid investment otherwise required in those countries.

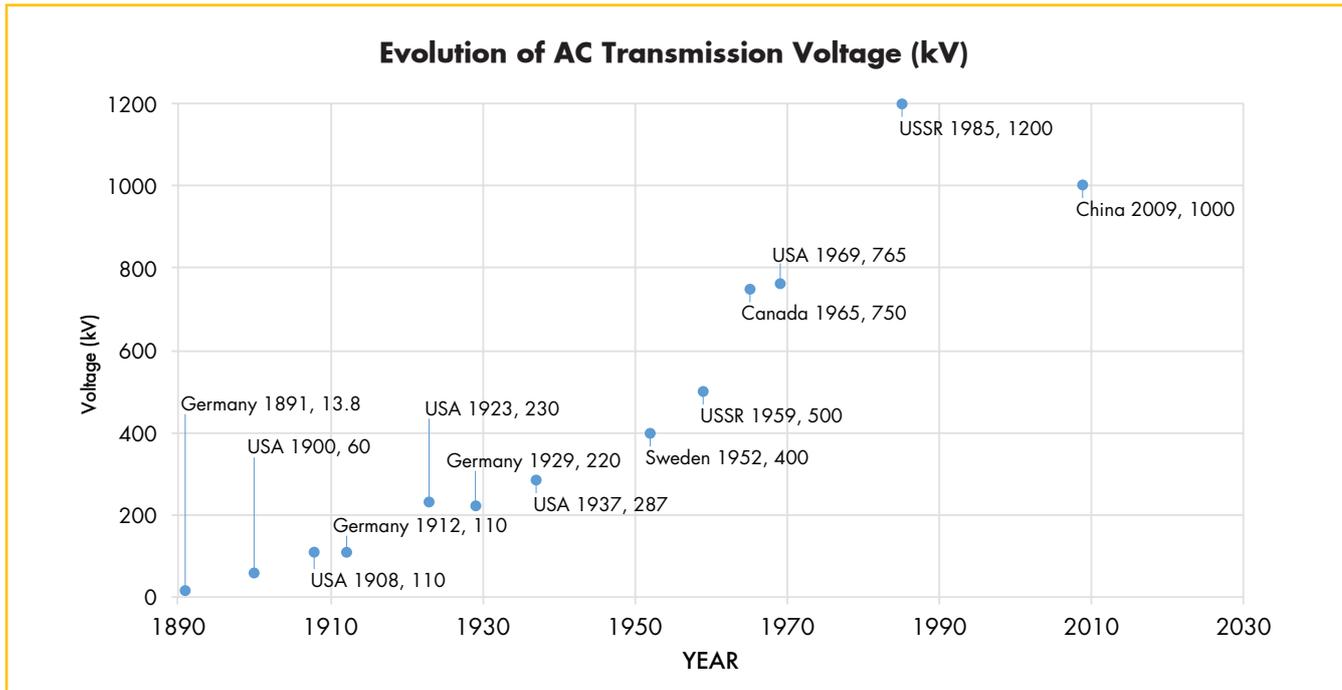
Trend towards higher transmission voltage

Higher voltages reduce resistance losses, and there has been a gradual increase in AC transmission voltage over time. (See chart overleaf). Higher voltages also increase the complexity of transmission projects, for example the need for higher towers to prevent ground arc. Underground transmission links are possible but are usually around six times more expensive to build than overhead lines.²¹⁶ However they can have lower losses and lower operational costs as they are less susceptible to weather damage, are more secure, require a smaller land corridor and clearly avoid the visual impact of massive towers and lines. Khandelwal and Pachori suggest a life-cycle costing approach which makes underground transmission a realistic economic alternative to above-ground lines.

²¹⁵ World Bank (2016) World Development Indicators, The World Bank, 1960 – 2015, last updated 17-Feb-2016, worldbank.org, <http://data.worldbank.org/data-catalog/world-development-indicators/>

²¹⁶ Khandelwal and Pachori (2013). Variation of Life Cycle Cost of Overhead Transmission Line and Underground Transmission Cable. *International Journal of Enhanced Research in Science Technology & Engineering*, 2(6), 55-64.

6. Electricity System continued



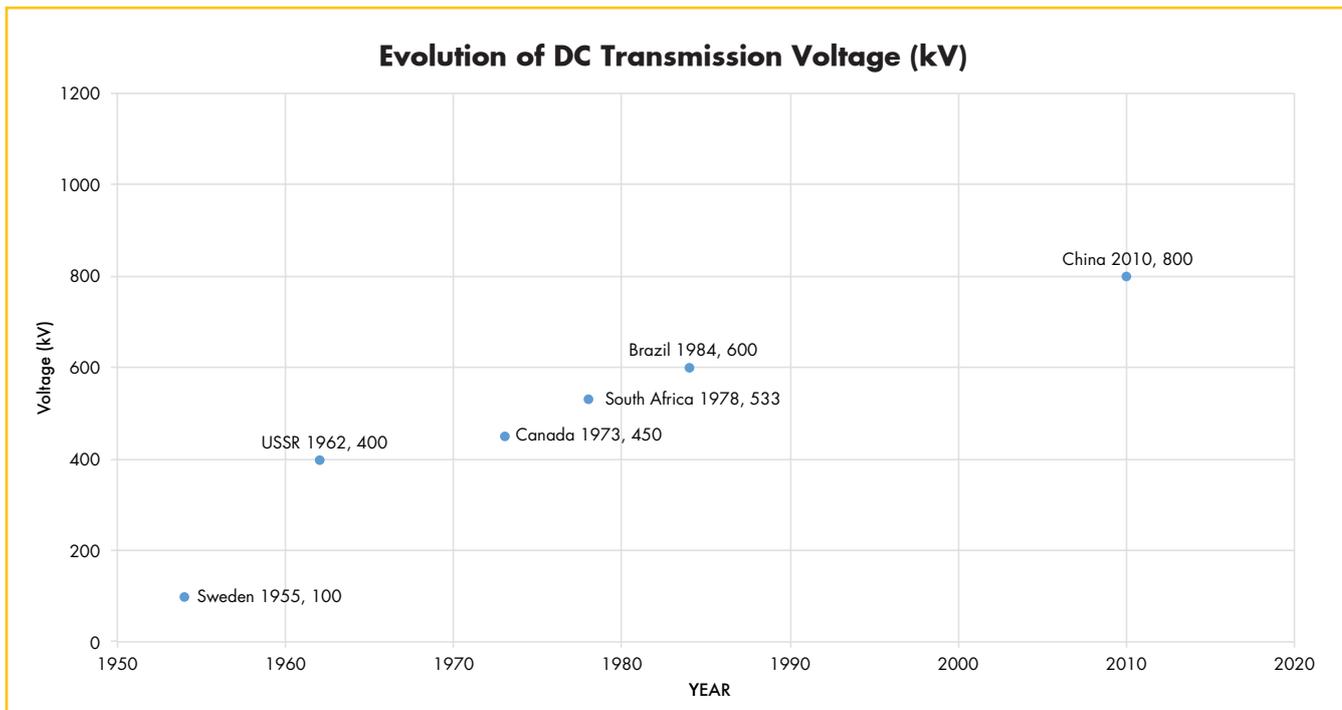
Sources: Liu²¹⁷, Kiessling et al²¹⁸

DC Transmission

Direct current (DC) was used in the earliest electricity distribution systems but alternating current (AC) has been used in the majority of energy supply applications. High-voltage DC (HVDC) transmission has better power capacity and reduced losses compared to AC for very large and long-distance electricity transmission projects, particularly in subsea and underground links as power

quality and capacitance issues are avoided which affect AC lines in these applications. HVDC transmission is also used to connect unsynchronised AC power systems.

The future of HVDC will be heavily influenced by the level of penetration of centralised renewables. Malavika Tohani, Energy and Power Systems research manager at Frost & Sullivan says, "Government policy towards



Source: Liu, Z. (2015). Global Energy Interconnection, 1st Edition, Academic Press

²¹⁷ Liu, Z. (2015). Global Energy Interconnection, 1st Edition, Academic Press.

²¹⁸ Kiessling, F, Nefzher, P., Nolasco, J. F. and Kaintzyk, U. (2014). *Overhead Power Lines: Planning, Design, Construction*: Springer.

renewable energy indirectly affects HVDC development. For example, offshore wind developments require connection to the main grid".²¹⁹

Chinese HVDC

China is by far the biggest HVDC investor, helped by its simple planning and policy structure. Several HVDC projects have been completed or are underway.

Two companies control electricity transmission and distribution in China: State Grid Corporation of China and Southern Grid.

State Grid Corporation of China (SGCC) was established as a state-owned enterprise on December 29, 2002. As the largest utility in the world, SGCC ranked seventh on Fortune Global 500 for three consecutive years.²²⁰

SGCC has recently pushed for approval of a massive \$250 billion upgrade plan that will link regional grids via twenty HVDC power corridors by 2020. The lines would help resolve China's geographical energy imbalance, according to SGCC. Power Engineering International²²¹ says, "Many also see the move as an attempt to strengthen SGCC's monopoly on power". The need for expansion of transmission is driven by the growth of generation, particularly renewables, as discussed in previous sections. The future generation mix will influence how much transmission is built in China. For example if there is substantial nuclear generation along the coast near the major demand centres, there will be many fewer major transmission projects. We expect a combination heavy in renewables and so predict the need for new Chinese transmission projects.

China is not only conducting the largest high voltage direct current (HVDC) implementation internationally, it is also establishing a manufacturing base that could challenge the biggest global players in the market. According to Bowden, "If China gets to build its complete HVDC grid, and it proves to be effective, the rest of the world will want one too".

DISTRIBUTED ENERGY RESOURCES

A number of previously-centralised, regulated industries have suffered disruption over the past few decades. Services previously only available from monopoly providers can now be obtained from other sources, for example mobile versus fixed telephone networks and ride sharing services versus taxis. This decentralisation trend has been apparent in electricity networks since the turn of the century and is gathering pace.

Electricity is needed to solve problems for people and businesses. Initially generated close to the point of use, the system became massively centralised during the twentieth century in most economies. Some generation has remained decentralised, particularly combined heat and power systems. Today, with the advent of inexpensive local renewables including photovoltaics, solar hot water and more recently cost-effective energy storage, it is now possible for many energy users to use distributed energy resources to meet at least some of their needs. The combination between centralised and distributed energy will be different in each economy, but the balance is generally shifting towards more distributed energy. To sense the potential of distributed energy, the incoming CEO of major European utility Engie, Isabelle Kocher, recently said that she expects decentralised end energy, mainly rooftop solar and batteries, to provide over half of global power generation in future: "As energy solutions become smaller and smaller, so energy itself is becoming increasingly local: looking to the future, more than 50 per cent of energy generation will rely on local sources."²²²

The decentralisation trend is particularly apparent in Australia, which otherwise has a highly-centralised power system but now also has the highest penetration of rooftop solar in the world. A disruptive transition is underway, from a stable centralised system with steady, predictable demand growth to a decentralised system with dynamic two-way flows, demand side participation and distributed generation eroding centralised demand. Australia also is seeing non-traditional competitors enter the utility market, including the largest telco, Telstra, who are considering offering rooftop PV and batteries bundled with internet and telephone services.²²³

²¹⁹ Bowden, J. (June, 2013). China takes HVDC to new level. *Power Engineering International*.

<http://www.powerengineeringint.com/articles/print/volume-21/issue-6/special-focus-hvdc/china-takes-hvdc-to-new-level.html>

²²⁰ Fortune Online, Global500; The Fortune Global 500 generated \$31.2 trillion in revenues and \$1.7 trillion in profits in 2014, State Grid, <http://fortune.com/global500/state-grid-7/>

²²¹ Bowden, J. (June, 2013). China takes HVDC to new level. *Power Engineering International*.

<http://www.powerengineeringint.com/articles/print/volume-21/issue-6/special-focus-hvdc/china-takes-hvdc-to-new-level.html>

²²² Engie (2015) World Gas Conference: Isabelle Kocher describes the energy transition as a "positive revolution", Engie.com, <http://www.engie.com/en/news/engie-world-gas-conference-2015-isabelle-kocher/>

²²³ Whelan, C. (2016) technology and the energy opportunity, Telstra, <https://exchange.telstra.com.au/2016/02/05/technology-energy-opportunity/>

6. Electricity System continued

The 2014 PWC report, "Utility of the future: A customer-led shift in the electricity sector",²²⁴ discusses "the introduction of new technologies and new value chain participants that will assist customers to take control of their energy management and increasingly their power generation and energy storage. These customer and technology factors will shape the electricity market of the future." Electricity utilities, it says, are about to face their "Kodak moment".

In 2012 the national research agency, CSIRO convened the Future Grid Forum²²⁵ which involved 120 representatives of the electricity industry, government and community to inform stakeholders, guide a national conversation and provide a way forward for the sector. This was a uniquely whole-of-system, long term view of a system which has been disaggregated and sub-optimised. In their latest publication on the subject, the follow on Network Transformation Roadmap Project with the Energy Networks Association, CSIRO states, "This transformation was initially driven by the mass adoption of distributed energy resources (in the form of rooftop solar panels), together with broad community acceptance of energy efficiency initiatives. The next decade has potential for subsequent waves of technological and business model transformation, driven by further, widespread adoption of energy storage, electric vehicles and community energy solutions... Distributed energy resources can both impose technical challenges on traditional electricity systems and deliver benefits to those systems. Effective integration of distributed energy resources can deliver benefits for both customers and the efficient operation of electricity networks. The important role of grid-connected distributed energy resources means, therefore, Australia needs to rethink electricity system design and operation."²²⁶

To some extent a similar decentralisation trend is likely in all nations with established centralised power systems, though to an extent which varies according to distributed energy resource availability, ease of connection, network constraints and other national issues. Nations still building their power network may find it cost effective to consider distributed energy resources rather than connecting a regional to the central grid. For example, APEC's project "Off Grid Electrification Option for Remote Regions" is examining the potential for off-grid electricity supply options using DC solar technology in

remote regions, particularly remote villages and islands, in APEC economies with a report due in 2017.²²⁷ This type of development appears particularly likely in countries such as India, Indonesia and the Philippines.

China, in contrast, has taken a path towards a much more centralised power system, though interestingly there have been several recent efforts to increase the uptake of distributed energy there. The 13th Chinese Five Year Plan (2016-20) mentions the need for a combination of centralised and distributed energy.²²⁸ In the resource-rich regions large centralised wind power and photovoltaic power generation stations will be favoured; in other regions, distributed wind and photovoltaic power generation will be important. Distributed photovoltaic power generation stations will be built in 30 regions, and there is a goal to explore distributed energy utilisation in a new energy system which is the combination of distributed photovoltaic, solar thermal, geothermal energy, energy storage and distributed natural gas.

Australia's CSIRO indicates that the likely result is neither extreme centralisation nor extreme decentralisation. Rather, a modernised electricity grid remains important to even the most decentralised scenarios. "The technologies and role of the network is set to change significantly with an increasingly 'two-way' network, with the business model of the network evolving fundamentally to become a 'platform provider', enabling new energy services and uses, as opposed to the conventional 'poles and wires' service."

This project team consulted broadly about the extent of decentralised energy expected to see in the countries of interest by 2030. Many, like Travers McLeod, CEO of the Centre for Policy Development, agreed that decentralisation is the logical outcome in many situations. McLeod referred to the work of Indian Nobel Laureate and economist Amartya Sen, who sees the decentralisation of telecoms and energy as a way of meeting the twin goals of economic development and achieving social justice in India. Sen argues the importance of expanding and safeguarding human capital in order to achieve sustained and sustainable economic growth.²²⁹ Providing basic services to those in need to expand their capability appears easier, in many cases, in a decentralised world. Sen writes of the

²²⁴ PriceWaterhouseCoopers (PWC) (2014). Utility of the future: A customer-led shift in the electricity sector, PWC.s <https://www.pwc.com.au/industry/energy-utilities-mining/assets/utility-of-the-future-apr14.pdf>

²²⁵ CSIRO (2015) Predicting the future of our grid, Future Grid Forum, CSIRO, <http://www.csiro.au/en/Research/EF/Areas/Electricity-grids-and-systems/Economic-modelling/Future-Grid-Forum>

²²⁶ Electricity Network Transformation Roadmap: Interim Program Report. (December, 2015), http://www.ena.asn.au/sites/default/files/roadmap_interim_program_report.pdf .

²²⁷ Wan, L. (November 2015). Overview of Renewable Energy in China Policy Strategy and Priority of New and Renewable Development. Paper presented at the APEC New and Renewable Energy Technologies Expert Group, 45th Meeting. <http://www.egnret.ewg.apec.org/meetings/egnret45/economy%20presentation/%5BChina%5D%20APEC%20EGNRET%2045%20Meeting%20China%2020151116.pdf>

²²⁸ China Daily (2015) 'Highlights of proposals for China's 13th Five Year Plan', ChinaDaily.com, http://www.chinadaily.com.cn/china/2015cpcplenarysession/2015-11/03/content_22361998.htm

²²⁹ Derbyshire, J. (August, 2013). Prospect interviews Amartya Sen (The full transcript). Prospect. 209. <http://www.prospectmagazine.co.uk/magazine/prospect-interviews-amartya-sen-the-full-transcript-jonathan-derbyshire>

“failure to develop a framework for assessing the comparative costs of different sources of energy (from fossil fuels and nuclear power to solar and renewable energy), inclusive of the externalities involved, which can take many different forms” and says, “Even if carbon emissions had not been such a big problem, the case for rapid development of the economic use of solar power would be important for many of the poorer parts of the globe in a way that the richer world, particularly affluent but sun-starved Europe, may not readily see.”²³⁰ McLeod notes also that China is very conscious of the need to transition its domestic energy system in the face of its pollution problems.

John Daley, CEO of the Grattan Institute says the decentralised energy trend is accelerating. Christopher Heathcote, CEO of the Global Infrastructure Hub says getting decentralised energy right could be a game changer for many Asian nations. CSIRO’s Paul Graham says decentralisation will occur in all countries, but the customised centralised-decentralised combination will be determined by the available local renewable resources and ability to harness them.

Energy Storage as an Enabler of Decentralised Energy

Adding storage to decentralised energy generation allows much more independence from the centralised energy system. Dr Gregor Verbic from the University of Sydney’s Electrical Engineering Department suggests that storage demand will be greatest where there is high penetration of decentralised photovoltaics, a good solar resource and low feed-in tariffs. This combination of factors has now occurred in Australia, and in 2015 residential storage products were launched in Australia by Tesla, Enphase and Sunverge.

Professor Tiho Ancev of the University of Sydney’s Economics Department believes household batteries are potentially a huge change factor for the energy system, especially if they can be scaled up to service larger buildings. As always, the success of distributed storage, and distributed energy more generally, will be influenced by regulatory and commercial responses to the new technology from governments and incumbent market participants.

Impact of decentralised energy resources on transmission and distribution

Intuitively it seems that decentralised energy resources will lower the requirement for investment in the centralised energy network and grid. Reduced peak load should at least defer the need for augmentation of the network. However, in many cases, particularly in the more

developed countries, the network has already been built and will simply be repurposed to be more of a two-way energy balancing resource, with further upgrades required to provide power stability and quality as many sources of unscheduled generation are added. In other cases where the existing network connection is minimal, unreliable or missing, decentralised energy may supplant the need for network extension and completed development.

A considered implementation of decentralised energy to a country’s power system offers an optimal balance of cost, reliability and emissions reduction, but requires significant changes in thinking from governments, regulators and industry participants.

PROJECTIONS FOR PENETRATION OF DECENTRALISED ENERGY

In this section the project team estimates the decentralised/centralised electricity mix for three of the countries of interest. Australia is analysed as an illustrative example, rapidly transitioning from a highly centralised electricity combination to now having a high penetration of distributed generation, mainly rooftop PV. China and India are analysed due their size and critical impact on the Asian copper demand.

This analysis nominates a metric to measure the decentralisation of an electricity system, the *decentralisation index*, to estimate the level of this index for the three countries in 2030. The decentralisation index is the share of total electricity generation in an electricity system produced by sources local to the load.

This analysis considers mainly distributed PV generation, with the addition of storage to a proportion of the PV systems. Undoubtedly other technologies will feature variously in a diverse range of distributed energy systems around the region, but we believe that these two will dominate until at least 2030.

Australia

Australia has the highest penetration of rooftop solar in the world and so is a useful reference case for this study. It already has over 4.6GW of small-scale solar PV deployed generating around 5.6TWh which is 2.5% of the total energy demand.²³¹ By 2030, CSIRO predicts that distributed generation, mostly small-scale solar PV will have capacity of between 40 and 81GW and generation in the range 48-98TWh, making up 20-40% of the total energy demand.²³² Taking the midpoint of these scenarios we estimate a 2030 decentralisation index for Australia of 30%.

²³⁰ Sen, A. (August, 2014). Global Warming Is Just One of Many Environmental Threats That Demand Our Attention. *New Republic*. <https://newrepublic.com/article/118969/environmentalists-obsess-about-global-warming-ignore-poor-countries>

²³¹ SunWiz Solar Industry Intelligence (2012) Australian PV Installations hit the 5GW mark, <http://www.sunwiz.com.au/index.php/2012-06-26-00-47-40/402-australian-solar-power-installations-hit-5gw.html>

²³² *Electricity Network Transformation Roadmap: Interim Program Report*. (December, 2015), http://www.ena.asn.au/sites/default/files/roadmap_interim_program_report.pdf

6. Electricity System continued

Distributed batteries are already being installed at Australian residences with PV systems. Morgan Stanley estimates the future residential storage market could be as many as 2.4 million installations.²³³

India

India's announced targets generally address centralised renewables rather than decentralised generation. However the government's electrification goals would be more easily and economically achievable with solar PV and batteries for many of the villages with little or no reliable grid power, and there are now signs that the state and central governments will encourage distributed energy resources. Of the 100GW total solar target for 2022, in March 2015 the Government set a target for 40GW of distributed rooftop solar²³⁴ as a way of circumventing the nation's massive grid losses, including an interim target of 10GW by 2018. This forecast is backed by Deutsche Bank,²³⁵ and residential rooftop PV is already growing rapidly with some policy support. Commercial decentralised generation is growing too, as companies opt for their own power sources, due mainly to the unreliability of grid electricity. Infosys recently invested in a 50MW local PV system while BMW generates 20% of its power locally. India already has the world's largest single rooftop system (12MW)²³⁶ and the Government is driving decentralised solar using its own rooftops and those of Government-owned corporations, including a goal for 1GW on railway buildings, on airports and even on top of canals.²³⁷ Some states and cities now require rooftop PV on all new construction.²³⁸

Another government estimate for India shows only 11GW of decentralised solar PV generation by 2030,²³⁹ implying a decentralisation index around 2%. We suspect that is highly conservative. McKinsey's 2014 report "India: Towards Energy Independence 2030"²⁴⁰ proposes an "Energy Security" scenario involving off-grid electrification of 50,000 villages with off-grid solar.

Energy Minister Goyal says there is "no one size fits all solution", and it appears a new energy ecosystem is already forming in complex and unpredictable ways. Some are not that sure the government's goals for centralised renewable "ultra-megaprojects" are achievable and discount the government targets by as much as 30%. Certainly land costs are starting to affect utility PV system cost and we suspect that in time the attractiveness of simpler, smaller local PV projects may tip the balance towards a more decentralised model. Local PV-based systems also offer a safety advantage over the "informal" network connections common in slum areas, so social decentralisation drivers exist as well.

Expert interviews on the subject indicate that real innovation may occur at the village level as much as in the huge generation and transmission projects. University of Sydney law researcher Penelope Crossley expects those areas with low access to electricity, will leapfrog the centralised grid system and solve their electricity needs with local systems, and Electrical Engineer Dr Gregor Verbic says off-grid solutions could be a much cheaper option for the country as a whole. Grattan Institute CEO John Daley, CSIRO's Paul Graham and Antony Sprigg, CEO of the Infrastructure Sustainability Council of Australia, all expect high levels of decentralisation in India over time. Global Infrastructure Hub CEO Chris Heathcote agrees, citing the high cost of grid losses although he suspects bureaucracy may slow or stop local projects. Amandine Denis of Climateworks expects decentralised solutions will apply in many cases such as telecoms. In 2012 the Telecom Regulatory Authority of India (TRAI) directed all cell tower companies to have 50% of their towers run on hybrid power in the rural areas and 30% in the urban areas.²⁴¹ Hybrid power is defined as a combination of grid supplies and renewable energy based on solar, wind, biomass or fuel cells. Indian telco Tata says more than 600,000 telecom towers in India use diesel generator sets to provide power to their antennas and

²³³ Gifford, J. (2015) Australia's battery pilot on a grand scale, PV Magazine, December 2015, http://www.pv-magazine.com/archive/articles/beitrag/australias-battery-pilot-on-a-grand-scale_100022649/86/?tx_ttnews%5BbackCat%5D=273&cHash=9937ac6f9edc5ad622c17be925b68cbe#axzz41JSi31Oy

²³⁴ Government of India (2015) Year End Review, Press Information Bureau, Government of India, Ministry of, New and Renewable Energy <http://pib.nic.in/newsite/PrintRelease.aspx?relid=133220>

²³⁵ Puri, A. (2015) India 2020: Utilities & Renewables, Deutsche Bank, Markets Research, <https://www.db.com/cr/en/docs/Deutsche-Bank-report-Make-way-for-the-Sun.pdf>

²³⁶ India Today (2015) Tata Power Solar commissions world's largest solar rooftop in Amritsar, IndiaToday.in, 10 December 2015, <http://indiatoday.intoday.in/story/tata-power-solar-commissions-worlds-largest-solar-rooftop-in-amritsar/1/543617.html>

²³⁷ Buckley, T. (November, 2015). *India's Electricity Sector Transformation: Global Capacity Building*. http://ieefa.org/wp-content/uploads/2015/11/IEEFA-India-Electricity-Sector-Transformation_Global-Capacity-Building_11112015.pdf

²³⁸ Kenning, T (2016) India's Chandigarh plans to make rooftop solar mandatory, PVTech, 24 February 2016, <http://www.pv-tech.org/news/indias-chandigarh-plans-making-rooftop-solar-mandatory>

²³⁹ NITI Aayog (2015). *A Report on Energy Efficiency and Energy Mix in the Indian Energy System (2030): Using India Energy Security Scenarios, 2047*. New Delhi, http://niti.gov.in/mgov_file/Energy_Efficiency.pdf.

²⁴⁰ Tuli, K. (Jan, 2014). *India: Towards Energy Independence 2030*, http://iitbaa-gbf.com/wp-content/uploads/2015/08/India_Towards_energy_independence_2030.pdf

²⁴¹ Parbat, K and Jai, S. (2013) Less than 1% of India's 4.4 lakh telecom towers powered by clean fuel, EconomicTimes.indiatimes.com, 28 September 2013, http://articles.economicstimes.indiatimes.com/2013-09-28/news/42481584_1_telecom-operators-tower-unit-telecom-companies



India's first solar park at Charanka
(CC BY-ND 2.0) by American Center Mumbai

have created a subsidiary to replace gensets with PV at a trial group of 25 sites.²⁴²

Taking all these factors into account, we have extrapolated the growth rate implied by the 40GW 2022 forecast, tempered somewhat in case that goal is not met and to allow for decreasing growth over time to yield a forecast of 80GW of distributed PV systems in India by 2030.

The unreliability of the Indian transmission grid has been discussed in a previous section and must be addressed to ensure India's goals for centralised renewables are achievable. The barriers to adding significant distributed generation are lower. Bridge to India estimates that the Indian distribution network "can easily accommodate up to 30% of distributed solar PV without any major changes to the distribution grid infrastructure".²⁴³ Good quality solar inverters could actually improve power quality and network stability at the fringes of the network where villages are already connected. So an 80GW 2030 prediction seems reasonable.

The estimate of 80GW of distributed solar would put India's 2030 decentralisation index at around 7% allowing for lower levels of other distributed generation. We believe there are advantages to higher decentralisation and India could become a much more decentralised system than is currently planned.

China

Amongst its renewables goals, China aims to become a world leader in distributed solar power and to build a smart power distribution network that adapts to high levels of distributed power generation. Zhang et al²⁴⁴ note there are several advantages of distributed PV over large-scale central generation in China: savings in land and transmission and reduced losses. Accordingly, there has been strong policy support for distributed generation since 2013, and there are indications that the Chinese government is not content with the slow uptake to date. At June 2014 just 1GW of distributed PV had been deployed in China, around 5% of the total PV capacity installed. This situation was the polar opposite of what had occurred in other nations where

²⁴² TATA Power (Tata Power is India's largest integrated power company) (2016), Renewable Energy, <http://www.tatapower.com/businesses/renewable-energy.aspx>

²⁴³ Magal, K, (2014) India's distribution grid is capable of handling up to 30% distributed solar without any upgrades, Bridge to India, <http://www.bridgetoindia.com/blog/indias-distribution-grid-is-capable-of-handling-up-to-30-distributed-solar-without-any-upgrades/#sthash.eirFbeAm.dpuf>

²⁴⁴ Zhang, F., Deng, H., Margolis, R., & Su, J. (2015). Analysis of distributed-generation photovoltaic deployment, installation time and cost, market barriers, and policies in China. *Energy Policy*, 81, 43-55.

6. Electricity System continued

PV deployment was led by households and businesses. In Australia in 2014, 98% of PV capacity installed was distributed systems connected to the low-voltage network.²⁴⁵

Cost appears not to be the primary barrier to distributed PV in China. Primary barriers have been concerns that projects were effectively limited to self-consumption rather than exporting energy and the uncertainty of financial returns. The Chinese government in September 2014²⁴⁶ introduced a goal to add 8GW of distributed PV as well as policy to provide guaranteed minimum feed-in tariffs and investment returns for distributed systems. These actions are likely to start to remove the barriers to decentralised generation, though policy flow-down will take some time. IEEFA forecasts 18-20GW new PV capacity will be installed in China in 2016, 40% of which will be distributed.²⁴⁷

Expert interviews on the subject suggest that distributed generation makes sense in China and will become part of the energy system complementing the grid investment. University of Sydney Electrical Engineering expert Dr Gregor Verbic says distributed generation will be economic for new greenfield projects, and the Grattan Institute's John Daley suggests that the economics of distributed PV will be appealing to companies. We expect centralised and decentralised solutions to co-exist, with the grid correcting large-scale regional imbalances like an energy highway, whereas local systems will reduce congestion on the local "roads" of the distribution network.

The NDRC's "China 2050 High Renewable Energy Penetration Scenario and Roadmap Study"²⁴⁸ estimates 260GW of distributed solar by 2050. While the study does not quantify a 2030 forecast, based on this number and its other forecasts we infer a 2030 projection of 100GW. Certainly there are signs that China will unlock the distributed PV market which will benefit its domestic PV industry as well. This would give China a 2030 decentralisation index of around 2%.

Summary

In summary then, it appears that Australia is likely to have a relatively high decentralisation index of 30% in 2030, followed by India at around 7% or perhaps a little higher, with China the most centralised of the three at around 2%.

With increasing levels of decentralised energy and falling battery costs, we expect significant deployment of distributed energy storage in each country, with the extent roughly proportional to the decentralisation index, though also influenced by electricity prices. At today's prices we expect less storage in China and India than in Australia.

IMPLICATIONS FOR COPPER

Much copper use is in transmission and distribution systems. Electricity transmission and distribution was the second largest market for copper in Asia at 13.5% of total demand.²⁴⁹ However distributed energy offers a higher copper content per unit of energy delivered.

Transmission and distribution

In the early years of the power industry copper was used almost exclusively in transmission and distribution, but was limited in overhead applications by its weight and lack of tensile strength. Copper cable diameter was selected on strength rather than on conductivity leading to larger cables than would otherwise be necessary. Aluminium, which is stronger and lighter, has allowed longer span lengths between towers and has been used in overhead transmission since 1895. Improved Aluminium Conductor Steel-reinforced cable (ACSR) was introduced 1907 and aluminium ceramic composite reinforced was introduced in 2010. Aluminium has only 60% of the conductivity of copper, so much more is used for the same level of losses, but even then the aluminium cable is lighter.

While overhead transmission cables are the domain of aluminium, copper is used widely in the distribution system and in subsea and underground transmission cables, and there is extensive use of copper in the associated transformers and power quality equipment. An emerging threat to copper in underground cables is high-temperature superconductor (HTS) cable. Further, solid state power electronics, applied at transmission scale, now threaten the need for copper in transformers.

Growth in the transmission sector, then, is positive for copper today, though the copper use factor is likely to decline over time to 2030. Above-ground HVDC transmission and long-distance interconnections will generally not be a great driver of copper use. Copper

²⁴⁵ SunWiz Solar Industry Intelligence (2012) Australian PV Installations hit the 5GW mark, Sunwiz.com.au, <http://www.sunwiz.com.au/index.php/2012-06-26-00-47-40/402-australian-solar-power-installations-hit-5gw.html>

²⁴⁶ Bloomberg News (2014) China Policy Spurs Rooftop Solar in World's Top Market, Bloomberg, 5 September 2014, <http://www.bloomberg.com/news/articles/2014-09-04/china-spurs-rooftop-solar-projects-with-call-for-higher-subsidy>

²⁴⁷ Institute for Energy Economics and Financial Analysis (IEEFA) (2016), China Delivers a World Record Wind Installs in 2015; India Announces Another Record Low Solar Tariff, IEEFA, 20 January 2016, <http://ieefa.org/china-delivers-a-world-record-wind-installs-in-2015-while-india-announces-another-record-low-solar-tariff/>

²⁴⁸ Energy Research Institute, NDRC (Apr, 2015). *China 2050 High Renewable Energy Penetration Scenario and Roadmap Study*, <http://www.efchina.org/Reports-en/china-2050-high-renewable-energy-penetration-scenario-and-roadmap-study-en>

²⁴⁹ ICA data supplied

gains are much higher for subsea and underground transmission. Substitution of distribution network for transmission, as occurs when decentralised energy resources are extensively deployed, would be positive for copper use.

Decentralised Energy

Decentralised energy resources generally use more copper than the equivalent centralised energy system. The ICA's Hal Stillman indicates, for example, that the copper content of solar rooftop PV is 4kg/kWp, including the grounding wire. Local minigrids and microgrids often duplicate an existing distribution system. The lower voltage requires higher current to deliver the same power and means bigger conductors are needed. In addition, local renewable energy generation involves considerably more copper than the same amount of central fossil capacity as observed in the previous section. Finally, the inverters, power quality equipment, batteries and other equipment used in local energy systems are copper-intensive.

Applying this factor to the projections above, expected copper gains resulting from distributed PV are around 240kt by 2030 in Australia, 320kt in India, and around 400kt in China; approximately one million tonnes in aggregate. We think the Chinese and Indian forecasts have considerable potential for future growth. Resultant requirements in LV network upgrades, power quality equipment and associated hardware are expected to multiply the copper demand of this decentralisation of energy. However, if local systems are not connected to the national grid, there will be some losses in transformers and associated equipment.

According to CSIRO's Paul Graham, a distributed energy system with storage removes "peakiness", implying that a smaller network is needed, but that reduction in network size is associated with technologies where copper has strong competitors and likely outweighed by the gains in the distributed energy system where copper has strong advantages. The ICA's Hal Stillman sees an advanced battery, beyond today's lithium ion technology in capability, at a price point of \$125/kWh by 2025 and expects significant energy system penetration at both the grid and distributed level. Copper use in batteries varies from 76g to 172g/kWh.^{250, 251} We estimate a typical residential battery will be 8kWh, representing between 0.6 and 1.4kg of copper. If the Morgan Stanley forecast is accurate, the Australian residential battery market could represent a gain of 1.4kt to 3.3kt, which is minor compared to the PV systems themselves.

SUMMARY AND CONCLUSION

The decentralisation of energy is an important positive trend for copper. We expect the copper gains to be more substantial for a power system with high levels of decentralised energy resources than for a highly centralised system with long-distance transmission and high levels of national and potentially international grid interconnection. The forecast national decentralisation index should be a good indicator of the copper gain potential in each country.

²⁵⁰ Cervone, A., et al. (2016). "Optimization of the battery size for PV systems under regulatory rules using a Markov-Chains approach." *Renewable Energy* 85: 657-665.

²⁵¹ Ellingsen, L. A. W., et al. (2014). "Life Cycle Assessment of a Lithium-Ion Battery Vehicle Pack." *Journal of Industrial Ecology* 18(1): 113-124



Modern High Speed Train

INFRASTRUCTURE AND TRANSPORT

INFRASTRUCTURE AND TRANSPORT OVERVIEW

GROWING ASIAN INFRASTRUCTURE NEEDS

Continuing urbanisation by 2030 will strain urban infrastructure across Asia. Sections above already discussed electricity and housing but other infrastructure should also be considered, particularly water (potable and sewerage) and transport. After a general introduction, this report will concentrate on transport.

Estimates vary, but analysts agree the scale of projected investment is enormous. The Asian Development Bank (ADB) Institute²⁵² estimated a required Asian infrastructure investment of US\$8 trillion between 2010 and 2020. HSBC says emerging Asia will need US\$11 trillion in basic infrastructure investment between 2014 and 2030.²⁵³

²⁵² Asian Development Bank and Asian Development Bank Institute, 'Infrastructure for a Seamless Asia', 2009.

²⁵³ Quinn, N, (2013) Surge in infrastructure spending likely to spur global growth, The Nation, 4 November 2013, <http://www.nationmultimedia.com/business/Surge-in-infrastructure-spending-likely-to-spur-gl-30218596.html>

The source of the capital will influence the infrastructure built. Institutions like the ADB, the International Monetary Fund (IMF) and the World Bank are important financiers for this forecast infrastructure spend. An important emerging player is the Asian Infrastructure Investment Bank (AIIB) proposed by China in October 2013, now establishing funding of US\$100 billion capital. While the IMF and World Bank are regarded as US and European initiatives, and the ADB, based in the Philippines, is largely led by Japan. The AIIB will use mainly Chinese capital and be headquartered in Beijing. Shares in the AIIB are based on relative economy size and defined fraction of authorised capital. China has 30% shares and 26% of the votes, India has 8.5 and 7.5% respectively, and other countries including Russia, UK, Germany, Korea and Australia have smaller stakes, while the US has not participated. It is significant that rising Asia is moving to become the prime financier of new Asian infrastructure.

Christopher Heathcote is CEO of the Global Infrastructure Hub, an initiative of the G20 which has a goal to unlock an additional US\$2 trillion in global infrastructure capacity by 2030. Heathcote predicts changes in infrastructure delivery by 2030, with more services delivered by decentralised infrastructure. Decentralised energy is discussed in the previous section, but this trend also applies to at least telephony and water services.

WATER INFRASTRUCTURE

The OECD estimates that the benefits of investment in water and wastewater are significant with a ratio of “positive externalities” to investment of between four and twelve to one.²⁵⁴ The need for water infrastructure in East and South Asia is significant, as recognised by the World Bank and the ADB. In its program “Water for All”, the ADB states that 318 million people in Asia do not have access to improved drinking water and that 1.7 billion people do not have access to proper sanitation facilities.²⁵⁵ The Millennium Development Goals aimed by 2015 to halve the proportion of people without sustainable access to safe drinking water and basic sanitation²⁵⁶ and have now been replaced by the Sustainable Development Goals which aim to “ensure availability and sustainable management of water and sanitation for all” by 2030.²⁵⁷ The ADB plans to spend

\$2.0 billion to \$2.5 billion annually or a total of over \$20 to 25 billion by 2020 on water infrastructure for Asia and the Pacific.²⁵⁸

TRANSPORT INFRASTRUCTURE

Dense cities can become constrained by transport congestion. High levels of transport by private vehicle are particularly problematic. Cities in Asia have been historically affected by congestion and local air pollution from internal combustion engine vehicles. Four solutions are emerging:

1. Improving the availability of multiple forms of public transport to reduce the number of private vehicles on the road network;
2. Introducing vehicle sharing and ride sharing schemes for the same reason;
3. Electrification of the vehicles that remain to improve local air quality; and
4. Increasing the capacity of the road network by employing autonomous vehicles.

This report examines the latter three in the next section on Light Vehicles and the first in the following section on Public Transport.

The overall national approach to passenger transport and mobility are examined in the following paragraphs, referring occasionally to the Intended Nationally-Determined Contribution (INDC) and Deep Decarbonisation Pathways Project (DDPP) report for each country, where available.

SELECTED COUNTRY SUMMARIES

China

The IEA says passenger transport tripled in China between 2000 and 2010.²⁵⁹ Ma et al²⁶⁰ forecasts that vehicle population in China will increase from 65 million in 2010 to 294 million in 2030. Other forecasts are much higher.

China’s INDC indicates the need to “properly allocate public transport resources in cities, giving priority to the development of public transportation and

²⁵⁴ *Infrastructure to 2030, Volume 2: Mapping Policy for Electricity, Water and Transport*. (2007). OECD.

²⁵⁵ Asian Development Bank (2016) *Water for All*, Water, ADB.org, <http://www.adb.org/sectors/water/main>

²⁵⁶ Asian Development Bank 7, MDG 7: Ensure Environmental Sustainability, Millennium Development Goals, pp. 169-181 <http://www.adb.org/sites/default/files/publication/175162/ki2015-mdg7.pdf>

²⁵⁷ UN Water (2015) *Water in the 2030 agenda for sustainable development*, Unwater.org, <http://www.unwater.org/sdgs/en/>

²⁵⁸ Asian Development Bank (2016) *Water for All-About*, Water, ADB.org <http://www.adb.org/sectors/water/about-water-for-all>

²⁵⁹ Dulac, J, (2013) *global land transport infrastructure requirements - Estimating road and railway infrastructure capacity and costs to 2050*, International Energy Agency, https://www.iea.org/publications/freepublications/publication/TransportInfrastructureInsights_FINAL_WEB.pdf

²⁶⁰ Ma L, Liang J, Gao D, Sun J, Li Z. The future demand of transportation in China: 2030 scenario based on a hybrid model. *Procedia Soc Behav Sci* 2012;54: 428e37. <https://www.researchgate.net/publication/257717203>

7. Infrastructure and Transport continued

encouraging the development and use of low-carbon and environment-friendly means of transport, such as new energy vehicles".²⁶¹ It aims to increase the share of public transport in motorised travel in big-and-medium-sized cities to 30% by 2020, promote alternative fuels, bicycles and walking. Its DDPP report²⁶² indicates that transport energy demand will increase 130% by 2050 and indicates changes are needed in sectoral structure and vehicle energy efficiency. It encourages rail transport for passengers and predicts a rail share of passenger transport by 2050 of 25%, up from 18% in 2010. The number of public transit vehicles per ten thousand people in 2050 is forecast to reach twelve, nearly three times higher than in 2010. Electrification of railway systems will increase rapidly to more than 90% of the system by 2050, from less than 50% in 2010. Electric and fuel cell vehicles are forecasted to be 60% of passenger car stock in 2050 and could be as high as 80%.

India

India already has severe air quality and traffic congestion issues as the number of road vehicles grows rapidly. Air quality in New Delhi is worse than Beijing.²⁶³ According to international public transport non-profit UITP, in early 2012 there were almost 160 million registered motor vehicles, a number which had grown at 10.5% per year over the previous ten years. Currently there are over 200 million registered vehicles, showing growth of 7.7% since 2012. The share of buses in total registered vehicles declined from 11.1% in 1951 to just 1% in 2012.²⁶⁴

The Indian Government indicates that overall annual per capita transport demand of 5,970km in 2012 will rise to 18,700 in 2047.²⁶⁵ Interpolating yields about 12,500km in 2030. As population is forecasted to increase over 19% by then, total Indian transport demand can be predicted to increase 2.5 times, from 7.5 to 19.1 trillion km. It is obvious that a reliance on personal vehicles for this level of transport demand in



Traffic in India in 2008
(CC BY 2.0) by Lingaraj GJ

²⁶¹ Wei, S. (30 June, 2015). *Intended nationally determined contribution - Enhanced Actions on Climate Change*. <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

²⁶² Qiang LIU, Y. C., Chuan TIAN, Xiaoqi ZHENG, Fei TENG, Alun GU, Xi YANG, Xin WANG. (Sep, 2015). *Pathways to deep decarbonization in China*. http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_CHN.pdf

²⁶³ Feaster, S. (2016) Data Bite: Beijing Gets Lots of Attention for Its Dirty Air, but New Delhi's Is Worse, Institute for Energy Economics and Financial Analysis (IEEFA), <http://ieefa.org/data-bite-beijing-gets-lots-of-attention-for-its-dirty-air-but-new-delhi-is-worse/>

²⁶⁴ UITP India (2015), *Sustainable public road transport in India - challenges & future roadmap*, The International Association of Public Transport (UITP), <http://www.india.uitp.org/sustainable-public-road-transport-india-challenges-future-roadmap>

²⁶⁵ NITI Aayog (2015). *A Report on Energy Efficiency and Energy Mix in the Indian Energy System (2030): Using India Energy Security Scenarios, 2047*. New Delhi, http://niti.gov.in/mgov_file/Energy_Efficiency.pdf.

India's already congested cities would be disastrous. Public transport solutions will be needed. Additionally, India already imports almost 75% of its crude oil, so alternative fuels including electricity will need to be explored for energy security purposes.

India's Smart Cities policy²⁶⁶ includes "applying Smart Solutions in the transport sector", particularly intelligent traffic management systems and aims to reduce average commute time to "have positive effects on productivity and quality of life of citizens". Its Atal Mission for Rejuvenation and Urban Transformation (AMRUT)²⁶⁷ focuses on ensuring basic infrastructure services, including transport, for 500 cities. Its INDC²⁶⁸ mentions "focusing on low carbon infrastructure and public transport systems" including "Urban Transport policies... to focus on moving 'people' rather than 'vehicles', in which Mass Rapid Transit System (MRTS) would play an important role." It says 39 urban transport and mass rapid transport projects have been approved of which 19 projects had been completed in mid-2015.

India's DDPP report²⁶⁹ notes that the transport sector is the country's second-highest greenhouse gas emitter after electricity and that transport energy requirements will increase by a factor of more than three between 2010 and 2030 under a conventional scenario. It, however, proposes a range of measures to limit the increase to a mere doubling. It notes the importance of modal shift to public transport in cities, reducing transport demand by better planning, alternative fuels and alternative (electric drive) vehicles. Relevant policy includes the National Urban Transport Policy (NUTP) (MoUD, 2006),²⁷⁰ the National Policy on Biofuels (NPB) (MNRE, 2009),²⁷¹ and the policy on electric vehicles (GoI, 2012).²⁷²

Japan

Japan has a modern public transport system and over 80 million registered vehicles.²⁷³ Passenger vehicle numbers are expected to be fairly stable at around 60 million to 2030,²⁷⁴ and little growth of the established public transport system is expected.

Japan's DDPP²⁷⁵ indicates transport greenhouse emissions in 2050 reduced by 82% compared with 2010 despite a 33% increase in passenger-km per capita. A major driver is a 69% reduction of energy demand in aggregate for transport resulting from efficient vehicles leading to 77% less energy content in passenger transport associated with the switch from fossil fuel to electricity and hydrogen. Electrification plays an important role, and electricity accounts for about half of total final energy consumption in passenger transport. Its INDC²⁷⁶ indicates a drop in transport emissions of 28% by 2030 driven by improvement of fuel efficiency, promotion of next-generation automobiles, promotion of public transport, modal shift to railway and rail energy efficiency improvements.

Korea

Seoul has a comprehensive public transport system, and high-speed rail connects the cities. Korea's INDC²⁷⁷ notes that the Korean government is "continuing to expand infrastructure for environment-friendly public transportation, while introducing low-carbon standards for fuel efficiency and emissions produced from automobiles". Korea has strengthened vehicle emission standards effective in 2020²⁷⁸ and provides incentives including tax reductions for electric and hybrid vehicles.²⁷⁹

²⁶⁶ Government of India, What is a Smart City, <http://smartcities.gov.in/writereaddata/What%20is%20Smart%20City.pdf>

²⁶⁷ Ministry of Urban Development, Government of India (2016) <http://amrut.gov.in>

²⁶⁸ *India's Intended Nationally Determined Contribution: Working towards Climate Justice*. (Oct, 2015). <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

²⁶⁹ P.R. Shukla, S. D., Minal Pathak, Darshini Mahadevia, and Amit Garg. (Sep, 2015). *Pathways to deep decarbonization in India*, http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_IND.pdf

²⁷⁰ Ministry of Urban Development (2014), National Urban Transport Policy, Government of India, www.itdp.in/wp-content/uploads/2014/11/NUTP-2014.pdf

²⁷¹ Ministry of New and Renewable Energy, National Policy on Biofuels, Government of India, www.mnre.gov.in/file-manager/UserFiles/biofuel_policy.pdf

²⁷² Department of Heavy Industries and Public Enterprises, National Electric Mobility Mission Plan 2020 government of India, <http://dhi.nic.in/writereaddata/Content/NEMMP2020.pdf>

²⁷³ Ministry of International Affairs and Communications (2015) Japan Statistics Yearbook 2015, Statistics, Statistics Japan, <http://www.stat.go.jp/english/data/nenkan/back64/1431-12.htm>

²⁷⁴ Hirota, K. (2007). "Passenger Car Ownership Estimation toward 2030 in Japan: BAU Scenario with Socio-economic Factors." *Studies in Regional Science* 1.37: pp. 25-39. https://mpr.a.ub.uni-muenchen.de/15139/2/MPPA_paper_15139.pdf

²⁷⁵ Kainuma, M., Toshihiko Masui, Ken Oshiro, Go Hibino (Sep, 2015). *Pathways to deep decarbonization in Japan*, http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_JPN.pdf

²⁷⁶ *Submission of Japan's Intended Nationally Determined Contribution* (July 2015), <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

²⁷⁷ *Intended Nationally Determined Contribution: Republic of Korea*. (30 June, 2015), <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

²⁷⁸ Miller&Façanha (2014). *The State of Clean Transport Policy: A 2014 Synthesis Of Vehicle And Fuel Policy Developments*. Washington DC. www.theicct.org/state-of-clean-transport-policy-2014

²⁷⁹ Go4SEM (2015) South Korea: Electric vehicle supply chain and opportunities for European SMES, global opportunities for smes in electro-mobility, funded by the European Union FP7Framework, http://www.go4sem.eu/public/global-opportunities/GO4SEM_SouthKorea_short.pdf

7. Infrastructure and Transport continued

Australia

Australia is large and highly reliant on motor vehicles for transport. Public transport in the large cities is reasonably developed. Australia's DDPP²⁸⁰ forecasts a 70% improvement in the energy efficiency of cars and light commercial vehicles, mostly through electrification combined with fuel efficiency improvements and a continuation of the trend towards smaller vehicles.

IMPLICATIONS FOR COPPER

Light vehicles and public transport are significant in terms of their potential impact on copper. They are discussed in more depth in the following sections.

On water, increasing water access tends to favour copper. While copper is not presently the prevailing material of construction used in pipes, the supporting infrastructure for potable water and sanitation services requires electric pumps and control systems. Extrapolating just the ADB's forecasts indicates a regional spend as high as US\$37.5 billion on water infrastructure, a small proportion of which should flow through to copper demand. We estimate the incremental demand is orders of magnitude less than the other technologies and trends discussed in this report and so have concentrated on transport infrastructure.

LIGHT VEHICLES

DISRUPTION IS COMING

According to McKinsey & Company²⁸¹ there is transformational change underway in the automotive industry, an industry which has seen little change and consolidation to date. They see four disruptive, interconnected and reinforcing trends. Future mobility will be increasingly diverse, autonomous, electrified and connected. McKinsey & Co predict that new car sales will continue to grow at 2% globally (much faster in many of the Asian countries of interest). However new mobility services, including car share and e-hailing, will grow in dense, congested urban areas.

The McKinsey research predicts that 10% of new vehicle sales by 2030 will be shared vehicles and up to 15% will be autonomous. Instead of owning a "one-size-fits-all" car, people will increasingly select a tailored mobility solution for each specific mobility need. McKinsey expects capital cost-parity of electrified vehicles (EV, hybrid, fuel cell) by 2025 and penetration rates between 10 and 50% by 2030 depending on location, led by dense cities with emission regulations. Dr Penelope Crossley of Sydney University says that

"air pollution will be a big driver for EV uptake". Traditional manufacturers will be challenged by new competitors including technology companies, specialist manufacturers and start-ups. Chinese manufacturers may play an important role globally.

In addition to a change in technologies and likely ownership models, the other key feature of the automotive industry landscape is a change in the countries and companies are producing vehicles. The growth of the auto sector in China, India and South Korea is expected to continue and the arrival of start-up companies such as Tesla will challenge incumbent players.

THE CHANGING OWNERSHIP MODEL

It is likely that the ownership model for cars will change in the coming decades; from the current model based almost entirely on private ownership, to the purchase of *mobility services*. This shift is already evident in some cities with the emergence of car sharing as people decide not to own a car but to pay for access to one when they need it. The introduction of autonomous vehicles is likely to further promote this development as people will not need to own a car, nor drive to satisfy their mobility needs.

What format mobility services assume in 2030 will be determined by the context of local requirements. For example, a dense city where private car ownership is supplemented with several other mobility options (including car share, ride share, e-hailing and public transport) will differ from rural locations where distance rather than congestion is the key factor.

While the changing model is likely to result in fewer vehicles per capita, overall numbers will still rise. The utilisation rate of shared vehicles, whether driven or autonomous, will be higher than those in private ownership, spending less time stationary. This will in turn lead to a faster turnover of the vehicle fleet, resulting in the need for new or perhaps re-manufactured vehicles.

Future light vehicle ownership is likely to be a mix of these options reflecting varying consumer preferences and means, as well as government policies. Private ownership will retain an appeal for many wealthier and status oriented Asian customers, while a focus on the mobility service rather than the vehicle itself is likely to gain appeal in many existing and emerging highly-urbanised markets.

²⁸⁰ Denis, A. et al (Oct 2015). *Pathways to deep decarbonization in Australia*, <http://deepdecarbonization.org/countries/#australia>

²⁸¹ Gao, P. Kaas, H. Mohr, D and Wee, D. (2016) Disruptive trends that will transform the auto industry, McKinsey and Company, January 2016, <http://www.mckinsey.com/industries/high-tech/our-insights/disruptive-trends-that-will-transform-the-auto-industry>

THE LIKELY TECHNOLOGY COMBINATION

The likely dominant technology in the world's light car fleet is a matter of conjecture, though current trends help indicate the likely future. A discussion on vehicle technology has two main areas of focus: the propulsion system and the control system. Both are undergoing radical transformation at a level not seen since the format of the conventional car was established in the early 20th century.

Propulsion technology

The system that propels the vehicle along the road has been dominated by the internal combustion engine since mass production commenced after World War I. Whether burning petrol (gasoline), diesel, liquid petroleum gas (LPG) or compressed or liquefied natural gas (CNG/LNG), engine technology has improved power, torque, efficiency and reliability, while remaining fundamentally unchanged for over 100 years. Although early electric and steam powered alternatives were produced, they were not successful in gaining market penetration, and the internal combustion engine has dominated.

However, since 1997, with the introduction of hybrid electric vehicles, a challenge to the conventional propulsion technology has been underway. There are now several technology alternatives, and many major existing and new market entrants are investing in the development of technologies that could ultimately replace the internal combustion engine.

The major propulsion alternatives include:

- internal combustion engine (ICE) - the status quo;
- hybrid electric vehicles - which feature a combination of both electric and internal combustion engines but only a single combustible-fluid fuel (HEV);
- plug-in hybrid electric vehicle - with dual fuel sources: electric and combustible-fluid fuel (PHEV);
- pure, single-fuel electric vehicle (EV) - sometimes referred to as a Battery Electric Vehicle (BEV); and
- fuel cell vehicles - which convert a single fuel, often hydrogen, direct to electricity for propulsion (FCV).

Although fuel cell vehicles offer the same pollution and emission benefits as EVs, this present research found broad scepticism about the likelihood of hydrogen becoming the dominant alternative technology rather than electric.

Although the world has long since become comfortable with petrol and its inherent safety risk as a highly combustible fuel, the real and perceived safety issues associated with hydrogen continue as a barrier to its acceptance as an alternative fuel. In addition, the

required production investment and need for an entirely new refuelling infrastructure capable of careful handling and storage of hydrogen fuel are barriers to large-scale market penetration. Finally, timing is likely to play a role in deciding the winner of the BEV versus FCV competition. From a "path-dependency" perspective, John Daley, CEO of the Grattan Institute points out that EVs will get to scale before hydrogen cars and will then be hard to stop. The automotive industry is built on economies of scale, and the scale of production of common automotive batteries will be boosted by the use of similar batteries for everything from mobile computing devices to stationary energy storage.

Automotive expert Tim Olding, previously Managing Engineer at General Motors Holden and Chief Engineer of EV Engineering Pty Ltd, observed that hydrogen technology may nonetheless have a role to play in long-distance transport operations where range is important and potentially where fast refuelling is a priority. Olding otherwise believes that the development of hydrogen-based propulsion technology may be a defensive strategy by incumbent automakers who recognise the huge barriers to new entrants should it become the dominant technology. This is in contrast to EVs which feature much simpler and more common systems than either conventional or hydrogen vehicles.

Control technology

The second major technology system in a light vehicle is the control system. Just as the internal combustion engine has carried over since the days of Karl Benz in the late 19th century, so too the basic steering, acceleration and braking controls have continued to be in the driver's control. The layout of these controls was eventually standardised into the format known today, and the sophistication of these systems to improve safety and comfort has seen the advent of anti-lock brakes, power steering, and traction control, etc. Today's cars start, stop and turn as directed by the driver.

Like the changes in propulsion technology, a range of alternatives is now emerging with both incumbent and new entrants investing and experimenting in these new technologies. The current major technologies include:

- conventional driver-controlled vehicles - the status quo, an evolution of the 1886 Motorenwagen invented by Karl Benz;
- Advanced Driver-Assistance Systems (ADAS) - conventional vehicles with the inclusion of automated accident avoidance systems as featured in current luxury vehicles;
- autonomous with manual driver override - vehicles that can drive themselves but still feature manual controls to allow driver override when selected; and
- fully-autonomous vehicles - automated vehicles that do not require (or allow) any driver control and have the potential to become networked.



THE DRIVERS FOR CHANGE

There are several factors that are likely to drive disruption and change in the light vehicle industry. The main ones are environmental concerns and the need to reduce congestion in dense cities. Other factors include energy security, consumer preference and customer-centred innovation. The major drivers are explained below.

Local air quality

Electrification of vehicles has the potential to contribute to improved air quality in dense urban environments due to the removal of tailpipe pollution. Of course, the total greenhouse emissions of an EV depend on the source of electricity used to charge the battery. A car charged with electricity generated by a coal-fired power station will account for a significant operational carbon footprint, whereas a car that is charged with renewable electricity will have a negligible operational carbon footprint. However, at point of use, electric vehicles, regardless of electricity source, do not generate the tailpipe pollution which is recognised as a significant contributor to local air pollution. This feature of EVs is of particular relevance to major cities in China and India that are grappling with very poor air quality.

“Pull” factors leading to increased demand for electric vehicles include consumers seeking cars with lower running and maintenance costs. “Push” factors include governments seeking to improve air quality of cities,

reduce overall greenhouse emissions and address energy security concerns through incentives such as rebates, tax breaks and preferential parking or travel lanes.

Road network congestion

There are many arguments in favour of a transition to autonomous vehicles but most involve reducing road congestion, including that:

- the driving and navigational systems are expected to all but eliminate road accidents resulting in reduced injuries and fatalities as well as reduced repair costs;
- this, and the ability for vehicles to travel much closer together, should reduce congestion; and
- the number of cars per person should be reduced.

HOW BIG WILL THE CHANGE BE?

Autonomous cars

Like any emerging technology, predicting the likely scale and impact of autonomous vehicles is difficult. However, recent developments give several reference points on which to base an understanding of possible futures that may eventuate. The number of automakers investing in autonomous vehicle technology includes Tesla, Toyota, Ford, Volvo, Audi, Land Rover Jaguar, Daimler, General Motors and Nissan. Technology companies Google, Apple, Intel and Uber are also investing heavily in this new technology, sometimes in collaboration with established automakers. This private-sector commitment is quickly bringing the first

generation of autonomous vehicles to market. Automotive expert Tim Olding says that “driverless cars will come quicker than you think, replacing taxis or car sharing schemes”.

Short of full autonomy, a strong consensus of experts expect the interim steps of internet connectivity and networking of vehicles. McKinsey & Co²⁸² predict that the number of networked cars will rise 30% annually for the next several years and by 2020, one in five cars will be connected to the Internet.

Electric Vehicle penetration

According to “Green Car Reports”²⁸³ the Chinese company BYD manufactured the most EVs in 2015 with approximately 60,000 built, ahead of Tesla from the USA with approximately 50,000. Nissan manufactured 50,000 EVs in Japan, BMW 30,000 in Germany and Ford and General Motors made approximately 20,000 units each in the USA. There are several other major manufacturers producing EVs such as Fiat-Chrysler and the VW Group, but it is noteworthy that the leader in 2015 was a Chinese company and that the top two manufacturers were not traditional automakers with a long industrial heritage. Disruption in the auto industry is here.

Company	Country of origin	Number sold in 2015
BYD	China	61,722
Tesla	USA	50,577
Nissan	Japan	50,000
BMW	Germany	30,000
Ford	USA	20,000
General Motors	USA	20,000

According to Navigant Research,²⁸⁴ the global light-duty EV market is expected to grow from 2.7 million vehicle sales in 2014 to 6.4 million in 2023 under a base scenario (i.e., based on assumptions that sit between aggressive and conservative levels).

To get an overview of the possible vehicle market make up in 2030, the IEA²⁸⁵ predicts the following vehicle type annual sales mix:

- Internal combustion engine (ICE): 39 million
- Hybrid electric vehicles (HEV): 25 million
- Plug-in hybrid electric vehicles (PHEV): 22 million
- Battery electric vehicles (BEV): 9 million
- Fuel cell vehicle (FCV): 6 million

A 2015 global tally of national goals by The International Council on Clean Transportation²⁸⁶ amounts to total stocks of at least 15 million electric vehicles globally by 2020, and more than 25 million by 2025-2030. Navigant²⁸⁷ predicts 5.8 to 6.4 million sales of electric-drive vehicles by 2024, half of which would be plug-in vehicles (BEV and PHEV). We take our forecasts from a country by country analysis which follows.

Once at scale and with charging infrastructure networks established, EVs should have a lower capital cost than ICE or FCV cars, as well as much lower operating and maintenance costs than either, much less than ICE cars. John Daley of the Grattan Institute points out that “EVs will get to scale first and then be hard to stop”. The significance of EVs as a likely future dominant technology is apparent. Tim Olding of Quickstep supports this prediction saying that “EVs win, especially for non-private vehicles due to operational and maintenance cost and declining battery cost. Hydrogen has a place for range and fast charge but that comes at a cost. Hydrogen could be seen as a defensive play for incumbents”.

²⁸² McKinsey & Company (2013) The road to 2020 and beyond: What’s driving the global automotive industry?, Advanced Industries, McKinsey, http://www.mckinsey.com/~media/mckinsey/dotcom/client_service/automotive%20and%20assembly/pdfs/mck_the_road_to_2020_and_beyond.ashx

²⁸³ Voelcker, J. (2016) Who Sold the Most Plug-In Electric Cars in 2015? (It’s Not Tesla Or Nissan), Green Car Reports, 15 January 2016, http://www.greencarreports.com/news/1101883_who-sold-the-most-plug-in-electric-cars-in-2015-its-not-tesla-or-nissan

²⁸⁴ Green Car Congress (2015) Navigant forecasts global light duty electrified vehicle sales to exceed 6.0M in 2024; PEVs to account for roughly half, [greencarcongress.com](http://www.greencarcongress.com), 21 December 2015, <http://www.greencarcongress.com/2015/12/20151221-navigant.html#more>

²⁸⁵ Global EV Outlook: Understanding the Electric Vehicle Landscape to 2020 (IEA 2013) https://www.iea.org/publications/globalevoutlook_2013.pdf

²⁸⁶ Lutsey, N. (Sep, 2015). *Transition To A Global Zero-emission Vehicle Fleet: A Collaborative Agenda For Governments*. International Council on Clean Transportation Washington, DC: http://www.theicct.org/sites/default/files/publications/ICCT_GlobalZEVAlliance_201509.pdf

²⁸⁷ Green Car Congress (2015) Navigant forecasts global light duty electrified vehicle sales to exceed 6.0M in 2024; PEVs to account for roughly half, [greencarcongress.com](http://www.greencarcongress.com), 21 December 2015, <http://www.greencarcongress.com/2015/12/20151221-navigant.html#more>

GEARING UP FOR CHANGE - COUNTRY BREAKDOWN OF POLICIES

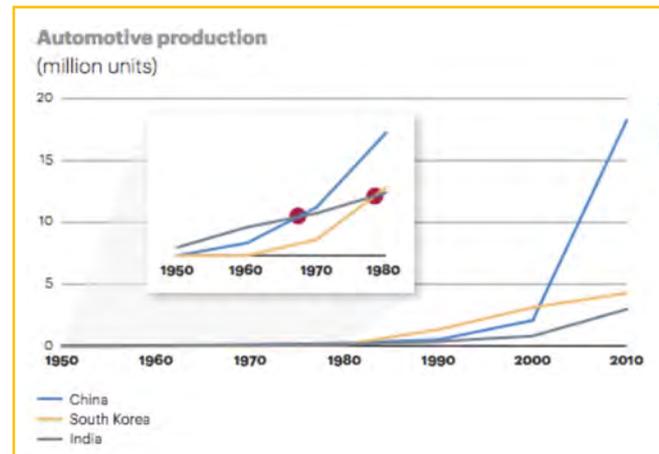
Of particular interest for the 2030 Roadmap is the ramp up of automotive production in the three largest car manufacturing economies within our scope, namely China, India and Korea. The chart (right) is from A T Kearney.

The following graph demonstrated automotive production in China, India and Korea (auto manufacturing historical graph).²⁸⁸

The fact that the auto-industry is in transition, added to the fact that so much manufacturing is occurring in our region of interest, makes a focus on this industry relevant to an understanding of the demand for copper.

China

Total auto manufacturing in China will continue to grow. China is the largest manufacturer of vehicles in the global market and according to research by Statista²⁸⁹ produced an estimated 21 million passenger cars and 3.4 million commercial vehicles in 2015, a huge leap from the respective 2005 figures of 3 million and 2.6 million.



Source: Society of Indian Automobile Manufacturers, Korea Automobile Manufacturing Association, China Automotive Industry Yearbook: A.T Kearney analysis

According to Wu et al²⁹⁰ (Tsinghua University, Beijing), car ownership in China will rise from 128 cars per 1000 capita in 2015 to 250 cars per capita by 2030, at which point car ownership rate will peak. It is expected that car ownership will saturate at 500 cars per 1000 capita by 2050. This is equivalent to an additional 175 million cars on Chinese roads from 2015 to 2030.



²⁸⁸ Klink, G. Kidambi, R. Sen, K and Mathur, M. (2013) The Contribution of the Automobile Industry to Technology and Value Creation, ATKearney, Ideas and Insights, https://www.atkearney.com.au/paper/-/asset_publisher/dVxv4Hz2h8bS/content/the-contribution-of-the-automobile-industry-to-technology-and-value-creation/10192

²⁸⁹ Production of cars in China from 2006 to 2016 (in 1,000 units) (2016), Statistics, Metals and electronics, Vehicle Manufacturing, <http://www.statista.com/statistics/281133/car-production-in-china/>

²⁹⁰ Wu, T., Zhao, H., & Ou, X. (2014). Vehicle Ownership Analysis Based on GDP per Capita in China: 1963–2050. *Sustainability*, 6(8), 4877-4899. <http://www.mdpi.com/2071-1050/6/8/4877>

From this growing base of demand and production, China is also preparing to increase production of EVs. Reports in the China Daily²⁹¹ quote Tong Guangyi, Vice-Director of the NEA Power Department, discussing a government goal to build a network of 12,000 charging stations to meet the needs of an anticipated 5 million EVs by 2020. Also part of the investment program are 4.8 million power poles, 3,850 charging stations for public buses and 2,500 for taxis to be built in the same period. The Chinese Ministry of Industry and Information Technology²⁹² has announced common guidelines for a nationwide charging network.

China is expecting significant growth in EV numbers, but notably, e-bike take up is already very large. Although this section of the roadmap is focused on light vehicles, the uptake of electric bikes and buses demonstrates the application of electricity-based propulsion is broader than just cars. Data from the International Energy Agency²⁹³ (IEA) indicates China had 280 million e-bikes and 83,000 EVs in service at the end of 2014. The IEA estimates annual domestic sales of EVs and PHEVs in China of 8.4 million a year by 2030. This implies total production by 2030 of over 40 million vehicles.

To conclude the overview of the Chinese car market, James Li of the International Copper Association observed that "Japan owns hybrid technology, and maybe Korea and/or Japan will own hydrogen, but China will own pure electric". Considering the command nature of the Chinese economy and the rise in production and profile of companies such as BYD, this prediction is noteworthy.

India

According to research by AT Kearney²⁹⁴, the Indian automotive industry is the sixth largest in the world by volume (3.16 million units produced in 2014²⁹⁵) and value and is made up of 35 automakers. In the ten

years from 2003 it grew 14.4% and accounts for 7% of GDP and 7-8% of employment.

As in other countries, the overall transport sector is facing significant changes. McKinsey & Co's 2014 report "India: Towards Energy Independence 2030" suggests that India is changing its transport modal mix and introducing efficiency measures.²⁹⁶ Despite having a lower average car size, meaning lower emissions and fuel consumption, McKinsey point out that Indian fuel efficiency standards lag behind the European Union. The fuel efficiency standard of trucks is even further behind the EU, attributed in part to poor infrastructure and older technology.

EVs in India have made little impact to date in the market with approximately 2,700 cars²⁹⁷ in the national fleet. However, India's INDC²⁹⁸ for the Paris Agreement, describes a program known as the Faster Adoption and Manufacturing of Hybrid & Electric Vehicles in India (FAME India). This is part of the National Electric Mobility Mission Plan 2020 (NEMMP)²⁹⁹ intended to incentivise faster adoption and manufacturing of hybrid and electric vehicles.

Indian car ownership, currently 34 cars per 1000 people, is expected to grow to 73 cars per 1000 people by 2030.³⁰⁰ In absolute terms this is 112 million cars on Indian roads in 2030.

The composition of the car fleet will be heavily influenced by climate policy. The NEMMP aims to increase the number of electric vehicles to 7 million by 2020, a penetration rate of about 10%, and turn the Indian electric vehicle manufacturing industry into a global player. We think that is unlikely given the standing start of the Indian industry and that the goal is higher than for China's well-established industry. The IEA³⁰¹ estimates annual domestic sales of EVs and PHEVs in India of 2.5 million a year by 2030. Assuming

²⁹¹ China Daily (2015) Governments and policies - Network of charging stations on cards, Chinadaily.com, 14 October 2015, http://www.chinadaily.com.cn/cndy/2015-10/14/content_22178732.htm

²⁹² Xinhuanet (2015) Major progress in standardizing electric vehicle charging ports announced, <http://news.xinhuanet.com>, 10 October 2015, http://news.xinhuanet.com/english/2015-10/02/c_134680202.htm

²⁹³ International Energy Agency (2010) Electric and plug-in hybrid vehicle roadmap, IEA.org, https://www.iea.org/publications/freepublications/publication/EV_PHEV_brochure.pdf

²⁹⁴ Klink, G. Kidambi, R. Sen, K and Mathur, M. (2013) The Contribution of the Automobile Industry to Technology and Value Creation, ATKearney, Ideas and Insights, https://www.atkearney.com.au/paper/-/asset_publisher/dVxv4Hz2h8bS/content/the-contribution-of-the-automobile-industry-to-technology-and-value-creation/10192

²⁹⁵ Passenger car production in selected countries in 2014, by country (in million units) (2014), Statistics, Metals and electronics, Vehicle Manufacturing, <http://www.statista.com/statistics/226032/light-vehicle-producing-countries/>

²⁹⁶ Tuli, K. (Jan, 2014). *India: Towards Energy Independence 2030*, http://iitbaa-gbf.com/wp-content/uploads/2015/08/India_Towards_energy_independence_2030.pdf

²⁹⁷ International Electric Agency (2015) Global EV Outlook (GEO 2015) OECD/IEA, 9 rue de la Fédération, 75739 Paris Cedex 15, France, http://www.iea.org/evi/Global-EV-Outlook-2015-Update_1page.pdf

²⁹⁸ *India's Intended Nationally Determined Contribution: Working Towards Climate Justice*. (Oct, 2015). <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>

²⁹⁹ Department of Heavy Industries and Public Enterprises, National Electric Mobility Mission Plan 2020 government of India, <http://dhi.nic.in/writereaddata/Content/NEMMP2020.pdf>

³⁰⁰ Arora, S., Vyas, A., & Johnson, L. R. (2011). Projections of highway vehicle population, energy demand, and CO2 emissions in India to 2040. *Natural Resources Forum*, 35(1), 49-62. <http://dx.doi.org/10.1111/j.1477-8947.2011.01341.x>

³⁰¹ International Energy Agency (2010) Electric and plug-in hybrid vehicle roadmap, IEA.org, https://www.iea.org/publications/freepublications/publication/EV_PHEV_brochure.pdf

7. Infrastructure and Transport continued

a ramping up of production to this level, we expect total production by 2030 of almost 15 million vehicles.

In summary, the Indian automotive sector is large in terms of volume and market players. It is important in terms of its share of GDP, growth and as an employer. Like other national auto industries, it is also facing pressures of fuel efficiency and a transition towards EVs.

Japan

The Japanese auto industry is the second-largest in the world and has produced electric vehicles since the 1970s.³⁰² The industry has, however, experienced a prolonged period of little growth. According to the Japan Automobile Manufacturers Association, "In 2014 motor vehicle production in Japan increased for the first time in two years, totalling 9.77 million units, up 1.5% from the previous year".³⁰³ Domestic sales have now grown for the past three consecutive years to around 5.4 million units.

Japan's fuel security issues have led to policy interventions which favour electric vehicles. In 1997, the government set a target for the diffusion of clean energy vehicles by 2010 including 110,000 EVs. This was evidently almost met as there are currently 108,000³⁰⁴ EVs in the national fleet. The Government's Next-Generation Vehicle Strategy requires the BEV/PHEV market share to reach 15-20% of total vehicle sales by 2020 and 20-30% by 2030,³⁰⁵ and the government targets deployment of 2 million slow chargers and 5,000 fast charging points by 2020.³⁰⁶ If no overall growth of annual sales is assumed to 2030, these production levels amount to EV production for the Japanese domestic market by 2030 of around 14 million vehicles.

Korea

Korea is the world's fifth-largest manufacturer of motor vehicles, producing 4.1 million units in 2014, and the eighth-largest car market in the world.³⁰⁷ The Economist³⁰⁸ reported that in 2014, "South Korea's car exports rose by 14% year on year in April to 299,268 units [for that month], according to new government data, driven largely by strong demand from China and the US". Korea's domestic light vehicle fleet is currently around 14 million vehicles with annual sales around 1.7 million units. Electricity prices are low, and gasoline prices are high, creating a good environment for electric vehicle uptake. Korea imports all its oil, so an energy security argument is also applicable.

The Korean government in 2011 set a target of 20 per cent vehicle electrification by 2020, is investing in R&D and is offering subsidies to stimulate uptake.³⁰⁹ The target has been revised downwards,³¹⁰ and it appears that EV sales in 2025 will be around 35,000 units, though other sources^{311, 312} show much higher numbers for a total fleet of 200,000 in 2020. We estimate total sales of EVs and PHEVs in Korea around 2.5 million between now and 2030.

There are plans to fully electrify the car fleet of the island province Jeju, which would create a fleet of 371,000 EVs by 2030.³¹³

Australia

EV uptake in Australia today is unsubsidised and has been low to date, though increased by four times in 2014 from a very small base. Energeia in a 2016 study³¹⁴ estimated the 2030 EV market in the country to be a "fleet of 2.2 million vehicles, consuming

³⁰² Electric Vehicle Association of Asia Pacific (EVAAP) (2016), Japan, EVAAP.org, <http://www.evaap.org/electric/electric.html?sgubun=6>

³⁰³ Reuters (2014) Japan auto sales up 0.1 pct in 2013 at 5.38 mln vehicles, Reuters.com, 6 January 2016, <http://www.reuters.com/article/japan-autos-sales-idUSL3NOKG0NS20140106>

³⁰⁴ International Electric Agency (2015) Global EV Outlook (GEO 2015) OECD/IEA, 9 rue de la Fédération, 75739 Paris Cedex 15, France, http://www.iea.org/evi/Global-EV-Outlook-2015-Update_1page.pdf

³⁰⁵ Ministry of Economy Trade and Industry (2010) Japan's Manufacturing Industry, Government of Japan, http://www.meti.go.jp/english/policy/mono_info_service/overall/overview.pdf

³⁰⁶ International Energy Agency (2013) Global EV Outlook, Clean Energy Ministeriac, OECD/IEA, 9 rue de la Fédération, 75739 Paris Cedex 15, France, https://www.iea.org/publications/global-ev-outlook_2013.pdf

³⁰⁷ Passenger car production in selected countries in 2014, by country (in million units) (2014), Statistics, Metals and electronics, Vehicle Manufacturing, <http://www.statista.com/statistics/226032/light-vehicle-producing-countries/>

³⁰⁸ Yang, Z. (2016) Promoting electric vehicles in Korea, The International Council on Clean Transportation, Blogs, 19 January 2016, <http://www.theicct.org/blogs/staff/promoting-electric-vehicles-in-korea>

³⁰⁹ Go4SEM (2015) South Korea: Electric vehicle supply chain and opportunities for European SMES, global opportunities for smes in electro-mobility, funded by the European Union FP7Framework, http://www.go4sem.eu/public/global-opportunities/GO4SEM_SouthKorea_short.pdf

³¹⁰ Jayto Dynamics (2015) from fiction to reality: the evolution of electric vehicles 2013 – 2015, Jayto, http://www.jayto.com/wp-content/uploads/2015/11/JATO-White-Paper_From-Fiction-To-Reality-The-Evolution-of-EVs-FINAL.pdf

³¹¹ Yang, Z. (2016) Promoting electric vehicles in Korea, The International Council on Clean Transportation, Blogs, 19 January 2016, <http://www.theicct.org/blogs/staff/promoting-electric-vehicles-in-korea>

³¹² The Economist (2014) South Korean car exports see double-digit rise, The Economist Automotive, 15 May 2014, <http://www.eiu.com/industry/article/1641814948/south-korean-car-exports-see-double-digit-rise/2014-05-15>

³¹³ Borowik, G., Chaczko, Z., Jacak, W., & Luba, T. (2015). *Computational Intelligence and Efficiency in Engineering Systems*: Springer International Publishing.

³¹⁴ Energeia (2016) Shifting Gears: The Australian Electric Vehicle Market to 2030 A Private Report for Strategic Research Service Clients, Energeia.com.au, <http://energeia.com.au/wp-content/uploads/2016/02/Shifting-Gears-The-Australian-Electric-Vehicle-Market-to-2030-EXTRACT.pdf>

4.4 TWh of electricity annually (2% of demand on the national electricity market), which represents 79 GWh of potential battery storage by 2030.”

SUMMARY

We expect the electrification of light vehicles to be significant by 2030. We expect capital cost-parity of electrified vehicles by 2025. Penetration rates may be as high as 50% by 2030 depending on the level of government support and approach of the local car industry in each country.

In total, for the countries studied, which should represent the bulk of demand for electric vehicles in the Asia region of interest, the production of electric cars, including plug-in hybrids, between now and 2030 should be in the region of 75 million. The mix is 55% in China, around 19% in each India and Japan, and around 3% each in Australia and Korea.

A key question is whether this number of vehicles can be reached in highly urbanised countries. Many cities will become constrained by congestion. The trends towards autonomous vehicles and car sharing would be required to increase the utilisation of vehicles and road capacity. People’s mobility needs are unaffected by transport technology, so when congestion constrains vehicle numbers there will be substitution into other modes of transport including walking, bicycles and public transport (see the following section).

IMPLICATIONS FOR COPPER

The data shows that the market share of these emerging technologies is small, but growing. Copper use in electric drive cars is significant due to the high currents involved. For the copper supply industry, the change in demand profile is noteworthy.

Inoue estimates that the use of copper in an electric vehicle is six times that of an ICE car, at an average 91kg compared to around 15kg.³¹⁵ The IEA suggests this may be much higher by 2030 as battery capacity increases, predicting copper content of 300kg per EV, 85kg per FCV, and 105kg per PHEV.³¹⁶ Given the level of urbanisation expected and the increasing specialisation of vehicles in future, we expect many of the EV fleet to be city cars which do not need a long range and so estimates in this report use a copper

content of 100kg per vehicle for both EV and PHEV until 2030.

The copper content of 75 million cars, then would be around 7.5 million tonnes. Assuming that these are not incremental vehicles but substitute for ICE cars, the incremental copper would be in the region of 6.4 million tonnes. As stated above, vehicle numbers this high may not be attainable due to city congestion unless there are significant advances in autonomous vehicle technology which increase road capacity and the expanded use of e-hailing, ride sharing and similar models to increase vehicle utilisation. Advanced mobility services are expected to increase copper demand.

Inoue³¹⁷ and others suggest that the copper impact of the charging network could exceed that of the vehicles themselves. As demonstrated in the Australian example, there will be significant additional load from the electrification of light vehicles. As much of this load may occur rapidly and since smart charging integrated into demand response systems could allow much of the charging to be done without increasing peak electricity demand, light EV energy demand does not necessarily translate into additional generation, transmission and medium-voltage distribution infrastructure. However there is certainly a copper demand increase from the significant new low voltage distribution to reach charge stations and reticulation in buildings, particularly the electrification of car parking areas.

PUBLIC TRANSPORT

MASS TRANSIT AND URBAN MOBILITY

Public transport is likely to play a big role in the rapidly growing and urbanising cities in developing countries that are the focus of this report. Mobility will need to be addressed as housing improves and as poor populations emerge into the middle class. Asian countries need to make a significant investment in improving urban transport infrastructure and systems. The UN Economic and Social Commission for Asia and the Pacific says “there is a need for evidence-based policies and sustainable and inclusive plans for the urban public transport systems” to tackle the mobility demands arising from rapid urbanisation.³¹⁸

³¹⁵ Inoue, Y., Kishita, Y., Fukushige, S., Kobayashi, H., & Umeda, Y. (2012). Resource Risks of Copper in Sustainability Scenario. In M. Matsumoto, Y. Umeda, K. Masui, & S. Fukushige (Eds.), *Design for Innovative Value Towards a Sustainable Society: Proceedings of EcoDesign 2011: 7th International Symposium on Environmentally Conscious Design and Inverse Manufacturing* (pp. 101-105). Dordrecht: Springer Netherlands. http://dx.doi.org/10.1007/978-94-007-3010-6_21

³¹⁶ *Energy Technology Transitions for Industry*. (2009). IEA, <https://www.iea.org/publications/freepublications/publication/industry2009.pdf>

³¹⁷ Inoue, Y., Kishita, Y., Fukushige, S., Kobayashi, H., & Umeda, Y. (2012). Resource Risks of Copper in Sustainability Scenario. In M. Matsumoto, Y. Umeda, K. Masui, & S. Fukushige (Eds.), *Design for Innovative Value Towards a Sustainable Society: Proceedings of EcoDesign 2011: 7th International Symposium on Environmentally Conscious Design and Inverse Manufacturing* (pp. 101-105). Dordrecht: Springer Netherlands. http://dx.doi.org/10.1007/978-94-007-3010-6_21

³¹⁸ United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) (2015) Transport and Communications Bulletin for Asia and the Pacific, No. 85 “Sustainable and Inclusive Urban Transport”, Journal available at <http://www.unescap.org/resources/transport-and-communications-bulletin-asia-and-pacific-no-85-sustainable-and-inclusive>

7. Infrastructure and Transport continued

Private transport is proving hugely popular in China and increasingly in India too. However the pressures of congestion, air pollution, and to a lesser extent public safety are prompting regional and city levels of government to plan and invest in public transport infrastructure. This will drive investment, employment, use of resources/materials and create change in the communities where mobility increases. The Asian Development Bank³¹⁹ estimates that road congestion already costs Asian economies 2–5% of GDP every year due to lost time and higher transport costs. The region's cities suffer from the highest air pollution levels in the world, with as much as 80% attributable to transport.

The ADB estimates that transport investments in developing Asia between 2010 and 2020 will be over US\$2.5 trillion required. It says, "As some large Asian cities are discovering, construction of urban roads will not alone provide a solution. Construction of new roads leads to more purchases of private vehicles which eventually leads to the roads again becoming congested. Moreover, further road building faces severe practical limitations and escalating costs due to the shortage of land in urban areas. Public transport systems are needed to provide urban populations with safe, secure, accessible, rapid, efficient, and user-friendly transport, and to reduce pollution, congestion, and accidents. ADB support will include bus rapid transit and rail-based public transport systems."

Delivery may be by the public sector, the private sector or a partnership of the two. There are some governance and transparency hurdles which vary by country, but ADB indicates that it is rapidly scaling up its urban transport operations. The Global Infrastructure Hub's Chris Heathcote says the new Asian Infrastructure Investment Bank, discussed earlier, will be an important player and likely more nimble than traditional development banks if it can achieve a good balance of governance and speed and develop the capacity to do many small projects.

At the national level, building new public transport capacity and improving existing systems provides a

recognised policy lever to reduce national greenhouse gas emissions. This is likely to receive renewed focus following the unanimity of the Paris Agreement and the Intended Nationally Determined Contributions each country committed to achieve, as discussed in previous sections. Over 61% of the INDCs proposed actions mitigate emissions from the transport sector.³²⁰

The UN Low Carbon Rail Transport Challenge Action Plan of September 2014³²¹ sets a 2030 target for a 50% increase in the rail share of passenger transport from 2010, along with a doubling of rail vehicle energy efficiency and a halving of greenhouse emissions intensity. These developments set the scene for an expected shift to rail and the electrification of rail transport by 2030. The UN report says, "Asia accounts for the majority of the projected growth in transport demand and presents the greatest opportunities for meeting the modal share targets through investment in low carbon rail transport."

International public transport non-profit UITP says of the Paris Agreement that "around a quarter of all countries that have identified specific transport interventions have pledged to focus efforts on public transport," and Secretary General, Alain Flausch says, "If governments are committed to making ambitious targets for CO₂-e reductions, they will need the public transport sector".³²² As Professor Jean-Pascal van Ypersele, Vice-Chair of IPCC says, "Traffic jams have huge costs for everyone, and public transport has a key role to play to improve living conditions and fight climate change."³²³ Siemens estimates³²⁴ that "worldwide, major cities stand to gain around \$800 billion per year of economic opportunity from 2030 by upgrading their public transportation networks."

It is likely that the \$100 billion of funding proposed as part of the Paris Agreement will, in part, be used to invest in public transport as an effective emission mitigation action. As the UK's Overseas Development Institute reports: "Big banks have pledged to scale up their investments in renewable and clean energy, green bonds, low-emission transport and agriculture."³²⁵

³¹⁹ Asian Development Bank (2013) Progress Report (2012-2013) of the MDB Working Group on Sustainable Transport, ADB.org, December 2013 <http://www.adb.org/documents/progress-report-2012-2013-mdb-working-group-sustainable-transport>

³²⁰ Dalkmann, H. Lefevre, B. Enriquez, A. and Yadav, N. (2015) After COP21, Time to Use Sustainable Transport to Make Good on Climate Commitments, World Resource Institute, 17 December 2015, <http://www.wri.org/blog/2015/12/after-cop21-time-use-sustainable-transport-make-good-climate-commitments>

³²¹ United Nations Climate Summit (2014) Transport: Low carbon rail transport challenge Action Plan, UN, New York, 23 September 2014, <http://www.un.org/climatechange/summit/wp-content/uploads/sites/2/2014/07/TRANSPORT-Action-Plan-UIC.pdf>

³²² UITP India (2015), The International Association of Public Transport (UITP), five takeaways for public transport from cop21, UITP, 15 December 2015, <http://www.uitp.org/news/five-takeaways-cop21>
<http://www.uitp.org/news/five-takeaways-cop21>

³²³ UITP India (2015), The International Association of Public Transport (UITP), public transport has a key role to play in the fight against climate change, UITP, 11 December 2015, <http://www.uitp.org/news/interview-JPVanYpersele>

³²⁴ Siemens (2014) Study: Cities can significantly boost their GDP by investing in public transport, June 2014, [http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2014/infrastructure-cities/ic201406009.htm&content\[\]=IC&content\[\]=Corp&content\[\]=MO](http://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2014/infrastructure-cities/ic201406009.htm&content[]=IC&content[]=Corp&content[]=MO)

³²⁵ The Overseas Development Institute (ODI) (2015) Climate finance: what was actually agreed in Paris?, ODI.org, 12 December 2015, <http://www.odi.org/comment/10201-climate-finance-agreed-paris-cop21>

Many of the expert interviewees raised the importance of public mass transit options in city design. John Freer at GE Global Research expects public transport growth in Asia. Grattan Institute CEO John Daley expects plenty of investment in heavy rail and buses, though notes capacity constraints will still be a problem unless networks are optimised for increased frequency, for example with driverless trains. Light rail is a useful complement for shorter journeys of 4km or less, he says, particularly suited to city centres. Antony Sprigg, CEO of the Infrastructure Sustainability Council of Australia, notes that 2030 capital budgets are largely committed already for many countries, so there is not too much guesswork estimating the extent of public transport in 2030. He says it is difficult to change cities quickly, and incremental tweaks to transport are more likely than quantum leaps in the 2030 horizon timeframe.

HIGH SPEED RAIL

High-speed rail supports energy independence and environmental sustainability. Electric trains use less energy to transport people and goods on a per unit basis and can draw power from more diverse sources of energy including renewables than automobile and aircraft which are more reliant on imported petroleum. Freeman and Kroeber³²⁶ describe Chinese high-speed rail as a sensible long-term economic investment. The introduction of high-speed railways in China is responsible for 59% of the increase in market potential for the secondary cities connected by these “bullet trains”, according to Zheng and Khan.³²⁷

Frost & Sullivan predict “an enormous modal shift from highways to rail” by 2025.³²⁸ They say the Chinese high-speed rail network will span over 25,600km by 2030, with track length exceeding Russia’s by 2020, and China Southern Rail and China Northern Rail will both become top three global rolling stock manufacturers. The Chinese high-speed rail investment by 2022 will be, by far, the largest in the world at 198 billion euros. They expect the other main players in Asia to be Japan at 28 billion euros, India at 12 billion and Korea at 9 billion. By 2025 they expect the first moves to connect Asia and Europe by high-speed rail. There are also plans for international high-speed rail

connections to ASEAN countries, according to ISCA’s Antony Sprigg, and a Beijing to Seoul high-speed rail proposed to open by 2030.³²⁹ Frost & Sullivan expect India and Malaysia to be the next centres of rail infrastructure expansion in Asia.

URBAN RAIL

Intra-city transport, interconnected to inter-city and local transport, is efficient and a key feature of a comprehensive mass transit system. Frost & Sullivan expect Asian urban rail investment by 2022 of 923 billion euros: 465 billion for metro rail, 286 billion for monorail, and 172 billion for light rail. They further predict that most Asian urban rail markets will be mature by 2025.³³⁰

ELECTRIC BUSES

CSIRO’s Paul Graham expects electric buses to make big inroads when costs reduce. Automotive technology expert Tim Olding agrees, noting this will be driven primarily by the urban air quality benefit compared to diesel buses. Sydney University’s Professor Joe Dong notes the profusion of electric subways in Chinese cities, even second tier cities, but also that electric buses are well established already. Navigant Research predicts that, between 2012 and 2018, the electric bus market will increase at an annual rate of 26%.³³¹ IDTechEx predicts that the market for medium and large hybrid and pure electric buses will be over \$72 billion in 2025.³³²

MOBILITY AS A SERVICE INCORPORATING PUBLIC TRANSPORT

Dean Economou, formerly of NICTA, expects the emergence of mobility as a service by 2030 to encourage public transport demand. In such a scheme passengers can substitute transport modes freely with a single payment to an integrated mobility service provider. Frost & Sullivan agrees, and says “The future of mobility is multi-modal commuting, combining door-to-door solutions using dedicated mobility platforms.” They mention the importance of “first-mile and last-mile”

³²⁶ Freeman, W. and Kroeber, A. (2010) China’s Fast Track to Development, The Wall Street Journal, 2 June 2010, <http://www.wsj.com/articles/SB10001424052748704025304575283953879199386>

³²⁷ Zheng, S., & Kahn, M. E. (2013). China’s bullet trains facilitate market integration and mitigate the cost of megacity growth. *Proceedings of the National Academy of Sciences of the United States of America*, 110(14), E1248–E1253. <http://doi.org/10.1073/pnas>

³²⁸ Frost & Sullivan (2013) Rail Outlook Study 2013-2022, Frost & Sullivan, May 2013, <http://www.slideshare.net/FrostandSullivan/rail-market-outlook-20132022>

³²⁹ Liu, L. (2015) Beijing to Seoul high-speed rail proposed to open by 2030, Shanghaiist.com, 24 March 2015, <http://shanghaiist.com/2015/03/24/beijing-seoul-high-speed-rail-2030.php>

³³⁰ Frost & Sullivan (2013) Rail Outlook Study 2013-2022, Frost & Sullivan, May 2013, <http://www.slideshare.net/FrostandSullivan/rail-market-outlook-20132022>

³³¹ Navigant (2012) More than 75,000 Electric Drive Buses Will Be on Roads Worldwide by 2018, Navigantresearch.com, 22 August 2012, <https://www.navigantresearch.com/newsroom/more-than-75000-electric-drive-buses-will-be-on-roads-worldwide-by-2018>

³³² Harrop, P. and Gonzales, F. (2015) Electric Buses 2015-2025, IDTechEx, <http://www.idtechex.com/research/reports/electric-buses-2015-2025-000429.asp>

7. Infrastructure and Transport continued

connectivity to public transport.³³³ Arup says, “Big data and the Internet of Things will allow transportation modes to communicate with each other and with the wider environment, paving the way for truly integrated and inter-modal transport solutions.”³³⁴

The future of mobility is likely, then, to be a combination of evolved light vehicle solutions as discussed in the previous section with much more extensive public transport options to offer people convenient, integrated mobility services. The experts interviewed for this report are deeply sceptical of predictions based on a single transport mode or technology. The future will be a combination of these, made possible by advanced ICT and emerging mobility integrators. Mobility solutions will be focussed on customer needs.

COUNTRY BREAKDOWNS

China

Credo Group, in a report for Siemens, forecasts a 44% increase in peak commuter volume by 2030 in Shanghai, 47% in Guangzhou and 48% in Beijing.³³⁵ Miller³³⁶, in an EY/Urban Land Institute report says “Trillions of dollars’ worth of infrastructure investment has transformed China into an exemplar of modern urban transit, expansive highways, vanguard high-speed intercity rail, and highly efficient ocean ports.” The report notes 27 subway-building programs are proceeding, including expansions of transit systems in Guangzhou and Shanghai.

ISCA’s Antony Sprigg says transport infrastructure progress in China “is huge and fast” with the shifts largely driven by air quality concerns. Paul Irwin and Penny Crossley raised similar points. The University of Sydney’s Professor Joe Dong notes in particular that high-speed rail is a key national technology, with investment of around one trillion RMB annually.

According to the International Railway Journal, China’s high-speed rail (HSR) network length reached 12,183km by October 2014, four times longer than the world’s next largest network (Spain).³³⁷ The Chinese government’s Mid-to-Long Term Railway Network Plan adopted in 2004, and updated in 2008, laid out a development strategy for the network for the period up to 2020, including the connection of all provincial capitals and cities above 500,000 people to a rapid rail network of 45,000km, including about 16,000km of high-speed lines.³³⁸ China appears to be exceeding its own targets for high-speed rail; the programme was later accelerated to achieve most of these objectives by 2015. In 2014, Hu et al³³⁹ stated a goal for the domestic high-speed network in 2020 of 20,000km. It appears this was conservative as one government source estimated the network was around 15,000km at the end of 2014³⁴⁰ and another said it was around 19,000km by the end of 2015 with a goal of 30,000km for 2020.³⁴¹ At that point we expect most cities of 500,000 people and larger will be connected to the network, though we expect some further growth in the following network to connect emerging centres and improve capacity on existing routes.

At the end of 2014 China had 1556 high-speed train sets.³⁴² We expect train numbers to grow roughly proportionally with the growth of the network.

Urban rail networks in China were around 3,000km in 2015 and should reach 6000km by 2020 according to the World Bank.³⁴³ Even at these levels, China’s cities are underserved by urban rail compared to Western cities,³⁴⁴ so we expect considerable growth by 2030. The International Railway Journal in August 2015 said over 6000km of metro lines are currently under construction.³⁴⁵ One estimate is for the Chinese urban rail network to grow to 17,000km in 2020 and 37,000km in 2030,³⁴⁶ though this seems aggressive.

³³³ Frost & Sullivan (2013) Rail Outlook Study 2013-2022, Frost & Sullivan, May 2013, <http://www.slideshare.net/FrostandSullivan/rail-market-outlook-20132022>

³³⁴ Arup (2014) Arup Future of Rail 2050, Arup, London, www.arup.com/~media/Publications/.../Arup_Future_of_Rail_2050.ashx

³³⁵ *The Mobility Opportunity: Improving public transport to drive economic growth.* (2014). Credo Group, <http://www.credo-group.com/downloads/Mobility%20Opportunity%20Study.pdf>

³³⁶ Miller, J. *Infrastructure 2013: Global Priorities, Global Insights.* Washington, D.C.: Urban Land Institute and Ernst & Young, 2013. [http://www.ey.com/Publication/vwLUAssets/Infrastructure_2013/\\$FILE/Infrastructure_2013.pdf](http://www.ey.com/Publication/vwLUAssets/Infrastructure_2013/$FILE/Infrastructure_2013.pdf)

³³⁷ International Rail Journal (2015) Chinese high-speed: an evaluation of traffic, IRJ, 8 February 2015, <http://www.railjournal.com/index.php/high-speed/chinese-high-speed-an-evaluation-of-traffic.html>

³³⁸ Takagi, Kiyoharu. “Development of high-speed railways in China.” *Japan Railway and Transport Review* 57 (2011): 36-41. <http://www.jrtr.net/jrtr57/pdf/36-41web.pdf>

³³⁹ Hu, Angang, Yilong Yan, and Xing Wei. *China 2030.* Springer Science & Business Media, 2014.

³⁴⁰ The State Council, The People’s Republic of China (2015) Now and then: China’s high-speed rail revolution, English.gov.cn, 26 January 2015, http://english.gov.cn/news/top_news/2015/01/26/content_281475045134034.htm

³⁴¹ CNTV (2016) China to build 30,000 kilometers high-speed railways by 2020, CNTV.com, 01 December 2015, <http://english.cntv.cn/2016/01/12/VIDE5vHxQhfEiwLpNyD5zQIX160112.shtml>

³⁴² Xinhuanet (2014) From December 10 and then transferred FIG railway, news.xinhuanet.com, 15 November 2014, http://news.xinhuanet.com/fortune/2014-11/15/c_1113263242.htm

³⁴³ World Bank; Development Research Center of the State Council, the People’s Republic of China. 2014. Urban China : Toward Efficient, Inclusive, and Sustainable Urbanization. Washington, DC: World Bank. © World Bank. License: CC BY 3.0 IGO, <https://openknowledge.worldbank.org/handle/10986/18865>

³⁴⁴ Wilkins, K. and Zurawski, A. (2014) Infrastructure Investment in China, Roya Bank of Australia, <http://www.rba.gov.au/publications/bulletin/2014/jun/pdf/bu-0614-4.pdf>

Another says China's urban rail mileage will reach 7,395km in 2020³⁴⁷ which seems consistent with another government source which says 7,000km in 2020.³⁴⁸ We predict that network growth continues but slows in the following decade and that the network in 2030 will be 11,000km.

When projecting rail vehicle numbers we note that, in 2013, the largest domestic manufacturer, CNR, supplied more than 2,000 subway and light-rail vehicles and carriages to twelve Chinese cities.³⁴⁹ The Beijing network of 554km is served by 4688 railcars,³⁵⁰ a ratio of vehicles per km of network of 8.46, whereas the Shanghai system appears to have a lower ratio of 6.10 with 3586 railcars to 588km.³⁵¹ We assume a ratio of 7 cars per km of network.

Chinese-made electric buses have been in service there since 2011 with 80,000 in service by 2014 of a total city bus fleet of around 500,000 according to Cleantecnica.³⁵² They have now been exported also to countries including India, Japan, Malaysia, Philippines and Singapore. According to Automotive World, "A recent announcement stipulated that starting in 2016, 20% of government vehicle purchases must have zero emission technology."³⁵³ According to Dr Peter Harrop, chairman of IDTechEx, "in China... over 100,000 electric buses a year will eventually be bought as part of the national programme".³⁵⁴

We expect very quick growth of the Chinese electric bus fleet driven by air quality concerns, leading to rapid

volume-driven price reductions which will increase uptake in other Asian nations. A PR Newswire report estimates that China will sell 154,000 electric buses in 2020.³⁵⁵

As mentioned in the previous section, China's Deep Decarbonisation Pathways Plan³⁵⁶ forecasts that the number of public transit vehicles in 2050 will reach twelve vehicles per ten thousand people, nearly three times higher than in 2010. Electrification of railway systems will increase rapidly to more than 90% of the system by 2050, from less than 50% in 2010.

India

Credo Group³⁵⁷ forecasts a 93% increase in peak commuter volume by 2030 in Delhi and 82% in Mumbai. According to Miller in 2013, "New Delhi alone is adding 1,400 new cars a day on road systems unable to handle current volumes, while the city's ten-year-old, world-class underground approaches overcapacity." Miller adds, "Every city in India is building its own metro system".³⁵⁸ The Indian government Railways Board's 2009 document "Indian Railways Vision 2020"³⁵⁹ stated an aim to add 25,000km of new lines between 2010 and 2020 to the total network (including inter-city). The network was a little over 64,000km at the time, already the fourth largest in the world.³⁶⁰ The IEA says that to date, 38% of the total railway network in India has been electrified and predicts only a slight increase by 2040, with the share of electricity in total rail fuel use increasing from 33% today to 37% in 2040.³⁶¹

³⁴⁵ International Roal Journal (2015) China embraces light rail, IRJ, 11 August 2015, <http://www.railjournal.com/index.php/asia/china-embraces-light-rail.html>

³⁴⁶ Zhenyu, Li, Zhang Min, and Chen Xumei. "Energy Efficiency Development of Urban Passenger Transport in China." *Sustainable Automotive Technologies 2012*. Springer Berlin Heidelberg, 2012. 253-259. http://link.springer.com/chapter/10.1007/978-3-642-24145-1_33

³⁴⁷ City-rail China (2015) The 9th Annual city-rail summit, Conference Details, <http://www.city-rail.com>

³⁴⁸ Export.gov (2016) Doing Business in China, Leading Sectors, export.gov, http://export.gov/china/doingbizinchina/leadingsectors/eg_cn_081032.asp

³⁴⁹ Nan, Z. (2014) Maglev trains speeding toward greener future, usa.chinadaily.com, 19 February 2014, http://usa.chinadaily.com.cn/epaper/2014-02/19/content_17291903.htm

³⁵⁰ National Bureau of Beijing Municipal Bureau of Investigation Corps Beijing (2015) 2015-02-12 http://www.bjstats.gov.cn/xwgb/tjgb/ndgb/201502/t20150211_288370.htm

³⁵¹ Wikipedia (2016) Shanghai metro, Wikipedia, accessed 01 February 2016, https://en.wikipedia.org/wiki/Shanghai_Metro

³⁵² Field, K (2015) Electric Bus Adoption Is Taking Off In China, Clean Technica, 26 November 2015, <http://cleantecnica.com/2015/11/26/electric-bus-adoption-taking-off-china/>

³⁵³ Automotive World (2014) All aboard the electric bus, automotiveworld.com, 13 October 2014, <http://www.automotiveworld.com/analysis/aboard-electric-bus/>

³⁵⁴ Feuilherade, P. (2013) Electric Urban transport: A revival after long decline, IEC e-tech, April 2013, <http://iecetech.org/issue/2013-04/Electric-urban-transport>

³⁵⁵ PR Newswire (2015) China Electric Bus Industry Report, 2015-2020, London, 12 November 2015, <http://www.prnewswire.com/news-releases/china-electric-bus-industry-report-2015-2020-300178202.html>

³⁵⁶ Qiang Liu, Y. C., Chuan Tian, Xiaoli Zheng, Fei Teng, Alun GU, Xi Yang, Xin Wang. (Sep, 2015). Pathways to deep decarbonization in China. http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_CHN.pdf

³⁵⁷ *The Mobility Opportunity: Improving public transport to drive economic growth*. (2014). Credo Group, <http://www.credo-group.com/downloads/Mobility%20Opportunity%20Study.pdf>

³⁵⁸ Miller, J. *Infrastructure 2013: Global Priorities, Global Insights*. Washington, D.C.: Urban Land Institute and Ernst & Young, 2013. [http://www.ey.com/Publication/vwLUAssets/Infrastructure_2013/\\$FILE/Infrastructure_2013.pdf](http://www.ey.com/Publication/vwLUAssets/Infrastructure_2013/$FILE/Infrastructure_2013.pdf)

³⁵⁹ *Indian Railways Vision 2020*. (2009). Government of India, <http://www.prsindia.org/uploads/media/Railways%20Vision%20Document%202020.pdf>.

³⁶⁰ Radhakrishnan, R (2014) The Reinvention of India: A Project Perspective, Project Management Institute, August 2014 <https://www.pmi.org/learning/PM-Network/2014/reinvention-of-india-project-perspective.aspx>

7. Infrastructure and Transport continued

India's Deep Decarbonisation Pathways Plan³⁶² mentions development of high-speed rail links between cities for passenger transport. The Indian government has expressed interest to construct about 4,500 km route length tracks of High Speed Rail lines over six corridors.³⁶³

India has four active metro rail systems totalling around 236 km according to India's INDC.³⁶⁴ According to UNEP, "The Planning Commission's proposal for the Twelfth Five-Year Plan for urban transport has recommended that all Indian cities with a population in excess of 2 million start planning rail transit projects, and cities with a population in excess of 3 million start constructing the metro rails. An estimated investment for the development of metro rails in Indian cities is USD 26.1 billion."³⁶⁵ The metro projects under construction total around 750km in length,³⁶⁶ and another 600 km are under consideration. It appears the 2030 total network length may be around 1600km if all current and planned projects are complete by then. However, research undertaken by the Indian Institute of Management in conjunction with the Japanese National Institute of Environmental Studies has predicted that 2000km of metro line will be complete by 2030.³⁶⁷

India is potentially the second-largest electric bus market in the world according to BYD's Michael Austin, and the Gujarat government recently announced plans to introduce a pilot project to run electric buses between Gandhinagar and Ahmedabad.³⁶⁸ The Government of India's National Electricity Mobility Mission Plan

(NEMMP) 2020³⁶⁹ will provide a subsidy for electric buses according to UNEP's "Promoting low carbon transport in India project."³⁷⁰

Japan

Credo Group forecasts an 8% increase in peak commuter volume by 2030 in Tokyo.³⁷¹ EY (Miller)³⁷² says past Japanese highway projects have offered limited mobility benefits, so public transport growth seems likely.

Japan previously had the longest high-speed rail network in the world at 2388km. There are some expansion plans,³⁷³ but passenger numbers are not expected to grow significantly, and generally we consider that Japan's network is largely built. An exception may be the "maglev" trains in development. According to Arup,³⁷⁴ the first test runs of Japanese maglev trains, designed to reach speeds of around 500km per hour, took place in June 2013. The trains are expected to be in commercial use by 2027. The ultimate aim is to establish a maglev track from Tokyo to Osaka by 2045, which will provide a high speed link between the north and south of Japan, slashing the journey time between the two cities to 67 minutes.

Japan has an extensive urban rail network, but new projects to 2030 will also be limited by lack of growth in passenger numbers.

Japan commenced trials of electric buses in 2011³⁷⁵ and is expected to have the highest penetration rate globally of electric buses, predicted by Navigant³⁷⁶ to

³⁶¹ International Energy Agency (2015) India Energy Outlook, International Energy Agency, 9 rue de la Fédération, 75739 Paris Cedex 15, France [iea.org, http://www.worldenergyoutlook.org/media/weowebsite/2015/IndiaEnergyOutlook_WEO2015.pdf](http://www.worldenergyoutlook.org/media/weowebsite/2015/IndiaEnergyOutlook_WEO2015.pdf)

³⁶² P.R. Shukla, S. D., Minal Pathak, Darshini Mahadevia, and Amit Garg. (Sep, 2015). *Pathways to deep decarbonization in India*, http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_IND.pdf

³⁶³ Mathew, Roy 13 Feb, 2012. "High Speed Rail Corridor set to become reality". *The Hindu*, <http://www.thehindu.com/news/national/kerala/article2888609.ece>

³⁶⁴ *India's Intended Nationally Determined Contribution: Working Towards Climate Justice*. (Oct, 2015). <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>

³⁶⁵ Goel&Tiwari (June, 2014). *Case Study of Metro Rails in Indian Cities*, http://www.unep.org/transport/lowcarbon/PDFs/CaseStudy_MetroRails.pdf

³⁶⁶ Niraj Sharma, R. D. a. G. S. (2013). "Critical Issues Related to Metro Rail Projects in India." *Journal of Infrastructure Development*, 5(1): 67-86. https://www.researchgate.net/publication/255710610_Critical_Issues_Related_to_Metro_Rail_Projects_in_India

³⁶⁷ Mittal, S., et al. (2015). "Low carbon urban transport scenarios for China and India: A comparative assessment." *Transportation Research Part D: Transport and Environment*. <http://www.sciencedirect.com/science/article/pii/S1361920915000346>

³⁶⁸ *Automotive World* (2014) All aboard the electric bus, [automotiveworld.com](http://www.automotiveworld.com/analysis/aboard-electric-bus/), 13 October 2014, <http://www.automotiveworld.com/analysis/aboard-electric-bus/>

³⁶⁹ Department of Heavy Industries and Public Enterprises, National Electric Mobility Mission Plan 2020 government of India, <http://dhi.nic.in/writereaddata/Content/NEMMP2020.pdf>

³⁷⁰ United Nations Environment Program (2010), Promoting low carbon transport in India, [UNEP.org/transport, http://www.unep.org/transport/lowcarbon/](http://www.unep.org/transport/lowcarbon/)

³⁷¹ *The Mobility Opportunity: Improving public transport to drive economic growth*. (2014). Credo Group, <http://www.credo-group.com/downloads/Mobility%20Opportunity%20Study.pdf>

³⁷² Miller, J. *Infrastructure 2013: Global Priorities, Global Insights*. Washington, D.C.: Urban Land Institute and Ernst & Young, 2013. [http://www.ey.com/Publication/vwlUAssets/Infrastructure_2013/\\$FILE/Infrastructure_2013.pdf](http://www.ey.com/Publication/vwlUAssets/Infrastructure_2013/$FILE/Infrastructure_2013.pdf)

³⁷³ Ministry of Land, Infrastructure, Transport and Tourism, Shinkansen Japanese High-speed rail, <http://www.mlit.go.jp/common/000127999.pdf>

³⁷⁴ Arup (2014) *Arup Future of Rail 2050*, Arup, London, www.arup.com/~media/Publications/.../Arup_Future_of_Rail_2050.ashx

³⁷⁵ Kakuham, Y., Kato, J., Fukuizuni, Y., Watabe, M., Fujinaga, T., and Tada, T. (2011), Next-generation Public Transportation: Electric Bus Infrastructure Project, Mitsubishi Heavy Industries Technical Review Vol. 48 No. 1 (March 2011), <https://www.mhi.co.jp/technology/review/pdf/e481/e481001.pdf>

reach 21.2% by 2023. Japan has a smaller proportion of buses to rail than many countries, however, with around 1500 buses serving Tokyo,³⁷⁷ as an example.

Korea

Credo Group forecasts an 11% increase in peak commuter volume by 2030 in Seoul.³⁷⁸ Like Japan, Korea has well-established urban rail networks. Seoul had the world's first commercial, all-electric bus service in 2010, and the government has announced that half of its fleet of 7,600 buses will be electric by 2020.³⁷⁹

Indonesia

EY says "remedying Jakarta's traffic gridlock takes on particular urgency,"³⁸⁰ and Credo Group³⁸¹ forecasts a 65% increase in peak commuter volume by 2030 in Jakarta.

After a decade of discussion of a high-speed rail project for Java, on 16 October 2015, Indonesia and China signed an agreement to build a 150km Jakarta to Bandung high speed rail link, the first stage of a planned 750km Javanese network.³⁸²

ISCA's Antony Sprigg expects massive growth in transport demand, but believes the government currently lacks the social license needed to achieve a coordinated transport system. Indonesia's Deep Decarbonisation Pathways Plan cites limited investment and little success to date introducing public transport.³⁸³

Malaysia

Significant rail investment is expected, as noted above. On 19 February 2013, Singapore and Malaysia announced that they officially agreed to build a 380km high-speed rail link between Kuala Lumpur and Singapore by 2020.³⁸⁴

However, ISCA's Antony Sprigg believes the government is struggling to find the balance between public transport and roads. He says at the moment mainly road projects are being funded as many unsolicited road proposals are made.

Vietnam

There have been a number of proposals for a 1,630km high speed rail link between Hanoi and Ho Chi Minh City,³⁸⁵ backed by Japanese aid, but these have not yet been confirmed, and it seems unlikely the project will be complete by 2030.

Thailand

Credo Group forecasts a 58% increase in peak commuter volume by 2030 in Bangkok.³⁸⁶ There have been various plans for high-speed rail working with Chinese and Japanese partners. Nothing has yet eventuated though Thailand and China recently agreed to build a US\$12.2billion railway line connecting the two countries.³⁸⁷

Philippines

ISCA's Antony Sprigg cites the Philippines as an example where poor city infrastructure development has already constrained growth due to air quality and congestion. The JICA roadmap for "Mega Manila" by 2030³⁸⁸ notes the need to improve public transport services and emphasises the need to establish better north-south connectivity and "appropriate hierarchy of different transportation modes such as roads, railways, and other mass transits". The roadmap also recommends planned and guided urban expansion to adjoining provinces through an integrated multi-modal public transport network and strengthening traffic management systems, noting "efficient public transport system is a pro-poor investment".³⁸⁹

³⁷⁶ Navigant Research (2015) Sales of Electric Trucks and Buses Are Expected to Reach Nearly 160,000 Annually by 2023, Navigant, 29 Jan 2015, <https://www.navigantresearch.com/newsroom/sales-of-electric-trucks-and-buses-are-expected-to-reach-nearly-160000-annually-by-2023>

³⁷⁷ Transportation in Tokyo, people.rit.edu, <https://people.rit.edu/~ixd2568/409/projects/project1/transport.shtml>

³⁷⁸ *The Mobility Opportunity: Improving public transport to drive economic growth.* (2014). Credo Group, <http://www.credo-group.com/downloads/Mobility%20Opportunity%20Study.pdf>

³⁷⁹ <http://inhabitat.com/south-korea-unveils-worlds-first-commercial-electric-bus/>

³⁸⁰ Miller, J. *Infrastructure 2013: Global Priorities, Global Insights.* Washington, D.C.: Urban Land Institute and Ernst & Young, 2013.

³⁸¹ *The Mobility Opportunity: Improving public transport to drive economic growth.* (2014). Credo Group, <http://www.credo-group.com/downloads/Mobility%20Opportunity%20Study.pdf>

³⁸² Karmini, N, (2015) China, domestic companies to build Indonesia high-speed rail, the Jakarta Post, 16 October 2015, <http://www.thejakartapost.com/news/2015/10/16/china-domestic-companies-build-indonesia-high-speed-rail.html>

³⁸³ Ucock W.R. Siagian, R. G. D., Iwan Hendrawan, Rizaldi Boer, Gito Emmanuel Gintings. (Sep, 2014). *Pathways to deep decarbonization - 2014 report; Indonesia chapter*, http://unsdsn.org/wp-content/uploads/2014/09/DDPP_2014_report_Indonesia_chapter.pdf

³⁸⁴ Maierbrugger, A. (2013) KL-Singapore High-Speed Link To Kick Off, investvine, 20 February 2013, <http://investvine.com/kl-singapore-high-speed-link-to-kick-off/>

³⁸⁵ <http://www.ppinpoint.com/property-new-articles/where-are-the-high-speed-rail-system-in-southeast-asia/>

³⁸⁶ *The Mobility Opportunity: Improving public transport to drive economic growth.* (2014). Credo Group, <http://www.credo-group.com/downloads/Mobility%20Opportunity%20Study.pdf>

³⁸⁷ Zhiming, X. (2014) High-speed rail link expands beyond borders, ChinaDaily.com, 19 December 2014, http://www.chinadaily.com.cn/opinion/2014-12/19/content_19121777.htm

³⁸⁸ Japan International Cooperation Agency (2014) JICA Video Presentation of Infra Roadmap for Mega Manila Released, JICA, Press Release, 19 June 2014, <http://www.jica.go.jp/philippine/english/office/topics/news/140619.html>

³⁸⁹ Japan International Cooperation Agency (2014) Philippines Government Adopts Manila Transport Plan Based on JICA Study, JICA News, 25 September 2014, http://www.jica.go.jp/english/news/field/2014/140925_03.html

7. Infrastructure and Transport continued

Australia

Credo Group forecasts a 28% increase in peak commuter volume by 2030 in Sydney and 29% in Melbourne.³⁹⁰

There have been several proposals for a high-speed rail link between Sydney and Melbourne, one of the busiest air routes in the world, but none has progressed, and we do not expect it to happen before 2030. The urban rail projects expected by 2030, particularly in Sydney, are significant for the nation, but the investment is small when compared to the other countries in the region. There is some interest in electric buses, but the relative scale is small.

Singapore

Singapore already has a comprehensive public transport based on an urban rail system 178km in length. Two new lines are underway, and Rail Journal suggests a doubling in capacity by 2030.³⁹¹ Singapore will continue to invest in public transport, but the scale has little impact on the overall regional investment.

SUMMARY

Congestion, air quality and climate concerns amid increasing urbanisation and population growth will encourage the growth of public mass transit over individual transport in and between the large Asian cities by 2030. This public transport will increasingly be electrified, with implications for growth in the associated electricity systems.

For high-speed rail, China is the key. Its domestic network will be by far the biggest in the world by 2030. China is developing critical international links and will finance, build and export technology that will transform other nations in the region. We expect the domestic Chinese network to achieve 30,000km by 2020 and then grow to around 40,000km by 2030. If the number of train sets grows proportionally (currently 1,556 serving a 15,000km network in 2014), numbers will grow to roughly 4,150 sets in 2030.

Our prediction of an 11,000km Chinese urban rail network in 2030 implies a fleet of 77,000 urban/subway railcars in 2030. The significant metro developments in India are an order of magnitude smaller than the Chinese plans, and the other countries

of interest are smaller again. China appears to be around 80-85% of the total Asian opportunity in the 2030 timeframe.

For electric buses, once again, as goes China so goes the region. For a production estimate we rely on the forecast of IDTechEx that over 100,000 electric buses a year will eventually be bought in China. We note that some forecasts are much higher. Assuming a steady build up from today's production levels to 100,000 a year in 2024 gives a total production to 2030 of 1.14 million vehicles for China domestic use. The numbers anticipated for Korea (3,800 by 2020), India and the other countries are comparatively small. Assuming, then, that China is again around 80% of the total Asian market suggests around 1.4 million vehicles for the region by 2030.

IMPLICATIONS FOR COPPER

High Speed Rail

Electric trains draw as much as 11MW. Multiple sources including Forbes³⁹² indicate that 10 tonnes of copper are used in the power and communication cables per kilometre of dual-track catenary system. Analyst Richard Mills says, "Copper is the key to the increased speed of modern high speed trains. Today's high speed trains do not have a motor located in the locomotive, instead they use a series of motors and transformers located under the length of the train."³⁹³

The ICA indicates that there is an additional 10 tonnes in the power and communication cables per kilometre of track, a number also quoted by Richard Mills: "An additional 10 tonnes is used in the power (catenary system – overhead cable made of copper or copper-alloy that is suspended horizontally above the track and supplies the trains electricity) and communications cables per kilometre of track."³⁹⁴

The technology used in Chinese high speed rail will be a big lever for future copper use. If the network grows to 40,000km as forecasted, using the factors above, the copper demand estimated is around 400kt for the tracks. The copper content for the vehicles would be approximately 41kt, an order of magnitude less than the tracks. So around 440kt additional copper is required for Chinese domestic high speed rail. Using Frost and Sullivan's estimate of the high-speed rail

³⁹⁰ *The Mobility Opportunity: Improving public transport to drive economic growth.* (2014). Credo Group, <http://www.credo-group.com/downloads/Mobility%20Opportunity%20Study.pdf>

³⁹¹ Briginshaw, D. (2014) Singapore to double rail network by 2030, IRJ, 28 August 2014, <http://www.railjournal.com/index.php/metros/singapore-to-double-rail-network-by-2030.html>

³⁹² Singh, S. (2014) A Closer Look at the Chinese High Speed Rail Juggernaut: The Chinese closer to Elon Musk's Hyperloop than the US (Part 2), Forbes, 4 August 2014, <http://www.forbes.com/sites/sarwantsingh/2014/08/04/a-closer-look-at-the-chinese-high-speed-rail-juggernaut-the-chinese-closer-to-elon-musks-hyperloop-than-the-us-part-2/#70f2d56b7b15>

³⁹³ Mills, R. (2011) Coppers Talking Infrastructure, aheadoftheherd.com, <http://aheadoftheherd.com/Newsletter/2011/Coppers-Talking-Infrastructure.htm>

³⁹⁴ Mills, R. (2011) Coppers Talking Infrastructure, aheadoftheherd.com, <http://aheadoftheherd.com/Newsletter/2011/Coppers-Talking-Infrastructure.htm>

investment forecast breakdown in Asia quoted above (80% China, 11% Japan, 5% Korea, 4% India), another 25% is added to get a rough order estimate for the total high-speed rail copper potential in the Asian countries of interest of 550 thousand tonnes. There is potentially significant additional demand if the international links are built, as seems likely, and if China's technology is used elsewhere in the world.

Urban Rail

Kabwe and Yiming state that the average railroad train uses 5,000kg of copper, while electric subway cars, trolleys, and buses contain a weighted average of 1043kg.³⁹⁵ If all of the 77,000 vehicles forecast above are produced between now and 2030 that would represent roughly 80,000 tonnes of copper for the vehicles.

The ICA indicates that there is an additional 107 tonnes of copper in the power, communication and ancillary systems per kilometre of urban metro rail track, which is often underground. This is an order of magnitude higher than for cross-country, above-ground high-speed rail. The 11,000km 2030 Chinese rail network should, then, contain almost 1.2 million tonnes of copper, much higher than the vehicles themselves. Given that around 3,000km is already built, that yields an incremental 856,000 tonnes of copper. If China is 85% of the total regional investment, then the total copper impact of Asian urban rail development, then, is estimated to be around one million tonnes.

Electric Buses

A China Market Research Report³⁹⁶ expects electric buses mainly to use LFP power batteries, often partnered with a supercapacitor. These configurations were employed in up to 82% of buses in 2015. Rated power of drive motors is in the range 80 kW to 120kW, largely asynchronous motors with still permanent-magnet synchronous motors expected in medium and small buses. While there is considerable variation, in estimates we use Kabwe's copper intensity estimate above of a little over one tonne of copper per electric bus to indicate the scale of the opportunity.

Charging of electric buses, including inductive charging underneath roads at bus stops, is a significant load requiring substantial network augmentation.

Using this factor and the forecast bus numbers above, the copper opportunity from electric buses is estimated to be around 1.5 million tonnes by 2030, not considering the charging infrastructure, which will be itself a considerable boost to electricity distribution network growth.

³⁹⁵ Eugie Kabwe, W. Y. (October 2015). "Analysis Of Copper's Market And Price-Focus On The Last Decade's Change And Its Future Trend." *International Journal Of Scientific & Technology Research* 4(10).
<http://www.ijstr.org/final-print/oct2015/Analysis-Of-Coppers-Market-And-Price-focus-On-The-Last-Decades-Change-And-Its-Future-Trend.pdf>

³⁹⁶ China Market Research Reports (2015) China Electric Bus Industry Report, 2015-2020,
<http://www.chinamarketresearchreports.com/115182-toc.html>



8

City Life Main Bazaar - Delhi, India

RESIDENTIAL BUILT ENVIRONMENT

RESIDENTIAL BUILDINGS

NEED TO UNDERSTAND BUILDING NUMBERS AND TYPES IN 2030

A nation's building stocks evolve with growth, development and urbanisation. The lifestyles that accompany different levels of economic development drive demand for materials, products and services as well as building materials. Copper is used in residential buildings for applications including electrical, communications and plumbing.

COUNTRY BREAKDOWNS

India and China are the largest drivers of residential building demand due to the population, urbanisation and income growth trends discussed earlier, so these two countries are the focus of this section.

India

India's massive population continues to grow, as outlined earlier, and is also changing with ongoing urbanisation and demographic shifts. The goal to elevate a significant portion of population out of poverty will drive significant new residential construction. The Indian Government's response has been to develop

the “Affordable Housing for All by 2022” policy³⁹⁷ (see breakout box below). If these goals are achieved, it will result in massive growth in the construction sector. Dr Satish Kumar³⁹⁸ predicts a “400% increase in aggregate floor area of buildings” in India by 2030, which equates to an additional 20 billion square metres of new building floor area. Another way to consider this likely growth is to acknowledge that, according to Kumar, “about 75% of the buildings expected to exist in India in 2030 have not been built.” In its Intended Nationally Determined Contribution³⁹⁹ (INDC) to the COP21 Paris Agreement, the Government estimated that “more than half of India of 2030 is yet to be built”.

What is driving such growth projections? According to DMG, India has an estimated urban housing shortage of 18.8 Million dwelling units and a housing shortage in rural India estimated at 47.4 Million units in 2012.⁴⁰⁰ About 95% of those without urban housing are people in the lowest two income groups, and 90% of those without rural housing live below the official poverty

line. With population growth, demand for new houses by 2017 could be over 88 million dwellings. There are currently 50 cities in India with over 1 million people, and this is predicted to become 87 by 2030.⁴⁰¹ In the large cities, it is expected that affordable housing will precede redevelopment of existing slum areas.

According to the UNEP,⁴⁰² India’s construction market is one of the fastest growing in the world, with an annual growth rate of 9.2%. This trend is linked to population growth, but also to rapid urbanisation. It is predicted that by 2020 approximately 40 per cent of India’s population will be living in cities, indicating a 12 per cent increase since 2008.⁴⁰³ The urban population is expected to more than double by 2050.

In dollar figures, rather than dwellings or square meters, it is estimated that “the Indian real estate market is estimated to be approximately USD 78.5 Billion in 2013 and is expected to grow to approximately USD 140 Billion by 2017”.⁴⁰⁴



Local solar PV installation in India
DIV at USAID. Flickr CC BY-NC-ND 2.0

³⁹⁷ Government of India (2015) “Housing for All by 2022” Mission - National Mission for Urban Housing, Cabinet, Press Information Bureau, 17 June 2015, <http://pib.nic.in/newsite/PrintRelease.aspx?relid=122576>

³⁹⁸ USAID ECO - III Project, 2011 <http://www.gbpn.org/activities/india>

³⁹⁹ *India’s Intended Nationally Determined Contribution: Working Towards Climate Justice*. (Oct, 2015). <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

⁴⁰⁰ ARB International (2015) Construction Market in India, DMG Events India, (http://www.arbinternational.es/ARCHIVO/documentos/sectorial/1431507298_construction-market-report.pdf)

⁴⁰¹ National Housing Bank (2014) “Report on Trend and Progress of Housing in India 2014”, <http://www.nhb.org.in/Publications/trends.php>

⁴⁰² United Nations Environment Programme (UNEP) (2016) Sustainable Social Housing Initiative (SUSHI), Case Studies India, SUSHI in India, http://www.unep.org/sustainable-social-housing/CaseStudies_India/India_sushi.asp

⁴⁰³ MCNEIL, M. A., IYER, M., MEYERS, S., LETSCHERT, V. E. & MCMAHON, J. E. (2008) Potential benefits from improved energy efficiency of key electrical products: the case of India. *Energy Policy*, 36, 3467– 3476.

⁴⁰⁴ Make in India (2016) construction, [makeinindia.com/sector/construction](http://www.makeinindia.com/sector/construction)

Affordable Housing for All by 2022

The “Affordable Housing for All” memorandum from 17 June 2015 covers four key components:⁴⁰⁵

- a) Slum rehabilitation of Slum Dwellers with participation of private developers using land as a resource;
- b) Promotion of affordable housing for weaker section through credit linked subsidy;
- c) Affordable housing in partnership with Public & Private sectors; and,
- d) Subsidy for beneficiary-led individual house construction or enhancement.

The policy covers the entire urban area of all India’s 4,041 statutory towns, focusing on 500 Class 1 cities and will be run in three phases:

- Phase 1 runs from April 2015 until March 2017 with 100 cities selected based on willingness to participate.
- Phase 2 will run from 2017-19 with 200 more cities followed by
- Phase 3 from 2019-22 for all remaining cities.

Funding will be via a credit linked subsidy scheme to the value of US\$1500/house and loan interest subsidy.

The policy has a stated ‘technology sub-mission’ to facilitate adoption of modern, innovative and green technologies and building material for faster and quality construction of houses and will also develop a virtual platform to obtain suggestions and inputs on house design, materials, technologies and other elements of urban housing.

Looking at the numbers involved in this policy shows the economic and social significance of the Affordable Housing for All policy. Drawing from analysis by KPMG,⁴⁰⁶ meeting the policy objectives will require:

- US\$2 trillion investment likely to be required.
- 110 million houses will likely be required by 2022
- 70 per cent of the urban housing need is in the affordable segment
- 78 per cent of investment in housing gets added to the GDP

Clearly this is a massive undertaking and will drive economic activity that, assumedly, will have a multiplier effect into the broader Indian economy.

An understanding of the rate and reliability of household electrification is also useful in understanding the Indian housing and energy challenges. Jairam Ramesh in the MIT Technology Review⁴⁰⁷ identified that 50 million homes are not electrified. Another article in the same edition says 300 million people (perhaps 400 million) are without electricity, and that a further 250 million people have “spotty” grid power available for only three to four hours a day. This poor access to reliable electricity is known to slow social and manufacturing advancement, not to mention quality of life. This is a problem not just in rural villages, but also in urban slums where the connection cost of \$105 per dwelling⁴⁰⁸ is recognised as barrier to more connections. There are thousands of unelectrified villages, most of which will never be connected to the grid. MIT Technology Review draws the conclusion that distributed generation is the

only way to electrify the rural villages, but goes on to point out that this a tough, low-margin business.

In addition to the *Affordable Housing for All by 2020* policy, the *100 Smart Cities*⁴⁰⁹ policy announcement by the Government of India is a significant initiative. The program’s objective is to promote cities that provide core infrastructure and give a decent quality of life to citizens, a clean and sustainable environment and application of ‘Smart’ Solutions. The focus is on sustainable and inclusive development, and the idea is to examine compact areas and to create a replicable model which will act like an exemplar to other aspiring cities. Indicative solutions are likely to include smart energy and water management, renewables, energy efficiency, green buildings and integrated multi-modal transport. The program hopes to drive economic growth

⁴⁰⁵ <http://pib.nic.in/newsite/PrintRelease.aspx?relid=122576>

⁴⁰⁶ KPMG (2014) Decoding housing for all by 2022, India’s commitment to inclusive, sustainable, and affordable development, [kpmg.com/in, https://www.kpmg.com/IN/en/IssuesAndInsights/ArticlesPublications/Documents/Decoding-Housing-for-all-2022.pdf](https://www.kpmg.com/IN/en/IssuesAndInsights/ArticlesPublications/Documents/Decoding-Housing-for-all-2022.pdf)

⁴⁰⁷ Martin, R. (Nov, 2015). India’s Energy Crisis. *MIT Technology Review* 118/6

⁴⁰⁸ Global Partnership on Output-Based Aid GPOBA (2015) India: Launch of Mumbai Slum Electrification Project, <https://www.gpoba.org/node/380>

⁴⁰⁹ Ministry of Urban Development (2016) Smart Cities Mission, Government of India, <http://smartcities.gov.in/>

and improve the quality of life of people by enabling local area development and harnessing technology, especially technology that leads to smarter outcomes.

The Smart Cities program will target 100 cities from 2015-2020 with a defined number per state with selection via a competitive process that promotes a strategy of area-based development. The Indian Government intends this to “capture the spirit of competitive and cooperative federalism”. Grants from the Federal Government will initially total US\$29 million. The policy states that the core infrastructure elements in a smart city would include at least:

- adequate water supply;
- assured electricity supply;
- sanitation, including solid waste management;
- efficient urban mobility and public transport;
- affordable housing, especially for the poor;
- robust IT connectivity and digitalisation;
- good governance, especially e-Governance and citizen participation;
- sustainable environment;
- safety and security of citizens, particularly women, children, elderly; and
- health and education.

The program will include the redevelopment and renewal of existing urban areas as well as development of new greenfield sites. It will also target the infrastructure linking different areas such as transport management and smart metering projects.

Other observations of note from the research phase of this project include the requirement that buildings older than 30 years must have their wiring certified and then recertified every five years.⁴¹⁰ Household electrical equipment and technology is changing with the uptake of LEDs, air conditioning and refrigerators. National building and electrical codes specify only copper for wiring, however sixteen states have altered these specifications. Copper is used for internal wiring although at varying thickness while feeders and bus bars are typically made from aluminium. Multishare risers are copper, and high rise buildings use bus bars.

The per capita residential building space was calculated to be 1.8m² in 2012. This is projected to grow to 35m² in 2047.⁴¹¹ Currently, 45% of the residential floor space

in urban areas is in high-rise buildings. It is projected that 50% of the new high rise buildings and 40% of horizontal buildings in 2047 are smart energy buildings.

As noted earlier, Indian residential power demand is rising quickly.^{412, 413} The increase of Indian GDP is resulting in increased consumer purchasing power which in turn leads to greater use of domestic appliances (see the following section). Household electrical demand is expected to rise sharply in the coming decade due to the growth of residential floor space combined with expectations of improved domestic comfort.

In terms of plumbing, the copper market share is small and will likely decline further.

China

Building construction in China has undergone massive expansion in the last 15 years. The scale of construction activity is vast. According to a recent Reserve Bank of Australia report,⁴¹⁴ 1.9 billion square metres of residential floor space was built in China in 2011, more than the entire residential building stock in Australia. To make another international comparison, the Economist Intelligence Unit⁴¹⁵ says China’s housing construction in the decade to 2010 was equivalent to all the housing in Japan and “in per capita terms, the average amount of floor space enjoyed by urban Chinese has doubled over the same period”. The scale of this remarkable residential construction is necessary, in part, to house the 20 million annual increase in the urban population, but also reflects the increasing wealth and expectations of the Chinese people. Not surprisingly, residential construction is a key driver of Chinese economic growth.



A construction site in China
Tauno Tohk: Flickr.com/CC-BY-2.0

⁴¹⁰ Tembhekar, C (2015) Month on, state yet to start electrical wire audit in buildings, The Times of India, 14 May 2015, <http://timesofindia.indiatimes.com/city/mumbai/Month-on-state-yet-to-start-electrical-wire-audit-in-buildings/articleshow/47276086.cms>

⁴¹¹ NITI Aayog (2015). *A Report on Energy Efficiency and Energy Mix in the Indian Energy System (2030): Using India Energy Security Scenarios, 2047*. New Delhi, http://niti.gov.in/mgov_file/Energy_Efficiency.pdf.

⁴¹² Central Electricity Authority, http://www.cea.nic.in/reports/monthly/executivesummary/2016/exe_summary-01.pdf

⁴¹³ Indian Ministry of Power, <http://powermin.nic.in/Overview-0>

⁴¹⁴ Berkemans and Wang, 2014 <http://www.rba.gov.au/publications/rdp/2012/pdf/rdp2012-04.pdf>

⁴¹⁵ The Economist Intelligence Unit, http://www.eiu.com/public/topical_report.aspx?campaignid=china_realestate_wp

8. Residential Built Environment *continued*

To help gain a picture of the likely direction of construction growth in China, the goals set out in the country's INDC tabled at the COP21 Paris conference include several key points specifically addressing the construction industry which will lead to low carbon development featuring green buildings, renewable energy, energy efficiency measures in both urban and rural areas (see breakout box below).

China's INDCs for Controlling Emissions from Building Sector⁴¹⁶

- To embark on a new pattern of urbanization, optimizing the urban system and space layout, integrating the low-carbon development concept in the entire process of urban planning, construction and management and promoting the urban form that integrates industries into cities;
- To enhance low-carbonized urbanization, improving energy efficiency of building and the quality of building construction, extending buildings' life spans, intensifying energy conservation transformation for existing buildings, building energy-saving and low-carbon infrastructures, promoting the reutilization of building wastes and intensifying the recovery and utilization of methane from landfills;
- To accelerate the construction of low-carbon communities in both urban and rural areas, promoting the construction of green buildings and the application of renewable energy in buildings, improving low-carbon supporting facilities for equipping communities and exploring modes of low-carbon community operation and management;
- To promote the share of green buildings in newly built buildings of cities and towns reaching 50% by 2020.

Yin and Chen⁴¹⁷ provide relevant data on per capita floor space for urban residential, rural residential and commercial buildings. In 2010 these were 21.7, 36.4 and 5.9 m² respectively, and all are expected to increase with income growth. Based on a number of sources,^{418, 419} Yin and Chen expect respective levels of 42.1, 50 and 21.5 m² per person in 2050. Total floor space of urban residential, rural residential and commercial buildings will increase from 145, 244 and 79 billion m² to 445, 193 and 310 billion m² in 2050 respectively.

Japan

As previously discussed, the Japanese economy has faced significant challenges of limited growth for an extended period, though the nation's significance should not be overlooked. In 2013, Japan's GDP reached 525.3 trillion JPY (3,621 billion EUR), third highest in the world after the United States and China.⁴²⁰

The construction sector plays a significant part in the Japanese economy, representing 10% of jobs⁴²¹ and a value of JPY23.5 trillion, of which residential comprises one third.⁴²² The sector experienced an extended slump, but since reconstruction works following the 2011 Tohoku earthquake and tsunami has experienced renewed activity. Government led infrastructure stimulus programs have also contributed to the sector's performance. Construction of over 147 million m² of buildings commenced in 2013, 62.1% of which was residential buildings.

Although significantly below the scale of the current Chinese and anticipated Indian housing construction sectors, nearly a million new residential construction starts (including apartments) were recorded in 2013, an increase of 11% from 2012, comprising 36.2% for owned houses, 36.4% for rental units and 26.9% for built-for-sale units.⁴²³

⁴¹⁶ Wei, S. (30 June, 2015). *Intended nationally determined contribution - Enhanced Actions on Climate Change*. <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

⁴¹⁷ Yin, X., & Chen, W. (2013). Trends and development of steel demand in China: A bottom-up analysis. *Resources Policy*, 38(4), 407-415. <http://www.sciencedirect.com/science/article/pii/S0301420713000482>

⁴¹⁸ Jiyong, E., Kyle, G.P., Clarke, L.E., Patel, P.L., Kim, S.H., 2012. China's Building Energy Use: A Long-Term Perspective Based on a Detailed Assessment. Pacific Northwest National Laboratory, Richland, WA.

⁴¹⁹ Liu, J., 2011a. China TIMES Model System and Impact Analysis on the Application of CCS Technology, School of Public Policy and Management. Tsinghua University, Beijing, China.

⁴²⁰ Australian Trade Commission (2016) Japan- Market Profile, Industries, Australian Government, http://www.eu-japan.eu/sites/eu-japan.eu/files/SustainableConstruction_final.pdf

⁴²¹ Australian Trade Commission (2016) Japan- Market Profile, Industries, Australian Government, http://www.eu-japan.eu/sites/eu-japan.eu/files/SustainableConstruction_final.pdf

⁴²² EU-Japan Centre for Industrial Cooperation (2015) Sustainable building and construction sector in japan and analysis of opportunities for European firms, INGÉROSEC Corporation <http://www.austrade.gov.au/Australian/Export/Export-markets/Countries/Japan/Industries/Building-and-construction>

⁴²³ Australian Trade Commission (2016) Japan- Market Profile, Industries, Australian Government, http://www.eu-japan.eu/sites/eu-japan.eu/files/SustainableConstruction_final.pdf

Japan's Deep Decarbonisation Pathways Project (DDPP) report⁴²⁴ cites one potential future scenario for the buildings sector in Japan which would drive energy consumption decreases substantially, with final energy demand being reduced by approximately 60% to 70% in 2050 compared with the 2010 level. This is mostly due to the decrease in final energy demand per capita by almost 45% in 2050 across all deep-decarbonisation scenarios. In addition to energy-efficiency improvement, the share of electricity increases from about 50% of all energy in 2010 to about 93% in 2050 in all deep-decarbonisation scenarios. These drastic changes are obtained mainly through the diffusion of technologies that electrify space conditioning, over current gas based technologies, and water heating in the buildings sector, such as heat pump water heaters and air conditioners. Further reductions are expected with new technologies impacting electricity demand for lighting and appliances. As a result of electrification in heating demand, pipeline gas and liquid fossil fuel consumption are substantially decreased in 2050 compared with the 2010 level. Due to electrification and electricity decarbonisation, CO₂e emissions in the residential buildings sector reaches almost zero in 2050.

Korea

Research by Reuters⁴²⁵ shows that the Korean construction industry recorded compound growth of 1.58% between 2008 and 2012. Within this meagre growth of the construction sector, "the housing market deflated in 2008 as interest rates began to rise and banks tightened their lending conditions". However, the housing market showed signs of recovery towards the beginning of 2014. According to the KOSIS,⁴²⁶ the housing purchase price index grew by 1.4% year-on-year in the first quarter of 2014.⁴²⁷

As part of the INDC commitments,⁴²⁸ which provide insight into a possible future development scenario for the building sector, the Korean government is seeking to manage energy efficiency from the design stage to the operation stage by means such as establishing the Green Building Standards Code and a system for the Performance Evaluation of Eco-friendly Homes. This is likely to encourage demand for energy efficient design, construction and uptake of efficient and smart

appliance, all of which offer potential for copper as a component material to meet the growing market need.

Australia

Building construction in Australia is a significant contributor to GDP. According to the Australian Industry Group,⁴²⁹ a peak industry association, "Direct construction industry output contributed 7.8% to Australia's Gross Domestic Product (GDP) in 2014-15 up from around 6.5% a decade ago". This makes construction the third largest economic contributor to the Australian economy (behind financial services and mining), worth AUD\$204.5 billion in real terms. Residential building is 26.6% of the total and grew by AUD\$6.5 billion over the decade in response to low interest rates, pent up demand and ongoing population growth. The short-term outlook for residential construction is, according to the AI Group research, very strong with anticipated growth in the value of apartment construction of 14.9% in 2015 and 4.1% in 2016.

Beyond continued growth in the construction industry driven by economic conditions and the growing population, future opportunities for copper are likely to be found in the shift to greater resource productivity, encompassing energy, water, waste and transport. Work undertaken as part of the "Pathways to Deep Decarbonisation in Australia"⁴³⁰ has identified an achievable "reduction in energy use per household of over 50%, while commercial sector energy use per square metre reduces by just under 50%."

To achieve the identified potential efficiencies will require significant skills growth. As John Fennell of the ICA pointed out, "In 2004 it was predicted that smart household wiring would become the norm. Although up to 40% new dwellings are now fitted out with smart wiring, builders don't get it so can't sell it".

⁴²⁴ Kainuma, M., Toshihiko Masui, Ken Oshiro, Go Hibino (Sep, 2015). Pathways to deep decarbonization in Japan. http://deepdecarbonization.org/wp-content/uploads/2015/09/DDPP_JPN.pdf

⁴²⁵ Reuters (2013) Research and Markets: Construction in South Korea - Key Trends and Opportunities to 2017, Press Release, 8 August 2013, <http://www.reuters.com/article/research-and-markets-idUSnBw086002a+100+BSW20130808>

⁴²⁶ Korean Statistical Information Service (KOSIS), <http://kosis.kr/eng/>

⁴²⁷ Construction in South Korea - Key Trends and Opportunities to 2018 (2014) PR Newswire, 13 October 2014, <http://www.prnewswire.com/news-releases/construction-in-south-korea-key-trends-and-opportunities-to-2018-279060261.html>

⁴²⁸ *Intended Nationally Determined Contribution: Republic of Korea*. (30 June, 2015), <http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx>.

⁴²⁹ AI Group (2015) Australia's Construction Industry: Profile and Outlook. July 2015, Economics Research, http://www.aigroup.com.au/portal/binary/com.epicentric.contentmanagement.servlet.ContentDeliveryServlet/LIVE_CONTENT/Economic%2520Indicators/Construction%2520Survey/2015/Construction%2520industry%2520profile%2520and%2520Outlook.pdf

⁴³⁰ Denis, A. et al (Oct 2015). *Pathways to deep decarbonization in Australia*, <http://deepdecarbonization.org/countries/#australia>

IMPLICATIONS FOR COPPER DEMAND

Building and construction is driven by population growth, urbanisation and personal wealth (GDP per capita). Each of these drivers will affect the copper intensity of buildings as well. Forecasting copper demand associated with building and construction is therefore a complex exercise. Population and urbanisation data (United Nations), in conjunction with an average copper content per household of 30 kg (ICA), number of people per residence,⁴³¹ and floor space per capita⁴³² are used to calculate cumulative copper stock and yearly copper consumption associated with urban residential housing.

The copper stock and yearly consumption for urban residential China and India are illustrated in the figure below. We estimate that there will be approximately 5800 kt and 3200 kt of copper demand from Chinese and Indian urban housing from 2015 to 2030, respectively. There is an apparent peak in the yearly Chinese copper demand associated with a peak in the rate of urbanisation.

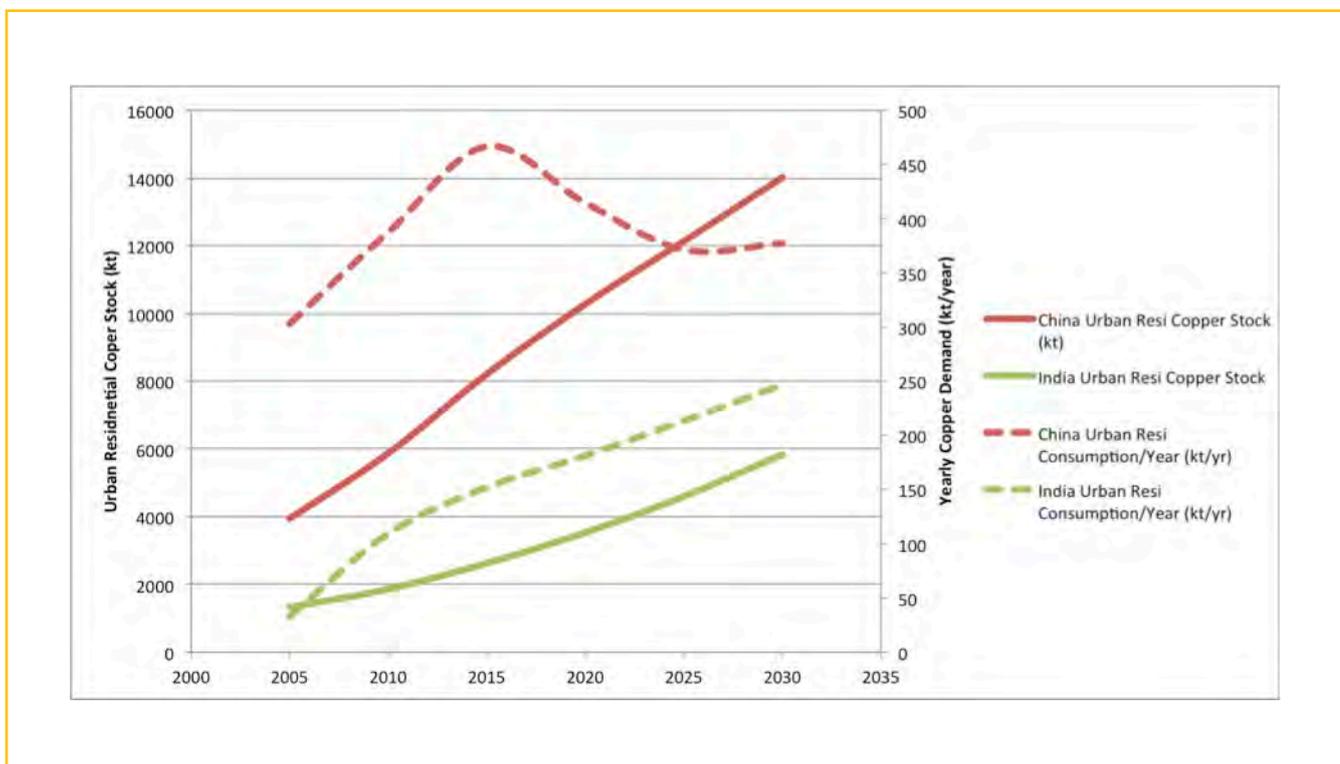
APPLIANCES

RELEVANCE OF APPLIANCES TO THE 2030 ROADMAP

Appliances are significant drivers of copper demand. All electrical appliances contain copper, and their use contributes to the demand for energy, which in turn requires more electricity infrastructure which also contains copper.

PATTERN OF MARKET DEVELOPMENT FOR APPLIANCES

The markets of the Asian region vary in terms of size, wealth, growth and urbanisation, so it is useful to consider the conventional pattern of market development. Yin and Chen⁴³³ observe that “the growth in ownership of vehicles and household appliances in response to economic factors is believed to follow an S-shaped curve with three phases: an initial slow-growth period, a boom period and a saturation period”. For this roadmap, significant variation exists between and within some countries in the study area. This means that different areas will be on different stages along this ‘S-curve’.



Source: Berkelmans, L. and H. Wang (2012)

⁴³¹ D’Arcy, P. and A. Veroude (2014). “Housing Trends in China and India.” RBA Bulletin 20.

⁴³² Berkelmans, L. and H. Wang (2012). Chinese urban residential construction to 2040, Economic Research Department, Reserve Bank of Australia.

⁴³³ Yin, X., & Chen, W. (2013). Trends and development of steel demand in China: A bottom-up analysis. *Resources Policy*, 38(4), 407-415. <http://www.sciencedirect.com/science/article/pii/S0301420713000482>

WHICH APPLIANCES MATTER MOST?

HVAC

Heating, ventilation and air condition (HVAC) is one of the biggest building-based drivers of energy consumption. In the residential setting, HVAC can be delivered via either individual systems (split or window-based), which are relatively easy to retrofit to older building stock, or centralised systems that run throughout a building, as fitted to most modern buildings. Air conditioning can be regarded as a marker of economic prosperity, as its penetration tends to increase as soon as people can afford it.

A key insight into an emerging major trend in the global HVAC market, identified by TechNavio in their 2014 report, is “the shift toward smart solutions”.⁴³⁴ They say “the world is focusing more on the effective distribution of energy, thus minimizing losses”. Initiatives are being implemented by many countries to roll out efficient hybrid systems using non-polluting refrigerants. We expect a growth in sensor manufacturing as sensors play a crucial role in the smart automation of HVAC and other equipment.

The HVAC sector is a significant business sector globally, especially in the Asia-Pacific region, as identified by Transparency Market Research.⁴³⁵ They valued the global HVAC equipment market at over US\$91 billion in 2013 and forecasted compound growth of 6.2% from 2014 to 2022. They say Asia Pacific alone accounted for more than 50% of the global HVAC market and will continue to lead by 2022.

Consumer Goods

Other appliances relevant to this roadmap fall into the category of consumer goods, including washing machines, dishwashers, water heaters, refrigerators and televisions.

Consumer electronics are also an important category, not only for entertainment and leisure, but for education. As Veena Sahajwalla, Professor at UNSW, observed: “consider that all school pupils and tertiary students will eventually have their own devices and classrooms and university lecture theatres will have electronics built into

them”. Device volumes will certainly increase though devices are becoming more energy efficient, so electricity demand growth will be slower than the growth of device numbers.

Analysts and manufacturers alike say that white goods will soon become part of the ‘internet of things’, meaning that appliances that were traditionally stand-alone labour saving devices will soon become ‘smart’ networked devices providing a higher level of service. This will present both challenges and opportunities for manufacturers.

Discussions with experts also identified a trend towards a ‘sharing economy’. This may restrain the proliferation of appliances, especially those that are easily portable and bought for occasional use. For instance an electric drill may be used occasionally for odd jobs and would suit being shared by a group of neighbours. Other appliances, such as a washing machine or air conditioner, are not easily moved, and once in place most households would want access whenever needed.

COUNTRY BREAKDOWNS

China

TechNavio⁴³⁶ forecasts compound growth of the Chinese HVAC equipment market of 8.51% over the period 2014-2019 with key drivers being overall construction growth and the push for energy efficiency. Existing HVAC penetration rates in major cities was calculated⁴³⁷ to be over 90% in 2009 (Shanghai 98.5%, Guangzhou 98.3% and Beijing 98.3%).

On consumer goods, HSBC analysis⁴³⁸ identifies that around 40 per cent of the world’s washing machines and refrigerators are made in China and approximately 70 per cent of the global air conditioners. Growth in demand for large domestic appliances like washing machines, fridges, air conditioners and water heaters is driven by improving lifestyles and better quality products. The Chinese urban market is already considered to be saturated⁴³⁹ but rural to urban moves provide opportunities for growth, and appliance penetration is expected to increase in rural properties over time. The HSBC analysis quotes market penetration figures from the China National Bureau of Statistics: “As of 2012, every 100 urban households own an average of 98

⁴³⁴ Research and Markets (2014) Global HVAC Equipment Market 2014-2018, Construction, HVAC, October 2014, http://www.researchandmarkets.com/reports/2603839/global_hvac_equipment_market_20142018#summary

⁴³⁵ HVAC Equipment Market Expected to Reach US\$ 155.10 Bn by 2022, Globally: Transparency Market Research (2015) Transparency Market Research, 17 July 2015, <https://globenewswire.com/news-release/2015/07/17/753086/10142122/en/HVAC-Equipment-Market-Expected-to-Rich-US-155-10-Bn-by-2022-Globally-Transparency-Market-Research.html>

⁴³⁶ HVAC Equipment Market in China 2015-2019 - Reportlinker Review (2015) PR Newswire, 27 October 2015, <http://www.prnewswire.com/news-releases/hvac-equipment-market-in-china-2015-2019-reportlinker-review-300167477.html>

⁴³⁷ Hakuodo (2011), Post-Millennium Asia’s First Decade - Durable Goods Penetration, Global Habit Survey, <http://www.hakuodo.jp/seikatsusha/research/pdf/2010.pdf>

⁴³⁸ Yan, L. and Rambourg, E. (2015) White goods, golden opportunity China: Right time, right place and the right people, HSBC, Consumer Brands AND Retail Equities, June 2015, http://www.haier.net/cn/investor_relations/stock_a/fxybg/201507/P020150706643330955595.pdf

⁴³⁹ <http://www.hakuodo.jp/seikatsusha/research/pdf/2010.pdf>

8. Residential Built Environment *continued*

washing machines, 99 fridges, 127 air conditioners and 92 water heaters. Outside the cities the numbers are 67 washing machines, 67 fridges and 25 air conditioners." With such a high urban penetration rate, the analysis concludes that "the white goods industry in China is well past the rapid growth stage and is now quite mature and consolidated." Within the cities the analysis notes, "As people get richer, the dull old appliances, which were a status symbol years ago, simply won't do any more. At the high end of the market, customers want energy efficiency, stylish design and the very latest technology, rather than the lowest price."

Despite this analysis concluding that the urban market is relatively saturated, other research points out that there are significant regional variations in the ownership rates for consumer appliances. For instance, Yin and Chen⁴⁴⁰ observe that "refrigerator ownership of urban households is highest at 108 per 100 households in Tianjin and lowest at 81 in Hainan in 2011, while that of rural households is highest at 104 in Beijing and lowest at 27 in Yunnan". While existing dwellings are well equipped with appliances, the continued demand for new urban dwellings will create continued demand for appliances.

India

According to "India HVAC Market Forecast & Opportunities, 2019,"⁴⁴¹ the HVAC market in India is forecast to reach US\$ 3.97 billion by 2019. This growth is driven, as previously observed, by changing lifestyle, increasing per capita income, and rising consumer expenditure on comfort solutions. The main market players offering HVAC systems in the Indian market are Daikin, Blue Star, Voltas, Carrier and ETA.

In terms of HVAC in India, according to ICA's in-country contributor, the copper market share is small and will decline further. In some areas aluminium has some significant disadvantages including coastal corrosion and reduced efficiency from contamination. Aluminium cannot be repaired and must be replaced, whereas copper can be repaired. Inverter penetration is growing from a small base. Imported HVAC products from Korea product are not proving successful, and local equipment manufacturers are using mainly copper in their equipment.

A related market in India of relevance to the Copper Roadmap is the sensors market, which, according to

Techsci research.com⁴⁴² is one of the fastest growing markets in Asia-Pacific with projected "compound annual growth rate (CAGR) over 20% through 2020". Sensors will have an increasing role to play in the networking of appliances and the shift to the 'internet of things' by using for instance touch and image sensors. Growth is coming from both consumer and industrial markets. The expanding consumer electronics and medical equipment sectors in India, added to the fact that these devices are getting smarter, is driving demand. Automation in the manufacturing (automotive, electronics, industrial and healthcare) sector is also contributing to this growth with the push for energy efficiency. Techsci research.com points out that "as sensors help in reducing energy consumption and wastage, while also reducing maintenance costs, the manufacturers are increasingly installing sensors in their manufacturing units." Sensors in HVAC systems enable automation and efficient operation.

Consumer goods: According to recent analysis conducted by Ernst and Young,⁴⁴³ penetration of consumer durables is significantly lower in India than global averages, suggesting a significant opportunity for growth. The table below summarises the EY research.

Appliance	India %	Global average %
Washing machines	8.8	70
Air conditioners	3	60
Refrigerators	21	85
Televisions	60	89

The report concludes that "the Indian market for white goods and televisions is poised for steady growth at ~17% annually, and given the sub-par market penetration levels, presents an attractive opportunity to manufacturers in this space".

Indonesia

Research published by the Global Business Guide⁴⁴⁴ on the Indonesian market for electronics identifies a general increase over the last decade. This matches the

⁴⁴⁰ Yin, X., & Chen, W. (2013). Trends and development of steel demand in China: A bottom-up analysis. *Resources Policy*, 38(4), 407-415. <http://www.sciencedirect.com/science/article/pii/S0301420713000482>

⁴⁴¹ TechSci Research (2014), HVAC Market Forecast and Opportunities, Report Description, <http://www.techsci research.com/report/india-hvac-market-forecast-and-opportunities-2019/541.html>

⁴⁴² TechSci Research (2015), India Sensors Market Forecast and Opportunities, Report Description, <http://www.techsci research.com/report/india-sensors-market-forecast-and-opportunities-2020/402.html>

⁴⁴³ Ernst and Young (2015) Study on Indian electronics and consumer durables segment (AC, refrigerators, washing machines, TVs), April 2015, [http://www.ey.com/Publication/vwLUAssets/EY-study-on-indian-electronics-and-consumer-durables/\\$FILE/EY-study-on-indian-electronics-and-consumer-durables.pdf](http://www.ey.com/Publication/vwLUAssets/EY-study-on-indian-electronics-and-consumer-durables/$FILE/EY-study-on-indian-electronics-and-consumer-durables.pdf)

⁴⁴⁴ Global Business Guide (2013), Indonesia: Manufacturing: Indonesia's Electronics and Home Appliances Sector, http://www.gbgingonesia.com/en/manufacturing/article/2012/indonesia_s_electronics_and_home_appliances_sector.php

growth in per capita purchasing power and increasing consumer sophistication. "Television sets are proving to be the leading contributor to electronics sales in Indonesia and accounted for 46% or \$505 million USD of total sales over the first half of 2012". This was followed by refrigerators at 22.4%, air conditioning units at 15.5% and washing machines at 13%. Although the growth in domestic demand for consumer appliances is in part a result of the growing middle class with an appetite for luxuries such as digital televisions, it is dominated by less wealthy consumers buying basic appliances such as rice cookers, stoves and mobile telephones.

SUMMARY

Taking the S-curve shape of market development for white goods and appliances, and combining this with projections of economic, population growth and the level of urbanisation, it is possible to extrapolate where the greatest market opportunities for appliances lie.

Population and economic growth will continue to drive a very significant uptake in appliances in Asia. This will be accompanied by a drive towards appliance efficiency which will increase the opportunity for copper in global appliance manufacturing, which is largely based in Asia. Though the appliances will be less electricity-intensive, the overall appliance demand will increase, so there is a double benefit for copper. The sharing economy may provide a slight restraint on the growth of small portable appliances such as hand tools but not large, copper-intensive appliances like HVAC and white goods.

INSIGHTS FOR IMPACT ON COPPER

Whilst appliance sales volumes are reported, associated copper demand must be derived from a combination of sales volumes and material composition of each appliance. Material composition data can be obtained from appliance Life Cycle Analysis (LCA).

A summary of the copper content and average mass of common appliances is shown below.

Copper content and average mass of common appliances.⁴⁴⁵

Appliance	Refrigerator	Washing Machine	Dishwasher	Microwave	Computer	Video	TV
Copper %	4	2.4	2.5	3.9	4.8	6	5
Average appliance Mass (kg)	50	75	50	23	10	5	30
Copper mass per appliance (kg)	2.0	1.8	1.3	0.9	0.5	0.3	1.5

The total, assuming one of each per house, is around 8kg of copper. Importantly, the HVAC copper content was included in the building copper estimate in the

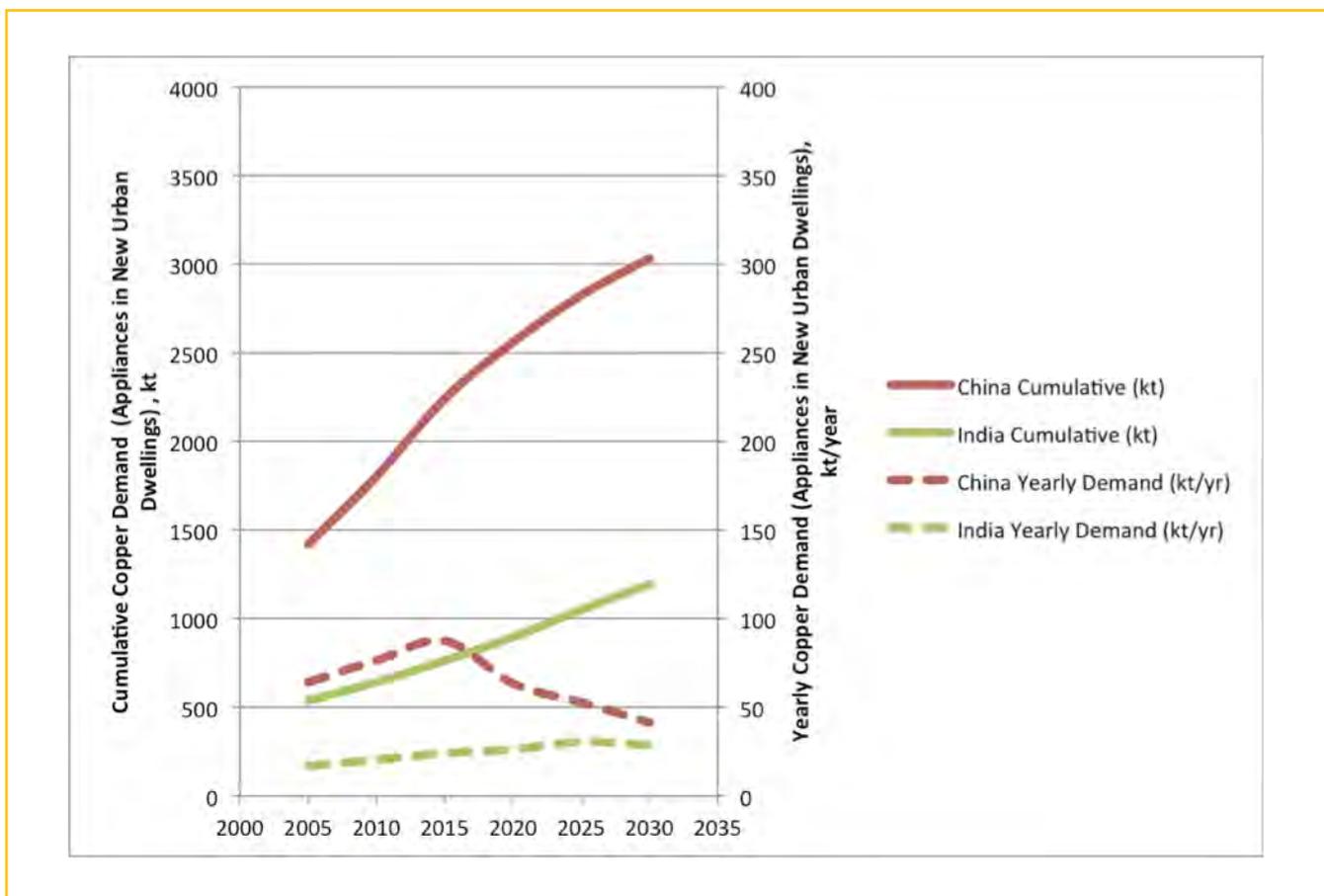
previous section. The numbers that follow are just for the consumer and whitegoods used in the buildings post-construction.

⁴⁴⁵ Truttmann, N. and H. Rechberger (2006). "Contribution to resource conservation by reuse of electrical and electronic household appliances." Resources, Conservation and Recycling 48(3): 249-262.

8. Residential Built Environment *continued*

Given that, in China, most urban homes already have a full complement of appliances, the level of copper demand from new appliances can be estimated by examining the number of new urban residential dwellings.

We expect copper producers and the ICA will have much more accurate local copper intensity factors for each country, but we can provide a rough order of magnitude of the copper opportunity by simply applying the 8kg per dwelling factor to the new urban housing to be built in India and China by 2030. Based on the building numbers forecast in the previous section, the associated appliance copper opportunity would be around 790kt for China and 430kt for India for consumer appliances supplied over the period 2015 to 2030.





9

SUMMARY OF IMPACT ON 2030 COPPER DEMAND

INSIGHTS FOR IMPACT ON COPPER BY 2030

Experts within the copper industry will have more sophisticated and nuanced copper intensity factors for each country than are presented in this report. This work is based mostly on the demand-side trends and gives directional indications of the copper impact of each of the trends. These forecasts should be considered in line with data from other sources such as internal proprietary data to refine the copper demand impact by country and market rather than the present style of high-level copper estimates as calculated.

ECONOMIC AND DEMOGRAPHIC DRIVERS

Population and economic growth in Asia will be macro-economic drivers for most commodities including copper. When analysing the effects of technology innovations on markets, it is important to focus on human needs and those superior products and services with better ways to solve people's problems rather than taking a product-centric approach. Acceptance of new solutions requires social acceptance and a social license to operate. The growing sustainability awareness appears to favour copper-intensive solutions

9. Summary of impact on 2030 copper demand continued

including renewables, decentralised energy, efficient buildings and appliances and electrified transport. The need for cities to adapt to climate change will require resilient local infrastructure including local renewable energy generation, storage and distribution. The efforts of China and India to deliver sustainable prosperity to their populations are the biggest factors determining the 2030 copper demand and should be positive. Increasing urbanisation also drives copper intensity.

DECARBONISATION

All nations have committed to decarbonise their economies. The main levers to achieve decarbonisation are generally positive for copper:

- a shift from fossil fuel to renewables in the electricity sector,
- increased electrification in sectors including building and transport, and
- enhanced energy efficiency.

Carbon pricing through a carbon tax or cap-and-trade mechanism would drive a cost competitive advantage against aluminium, particularly where aluminium and electricity production are less efficient than best practice. Pursuing carbon pricing could drive substitution towards copper and away from aluminium in materials selection.

ELECTRICITY

Developments in the large Asian power markets over the next fifteen years will be an important driver of global copper use. Asia is predicted to represent almost half of world electricity demand by 2030, two-thirds of which originates from China. There will be an enormous growth in power generation, transmission, distribution and residential electrification in Asia by 2030, clearly positive for copper. Underground projects for both transmission and distribution could prioritise copper selection by arguing the life-cycle benefits. The rapid shift away from fossil fuels in China combined with India's ambitious renewable deployment ambitions will favour copper. International interconnections tend not to favour copper, but we suspect few will be built by 2030 and that a decentralised energy future is more likely.

Decarbonisation of electricity

Renewables use four to twelve times more copper than fossil fuel generation. Coal generation may already have peaked, and the Asian countries of interest have already installed significant amounts of renewable generation with plans to continue very significantly through 2030. By 2030 almost half of the copper stocks in power generation equipment will be in wind and solar PV equipment.

The copper demand from the two main renewable generation technologies by 2030, in China and India alone, are as follows:

- Solar PV: 6500kt,
- Wind: 3600kt

Transmission and distribution impacts are not included, but are higher per unit of generation for renewables than fossil fuels.

Decentralisation of electricity

The decentralisation trend is positive for copper which has high relative penetration in low voltage distribution systems and distributed energy resources. Substitution of distribution for transmission should be encouraged. Growth in transmission is positive for copper, though long-distance transmission projects are not a significant driver except for sub-sea or underground cables. Distributed energy resources often duplicate existing distribution systems, though areas with little or no grid connection may be powered with distributed energy rather than connected to the grid.

We examined decentralisation in three countries: Australia is likely to have a relatively high decentralisation index of 30% in 2030, followed by India at around 7% or perhaps a little higher, with China the most centralised of the three at around 2%. Based on this, the copper demand related to distributed solar PV assets in these countries by 2030 should be around 1000kt: 40% in China, 35% in India, and 25% Australia. There will be further significant copper demand related to decentralised energy in other parts of the region, particularly Indonesia, Philippines and Vietnam.

We conclude that decentralisation of energy will significantly increase the copper intensity of electrical distribution.

TRANSPORT

Electrification of light vehicles and buses represents a significant opportunity for copper. However, cities will increasingly be constrained by vehicle congestion, so efficient public mass transit will be required, even noting that the total copper opportunity is lower in that case. We conclude that electrification will significantly increase the copper intensity of transportation.

Light Vehicles

There is likely to be enormous growth in light vehicle numbers in Asia. Autonomous vehicles promise to increase road capacity. This growth may be tempered by congestion and emerging mobility services such as car sharing and e-hailing, though these do not reduce

the total commuting load. Higher utilisation in fewer vehicles may lead to great wear and more frequent vehicle turnover. Ride sharing and change of modes to public transport, however, would likely reduce copper demand. There are significant copper opportunities in electrified mass transit.

The copper impact of the predicted 75 million electric and plug-in hybrid vehicles is around 6400kt for the vehicles only. Approximately 55% of these vehicles will be in China, with around 19% each in India and Japan. There is clearly significant additional copper opportunity in the LV distribution network and equipment for charging these plug-in vehicles, but this is difficult to quantify as at least some of it is built into the electricity load forecasts discussed earlier.

Policies supporting the uptake of both electric and autonomous vehicles are advantageous for copper demand.

Public Transport

The copper impact of the three public transport modes examined by 2030 are as follows:

- High Speed Rail:
 - 550 kt
 - Includes tracks and vehicles
 - 80% in China
 - Significant possible increase for estimates if the international links are built, as seems likely, and if China's technology is used elsewhere in the world.
- Urban Rail:
 - 1000 kt
 - Includes tracks and vehicles
 - 85% in China
- Electric Buses:
 - 1500 kt
 - Includes the vehicles only, exclusive of charging infrastructure
 - 80% in China

RESIDENTIAL BUILDINGS

Population and economic growth will drive an increase in the number of dwellings, size of dwellings and electricity use per dwelling in the main countries of interest. Housing construction growth is also expected in the more stable, developed economies of Japan, Korea and Australia. In all countries there will be a drive towards energy efficiency which will drive up the copper intensity of new construction.

Chinese population growth to 1.4 billion and urbanisation to 65% by 2030 will drive housing demand in cities. Construction of urban dwellings will generate around 5800 kt of copper demand from 2015 to 2030. Indian population will be higher than China at 2030, but the urbanisation will be significantly less, at 40%. Construction of urban dwellings will generate 3200 kt of copper demand from 2015 to 2030.

APPLIANCES

Population and economic growth will drive a significant uptake in appliances in Asia. Though the appliances will be less electricity-intensive, the overall appliance demand will increase, so there is possibly a double benefit for copper. The sharing economy may provide a slight restraint on the growth of small portable appliances such as hand tools, but not large, copper intensive appliances like HVAC and white goods.

Appliance demand will be led by new urban housing required in China and India. Using a simple factor representing the copper in a set of household appliances, a future copper demand is calculated at 790 kt for China and 430 kt for India to 2030 due to the increase in urban population. HVAC copper content is included in the buildings estimate from the previous section.

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